Support system based on GIS and weighted sum method for drawing up of land suitability map for agriculture – Application to durum wheat cultivation in the region of Tiaret in Algeria.

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Abstract: - Due to the observed decreasing farmlands, it is important to identify the best lands useful for a sustainable agriculture (a productive and profitable agriculture that protects the environment and that is socially equitable). This identification is resulted in the development of land suitability maps for agriculture by combining several factors of various natures and of unequal importance. Spatial analysis approaches, based on the concepts of the weighted sum, combined with a Geographical Information System (GIS) offer the possibility to determine this type of maps. Indeed, GIS is a powerful tool for analyzing spatial data and establishing a process for decision support. The functions of the weighted sum shall make it possible to assign numerical weights, to distinguish between positive and negative criteria and to rank alternatives. A spatial decision support system has been developed for establishing the land suitability map for agriculture. It incorporates a version of the weighted sum method SAW (Simple Additive Weighting), applicable to the vector data model, in ArcGIS without leaving the GIS program package environment. This approach has been tested on Tiaret (Algeria) to assess the land suitability for the durum wheat agriculture. The parameters and the classification system used in this work are inspired from the FAO (Food and Agriculture Organization) approach dedicated to a sustainable agriculture. The coherence of results confirms the system effectiveness.

Key-Words: suitability for agriculture, FAO classification, Geographical Information System, spatial analysis, weighted sum, Algeria.

1 Introduction

The modest growth in agricultural production and the rapid increase in population ranks Algeria among the main importing countries of food and agricultural products at the worldwide level. Moreover, a large part of soil is poor and subjected to erosion. The water supply is generally irregular and insufficient. Consequently, the soil becomes not productive. Climate change could disrupt agricultural trends and would undermine the future of the earth. Therefore it is necessary to move toward an agriculture that would preserve the nature and guarantee the desired sustainability for future generations. This is therefore referred to as sustainable agriculture. In order to change the deplorable situation of agriculture and to guard against future problems, a reallocation of land according to their suitability for specific cultivations in terms of sustainable development is necessary. Traditional methods become increasingly cumbersome to implement or even inappropriate. Current approaches, based on GIS, spatial analysis and criteria weighting, are available and are able to assist in management and decision-making (Mendas *et al.*, 2007). The main purpose of this research is to propose a conceptual and methodological framework for the combination of GIS and a weighted sum method, adapted to vector data, in a single coherent system that takes into account the whole process from the acquisition of spatial referenced data to the decision-making. In this context, a spatial decision support system, for carrying out of land suitability maps for agriculture, has been developed. It incorporates a multicriteria method characterized by an additive aggregation of criteria by weighted summation, based on spatial analysis, namely SAW method, in ArcGIS 9.2 of ESRI. The system consists of a section for data preparing and another for data processing. It was tested on an area of Tiaret in Algeria.

2 Methodology

An assessment of suitability for agriculture may be done through overlay operations on numerous multidisciplinary data mainly related to soil, climate and crop. These data can be represented as layers and tables. The spatial aspect of our problem led us to use GIS and spatial analysis. Indeed, GIS are seen as decision support tools for solving territorial

problems. The spatial analysis is a vital part of the GIS and can be used in several applications such as the land suitability for agriculture (Raju, 2003).
Despite their enormous potential, GIS contribute little to solving specific problems of decision-makers. In order to fill these gaps in terms of decision support, other analytic capabilities must be incorporated into GIS (Mendas et al., 2010).

2.1 Spatial analysis and suitability for agriculture

Spatial analysis existed long before the development of GIS. The suitability map for agriculture was usually produced by manual overlay of various criteria maps. As a result of the computer science development, this analysis has been incorporated in GIS. Thus, current GIS are equipped with modules and tools of modeling for improving the decision support process. Some techniques are already implemented and can be used for determining the land suitability for agriculture. These include the computer-aided combination of maps (with multicriteria evaluation) (Malczewski, 2004). It is a method based on the mapping algebra techniques including overlay analysis (Tomlin, 1990). These techniques are often referred to as multicriteria evaluation. They are the most used approaches for assessing the land suitability for agriculture. The user will provide the criteria maps and the constraints maps. Therefore, it was found that SAW is widely used in GIS, but implemented only for raster data. In order to meet our own needs, we implemented a version of this method applicable to vector data. Each land unit will be classified on the basis of its suitability for a particular crop type.
The process to determine land suitability begins by understanding the problem. The capacities of GIS are used to define the potential land units and to identify the full set of criteria. Capabilities of GIS concerning the displaying and the representation of data are used to present the obtained results. The proposed solution is an automation of the main steps to determine the land suitability for agriculture according to the diagram illustrated on Fig. 1.

Fig. 1 Main steps of the drawing up of land suitability map for agriculture.

