Proposal of a Web-Based Multi-criteria Spatial Decision Support System (MC-SDSS) for Agriculture

Giuseppe Modica, Maurizio Pollino, Luigi La Porta and Salvatore Di Fazio

Abstract The paper reports the main technological characteristics and functionalities of a web-based Multi-criteria Spatial Decision Support System (MC-SDSS) implemented on free open source software for geospatial (FOSS4G) environment. The web-based MC-SDSS was designed to perform land suitability evaluation (LSE) for olive crops and applied to the territory of Calabria (Italy). From a technological point of view, the MC-SDSS was designed on a multi-tier architecture compliant with the Open Geospatial Consortium (OGC) services (WFS, web feature service; WCS, web coverage service, and WMS, web map service. Moreover, it was enabled to processes executable via OGC web processing services (WPSs). LSE of olive crops is provided following the analytical hierarchy process (AHP) based on the different judgements obtained from experts and aggregated through the weighted linear combination (WLC). With the aim to implement an effective planning tool, the WebGIS client was designed to manage three different type of users with different level of privileges: Guest, Expert and Decision Maker. The results are expressed as multi-attribute geospatial maps (land suitability maps) and as distribution graphs according to the envisaged land suitability classes (not suitable, low, medium, high and very high suitability).

Keywords Land Suitability Evaluation (LSE) · Multi-criteria Spatial Decision Support System (MC-SDSS) · WebGIS

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1 Introduction

The main aim of the land suitability evaluation (LSE) is to give an effective support to environmental managers and planners in analysing the interactions among location, development actions, and environmental elements (Collins et al. 2001) in order to evaluate different scenarios. In this framework, Multi-criteria Spatial Decision Support Systems (MC-SDSSs) are effective tools that allow to accomplish LSE for agricultural or forest environments (Malczewski 1999; Modica et al. 2014). In this paper, we synthetically show the main characteristics and functionalities of a web-based MC-SDSS platform specifically implemented to perform LSE for olive crops (Modica et al. 2016). Such tool is based on a free open source software for geospatial (FOSS4G) environment (Steiniger and Hunter 2012), accessible through a user-friendly geographical user interface (GUI), capable to perform geospatial analyses (Pollino and Modica 2013). The MC-SDSS has been implemented with a multi-tier architecture, enabling to:

– Manage geospatial data and produce output maps via the largely used OGC (Open Geospatial Consortium) services (OGC® Standards): web feature service (WFS), web coverage service (WCS) and web map service (WMS);
– Manage processes executable via OGC web processing services (WPSs).

In the current version of MC-SDSS platform, data aggregation is provided by means of the weighted linear combination (WLC), using the different weights obtained from the judgements provided by experts (Modica et al. 2016) and following the analytical hierarchy process (AHP) proposed by Saaty (1980). To this end, the platform represents an effective solution, accessible also to non-experts, and based on specific online tools. For example, the WPS was configured to provide web-based processing (GIS geoprocessing) and multi-criteria assessment web-functions, including access to pre-programmed calculations and/or computation models, operating on geospatial data (both vector and raster formats) (Modica et al. 2016).

Taking into account the general framework and the processing steps required, the proposed WebGIS application (hereafter referred as "WebGIS Suitability-Olive") was specifically implemented and released (Modica et al. 2016). It represents the front-end interface of the MC-SDSS platform, through which the user is able to access data, perform calculation and assess the obtained results that are constituted by land suitability maps, distribution graphs, etc. Moreover, with aim to implement an effective planning tool, the WebGIS client was designed to manage three different types of users with different levels of privileges: Guest, Expert and Decision Maker.

2 The Methodological Approach

As introduced, to perform the analyses, the WLC technique (Vizzari and Modica 2013) was implemented within the proposed MC-SDSS, specifically providing factors and criteria for the approach adopted. From a practical point of view, each factor represents a specific map (i.e., a GIS layer) and, by means of GIS spatial overlay (Geoprocessing or Map Algebra) (Eastman et al. 1995), it is possible to integrate the variables through the use of appropriates weights, which are typically provided by one or more experts. Each attribute represents a "criterion": to each criterion is assigned a weight, on the basis of its own relative importance. The possible options represent single parts of the analysed territory on which the variables can assume a given value, leading to the evaluation of a well-defined area in which a suitability value is assessed. The results are expressed as multi-attribute geospatial maps (land suitability maps) and as distribution graphs according to the envisaged land suitability classes (not suitable, low, medium, high and very high suitability).

