Paper

Site selection for waste disposal through spatial multiple criteria decision analysis

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Abstract—This article deals with the application of spatial multiple criteria evaluation (SMCE) concepts and methods to support identification and selection of proper sites for waste disposal. The process makes use of a recently developed SMCE module, integrated into ITC's[1] existing geographic information system called ILWIS. This module supports application of SMCE in planning and decision making processes through several compensatory and non-compensatory approaches, allowing inclusion of the spatial and thematic priority of decision makers. To demonstrate the process, a landfill site selection problem around the town of Chinchina, in Colombia, is used as an example. Based on different objectives, a spatial data set consisting of several map layers, e.g., land use, geological, landslide distribution, etc., is made available and used for modeling the site selection process.

Keywords*—*SMCE, geographic information systems, planning, decision-making, site selection.

1. Introduction

There are four analytical function groups present in most geographic information systems (GIS) models: selection, manipulation, exploration and confirmation. Selection involves the query or extraction of data from the thematic or spatial databases. Manipulation entails transformation, partitioning, generalization, aggregation, overlay and interpolation procedures. Selection and manipulation in combination with visualization can be powerful analysis tools. Data exploration encompasses those methods which try to obtain insight into trends, spatial outliers, patterns and associations in data without having a preconceived theoretical notion about which relations are to be expected [1, 2]. The data driven approach, sometimes called data mining, is considered very promising, due to the fact that theory in general in many disciplines is poor and moreover, spatial data is becoming increasingly available (rapid move from a data poor environment to a data rich environment).

Confirmative analysis, however is based on a priori hypothesis of spatial relations, which are expected and formulated in theories, models and statistical relations (technique driven). Confirmative spatial methods and techniques originate from different disciplines like operation research, social geography, economic models and environmental sciences. The four analytical functions can be considered as a logical sequence of spatial analysis. Further integration of the maps/results from spatial analysis is an important next step to support decision-making, which is called evaluation [2]. The lack of enough functionality especially in exploitative and confirmative analysis and evaluation in GIS packages has been the topic of many debates in the scientific communities and as a result techniques to support these steps have gained more attention. In this context several studies have demonstrated the usefulness of integrating multi-criteria decision analysis techniques with GIS in a user-friendly environment. However, there is a trade-off between efficiency, ease of use, and flexibility of the system. The more options are predetermined and available from the menu of choices, the more defaults are provided, the easier it becomes to use a system for a progressively small set of tasks.

In this context, a spatial multiple criteria evaluation (SMCE) module has been developed and integrated in a user-friendly environment into ITC's existing geographic information system called ILWIS. This module supports the implementation of framework for the planning and the decision making process as described by [3] and includes several compensatory and non-compensatory approaches, enhancing the spatial data analysis capability of GIS to support planning and decision-making processes. This article tries to demonstrate this capability in a site selection process for waste disposal in Chinchina, located in the Central Cordillera of the Andes in Colombia (South America).

2. Theoretical framework

2.1. Spatial multiple criteria evaluation

Conventional multi-criteria decision making (MCDM) techniques have largely been non-spatial. They use average or total impacts that are deemed appropriate for the entire area under consideration [4]. The assumption that the study area is spatially homogenous is rather unrealistic because in many cases evaluation criteria vary across space. The most significant difference between spatial multi-criteria decision analysis and the conventional multi-criteria decision analysis is the explicit presence of a spatial component. Spatial multi-criteria decision analysis therefore requires data on the geographical locations of alternatives and/or geographical data on criterion values. To obtain information for the decision making process the data are processed using both MCDM and GIS techniques.

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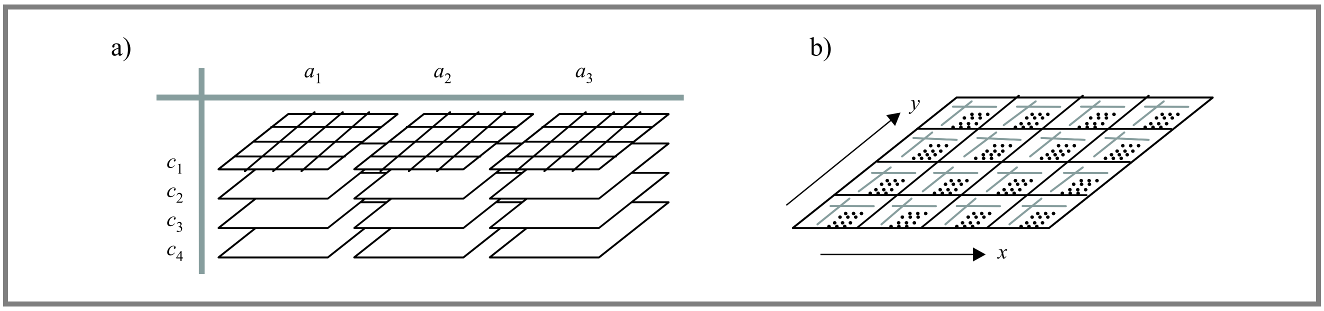

Fig. 1. Two interpretations of a 2-dimensional decision problem (a) table of maps; (b) map of tables.