The particularity of this model lies in the:

1. Determination of land units: to allow the user to specify land units for which will be estimated the suitability for agriculture.
2. Association, to each criterion, of an aggregation rule for overlay: to achieve the spatial joint it is necessary to specify the aggregation rule to be applied on criteria maps.
3. Opportunity to choose among the 85 defined criteria: in order to assess the land suitability for any crop type all possible criteria have been collected. Selections are possible on the criteria during the choice of a particular type of crop.
4. Automation of the definition of classes: the user can define the limits of classes of suitability according to the values of the aggregation result.

Each criterion evaluation takes a value from: 1, 2..., number of classes. 1 being the worst value and Class 1 will be the worst class. But before the user does not define the class boundaries, theoretical limits are proposed using the following rule: the maximum value of suitability that may take a land unit against a given class corresponds to maximum values that can take this unit for each criterion with respect to the same class. For example, if we had four classes and 10 criteria where three criteria are of high importance (3), four criteria are of medium importance (2) and the remaining three criteria are of low importance (1), the theoretical limits will be defined according Fig. 2.

Fig. 2 Example of classification (theoretical limits).

2.2 Concept of the solution

In this study it proved unnecessary to incorporate analysis methods in GIS independently of a special theme. In other words, it would be preferable to implement modules easily integrated in GIS and dedicated to specific applications. These modules will present interfaces that use terms related to the field under consideration. Moreover, they will integrate only the most appropriate analysis methods. The addressed issue is the land suitability for agriculture. The ideal solution would be to incorporate, in a GIS, a module including important classification methods, as well as appropriate analysis methods, independently of data, of the study area or of the crop type. It will represent a spatial decision support system dedicated to the carrying out of land suitability maps for agriculture. In the developed system, the FAO classification method has been implemented for the following main reasons.

1. Simplicity, objectivity and opportunity to develop automated procedures (Delli et al., 1996).
2. The method has been revised to adapt to new technologies: GIS, remote sensing, etc. (FAO, 2007).

3. It takes into account the criteria useful to develop a sustainable agriculture.
4. It is general and independent of the area of interest and land use type.

Simple Additive Weighting method was chosen in this work. It is among the most often used techniques for resolving spatial decision making problems. The decision maker directly assigns weights of relative importance to each attribute. A total score is then obtained for each alternative (land unit) by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. The alternative with the highest overall score is chosen (Malczewski, 1999). According this author, the GIS-based Simple Additive Weighting method involves the following steps:

1 Define the set of criteria and the set of potential alternatives.
2 Standardize each criterion map.
3 Define the criterion weight.
4 Construct the weighted standardized map.
5 Generate the overall score for each alternative.
6 Rank the alternatives according to the overall performance scores.

The SAW method can be supported by any GIS system having overlay capabilities. The overlay techniques allow the aggregation of criterion map to determine the final map. This method can be implemented in raster or vector GIS environments (Malczewski, 1999).

In this study all these approaches (SAW and FAO classification) have been integrated in ArcGIS 9.2 of ESRI (ESRI, 2005) to develop a spatial decision system. This system is independent of the study area and the type of crop.

2.3 Description of the system

Our system consists of two parts. The first is devoted to data preparation and the second is intended to land suitability assessment as illustrated on Fig. 3.

Fig. 3 Main components of the system.

The user can access the ArcMap menu via a button that enables to hide or activate it (Fig. 4). In this way, the user can use all available tools in ArcMap, without cluttering the interface nor misleading uninitiated users. The interface is designed so that the user realizes that he is using a tool conceived for the assessment of land suitability for agriculture and not a simple ArcMap tool.

Fig. 4 Main graphical user interface of the achieved system.

2.4 Data preparation

This part is important insofar as it includes a set of tools to facilitate analysis, on the one hand, and to use some existing data and to adapt them to the project, on the other. Three tools have been developed. These are the tools of proximity, zoning and standardization. The *proximity* tool makes it possible to carry out a map which will be used when the specified criterion is expressed in proximity to specific items as, for example, roads, rivers, etc. This map is produced by a set of buffers associated with specified distances. The *zoning* tool gives the possibility to create shapefiles corresponding to areas that the user has defined, either by specifying already existing areas or by defining himself these areas. Thus, the user will be able to have a clear vision of the area that will be taken into consideration during the assessment. Because of the difficulties encountered during the preparation of project data, we have given thought to a *standardization* tool. On the one hand, it facilitates the data manipulation, and, on the other, it can give the user an overall vision on data and on the spatial distribution of attribute values contained therein. This tool also allows the establishment of the constraints map. The user will have to choose criteria deemed useful to assess the suitability for a particular type of crop. In this way the application will be conducted for any type of crop. Here weights recommended by FAO (FAO, 1977) (3 for very important; 2 for moderately important; 1 for unimportant) are taken into account. The 85 criteria are regrouped according to the 32 factors and the five categories defined by FAO (FAO, 1989).