Here follows an example of exploitation of a WLC: (i) a set of continuous criteria are assigned to defined intervals; (ii) the numerical ranges are combined by a weighted average; (iii) user (e.g., an expert supporting the final decision-maker), through a specific procedure, assigns weights directly to each mapped GIS layer; (iv) the overall score for each option is calculated by multiplying the weight assigned to each attribute by the (normalized) value of the attribute itself within each alternative and, then, by adding the products of all the attributes; (v) by spatially combining the evaluation criteria associated with each GIS layer, it is possible to obtain a suitability map for the area of interest.

According to the approach proposed by Saaty (1980), and based on the pairwise comparisons according to the so-called Saaty's fundamental scale, when comparing two variables, the evaluator (i.e., the expert), has to indicate which is the most important on a scale of scores ranging from 1 to 9, which express the relative importance of the first variable with respect to the second. To compare all possible couples of variables, the scores are organized into a pairwise comparison matrix (PCM) (Modica et al. 2015).

The AHP is also a powerful tool thanks to the possibility to involve in the evaluation process multiple experts with different skills. To this end, the MC-SDSS platform has been structured to support groups of experts/evaluators, implementing a multi-user approach in which it is possible to provide individual evaluations (and to produce the related results) and then to aggregate them into a final synthetic evaluation.

The input geospatial layers (and consequent factors) considered are the following: *Elevation*, *Acclivity*, *Aspect*, *Land use/Land Cover* and *Pedology*. These information layers were acquired from various public data repositories (ISPRA-SINAnet, Regione Calabria, etc.). Subsequently, they were converted from their native format into raster format and resampled to a spatial resolution of 20 m × 20 m.

The evaluation workflow, on the whole, is articulated into the following steps (Modica et al. 2016):

– Step 1: Criteria definition and selection. Evaluation criteria, organised following the work of Eastman et al. (1995) as factors and constraints, are defined and selected.

– Step 2: Data Normalization. By means of a standardization procedure, all the criteria are represented within a common reference interval [0–1], through different approaches (e.g., fuzzy logic).
– Step 3: Weights Definition (AHP-based approach). To obtain the weights of the criteria considered, each expert has to provide a judgment for each pair of the *n* elements into the pairwise comparison matrix (PCM) (Vizzari and Modica 2013; Forman and Peniwati 1998), expressing it on the basis of the Saaty's fundamental scale (Saaty 1980).
– Step 4: WLC and suitability maps (Map Algebra technique). According to his own evaluation, each Expert is allowed to view the obtained assessment as a land suitability map.
– Step 5: Results aggregation—Final suitability map production. Results coming from each involved expert are aggregated to obtain the final land suitability map for olive crops.

3 "Suitability-Olive": The WebGIS Interface of MC-SDSS

The WebGIS *Suitability-Olive* was conceived and designed to share and make available territorial information and to support decision-making processes. It represents the interface of the MC-SDSS (Modica et al. 2016), also allowing processes execution. Thus, the WebGIS provides a wizard-like structure, to drive the user through a series of well-defined steps (that we called "Processing Widgets") in order to perform the multi-criteria spatial analysis, such as:

– launch and execute data normalization processes ("Normalization Widget");
– calculate the "WLC—Weighted Linear Combination" ("AHP Widget").

The multi-user architecture implemented allows the experts to provide their evaluations and, at a higher level, the overall management of the platform and the synthesis of the results. To this end, three categories of users—with different roles and privileges—are defined: *"Guest", "Expert"* and *"Decision Maker"* (i.e. the platform administrator) (Fig. 1).

3.1 Expert's Evaluations

The so-called "Expert" users are enabled to provide their own evaluations, by performing the various steps previously described. For each of them, a specific access to the Web-GIS platform is provided by means of a username and a password. The first step that each expert must perform the normalization, managed through the "Normalization Widget", that allows to manage the trade-off between all the evaluation factors. This Widget is organized in five different sections (TABs), each dedicated

