A Multicriteria- Spatial Decision Support System (MC-SDSS) development for siting a landfill in the Province of Torino (Italy)

A Multicriteria Spatial Decision Support System Development for Siting a Landfill in the Province of Torino (Italy)

VALENTINA FERRETTI*
Land, Environment and Geo–Engineering Department, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

ABSTRACT
The present paper proposes a spatial multicriteria approach for supporting Decision-Makers in the siting process of a Municipal Solid Waste landfill in the Province of Torino (Italy).
In particular, the contribution illustrates the development of a Multicriteria-Spatial Decision Support System based on the integration of Geographic Information Systems and a specific Multicriteria Decision Analysis technique, named Analytic Network Process (ANP). This technique, which represents the generalization of the more well-known Analytic Hierarchy Process to dependences and feedbacks, is particularly suitable for dealing with complex decision problems which are characterized
by inter-relationships among the elements at stake.
The application allows the dependence relationships among the criteria to be assessed, and the relative importance of all the elements that play an influence on the final choice to be evaluated.
The purpose of the study is to generate a suitability map of the area under analysis for locating a waste landfill, paying particular attention to the contribution that the spatial ANP offers to sustainability assessments of undesirable facilities.
To this end, the simple network structure has been used and both exclusionary and non-exclusionary criteria have been identified and grouped into clusters.
The results are obtained in the form of suitability maps analysed through ILWIS 3.3 software (52North, ITC, Enschede, The Netherlands) and have been further verified through a sensitivity analysis with reference to the clusters priorities in order to test the robustness of the proposed model.
The main findings of this research have proved that the spatial ANP is a useful tool to help technicians to make their decision process traceable and reliable.Moreover, this approach helps Decision-Makers to undertake a sound reflection of the siting problem.
Finally, the implementation of the spatial ANP technique gives an originality value to the present research because it represents one of the first applications at both the national and international level.

KEY WORDS: Multicriteria-Spatial Decision Support Systems; Multicriteria Analysis; Analytic Network Process; Geographic Information Systems; waste management; land suitability analysis

1. INTRODUCTION

The Municipal Solid Waste Management (MSWM) process has the aim of recycling most of the waste materials that are produced, whereas the non-recyclable fractions of the wastes are dumped in landfills or treated in specific waste incinerator plants. These types of industrial plants thus belong to the group of undesirable facilities whose location presents two main problems, (i) social opposition and (ii) a huge number of social, economic and environmental data that have to be taken into account (Aragonés-Beltrán et al., 2010).
The selection of the appropriate landfill site can be viewed as a complex multicriteria decision-making problem that requires an extensive evaluation process of the potential locations and other factors as diverse as economic, technical, legal, social or environmental issues (Geneletti, 2010). Siting a municipal solid waste landfill is a challenging task because various interconnected and conflicting parameters should be considered. In such a context, a useful support is provided by a specific family of Decision Support Systems (DSS; Burstein and Holsapple, 2008), named Multicriteria Spatial Decision Support Systems (MC-SDSS;Malczewski, 1999), which is based on Geographic Information Systems (GIS) and Multicriteria Decision Analysis (MCDA) coupling.
Although conventional multicriteria decision-making (MCDM) techniques have largely been non-spatial, using average or total impacts that are deemed appropriate for the entire area under consideration, MC-SDSS integrate the

sustainability dimensions while offering a systematic approach able to prove the importance of 'where' in addition to 'what' and 'how much'.
In reality, many decision-making problems are based on spatial (geographical) information. These kinds of decisions are called location decisions and represent now a major part of operations research and management science (Farahani et al., 2010).
The most significant difference between spatial multicriteria decision analysis and conventional multicriteria techniques is thus the explicit presence of a spatial component. The former, as a matter of fact, requires data on the geographical locations of alternatives and/ or geographical data on criterion values (Sharifi and Retsios, 2004), whereas the latter usually assumes spatial homogeneity within the area under consideration, without paying attention to the fact that in many cases evaluation criteria vary across space. Spatial MCDA can also facilitate communication among Decision-Makers and stakeholders in order to reach a justifiable decision through a systematic, transparent and documented process. Moreover, spatial MCDA provide significant support for the generation and comparison of the alternatives through an active participation of the stakeholders involved in the decision- making process, thus becoming one of the most interesting evolution in the context of environmental assessment procedures (such as the Environmental Impact Assessment and the Strategic Environmental Assessment which are defined at the European level by the Directives 1997/11/EC and 2001/42/EC, respectively), where the comparison of different alternatives represents the heart of the whole process and where the complexity of the problems and the need for technical support in the decision-making process is particularly real.
From the methodological point of view, the present application proposes the development of an MC-SDSS for assessing the land suitability of part of the Province of Torino to host a waste landfill.
The remainder of the paper is organized into five sections. A brief literature review regarding the application of DSS and MSWM—related problems is presented in the next section. Section 3 illustrates the state of the art of MC-SDSS and provides the methodological background for the model developed in the present study. Subsequently, Section 4 presents the application of the spatial ANP model to the case study according to the four-stage decision-making process proposed by Simon (1960). Finally, Section 5 discusses the main findings of the application and summarizes the conclusions that have been drawn from the study, highlighting the opportunities for further developments.