2.5 Determination of land suitability

That consists of specifying (i) the title of the suitability map and (ii) land units for which will be conducted the assessment. There should be a field containing the constraints value (0 or 1). The value 0 corresponds to land units not used for agriculture. The value 1 corresponds to efficient land units that can be grown and (iii) the number of classes that must be greater than or equal to 2. In our case, according to the FAO guide (FAO, 1977) we have 4 classes (S1: very suitable, S2: moderately suitable, S3: marginally suitable and N: not suitable). A fifth class corresponds to units outside assessment. The user can choose between legends random or in line with those defined for the final map. The analysis by the SAW method incorporated into the ArcGIS software is coherent with the methodology set out in the FAO guide (FAO, 1977). Legends corresponding to predefined classes are associated for each criterion.

The user will subsequently indicate data of criteria maps and fields containing their assessment. Then, he should follow the below steps.

1. Data overlay whose main purpose is to recover land units assessments for every chosen criterion. A spatial joint is carried out between layers according to the scheme illustrated in Fig. 5.

Fig. 5 Overlay operations.

2. Data aggregation by the algorithm most used in GIS namely the weighted sum (SAW). But this algorithm is applicable only on raster data creating land units with no meaning. However, our problem requires the determination of suitability for land units well delineated. This led us to propose a version of this algorithm applicable to vector data, especially to polygons.
3. Classification of land units. The user must first specify the limits of his classes. Here the maximum number of classes is limited to 7. To define his classes, the user must specify their lower limits. The interface for determining classes is designed so that the user should have an idea about the extent of each class. It also informs him on the minimum and maximum value of the aggregation. A legend is defined.
4. By taking into account the constraints field (value 0 and 1) we will obtain the final map which initially involved all land units.

Our system consists of two parts. The first is devoted to data preparation and the second is intended to land suitability assessment as illustrated on Fig. 3.

3 Application and results

3.1 Problematic situation

About the plight of agriculture Algeria decided in 2000 to establish a plan to revive this sector. This is the national plan of agricultural development (PNDA) that became in 2002 the national plan of agricultural and rural development (PNDAR). The plan aims to adapt production systems to physical and climatic conditions of various production areas. However, the classification of agricultural lands is one of the priority actions initiated by the plan. The investment operation for this project aims to carry out some tools, including the agricultural lands potentialities map, indispensable to the decision making in the field of affectation, use, exploitation, management, protection and preservation of agricultural lands (INSID, 2005). The sustainable agriculture concept involves a quality production in a supportive environment, socially acceptable and economically efficient, i.e. an optimum use of available natural resources for an efficient agricultural production. To satisfy these principles, we should grow crops where they are best suited and for which the first and most important condition is to conduct land suitability studies. In order to test the developed system, the region of Tiaret in Algeria (Fig. 6) has been chosen for the simple reason that it was already used in a project of carrying out of the suitability map for the durum wheat agriculture using the classification method of FAO (SGIIAR, 2000).

Fig. 6 Situation of study area.

3.2 Land units and constraints

Here, each land unit represents an alternative. The land units map (147 units) has been obtained by digitizing. However, to carry out our application, global data (either at a national scale or at a worldwide scale) have been used. The constraints map was produced from the map of land use types. It is obtained by adding a field to the associated attribute table that contains the value 1 for the selected land types and 0 for eliminated types. It first speeds up the processing and, secondly, facilitates the interpretation of outcomes. Indeed, units of value 0 in the added field are directly eliminated and assigned to the outside assessment class.

3.3 Identification of criteria

The main criteria necessary to establish the suitability map for agriculture are deducted from (i) agronomic factors, (ii) planning, (iii) land enhancement and improvement, (iv) soil conservation and environment protection and (v) socio-economic conditions (FAO, 1989).

On the basis of these factors we identified 11 criteria (necessary for durum wheat), to which we added the two criteria of proximity and availability of labour. These 13 criteria are regrouped in Table 1 according to the corresponding data source.

Table 1 Main used criteria.

Each criterion is represented as a "criteria map". Criteria maps, particularly those related to soil, were obtained by performing a number of operations.

1. By applying the zoning tool on the global soil map we obtained the one the region of Tiaret.
2. The information on the soil map, necessary to our study, are available in an ACCESS database containing also associated meta-data. They were translated into attribute tables of criteria maps related to soil.
3. For all criteria maps, we used the standardization and the proximity tools to identify the final data to be used for the application.

3.4 Results and discussion

Once data are prepared, the necessary parameters to operate the system have been defined as land units, criteria and criteria maps. The implementation of the achieved system has led to the map shown in Fig 7. The outcome of this procedure has more correspondence (more than 50% of correspondence) with the result obtained by the study conducted by FAO (SGIIAR, 2000). This rate may be explained by the limited number of used criteria, because of the problem of availability and quality of used data. Therefore, it would suffice to have all reliable and necessary data relating to the case study if better outcomes were to be expected. These data are easily introduced in the system and can be updated in any time if necessary.