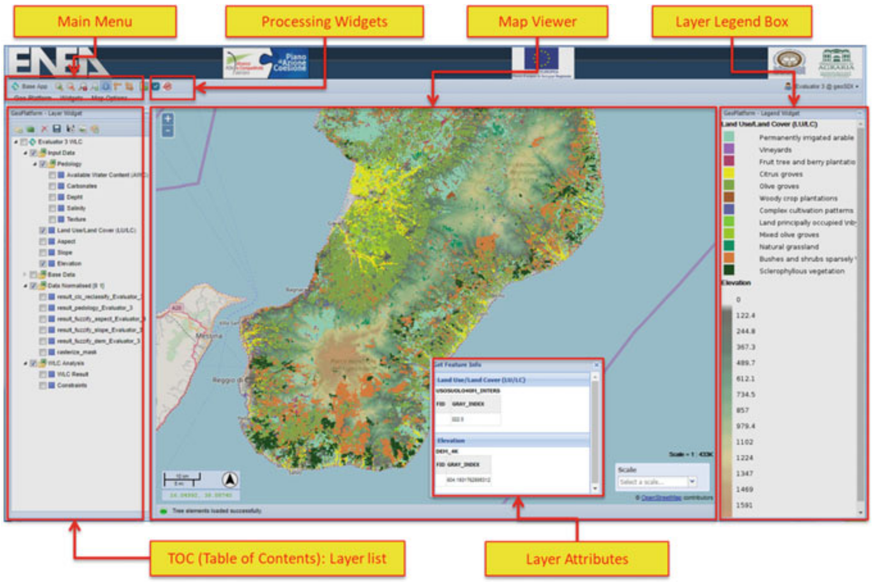

Fig. 1 WebGIS *Suitability-Olive*, example of layout with the different sub-sections labeled (red arrows). In this screenshot, the Land cover map is showed

to the normalization of a specific factor according to the most appropriate method. In particular, based on a fuzzy approach, the so-called Ordered Weighted Averaging (OWA) operators (Yager 1988) were implemented for *Elevation*, *Slope* and *Aspect* factors (Fig. 2). Thanks to this Widget, the Expert can set the "transition" from the values considered as unsuitable to those most suitable.

To normalize the *Land Use/Land Cover* factor (Fig. 3), for each class considered it is possible to indicate the relative relevance, by selecting the values in a continuous range from 0 ("Very Low") to 1 ("Very High"). Then, *Pedology* can be normalised through a pairwise comparison between the five sub-factors characterising the layer (texture, salinity, depth, water content and carbonates).

After the normalization step, it is possible to perform the calculation of the WLC. By means of the module called "AHP Widget" the expert can assign weights to each of the five considered factors (*Elevation, Slope, Aspect, Land Use/Land Cover and Pedology*) using the pairwise comparison technique (AHP), on the basis of the reference scale indicated by Saaty (ranging from 1 = "equal importance" to 9 = "extremely more important").

Finally, according to the parameters set-up during the above described procedure and as result of the WLC (Fig. 4), the related GIS layer (suitability Map) is produced as output and automatically made available within the WebGIS view.

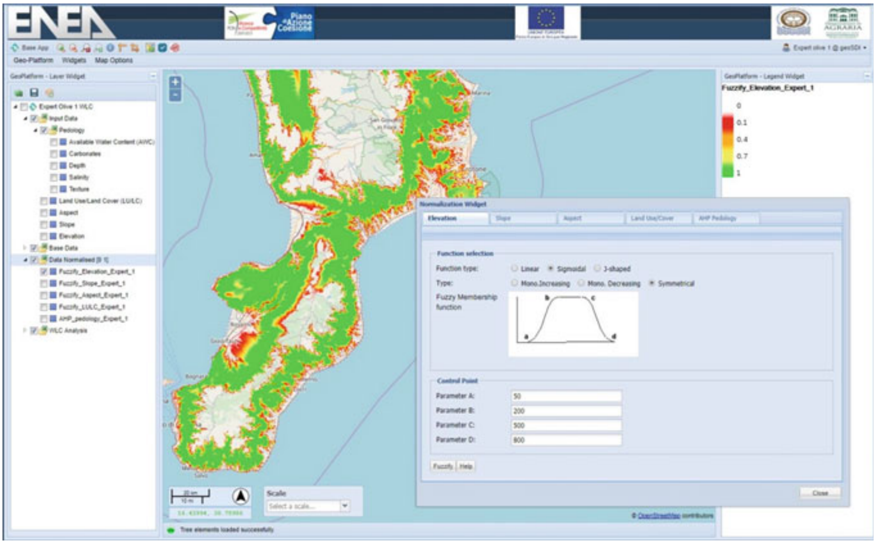

Fig. 2 Normalization Widget: example of *Elevation* factor normalization trough fuzzy logic based on linear, sigmoidal and j-shaped membership functions