2. MUNICIPAL SOLID WASTE MANAGEMENT AND DECISION SUPPORT SYSTEMS: LITERATURE REVIEW

The problem of undesirable facility location selection has been extensively studied in the literature. Since the 1960s, many studies have been developed concerning the modelling of MSWM problems. The first applications referred to land use models and had the aim of optimizing collection routes and facilities for the selection of a site, focusing only on financial criteria (Truitt et al., 1969). Environmental consideration in the 1980s and 1990s draw much attention to the potential of pollution due to waste disposal which led to more restrictive environmental regulations and to increase the emphasis given to other criteria in the process of undesirable facilities location. According to the sustainable development approach, a waste management system has now to be environmentally effective, economically affordable and socially acceptable (Bottero and Ferretti, 2011).
The mathematical models for problem-solving have evolved from the single criterion, maximin models (maximizing the average or minimum distance between the customers and the facility) (e.g. Hale and Moberg, 2003), to multicriteria models which include conflicting criteria in problem analysis and to Life Cycle Analysis, which aim at making a comprehensive assessment of the MSWM strategies impacts on the environmental system (e.g. McDougall et al., 2001). Many MCDA models are available to address MSWMproblems and the criteria to be considered vary depending on the specific context, as reviewed by Aragonés-Beltrán et al. (2010). Besides the criteria, also the approaches for undesirable facilities siting vary considerably. Alumur and Kara (2007) and Colebrook and Sicilia (2007), among other authors, solved multiobjective problems without using a set of predefined starting candidate sites. Starting instead from a small predefined set of candidate sites, Cheng et al. (2003), Norese (2006) and Queiruga et al. (2008), among others, used Multicriteria Decision Analysis methods (as PROMETHEE and ELECTRE methods) to address MSWMproblems. Another approach for siting undesirable facilities that has been used in the literature refer to the Analytic Hierarchy Process (AHP) (e.g. Dey and Ramcharan, 2008) and to its generalization as the ANP (e.g. Khan and Faisal, 2008; Aragonés-Beltrán et al., 2010; Tseng, 2010; Bottero and Ferretti, 2011).
The siting process of undesirable facilities depends on an ever increasing variety of factors, laws, and regulations and a large volume of spatial data should be evaluated and processed. Although GIS is a very useful tool in siting experiences, it lacks the ability to locate an optimal site unless an optimization arrangement is introduced (Sharifi et al., 2009).
In a preliminary screening stage, the utilization of GIS normally involves employing a set of criteria in order to classify an area into defined classes by creating buffer zones around geographic features to be protected (Changa et al., 2008).

All map layers are then intersected so that the resulting composite map classifies the areas into suitable and unsuitable ones. With the aid of this functionality, GIS has been widely used in order to facilitate and lower the cost of the selection process of sites for various purposes (Sharifi and Retsios, 2004). In this context, it is worth mentioning the study developed by Higgs (2006) in which he highlights the potential of integrating multicriteria techniques with GIS in waste facility location. The applications of spatial MCA to solve location problems were few for many years, but in the past decade, presenting and solving multicriteria location problems have undergone a substantial growth and have opened windows to location science in different business (Farahani et al., 2010).
With particular reference to the social aspects of MSWM problems, the models have to be able to reflect the public's opinions concerning landfills and other waste management plants. The point of view of the population involved in the problem usually presents the characteristics of social opposition that affects the construction of undesirable facilities. This phenomenon is also known as Not-In-My-Back-Yard (NIMBY), Not-Over-There-Either (NOTE), Locally-Unacceptable-Land-Use (LULU) and Build-Absolutely- Nothing-Anywhere-Near-Anything (BANANA). An analysis of the literature pertaining to this context has highlighted a lack of models that are able to consider the three dimensions of sustainability together and to reflect the intergenerational effects of the proposed MSWM strategies (Morrissey and Browne, 2004; Erkut et al., 2008).