Fig. 7 Suitability map for durum wheat agriculture in the region of Tiaret (ELECTRE Tri method).

It is clear that this map does not represent a definitive result of the suitability. By the way, it is the very principle of the spatial decision support. We don't take a decision instead of the decision-maker, but we provide him the necessary elements in order to make his own choices. However, it must be recognized that the SAW method provides more accurate and better results than those obtained by the classic method if all necessary data are available.

The SAW method is easier to use and requires few parameters for its execution. But it should be recognised that it is more sensitive to the data. As for the limits of classes, they depend solely on the user. It should be remembered that in this application, we have considered only the four classes: S1, S2, S3, N and a fifth class corresponding to units outside assessment. The subclasses were not taken into consideration. All criteria have been deducted from FAO guide (FAO, 1977). Each criterion is unique to eliminate the redundancies. Among the 85 criteria previously identified, only 13 criteria inherent to durum wheat were used. The importance of the criteria was taken into account. Through this application, we have not tried to identify the most appropriate type of land use, but rather to assess the suitability of land units for the cultivation of durum wheat. The classification result was presented as a suitability map.

The consistency of the outcomes reproduced here increases the degree of confidence of the decision-makers and affirms the efficiency of the used method. In this context, we also note that results obtained in this study come closest to conclusions presented by the study conducted by FAO. With a GIS, such information may be made available in a format that will be easily interpreted, can be interactively displayed, and is amenable to many types of data processing, which subsequently enables updating. The saving time during the carrying out of the land suitability map for the agriculture of the durum wheat was considerable.

4 Conclusion

This paper studied the interest and problems related to the determination of land suitability for agriculture. The most adequate solutions based on modern approaches were then to be proposed. Spatial and multicriteria aspects of the studied problem led us to develop a spatial decision support system. This system incorporates a weighting method (SAW) in ArcGIS. It is a method based on the concept of the weighted sum intended to vector data and consists in classifying land units in accordance with the defined criteria and their importance as well as the limits predefined by users. This method is easily adapted to the classification mode used by FAO and retained in this research. But its use requires a good understanding of the problem, on the one hand, and data availability, on the other hand. However, this approach uses the concepts of spatial analysis whether in the preparatory phase of data or during processing and aggregation procedures of evaluations and preferences of decision-makers. The developed system is of a special importance insofar as it integrates GIS functionalities and a weighted sum method in a single framework. It includes the 85 criteria of land assessment for agriculture established by FAO and all parameters needed to data aggregation. It is general and does not depend on the study area or crop type. The exploitation of graphical display potentialities of this system provides the decision maker with information increasingly richer and easier to grasp. All land units were assigned to five categories (S1, S2, S3, N and outside assessment). Through the obtained

results, it appears that the SAW method, integrated into ArcGIS 9.2 of ESRI, is better suited to the problem of land suitability for agriculture. The power of this method lies in the aggregation mode of decision-maker preferences and in the ranking and assignment of land units in accordance with predefined classes. It is true that the definitive decision is also the outcome of other processes, such as the political strategies which can not be formalized, but the scientific identification of land suitable for a particular cultivation is an important aid to the decision making. It should be pointed out that in practice a good assessment of the land suitability for agriculture requires the availability of multidisciplinary data. Finally, this technology based on the combination of GIS, spatial analysis and other methods of analysis has proved its worth in geographical problem solving in developed countries. Thus, its use by concerned services in Algeria is desirable or even necessary due to its multiple advantages.
The work currently being carried out is aimed at integrating other multicriteria analysis methods for decision making to give more finesse to the expected outcomes. We are also proposing to give the user the possibility to manipulate, in the system, data in raster or vector format.

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FIGURE CAPTIONS

Fig. 1 Main steps of the drawing up of land suitability map for agriculture.

Fig. 2 Example of classification (theoretical limits).