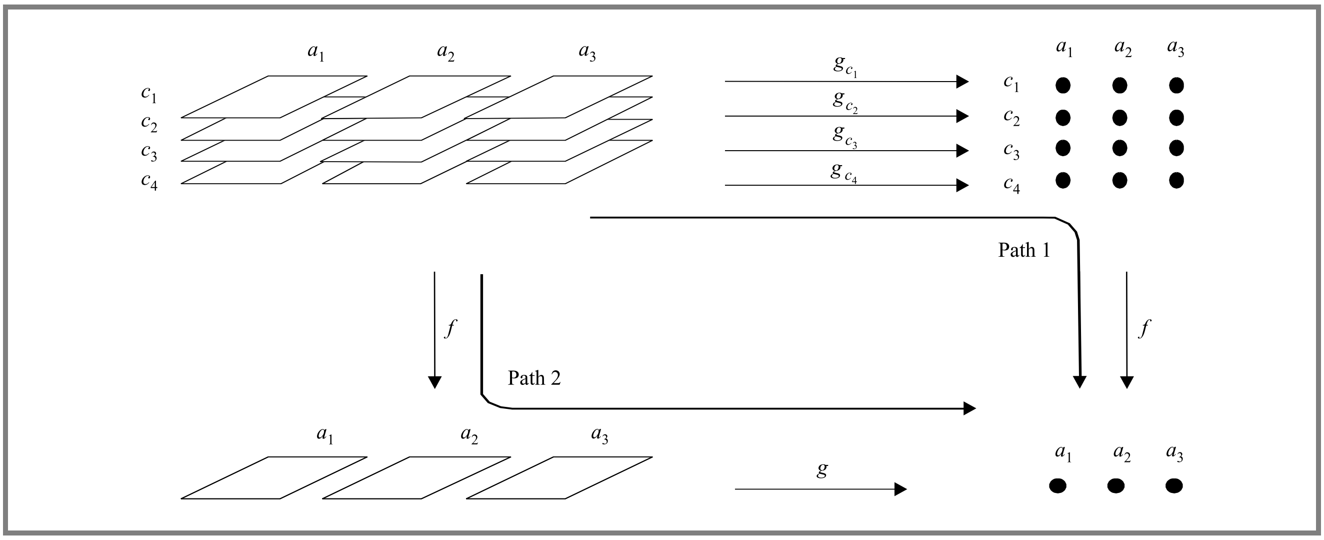

Fig. 2. Two paths of spatial multi-criteria evaluation.

Spatial multi-criteria decision analysis is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. In this process multidimensional geographical data and information can be aggregated into one-dimensional values for the alternatives. The difference with conventional multi-criteria decision analysis is the large number of factors necessary to identify and consider, and, the extent of the interrelationships among these factors. These factors make spatial multi-criteria decision analysis much more complex and difficult [5]. GIS and MCDM are tools that can support the decision makers in achieving greater effectiveness and efficiency in the spatial decision-making process. The combination of multi-criteria evaluation methods and spatial analysis is referred as spatial multiple criteria evaluation. SMCE is an important way to produce policy relevant information about spatial decision problems to decision makers.

An SMCE problem can be visualized as an evaluation table of maps or as a map of evaluation tables as shown in Fig. 1 [6].

If the objective of the evaluation is to rank all alternatives, the evaluation table of maps has to be transformed into a single final ranking of alternatives. Actually, the function has to aggregate not only the effects but also the spatial component. To define such a function is rather complicated. Therefore, the function is simplified by dividing it into two operations: 1) aggregation of the spatial component and 2) aggregation of the criteria. These two operations can be carried out in different orders, which are visualized in Fig. 2 as Path 1 and Path 2. The distinguishing feature of these two paths is the order in which aggregation takes place. In the first path, the first step is aggregation across spatial units (here spatial analysis is the principal tool); the second step is aggregation across criteria, with multi-criteria analysis playing the main role. In the second path these steps are taken in reverse order. In the first case, the effect of one alternative for one criterion is a map. This case can be used when evaluating the spatial evaluation problem using so called Path 1. In the second case, every location has its own 0-dimensional problem and can best be used when evaluating the spatial problem using the so called Path 2 (Fig. 2).

2.2. SMCE and integrated planning and decision support system

Advances in information technology and remote sensing have provided extensive information on processes that are taking place on the earth's surface, much of which is organized in computer systems, some is freely available and other is accessible at an affordable price. Research in disciplinary sciences has also produced insight into many physical and socio-economic processes. Yet much of the existing information and knowledge is not used to support better management of our resources. Geo-information technology has offered appropriate technology for data collection from the earth's surface, information extraction, data management, routine manipulation and visualization, but it lacks well-developed, analytical capabilities to support decision-making processes. For improved decision-making, all these techniques, models and decision-making procedures have to become integrated in an information processing system called integrated planning and decision support system (IPDSS). The heart of an IPDSS as defined by [7] is model based management, which includes quantitative and qualitative models that support resource analysis, assessment of potential and capacity of resources at different levels of management. This is the most important component of the system, which forms the foundation of model-based planning support [8]. It includes three classes of models, which make use of existing data, information and knowledge for identification of a problem, formulation, evaluation and selection of a proper solution. These models are:

- A process/behavioural model describing the existing functional and structural relationships among elements of the planning environment to help analysing and assessing the actual state of the system and identify the existing problems or opportunities. This also supports "resource analysis", which clarifies the fundamental characteristics of land/resources and helps understanding the process through which they are allocated and utilized [8, 9].
- A planning model, which integrates potential and capacity of resources (biophysical), socio-economic information, goals, objectives, and concerns of the different stakeholders to simulate the behaviour of the system. Conducting experimentation with such a model helps understanding the behaviour of the system and allows generation of alternative options/solutions to address the existing problems.
- An evaluation model, which allows evaluation of impacts of various options/solutions and supports selection of the most acceptable solution, which is acceptable to all stakeholders, and improves the management and operation of the system.

Spatial multiple criteria evaluation can play a very important role in the development and application of above models. In the process/behavioural model it will help to assess the current state of the system. Today, sustainability assessment of the resource management is one of the very critical issues in the management science. There is great interest to assess sustainability of agricultural development, sustainability of forest management, sustainability of cities, etc. What is sustainable management and how it can be assessed and improved is, however a very important research question in many cases.