3. MULTICRITERIA SPATIAL DECISION SUPPORT SYSTEMS

3.1. State of the art

One of the first experiences concerning the use of maps in decision-making processes refers to the work of McHarg (1969), where the basic concepts that would be later developed in Geographic Information Systems (Charlton and Ellis, 1991) are set forth. Although DSS and GIS can work independently to solve some simple problems, many complex situations demand the two systems to be integrated in order to provide better solutions (Li et al., 2004). In this context, it can be stated that the development of Spatial Decision Support Systems (SDSS) has been associated with the need to expand the GIS system capabilities for tackling complex, not well defined, spatial decision problems (Densham and Goodchild, 1989). The concept of SDSS evolved in the mid 1980s (Armstrong et al., 1986), and, by the end of the decade, many works concerning SDSS were available (Densham, 1991; Armstrong, 1993; Goodchild, 1993). Over the course of the 1990s, there has been considerable growth in the research, development and applications of SDSS, and, in recent years, they have been expanded to include optimization (Aerts et al., 2003, Church et al., 2004), simulation (Wu, 1998), expert systems (Leung, 1997), multicriteria evaluation methods (Janssen and Rietveld, 1990; Carver, 1991; Eastman et al., 1993; Pereira and Duckstein, 1993; Jankowski and Richard, 1994; Laaribi et al., 1996; Malczewski, 1999; Thill, 1999; Feick and Hall, 2004), on-line analysis of geographical data (Bedard et al., 2001) and visual–analytical data exploration (Andrienko et al., 2003), with the aim of generating, evaluating and quantifying trade-offs among decision alternatives. The field has now grown to the point that it is made up of many threads with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS and SDSS based on spatial knowledge and on expert systems (Malczewski, 2006). With specific reference to GIS-based multicriteria decision analysis, the full range of techniques and applications has been recently discussed in a detailed study developed by Malczewski (2006). The literature now contains a wealth of references to MC-SDSS developments and applications in a variety of domains,most of which are commonly applied to land suitability analysis in the context of urban and regional planning and are usually based on a loose coupling approach and on a value-focused thinking framework (Ferretti, 2011). A full description of the MC-SDSS state of the art is beyond the scope of this paper. The interested reader is referred to Malczewski (2006) and to Ferretti (2011) for an overview of the recent global trends in MC-SDSS research. With specific reference to the development of MCSDSS models for tackling landfill siting problems, it is worth mentioning the recent studies of Buenrostro Delgado et al. (2008), Geneletti (2010), Nas et al. (2010), Sharifi et al. (2009), Sumathi et al. (2008) and Wang et al. (2009).

3.2. Methodological background

The waste problem has been getting more and more acute over the years, and the siting process of waste facilities has become conflict-ridden. In this context, Decision-Makers have to be able to justify their choices concerning the location of disposal sites through a systemic, transparent and documented process. A very useful support is thus provided by the family of MCDA (Figueira et al., 2005; Bouyssou et al., 2006) and, particularly, by MC-SDSS. Spatial MCDA 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 and the preferences of the DM, and the manipulation of data and preferences according to specified decision rules (Sharifi and Retsios, 2004; Malczewski, 2006). This approach takes advantage of both the capability of GIS to manage and process spatial information, and the flexibility of MCA to combine factual information (e.g. soil type, slope, infrastructures) with value-based information (e.g. expert's opinion, quality standards, participatory surveys) (Geneletti, 2010). The main rationale for integrating GIS and MCDA is that they have unique capabilities that complement one another. On the one hand, GIS has great abilities for storing, managing, analyzing and visualizing geospatial data required for the decision-making process. On the other hand, MCDA offers a collection of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives (Malczewski, 1999). The present application proposes the integration between GIS and the ANP methodology to assess the suitability of part of the province of Torino (Italy) to host a waste landfill. The ANP (Saaty, 2005) represents a generalization of the well-known AHP (Saaty, 1980), which allows interdependencies between decision elements to be taken into account. Both methods use expert opinions as inputs for evaluating decision factors. However, the ANP has the advantage of allowing network model structuring, which is good for reflecting interdependence between real-world elements. This is the case with the aspects that influence the land suitability to host a Municipal Solid Waste (MSW) landfill. The reasons for using an ANP-based decision analysis approach in the present work are as follows:

(i) the location of an MSW landfill is a multicriteria decision problem; (ii) there are dependencies among groups of criteria and between these that have to be analysed; (iii) the detailed analysis of the interrelationships between clusters forces the DMs to carefully reflect on their project priority approach and on the decision-making problem itself. This helps DMs to gain a better understanding of the problem and to make a more reliable final decision. Due to the incorporation of the AHP calculation block in the IDRISI 3.2 software package (Clark Labs, Clark University, Worcester, MA, USA), it has become much easier to apply this technique to solve spatial problems. Applications of the ANP, which is particularly suitable for dealing with complex decision problems that are characterized by interrelationships among the elements at stake, are instead scarce (Neaupane and Piantanakulchai, 2006; Levy et al., 2007; Nekhay et al., 2009). The present study thus represents one of the first experimentations at both the national and international level.