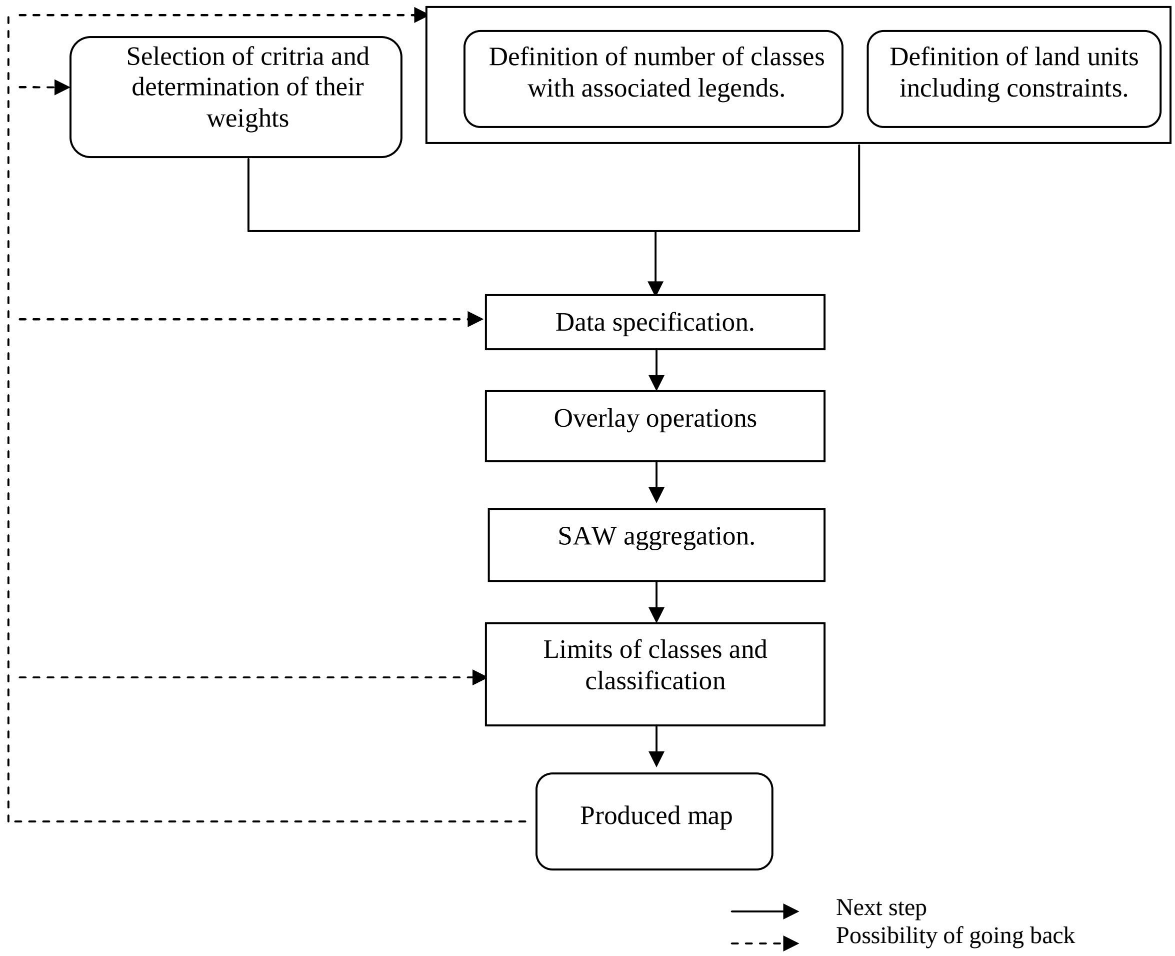
Fig. 3 Main components of the system.

Fig. 4 Main graphical user interface of the achieved system.

Fig. 5 Overlay operations.

Fig. 6 Situation of study area.

Fig. 7 Land suitability map for durum wheat agriculture in the region of Tiaret (ELECTRE Tri method).



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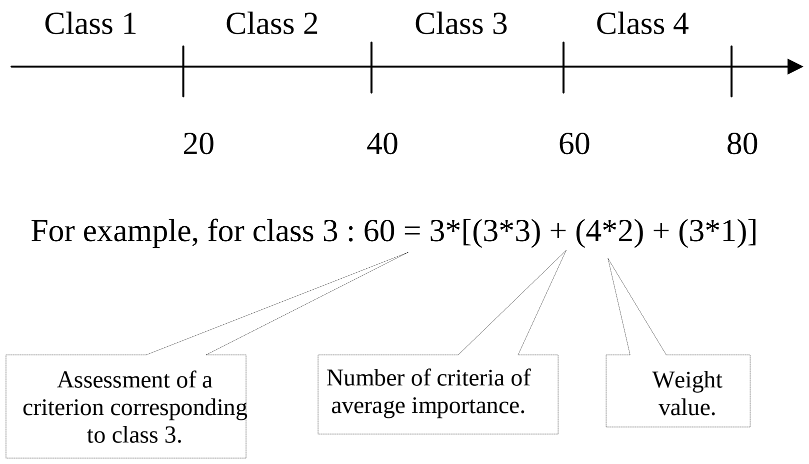