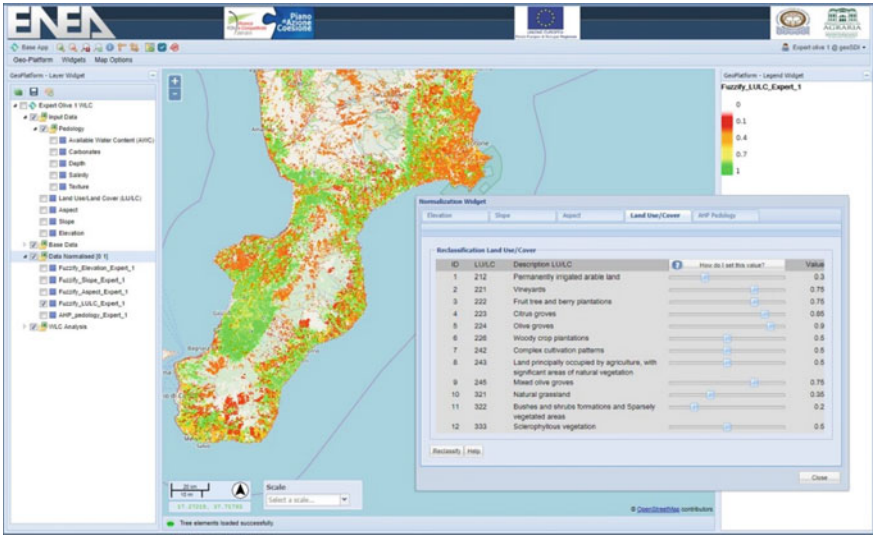

Fig. 3 Normalization Widget: example of *Land Use/Land Cover* factor normalization

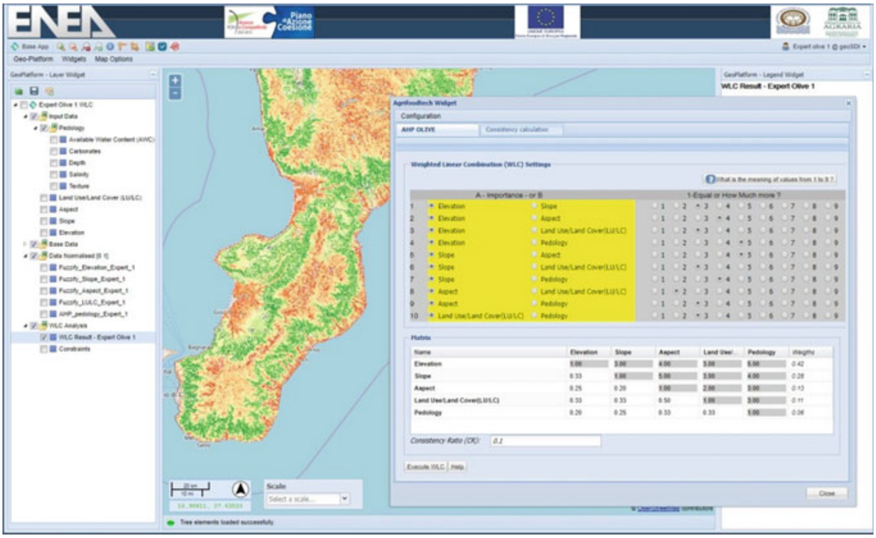

Fig. 4 Weighted Linear Combination (WLC): visualization of the Widget mask allowing an Expert to input the parameters (according to the AHP procedure) and produce its own suitability Map

3.2 Suitability Map Production

The "Decision Maker" (DM) is the *super-user* enabled to collect the results produced by each expert (according to their specific evaluations). A specific processing module, which elaborates the individual results of each expert, allows the DM to aggregate all the intermediate results (through a geometric mean) and to generate the final Suitability Map (Fig. 5), as the synthesis of the *n* evaluations provided.

4 Conclusions

In this paper we have described the design and development of a web-based MC-SDSS, relying on a FOSS4G architecture, aiming at performing spatial and environmental analyses, in order to support decision-making processes related to the agro-forestry LSE.