Spatial multiple criteria evaluation can also be applied in the evaluation and planning model. In the evaluation it will allow assessment and multiple criteria evaluation of several options/alternatives in order to help understanding their impacts, pros and cons, their related trade-offs and the overall attractiveness of each option or alternative. Here the alternatives have specified locations (boundaries) and their performance on each criterion can be represented by a separate map (more than one-dimensional table of maps). This type of analysis is based on the multiple attribute decision analysis techniques [6]. In the planning model, it can help to formulate/develop alternative options. Here, in the planning process alternatives are formed out of pixels of one map. The types of analysis that are applied here, are based on the multiple objective decision analysis techniques [6]. In this process, the whole decision space is divided in two sets, mainly the efficient and non-efficient ones, which are then used for proper design of alternatives. A good example of SMCE application in planning and decision models is site selection, which will be demonstrated through a case study explained in the following sections of this article.

3. Case study

In this chapter, a case study on selection of a waste disposal site is carried out in order to demonstrate some of the capabilities of SMCE as implemented in the ILWIS GIS.

3.1. Problem definition

The municipality of the town of Chinchina, located in the Central Cordillera of the Andes in Colombia (South America), wants to investigate areas suitable for waste disposal. Up till today all the garbage from the city of 150 000 inhabitants is dumped in a river. However, due to an increase in environmental awareness, the municipality of Chinchina has decided to construct a proper waste disposal site. For this purpose, assistance from the regional planning department has been requested. The planning department forms a team, consisting of a geologist, a geomorphologist, a hydrologist and an engineer.

After a one-month period in which field studies were conducted and multidisciplinary plenary meetings were held, the team submitted a report to the municipality, in which the following criteria in selecting areas suitable for waste disposal were considered:

Biophysical criteria

Constraints[2]

- The waste disposal site cannot be built on landslides which are active or may become active in the future.

[2]Constraints are binding criteria (no compensation is allowed).

- The waste disposal site can only be constructed in areas which do not have an important economic or ecological value.
- Areas should have sufficient size/capacity (at least 1 hectare) to be used as a waste disposal site for a prolonged time.

Factors[3]

- The waste disposal site should preferably be constructed on areas with no landslides.
- The waste disposal site should preferably be constructed on areas with the least important economic or ecological value.
- The waste disposal site should preferably be located on a terrain with a slope less than 20 degrees.
- The waste disposal site should preferably be located within 2 km from the city limits of Chinchina.
- The waste disposal site should preferably be located at least 300 meters from any existing built-up area.
- The waste disposal site should be constructed on clay-rich soils (preferably more than 50% clay).
- The waste disposal site should have a high soil thickness.
- The waste disposal site's soil should have a very low permeability (preferably 0.05 meters per day or less).

Socio-economic criteria (*factors*)

- The overall site transportation costs should be as low as possible.
- Once a waste disposal site is introduced, the land value of the surroundings and other locations will change. The negative effect on the land value should, if possible, be minimized for land that currently has a significant value.
- Once a waste disposal site is introduced, the pollution of the surroundings and other locations will change. The effect on the pollution should be as low as possible to locations that are sensitive to it.

The following digital raster maps were made available to be used for analysis of the biophysical criteria:

- "Slide": a map whereby each pixel is classified in one of four classes: 'no landslide', 'stable', 'dormant' and 'active'.
- "Landuse": a map whereby each pixel is classified in one of eight classes: 'built-up area', 'coffee', 'shrubs', 'forest', 'pasture', 'bare', 'riverbed', 'lake'.

[3]Factors are non-binding and are considered as preferred situations that can compensate each other.

- "Slope": a map whereby for each pixel the average slope of the corresponding area is stored, as a numerical value (in degrees).
- "Geol": a geological map of the area with several attributes, one of them being the geological class, another the average clay thickness, another the average clay percentage, and another the average permeability.
- "Distance_from_city": a map whereby for each pixel its distance from the nearest point of the city of Chinchina is stored, as a numerical value (in meters).
- "Distance_from_built_up": a map whereby for each pixel its distance from the nearest built-up area is stored, as a numerical value (in meters).

Maps for the socio-economic criteria are not yet available. They can only be produced for a potential site.

3.2. Site selection process

The site selection process is carried out in two phases: in phase one, SMCE is applied in order to identify (design) potential areas, which are biophysically suitable for waste disposal. In the next phase, SMCE is applied to compare/evaluate potential sites considering their socio-economic and biophysical characteristics in order to make the final recommendation (choice of a solution). The socio-economic characteristics reflect the impact of a site on several spatial (and sometimes non-spatial) aspects. They can only be assessed for a potential site, which is why they cannot be used as a criterion in the design phase. In the choice phase of the site selection process, the suitability of each site, which is identified as a potential site in the first phase, will be assessed by means of SMCE, considering socio-economic factors. Figure 3 presents the site selection process.

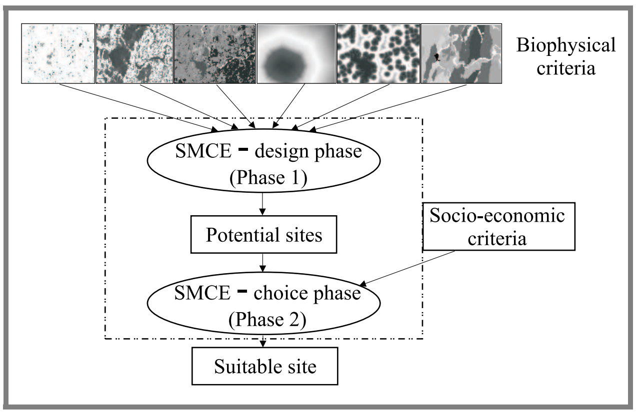

Fig. 3. Flowchart for the entire site selection process. Due to printing limitations, original color maps had to be converted to black and white, with loss of some detail.