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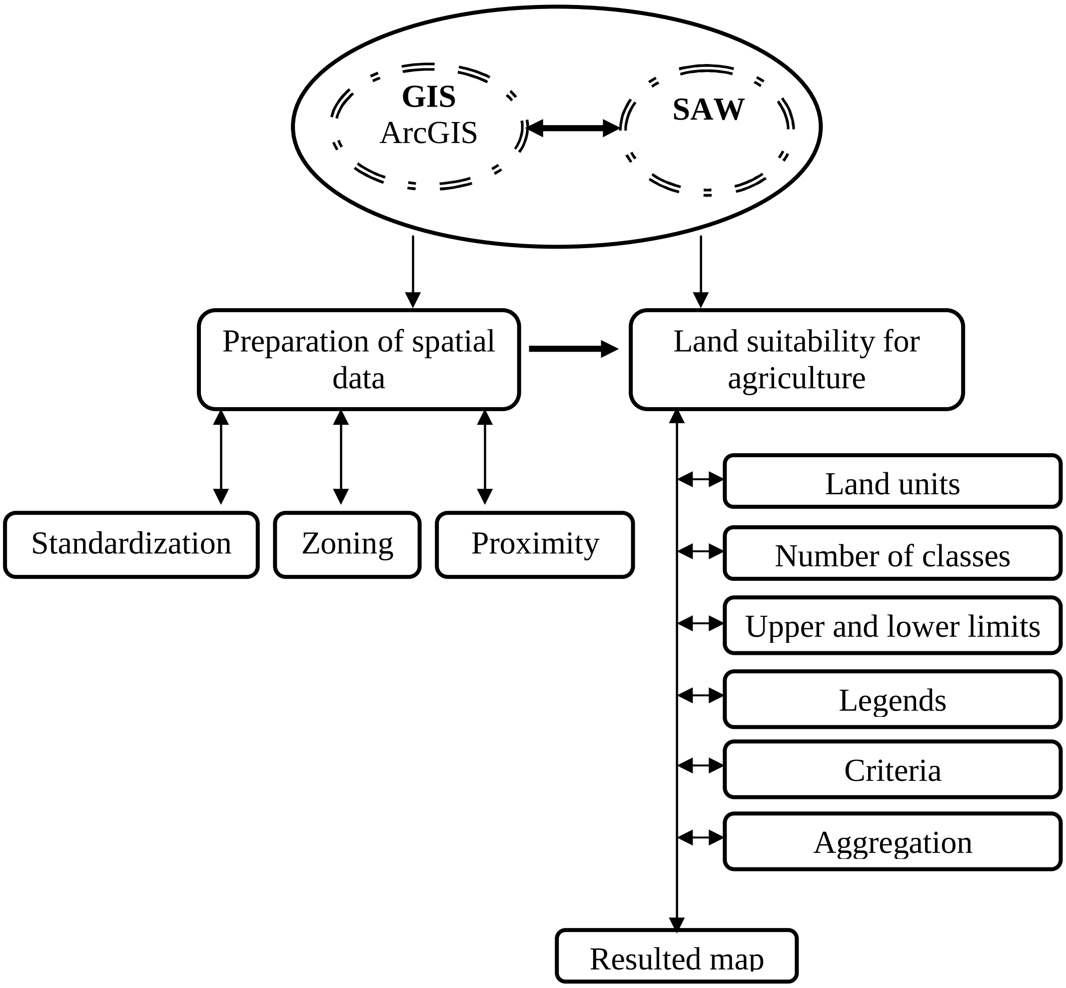

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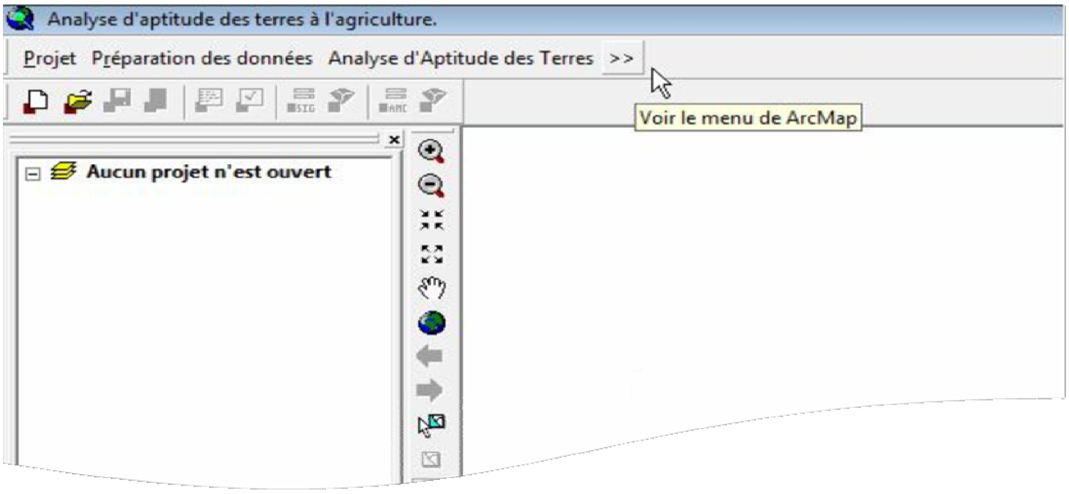