What makes the ANP different from the AHP is that the former incorporates the influences and interactions among the elements of the system (criteria and alternatives), as perceived by the DM, and groups them into clusters inside a network. Many decision problems cannot in fact be structured hierarchically because they involve the interaction and dependence of the higher-level elements in the hierarchy on the lower-level ones. Moreover, the feedback networks lead to the consideration that the importance of the alternatives determines the importance of the criteria, whereas the traditional hierarchy only leads to the consideration that the importance of the criteria determines the importance of the alternatives (Saaty, 2003). A very large and consolidated amount of MCDA literature exists in which it is possible to find a wide range of techniques (Figueira et al., 2005). As far as both the AHP and the ANP are concerned, the basic reference is the literature production of the American researcher T.L. Saaty, starting from 1980. With particular reference to ANP, the literature is more recent and some publications can be found in different fields. With the aim of giving a snapshot of the heterogeneity of the application domains in which the ANP is being applied, mention can be made of some studies in the sphere of waste management (Khan and Faisal, 2008; Aragonés-Beltrán et al., 2010), transport infrastructures (Tuzkaya and Onut, 2008), strategic policy planning (Ulutas, 2005), environmental impact assessment of territorial transformations (Bottero et al., 2008; Liu and Lai, 2009), market and logistics (Liang and Li, 2008; Razmi and Rafiei, 2009), economics and finance (Niemura and Saaty, 2004) and civil engineering (Neaupane and Piantanakulchai, 2006). From the methodological point of view, the development of the spatial ANP model applied in the present study involves the following steps:

1 Problem structuring and model development. This step consists in developing the structure of the decisionmaking process and involves defining the main objective and identifying groups or 'clusters' constituted by various elements ('nodes') that influence the decision. In a spatial ANP criteria can be both exclusionary (constraints) and non-exclusionary (factors). All the elements in the network can be related in different ways because the network can incorporate feedbacks and complex inter-relationships within and between clusters, thus providing a more accurate modelling of complex settings. The network construction represents an important and very creative phase in the problem-solving process and the right consideration of all the factors, interactions and feedbacks involved in the problem is the necessary condition for the right solution.

2 Raw data acquisition. In this step, a thematic map has to be constructed for each identified factor and constraint.

3 Processing. In this step, maps are computed through basic GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.).

4 Standardization. In this step, impact scores are made dimensionless and mutually comparable through the identification of the relevant transformation functions that convert the data related to each criterion to a value judgement. This process identifies the partial attractiveness of each pixel of the maps with respect to each criterion.

5 Pair wise comparison and relative weight estimation. This step consists in the identification of the relative importance of each criterion with respect to the others, in order to find the level of contribution of each criterion to the achievement

of its related objectives (weight assessment). Comparative or relative judgements are made on pairs of elements. In paired comparisons, the smaller element is used as the unit, and the larger element becomes a multiple of that unit with respect to the common property or criterion for which the comparisons are made. It is important to highlight that there are two levels of pairwise comparisons in the ANP, the cluster level, which is more strategic, and the node level, which is more specialized. In pairwise comparisons, a ratio scale of 1–9, that is the Saaty's fundamental scale, is used to compare any two elements. The main eigenvector of each pairwise comparison matrix represents the synthesis of the numerical judgements established at each level of the network (Saaty, 1980).

6 Super matrices formation. This step consists of the progressive formation of three supermatrices, the initial or unweighted one, the weighted one and, finally, the limit one. The unweighted supermatrix contains all the eigenvectors that are derived from the pairwise comparison matrices of the model. The eigenvector obtained from the cluster level comparison, with respect to the general goal, is applied to the initial supermatrix as a cluster weight, and the result is the weighted supermatrix. The supermatrix elements allow a resolution to be made of the interdependencies that exist between the elements of the system.

7 Results aggregation. An overall suitability index for each potential site of the study area is calculated using an adequate aggregation rule.

8 Sensitivity analysis. This step has the aim to test the robustness of the results and the role played by uncertainty factors.

A number of frameworks exist for the analysis of the decision-making process. The present application will follow what is perhaps the most widely accepted generalization of the decision-making process, which was first introduced by Simon (1960) and then adapted to territorial planning by Sharifi and Rodriguez (2002). The aforementioned framework divides the decisionmaking process into the following four major phases: intelligence, design, selection and choice and detailed analysis and implementation (review). This model has been adopted to develop a method to support the identification of suitable landfill sites, as shown in Table I and explained in details in the following sub-sections. Particularly, a value-focused approach has been applied, thus considering the values as the fundamental elements in the decision analysis. Therefore, the study first focuses on the specification of values (value structure), and then, considering the values, develops feasible options to be evaluated according to the predefined criteria structure. This implies that decision alternatives are to be generated so that the values specified for a decision situation are best achieved. In other words, the order of thinking is focused on what is desired, rather than on the evaluation of alternatives. In fact, alternatives are considered as means to achieve the more fundamental values, rather than being an end to themselves (Keeney, 1992).