3.3. SMCE application in identifying potential sites (Phase 1—design)

In this phase, SMCE is used as a basis for a planning model, which can support development/design of alternative solutions. Here each point/pixel in the map (area of interest) is considered as a potential element of a site. Therefore their related quality and characteristics are evaluated through SMCE (map of tables). This process is implemented through the following main steps (Fig. 4):

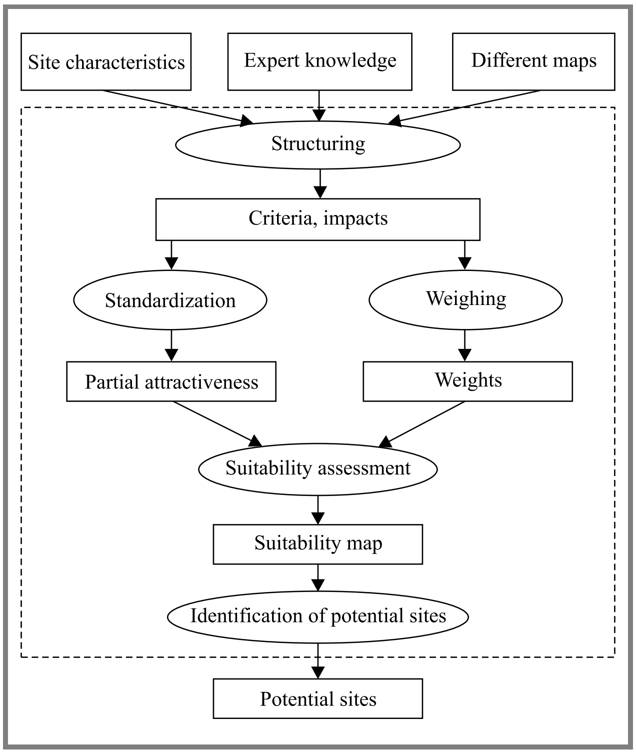

Fig. 4. Flowchart for the SMCE design phase, which results in selection of potential sites.

1. Problem structuring, which leads to identification of the main criteria that should be considered absolutely necessary as well as those that are preferable. Naturally, the information related to those criteria has to be collected and presented in the proper format.
2. Identification of the relevant transformation functions that convert the facts (data) related to each selected criterion to a value judgment, the so-called "utility". This process identifies the partial attractiveness of the region of interest for a site with respect to each criterion.
3. Identification of the relative importance of each criterion with respect to the others, in order to find the level of contribution of each criterion into the achievement of its related objectives (weight assessment).
4. Assessment of the overall attractiveness of every point in the map (pixel) applying the proper decision rule.
5. Formation of the potential sites by connecting the suitable points (pixels) in order to design potential sites with the required size and capacity.

Above steps are explained in the following paragraphs.

3.3.1. Structuring

Structuring in SMCE refers to the identification of alternatives, criteria that are used for their assessment, together with measurement or assessment of the performance of each alternative with respect to each criterion "impact" or "effect". In the same way here structuring refers to identification of the biophysical quality and quantity of site-characteristics, and their relationships, which should be considered in the determination of sites for suitable waste disposal. The relationships between the site characteristics/criteria are established by development of a so-called "criteria tree", which considers all the relevant criteria and groups them in clusters of comparable criteria that are forming a specific quality of the potential sites. Next, a map representing land quality in the area of interest is prepared.
In the SMCE module implementation in ILWIS this process is greatly facilitated through development of the criteria tree structure. The leaves of the tree are indicators that are represented by separate maps. The related map will eventually be assigned to each leaf in the tree. As was mentioned earlier, some of the criteria are binding and act as constraints (can not be compensated) and some act as factors that can be compensated. These are presented in Fig. 5, which presents the criteria tree of the case.

3.3.2. Partial valuation (standardization)

In Fig. 5, at the leaves of the criteria tree, each criterion is represented by a map of a different type, such as a classified map (forest, agriculture, etc.) or a value map (slope, elevation, etc.). For decision analysis the values and classes of all the maps should be converted into a common scale, which is called "utility". Utility is a measure of appreciation of the decision maker with respect to a particular criterion, and relates to its value/worth (measured in a scale 0 to 1). Such a transformation is commonly referred as "standardization".
Different standardization is applied to each different type of maps:

- For "value maps", standardization is done by choosing the proper transformation function from a set of linear and nonlinear functions. The outcome of the function is always a value between 0 and 1. The function is chosen in such a way that pixels in a map that are highly suitable for achieving the objective result in high standardized values, and unsuitable pixels receive low values. ILWIS' SMCE module provides a number of linear and nonlinear functions. Possible standardization methods for value maps in the