A WebGIS application (namely "Suitability-Olive") was specifically implemented as multi-user interface of the MC-SDSS, to perform spatial analyses via web and to support the evaluation processes accomplished by different/multiple experts. Then, the final decision maker can easily collect and manage the results provided by the various experts involved in the evaluation phase, obtaining a final susceptibility maps as result of the overall LSE process. Feedbacks from the experts that are currently testing the application will be considered to address the future developments of the

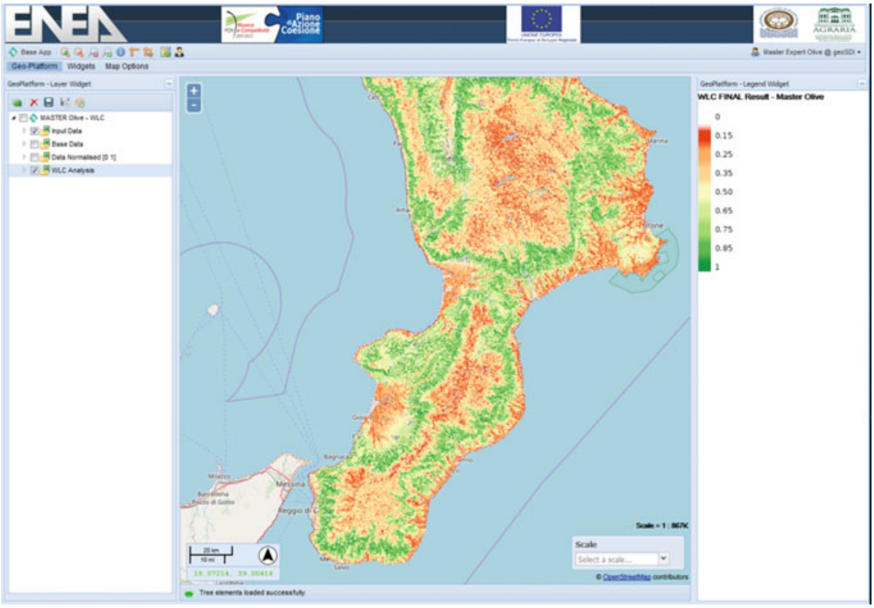

Fig. 5 Example of final Suitability Map, produced as the synthesis of the evaluations provided by the different Experts

MC-DSS, in order to enhance its capabilities. For instance, additional features may be implemented, to take into account other environmental aspects and to support more efficiently decision processes.

References

Collins, M. G., Steiner, F. R., & Rushman, M. J. (2001). Land-use suitability analysis in the United States: Historical development and promising technological achievements. *Environmental Management, 28,* 611–621.

Eastman, R., Jin, W., Kyem, P. A. K., & Toledano, J. (1995). Raster procedures for multi-criteria/multi-objective decisions. *Photogrammetric Engineering and Remote Sensing, 61,* 539–547.

Forman, E., & Peniwati, K. (1998). Aggregating individual judgments and priorities with the analytic hierarchy process. *European Journal of Operational Research, 108,* 165–169.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. New York: Wiley.

Modica, G., Laudari, L., Barreca, F., & Fichera, C. R. (2014). A GIS-MCDA based model for the suitability evaluation of traditional grape varieties: The case-study of "Mantonico" grape (Calabria, Italy). *International Journal of Agricultural and Environmental Information Systems, 5,* 1–16.

Modica, G., Merlino, A., Solano, F., & Mercurio, R. (2015). An index for the assessment of degraded Mediterranean forest ecosystems. *For. Syst., 24,* 13.

Modica, G., Pollino, M., Lanucara, S., La Porta, L., Pellicone, G., Di Fazio, S., Fichera, C. R. (2016) Land suitability evaluation for agro-forestry: Definition of a web-based multi-criteria spatial decision support system (MC-SDSS): Preliminary results. In: O. Gervasi et al. (Eds.), *Computational science and its applications—ICCSA 2016*. Lecture Notes in Computer Science (Vol. 9788). Cham: Springer.

OGC® Standards. Retrieved from https://www.opengeospatial.org/standards.

Pollino, M., & Modica, G. (2013). Free Web mapping tools to characterise landscape dynamics and to favour e-participation. In B. Murgante, S. Misra, M. Carlini, C. M. Torre, H.-Q. Nguyen, D. Taniar, B. O. Apduhan, & O. Gervasi (Eds.), *ICCSA 2013, Part III* (Vol. 7973, pp. 566–581)., LNCS Heidelberg: Springer.

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation*. New York: McGraw-Hill.

Steiniger, S., & Hunter, A. J. S. (2012). Free and open source GIS software for building a spatial data infrastructure. In E. Bocher & M. Neteler (Eds.), *Geospatial free and open source software in the 21st century* (pp. 247–261). Heidelberg: Springer.

Vizzari, M., & Modica, G. (2013). Environmental effectiveness of swine sewage management: A multicriteria AHP-based model for a reliable quick assessment. *Environmental Management, 52,* 1023–1039.

Yager, R. R. (1988). On ordered weighted averaging aggregation operators in multicriteria decision making. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 18,* 183–190.