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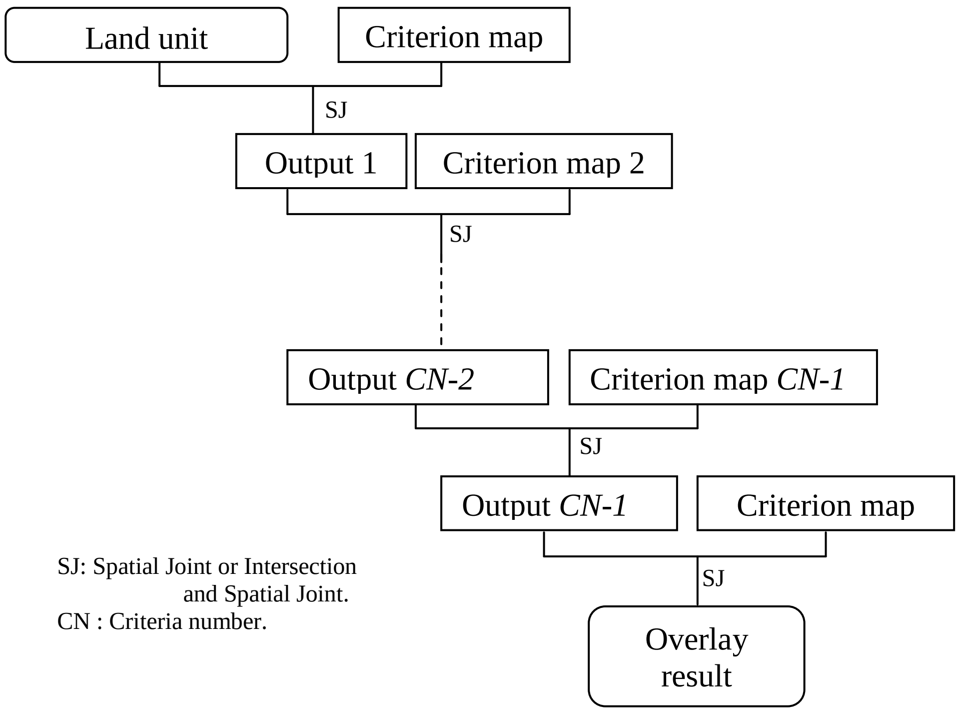
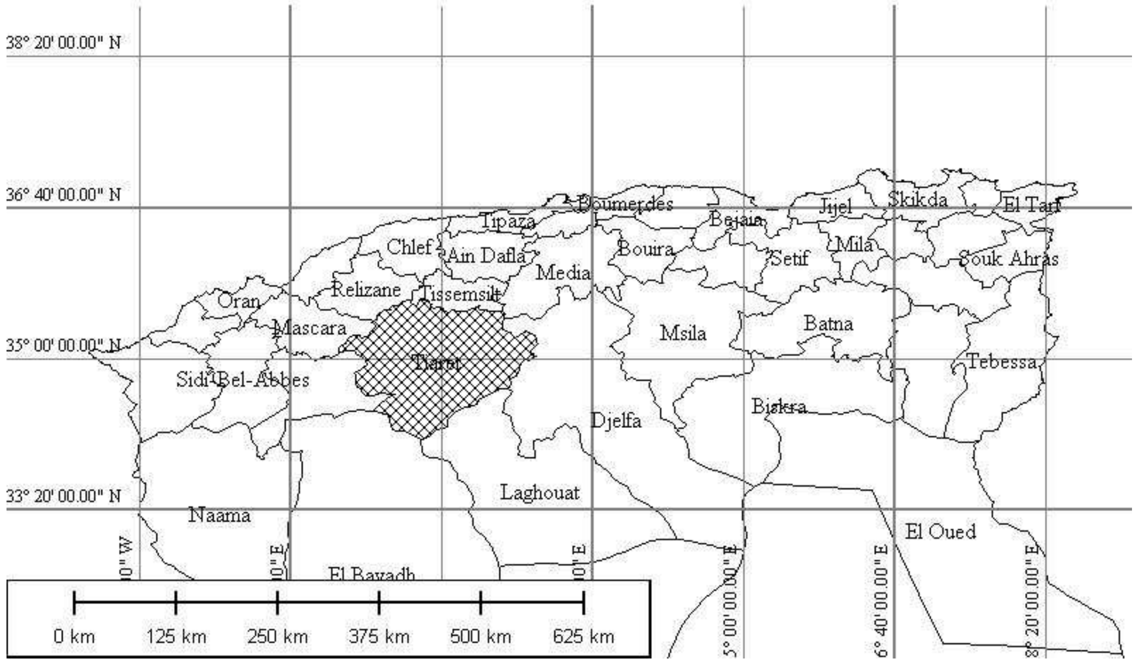


Fig. 5 Overlay operations.