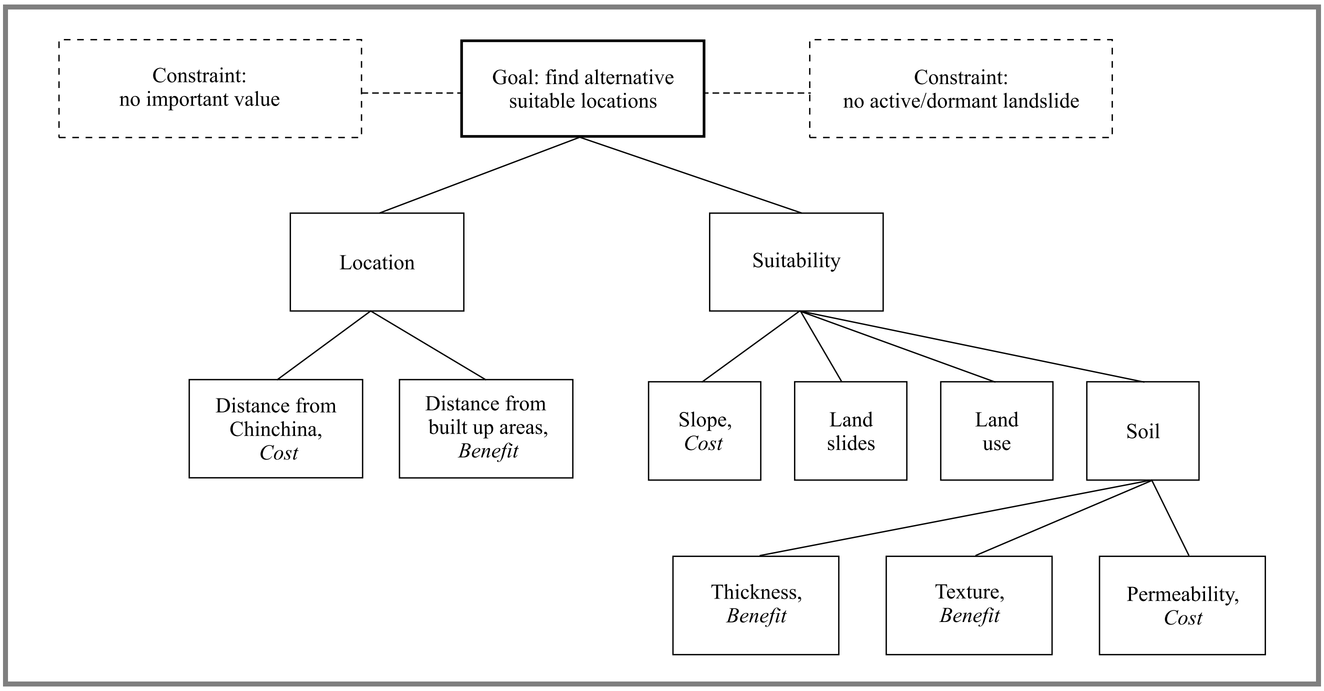

Fig. 5. Criteria tree for identifying the potential site for waste disposal.

developed SMCE module are, e.g., "Maximum", "Interval" and "Goal". Together with the "cost/benefit" property of the criterion, this information is sufficient for applying the selected standardization method in the correct way.

- For "classified maps", standardization is done by matching a value between 0 and 1 to each class in the map. This can be done directly, but also by pair wise comparing or rank-ordering the classes.

3.3.3. Weighing

The next step in SMCE is the identification of the relative importance of each indicator, the so-called weights. ILWIS' SMCE module provides support for a number of techniques (direct, pair wise comparison and rank-ordering) that allow elicitation of weights in a user-friendly fashion, at any level and for every group in the criteria tree. The criteria tree designed in the first step enables giving weights to a few factors at a time, as the branches of one group only are compared to each other. Starting, e.g., with the group "Soil", the factors "Thickness", "Texture" and "Permeability" are compared to each other and a weight is assigned to them. Factors are always weighed, but for constraints there is no weight involved, because they simply mask out the areas which are not interesting.

3.3.4. Suitability assessment/derivation of overall attractiveness

After partial valuation and identification of the relative importance of each criterion in the site selection process, the next step is to obtain the overall attractiveness (suitability) of each point (pixel) in the map (composite index map) for waste disposal. For this process, ILWIS' SMCE module supports several techniques. One of the most transparent and understandable techniques is the weighted summation that is implemented in a user-friendly fashion at each level, for every group of indicators. For the waste disposal criteria tree, starting at the beginning of the tree, a weighted sum formula is written out based on the two first level groups:

$\texttt{suitability\_map} = \texttt{w}_1\texttt{*Location} + \texttt{w}_2\texttt{*Suitability}$

Here $\texttt{w}_1$ and $\texttt{w}_2$ are the weights that were produced in the weighing process.

Then, recursively, the groups are substituted by the formula that will generate them from their components, which results in the following:

$\texttt{suitability\_map} =$
$\texttt{w}_1\texttt{*(w}_{11}\texttt{*Distance\_from\_Chinchina} + \texttt{w}_{12}\texttt{*Distance\_from\_builtup\_areas)} + \texttt{w}_2\texttt{*(w}_{21}\texttt{*Slope} + \texttt{w}_{22}\texttt{*Land\_slides} + \texttt{w}_{23}\texttt{*Land\_use} + \texttt{w}_{24}\texttt{*Soil)}$

Here, `Distance_from_Chinchina`, `Distance_from_builtup_areas`, `Slope`, etc. represent the "standardized" version of the corresponding maps.

Substituting the group "Soil" will make the formula even longer.

At the end, the "standardized" maps are written in terms of the original maps and the corresponding value function that will standardize them.

In the developed SMCE module, it is a one step process (single mouse-click) to produce the formula that corresponds to the criteria tree and execute it in order to generate the composite index map named `suitability_map`. Although not explicitly mentioned, the constraints are also taken care of in this formula.