Table I. Sequence of activities performed in the study

Phases	Activities
Intelligence	1. Problem structuring and model development: -identification of the main objective -definition of the criteria structure according to the network approach -definition of constraints 2. Raw data acquisition 3. Processing
Design	4. Standardization 5. Pairwise comparisons and relative weight estimation 6. Super-matrices formation
Choice	7. Results aggregation
Detailed analysis and implementation (Review)	8. Sensitivity analysis 9. Results and recommendations

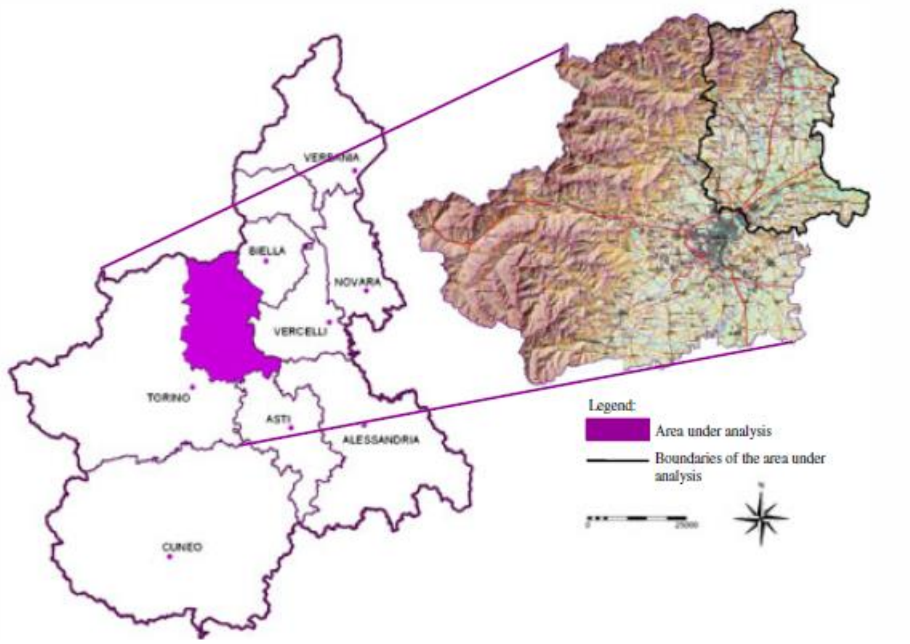
4. RESEARCH OBJECTIVES AND CASE STUDY DESCRIPTION

As already mentioned, the case study considered in this paper refers to the location of a waste landfill which has to be constructed in the Province of Torino (Northern Italy), in order to service the incinerator plant under construction near the city of Torino. The purpose of the paper is thus to experiment the application of the spatial ANP technique for the synthesis of the available data in the decision problem. The area under analysis, which has been defined according to the indications of the Municipal Solid Waste Management Plan (PPGR, 2006; TRM; 2010) is located in the North-East part of the Province of Torino (Figure 1) and expands within 127 municipalities.

This area is characterized by a very intensive land use due to residential expansion, industrial and tourism development, transportation infrastructures and agriculture. Urban settlements, infrastructures, agriculture, and natural areas all compete for space. To complicate matters even further, geomorphologic constraints reduce the areas suitable for new construction. The landfill will have a capacity of about 3 500 000m^3 and a life cycle of approximately 10–11 years (TRM, 2010). At the time this research started, no alternative sites had officially been selected for siting the waste landfill. However, a number of possible locations were drafted in a scientific study developed by the Provincial Administration (TRM, 2010).

With specific reference to the location of waste management facilities, the MSWM Plan of the Province of Torino requires a stepped procedure that can be described as follows:

• Phase 1: Macro-localization (competence of the Province) In this phase, the requirements coming from the legislation and the indication provided by the local



planning tools are considered for identifying the potential sites. The result of this investigation is a classification of the areas in two classes, 'non-suitable areas' and 'potentially suitable areas'.

• Phase 2: Micro-localization (competence of the Provincial Association for the Management of Wastes)

The potentially suitable areas are investigated in depth with reference to different parameters, such as preferential factors (e.g. accessibility, centrality, etc.), dimensional and geomorphologic characteristics of the area etc. From this investigation, a set of candidate sites is obtained, which is further investigated through a more detailed analysis and specific surveys. The present study thus provides an illustrative example concerning the development of anMC-SDSS model aiming at supporting themacro-localization phase in the context of undesirable facilities location problems,

making use of the publicly available data concerning the area under analysis and simulating the decisionmaking process for the elicitation of the preferences of the DMs. Therefore, the study does not aim to evaluate the final project blueprint but rather to provide a preliminary analysis of the land suitability to host the facility.
When investigating potentially suitable sites for landfill location, it is fundamental to meet the necessary conditions for preventing pollution of the soil, of groundwater and surface water, and ensuring efficient collection of leachate. Furthermore, a landfill site should be kept as far as possible away from densely populated areas, for reducing pollution impact to public health. On the other hand, the landfill site should be placed as close as possible to existing roads for saving road development, transportation and collection costs. Moreover, sites with slope either too steep or too flat are not appropriate for constructing the landfill (Nas et al., 2010). Many of the attributes involved in the landfill siting process have thus a spatial representation. This is why a spatial MCDA is proposed in order to identify potentially suitable areas.