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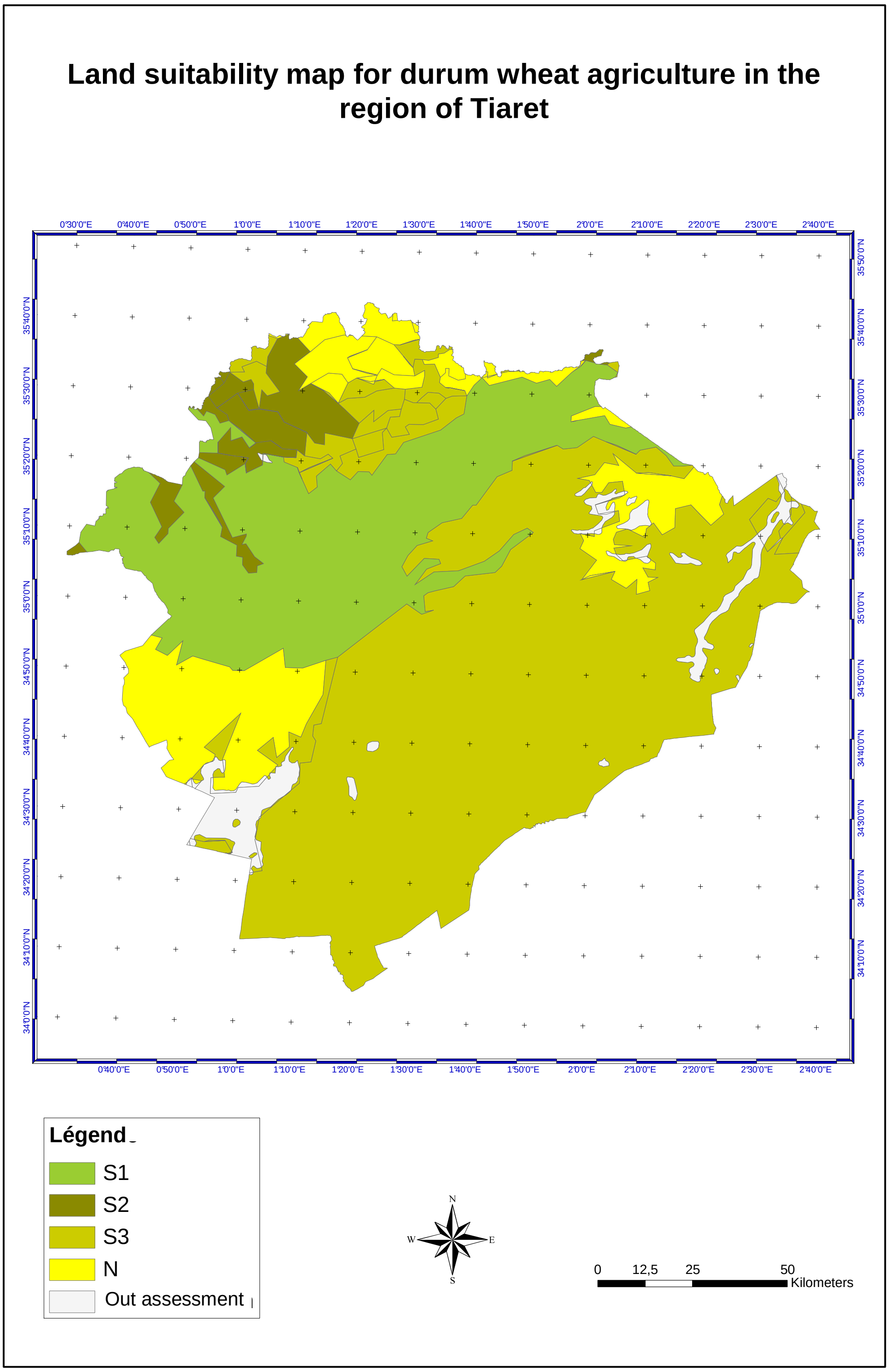

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TABLES

Table 1 Main used criteria.

Criteria	Data source
CEC	Global database of soils (www.gadm.org). Data in raster model have been translated to vector model. Data of the region of Tiaret have been extracted from administrative apportionment map of Algeria.
Soil water	
Soil useful depth	
CACO3	
Sodicity	
Drainage	
Organic matter	
Salinity	
Availability of labour	World population map (www.diva-gis.org).
Slope	Aster GDEM by using ArcGIS (www.gdem.aster.ersdac.or.jp).
Services (roads)	Topographical map on a scale of 1/25 000.
Rainfall	National Agency of Water Resources (ANRH, Algeria).
Temperature	