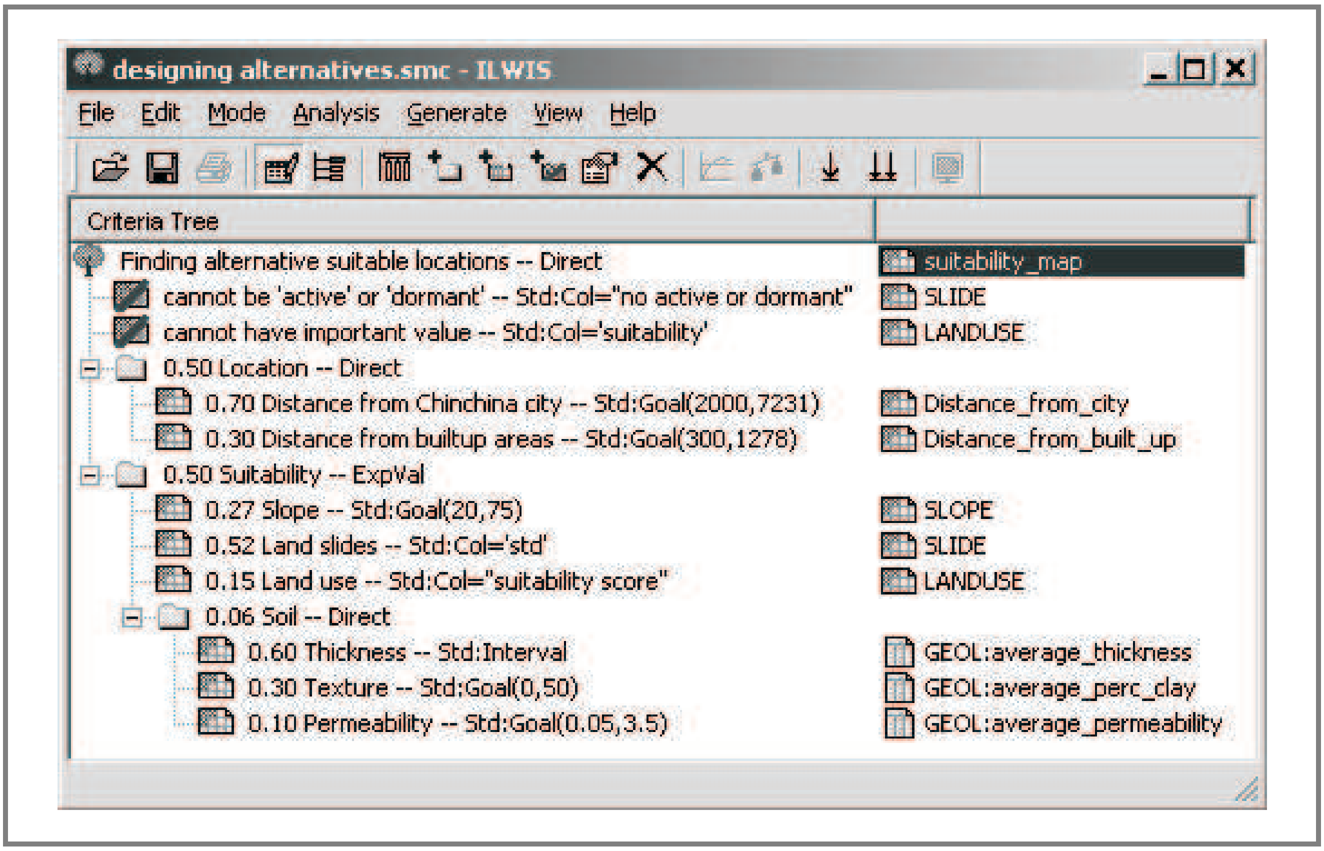

Fig. 6. Criteria tree for identifying suitable waste disposal sites in the SMCE module.

3.3.5. Identification of potential sites

The resulting suitability map for waste disposal is showing the overall attractiveness of each point (pixel) presented in the scale between 0 and 1 for the whole area of interest. In this map each map element (pixel) is 156 m^2 (12.5×12.5 m) with a composite index between 0 and 1. The higher the index, the more suitable the land is. Based on expert knowledge the potential site should have an area of at least 10 000 m^2, corresponding to at least 64 connected pixels. To identify the most suitable locations with sufficient capacity (size) the following steps are implemented:

1. By setting a threshold on the suitability index, the whole area is classified to the classes "suitable" and "unsuitable". This will generate a map with several "suitable" sites.

2. From the "suitable" sites, the ones with sufficient capacity are identified. The "minimum area" (in m^2) required for a site is considered here.

The threshold on the suitability index mentioned in Step 1 is found by trial and error, so that a reasonable number of candidate sites can be designed.
The result of this process is the final output of the design phase: the "potential sites" which satisfy the biophysical factors as good as possible, and have sufficient capacity for being used as a waste disposal site for a longer period.

3.3.6. Practical use of the developed SMCE module in the design phase

Structuring the criteria to determine their impact by setting the relation between factors, constraints and the objective, standardizing and weighing and finally performing the weighted summation is integrated into a few easy steps with the SMCE module developed. Figure 6 shows the module's window at the moment when the waste disposal criteria tree has been fully defined, all criteria standardized and all groups weighed.

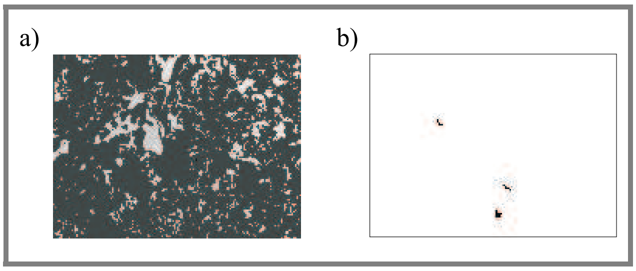

Fig. 7. The suitability map on the left (a) gives the three potential sites on the right (b). Due to printing limitations, the maps are printed as black and white, and the red–yellow–green gradation was converted to black–grey–white.

Generation of the composite index map (the "suitability_map") is now single mouse-click away. Unsuitable areas, i.e., areas with suitability value 0, are denoted with the red color. When suitability increases, the color gradually transits to yellow, and then to green as suitability gets closer to 1. With a few more steps, the suitability map translates to a map indicating the potential sites for waste disposal. Three sites are identified to have both high suitability and sufficient capacity (Fig. 7).

3.4. SMCE application for site selection (Phase 2—choice)

In the previous phase SMCE was used to identify potential sites (planning mode). In this phase, SMCE will be used

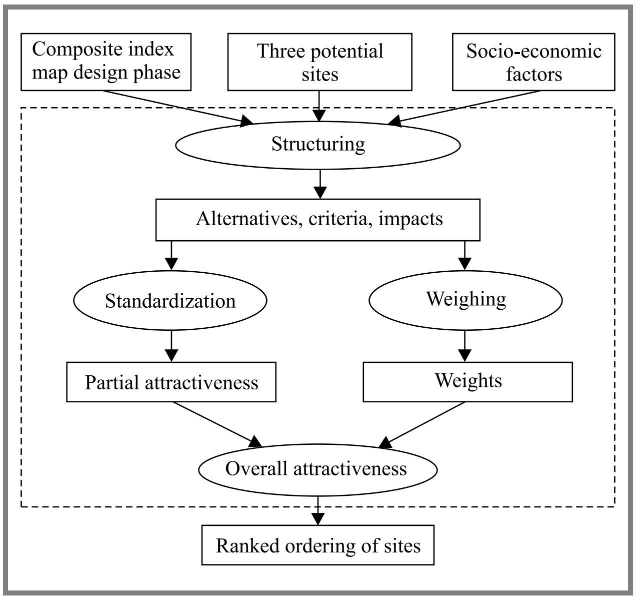

Fig. 8. Flowchart for the SMCE choice phase, which results in ranking of potential sites.

to rank them and choose the most attractive site (choice mode). In the same way as was presented in Fig. 4, this phase includes the following steps (Fig. 8):

1. Problem structuring: identification of alternatives, criteria and their impacts. Here, each of the potential sites from the previous phase is an alternative from which a final choice has to be made. One of the criteria considered in this phase is the suitability of each of the potential sites. The other are the socio-economic criteria.