4.1. Intelligence phase

The problem definition overlaps the decision-making intelligence phase, which refers to the structuring of the problem, the identification of the objectives and the selection of criteria or attributes to describe the degree of achievement of each objective. The location of a waste landfill is a complex land use planning problem in which the presence of interrelated elements and conflicting aspects suggests the use of an MCDA that is able to provide a rational base for the systematic analysis of the alternative options. Because ofthe aforementioned complexity of the problem under analysis, and with the aimof finding the most significant aspects involved in the decision and the most suitable location for the project, the ANP method has been developed according to the simple network structure.
Mention should bemade to the possibility of structuring the decision problem according to the complex network structure (Saaty, 2005) which is usually based on four sub-networks, Benefits, Costs, Opportunities, and Risks. These sub-networks allow all dimensions of the decision problem to be considered.The network structure of the problem and the interdependences among the clusters were simulated using Super Decisions 1.6.0 Software,[1] which automatically creates a list of the pairwise comparisons needed to run the evaluation. The identification of alternative suitable landfill sites was carried out by using the GIS software ILWIS 3.3 (52North, ITC, Enschede, The Netherlands) (ITCILWIS, 2001).[2]
Starting from the overall objective of the analysis, which is the identification of the most suitable site for the location of a Municipal Solid Waste landfill, a comprehensive set of evaluation criteria that reflect all the concerns relevant to the decision problem has been identified (Figure 2). Taking into account the full range of aspects relevant to the decision problem enhances the quality of the final decision, allowing the totality of the effects of the transformation project to be considered and the negative externalities and the intergenerational effects to be minimized (Bottero and Ferretti, 2011). The siting process is an MCDA problem requiring consideration of a comprehensive set of attributes in determining the suitability of a particular area for a defined land use (Gamboa and Munda, 2007; Tsoutsos et al., 2009). These attributes involve constraints which are based on the Boolean relation (true/false) and limit the study area to particular sites, and evaluation criteria which define a degree of continuous measure of suitability for all feasible alternatives (Tegou et al., 2010). In locating a landfill site, consideration of environmental factors is important because the landfill may create certain environmental risk to the biotic environment in the surrounding area (Siddiqui et al., 1996; Kontos et al., 2003). At the same time, it is necessary to consider socio-economic factors which include the costs associated with the acquisition, development and operation of the site (Delgado et al. 2008), as well as social and political opposition (Lober, 1995).

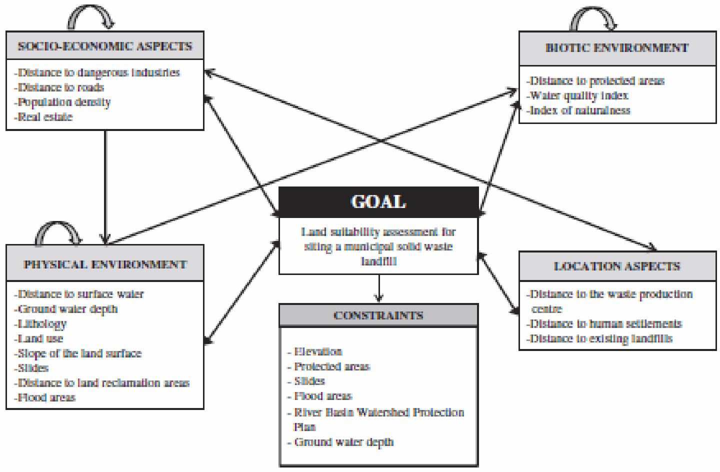


Figure 2. The ANP network structure for the case under examination.

In the present study, 24 criteria are involved in the computation process, distinguished as exclusionary (6) and non-exclusionary factors (18). These criteria are clustered in five main groups including socio-economic aspects, factors influencing the biophysical environment, factors influencing the biotic environment, location aspects, and constraints (Figure 2).

It is necessary to highlight that the criteria considered in the present application were selected based on the relevant international literature (Kontos et al., 2003; Buenrostro Delgado et al., 2008; Sumathi et al., 2008 Sharifi et al., 2009, Wang et al., 2009; Geneletti, 2010; Nas et al., 2010) and on the requirements coming from the legislative framework in the field of waste management (Waste Management Plan of the Province of Torino; PPGR, 2006) which provides a list of aspects to be considered for the location of waste facilities. Mention should be made to the fact that location aspects deserve a dedicated cluster because a site is suitable for hosting a waste landfill thanks to its position, which can maximize the positive factors that derive from the location and thus create added value. The negative drawbacks can, in fact, be minimized for all the alternative sites through the use of the best available technologies (Sharifi and Retsios, 2004; Bottero and Ferretti, 2011). As far as the structuring of the network in concerned, mention should be made to the fact that, as stated by Miller (1956), it is important not to have too many elements to compare through the expression of relative judgements because the decision aid tool should not be interpreted as an algorithm that is able to automatically give the desired solution, but it should instead support the DM who has to make a systematic analysis of the alternative solutions and who is solely responsible for the final choice. For the sake of coherence, particular care has been taken in the present application to have clusters that are easily manageable by the Decision Makers. In the design of the model, small and balanced clusters have thus been considered. This is particularly important from a cognitive point of view because it has been generally agreed that DM tend to give more importance to those aspects that are described by a higher number of elements in the model (Simon, 1960; Saaty, 1980).