2. Partial valuations of all alternatives on each criterion. This is carried out through a value function that is based on the attractiveness of each criterion. In this way all criteria are standardized and will represent the level of appreciation and contribution of each indicator to the overall attractiveness of each site.

3. Identification of the relative importance of each criterion in the overall attractiveness of the site, which leads to elicitation of weights for the socio-economic and biophysical factors.

4. Identification of the overall attractiveness of each alternative (each of the potential sites) and ranking and recommendation of the most suitable site.

The most important difference between this phase and the design phase is that here several data sets, one set for each potential site, go through the same SMCE process as in the design phase and result in one composite index map for each potential site. The data sets are not handled independently. The same criteria tree is used and the same weights are used for all, and the standardization step gets an extra dimension.
The identified steps are explained in the next sections.

3.4.1. Structuring

In this step, the problem is structured, by identifying which are the alternatives, on which criteria the decision should be based, and what is their impact. In the design phase, three sites were identified as being the potential sites. Those are then the three alternatives from which a choice is made in this phase.
The criteria on which the decision is based are the site suitability calculated in the design phase, and the socio-economic criteria "transportation cost", "land value reduction" and "effect on pollution". Those are grouped and inserted into a criteria tree in order to determine their impact (Fig. 9).

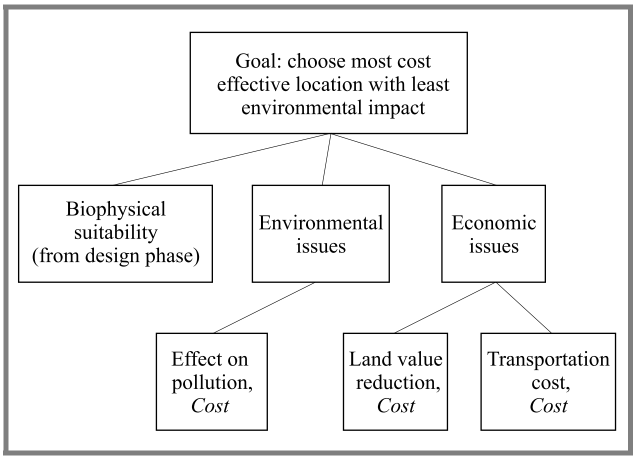

Fig. 9. Criteria tree for the SMCE choice phase of the selection of a waste disposal site.

This criteria tree shows that the impact of the biophysical suitability is on the same level as the environmental and economic criteria of the sites. All environmental and economic criteria are costs to the objective: "most economic location with least environmental impact", but the site suitability is a benefit. The maps for these criteria can only be generated now that the potential sites are known, as they depend on knowledge of the potential site.
For the site suitability criterion, one suitability map per potential site is produced, based on the composite index map from the design phase. This is a simple step, where the suitability of the areas in the composite index map that don't

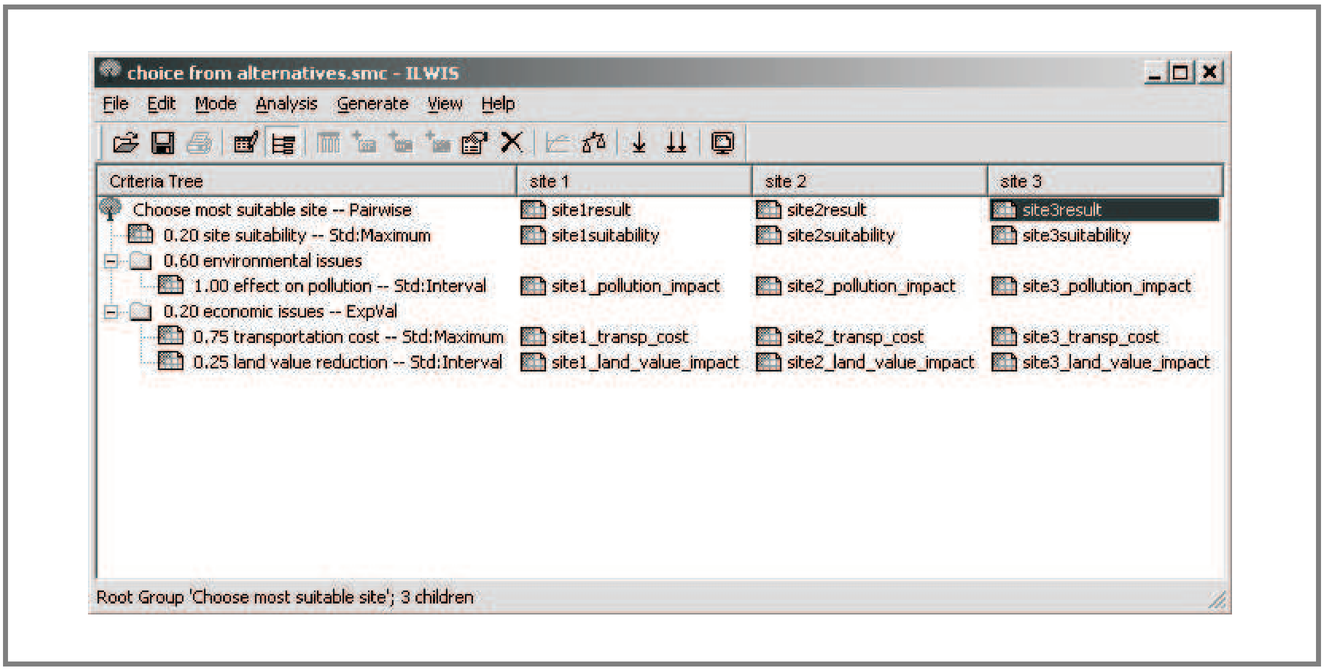

Fig. 10. The SMCE module in the choice phase; deciding on the best from three sites.