According to the ANP methodology, once the network has been identified, it is necessary to represent the influences among the elements. To this end, each criterion is analysed in terms of which other criteria exert some kind of influence upon it; then the corresponding pairwise comparison matrices of each criteria group are generated in order to obtain the corresponding eigenvectors. It has been chosen to approach this task according to the following strategies. To start with, all the elements in the clusters are supposed to have an influence on the general goal. Further relationships have then been identified concerning the potential influences among the elements of each cluster. These influences reflect the natural dynamics of the environmental and territorial systems, where link and interaction pathways exist between individual elements, which can, positively or negatively, affect each other (Bottero and Ferretti, 2011). For instance, the 'index of naturalness' is influenced by the 'land use' and by the 'distance to protected areas', as well as the 'distance from the waste production centre' is influenced by the 'distance to the roads network', and the 'residential real estate' is influenced by the 'distance to dangerous industries' and by the 'distance to existing landfills' (Figure 2). The direction of the arrows in Figure 2 indicates the interdependence relationships between the factors. A single direction arrow shows the dominance of one factor by another. A double direction arrow shows mutual influence between the factors. The loops indicate inner dependences. In the next phase, evaluation criteria and constraints that score the potential sites were represented as raster map layers in a GIS database. The study area was discretized using a grid cell size of 25m_25m. It is worth specifying the difference between the following:

• Constraints, which are non-compensatory criteria that determine which areas should be excluded from or included in the suitability analysis. The excluded areas will get a nil (0) performance value in the composite index map, whereas the remaining areas will obtain a value between 0 and 1. Constraints are thus expressed in the form of a Boolean (logical) map. They depend on standing legislation and on the characteristics of the area under analysis. In this study, they were selected in accordance with the legislation in the waste management field (PPGR, 2006). The overall constraint map is calculated by multiplying all the constraints layers.

• Factors, which are compensatory criteria that contribute to a certain degree to the output (suitability). There are two types of factors, (i) benefit criteria and (ii) cost criteria. A benefit criterion contributes positively to the output (the higher are the values, the better it is), whereas a cost criterion contributes negatively to the output (the lower are the values, the better it is). As opposed to constraints, which cannot be compensated, poor performance of a factor can be compensated by good performance of another factor. Using compensatory decision rules, such as a weighted sum, this can still lead to good overall performance in the composite index map (Zucca et al., 2008)

A thematic raster map has been constructed for each of the identified factors and constraints. Maps were computed through basic GIS operations (map overlay, buffering, distance mapping, spatial queries, etc.). Table II lists the criteria considered in the analysis and provides for each of them the data source and scale, the source maps used to represent them and the derived maps produced for the study. Mention should be made to the fact that the seismic activity has not been considered as criterion in the present study because it presents a homogeneous distribution in the area under consideration. As it can be noticed from Table II, most of the derived maps are distance maps. A distance map is a derived raster map where each pixel has a value corresponding to the distance from source pixels in the original map. As a matter of fact, a landfill site must be situated at a fair distance away from biophysical elements such as water, wetlands, critical habitats and wells to reduce the risk of contamination (Sharifi et al., 2009).
In particular, the proximity of a landfill to groundwater sources is an important environmental consideration in the landfill site selection, so that aquifers may be protected from the runoff and leaching of the landfill. Moreover, when considering economic feasibility of a candidate landfill site, the proximity to waste production centres is an important factor because landfill sites close to the waste production centres will decrease transportation costs. At the same time, the landfill is considered to have a significant impact on those living within close proximity to the site, due to public concerns, such as aesthetics, odour, noise, decrease in property value and health concerns. The landfill should thus be situated at a significant distance away from urban residential areas, because, among other factors, once a waste disposal site is introduced, the land value of the surrounding locations will change. The negative effect on the land value should, if possible, be minimized for land that currently has a significant value (Sharifi and Retsios, 2004).

4.2. Design phase

The design phase involves the standardization and
weighting of all the factors being considered in the analysis. Because both the operations are largely subjective, a focus group has been organized where several experts have been involved in order to discuss and evaluate the general aspects of the problem. With the aim of making up a multidisciplinary group able to approach the complexity of the problem under analysis, the focus group brought together experts in the field of spatial analysis, environmental engineering, landscape assessments and sustainability assessment procedures. The different experts worked together in order to achieve a consensus with reference to both the