belong to the potential site is set to 0. Instead of having the suitability as one value (by taking, e.g., the average for each site), the spatial aspect is preserved.
The maps for the socio-economic criteria are based among others on the location of the potential sites identified in the design phase. Each of the three criteria is handled in its own way:

1. "Transportation cost": The overall city to site transportation costs should be minimized. For each site, a map is calculated that indicates the cost for transporting garbage to the waste disposal site for each point in Chinchina city.

2. "Land value reduction": The impact on the land value should be as little as possible. To calculate this, a map with the original land value is used in order to calculate a map for each site with the change in land value.

3. "Effect on pollution": The effect on the pollution should be as little as possible. To calculate this, a map with the originally polluted areas around the river is used together with a map indicating the sensitivity of different areas to pollution. The result is a map with the effect on the pollution for each site.

Calculating the required maps is done with functionality of the GIS into which the SMCE module is integrated.

3.4.2. Standardization

As in the design phase, the "utility" must be determined for each criterion, i.e., the function that converts the pixels of the three corresponding maps (one for each site) to a value between 0 and 1. In this phase, an extra dimension is given to this process by making sure that the range is the same for all three sites per criterion. Only then it is meaningful to compare maps of the three sites to each other.
This changes the way in which histogram values used in standardization functions are calculated. Where the maximum in the design phase was simply the maximum value of one map, here it is the maximum value of all the alternative maps for one criterion. The same goes for the minimum.

3.4.3. Weighing

As in the design phase, every group in the criteria tree has to be weighed. The same weigh methods are available.

3.4.4. Assessment of the overall attractiveness of the sites

As in the design phase, a weighted summation formula is generated for the criteria tree. The difference is that it is applied once for each potential site. The maps calculated for each site are used as input. The result is one composite index map for each potential site.

3.4.5. Final site selection

The composite index maps can be compared to each other in several ways, in order to rank-order the sites. The most common way is to aggregate the composite indexes of each site through their histogram values (e.g., maximum, average, sum, connectivity index) and rank-order the sites accordingly. The one with the most favorable selected histogram value becomes the site recommended by the SMCE process.

3.4.6. Practical use of the developed SMCE module in the choice phase

As in the design phase, development of the criteria tree, standardization, weighing and performing the weighted summation is a matter of few easy steps with the SMCE module developed. In the window of Fig. 10 the complete criteria tree for choosing one of the three potential waste disposal sites is shown.

Equivalent to the composite index map generated in the design phase, when selection of a site has an unacceptable effect to an area, i.e., the composite index value is 0, this is denoted with the red color. As the effect becomes more acceptable, the color gradually transits to yellow, and finally to green to denote a satisfactory effect with composite index value 1. In this way, the composite index maps indicate not only how much more attractive a site is compared to another, but have this attractiveness distributed spatially (Fig. 11).

Fig. 11. The three composite index maps that correspond to the three sites. The maps are printed as black and white, and the red–yellow–green gradation was converted to black–grey–white.

If at this point the location that becomes better or worse is not interesting, other values could give an outcome. As an example, the sites are rank-ordered as follows: first preference is given to the site with the largest area with high values. In case of equality, preference is given to the site with the smallest area with low values.

For the three composite index maps, the aggregated information in Table 1 helps the rank-ordering.

Table 1
Values taken from the histogram of the three composite index maps

Area [m^2]	Site 1	Site 2	Site 3
With composite index $>= 0.58$	5 469	20 781	5 469
With composite index $<= 0.45$	178 594	78 906	170 469

This results in the rank-ordering site 2, site 3 and site 1. The final choice according to the criteria used is thus site 2.

4. Concluding remarks

With the development of GIS, environmental and natural resource managers increasingly have information systems at their disposal in which data are more readily accessible, more easily combined and more flexibly modified to meet the needs of environmental and natural resource decision making. It is thus reasonable to expect a better informed, more explicitly reasoned decision-making process. But despite the proliferation of GIS software systems and the surge of public interest in the application of a system to resolve real world problems, the technology is commonly seen as complex, inaccessible, and alienating to the decision makers [10]. The reasons for this estrangement are varied. In part the early development and commercial success of GIS was fuelled more by the need for efficient spatial inventory rather than decision support systems. As a result, few systems yet provide any explicit decision analysis tools. To alleviate above problems, enough analytical capability should be integrated/connected to GIS in order to provide DSS functionality in a user friendly environment.

One of the very important analytical capabilities is spatial multi-criteria evaluation which together with the analytical functionality of GIS, supports producing decision and policy relevant information about spatial decision problems to decision makers. GIS and MCDM can support decision makers in achieving greater effectiveness and efficiency in the spatial decision-making process, therewith enhancing the use of geo-information. In this context a user friendly SMCE module has been developed and integrated into ITC's geographic information system called ILWIS. This module, which is based on the framework for the planning and decision making process as developed at ITC, is designed and implemented in such a way that can help the integration of information from a variety of sources (spatial, non-spatial) to support planning and decision making processes.

A good example of ILWIS' SMCE module in planning and decision making modes is site selection, which has been demonstrated through the case study in this paper. The case shows how effectively and efficiently SMCE can be applied in the process of designing and ranking of alternative sites for waste disposal.

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