Table II. Maps used to represent the criteria

	Criteria	Data source and scale	Source map	Derived map
Constraints	Ground water depth	TP, 1:50 000	Map of ground water depth	Map of ground water depth
	Flood areas	TP, 1:100 000	Map of flood areas	Map of flood areas
	Protected areas	TP, 1:10 000	Map of protected areas	Map of protected areas
	Elevation	TP, 1:10 000	Map with surface elevation values	Map with surface elevation values
	Slides	TP, 1:100 000	Map of dormant and active slides	Map of dormant and active slides
	River basin watershed protection plan	TP, 1:25 000	Map of the protection buffers for the river basins	Map of the protection buffers for the river basins
Factors	Distance to surface waters	PR, 1:100000	Map of surface water bodies	Distance map
	Ground water depth	TP, 1:50 000	Map of ground water depth	Map of ground water depth
	Water quality index	PR, 1:100000	Map of the water quality index	Distance map to the highly quality classes
	Index of naturalness	PR, 1:100000	Land use map	Map with the naturalness index values
	Lithology	PR, 1:100000	Map of the lithological composition of the soil	Map of the lithological composition of the soil
	Slope of the land surface	PR, 1:100000	Digital elevation model	Map with slope values between 0 and 100%
	Land use	PR, 1:100000	Land use map	Map of land use classes (urban areas, agricultural areas, protected areas, forest and wetlands)
	Distance to human settlements	PR, 1:100000	Map of human settlements	Distance map
	Distance to protected areas	PR. 1:100000	Map of protected areas	Distance map
	Distance to roads	PR, 1:10000	Map of roads	Distance map
	Distance to existing landfills	TP, 1:100 000	Map of the existing landfills	Distance map
	Residential real estate	AG***, 1:100000	Real estate values	Map with the real estate values of each municipality
	Distance to the waste production centre	PR, 1:100000	Map of the municipalities	Distance map
	Slides	PR, 1:100000	Map of slides classes	Map of slides classes
	Flood areas	PR, 1:100000	Map of flood areas	Map of flood areas
	Distance to dangerous industries	TP, 1:100 000	Map of dangerous industries	Distance map
	Population density	IM****, 1:100 000	Population density values	Map with the population density values for each municipality
	Distance to contaminated areas	TP, 1:100 000	Map of contaminated areas	Distance map

*TP (Torino Province)
**PR (Piedmont Region)
***AG (www.agenziaterritorio.it)
****IT (Italian Municipalities, www.comuni-italiani.it)

weighting of the elements involved in the decision andthe standardization of each factor map. As previously explained, 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 in which the values represent a measure of the appreciation of the DM with respect to a particular criterion, and relate to its value/worth (measured in a scale from 0 to 1). Such a transformation is commonly referred to as standardization (Sharifi and Retsios, 2004). In the present study, standardization was performed by using linear functions that converted the originalfactor scores (each expressed in its own unit of measurement) into dimensionless scores in the 0 (worst situation) 1 (best situation) range. This method assumes that a linear relationship exists between the impact scores and the perceived significance of the impacts. Furthermore, this method offers the advantage of keeping the ratio between the original impact scores and the standardized ones. Table III describes the criteria considered in the present study and explains how each criterion has been standardized.
With the aim of giving an example, Figure 3 shows the source map (Figure 3a) and the standardized one (Figure 3b) for the factor ‘distance to dangerous industries’, whereas Figure 4 provides the standardized maps for all the factors and constraints considered in the analysis. Once all the maps were converted to partial suitability, and standardized to the same value range, their corresponding relative importance weights were assigned. As a matter of fact, the different evaluation criteria are usually characterized by different importance levels, which need to be included into the evaluation. These are obtained by assigning a weight to each criterion.
Weighting represents a critical stage aimed at including into the analysis the viewpoints of DMs and stakeholders. Constraints do not participate in the weight assignment process, whereas all factors are assigned factor weights, according to their relative importance, based on the ANP (Saaty, 2005) technique. The weights indicate how factors compensate for each other in each cluster. During the pairwise comparison process of all the factors, the consistency of the responses must be checked by calculating the Consistency Ratio (CR). According to Saaty (1980), the CR should be less than 0.1, otherwise the responses should preferably be revised in order to improve the measurement accuracy. Once all the pairwise comparison matrices have been filled in, the totality of the related priority vectors at the node level forms the unweighted supermatrix. By multiplying the unweighted supermatrix for the clusters weighted matrix, the weighted supermatrix is obtained. This last is raised to a limiting power, as in Equation (1), in order to converge and to obtain a long-term stable set of weights that represents the final priority vector of all the elements being considered in the analysis.

$$\lim_{k\to\infty} W^k \qquad (1)$$

The ILWIS’ spatial multicriteria evaluation module provides support for a number of techniques (direct, pairwise 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. Choosing the direct method, the priorities obtained from the ANP model have thus been assigned to the factor raster layers created previously into the spatial multicriteria analysis. The priorities of the clusters and of the elements considered in the analysis are shown in Table IV.

4.3. Selection and choice phase

Once the maps have been obtained for each criterion and the factors weights have been established, it is necessary to combine all the information in order to obtain the overall suitability map. In the present study, an intermediate suitability map has been obtained for each group of factors or clusters (Figure 5). A weighted linear combination (Equation (2)) has then been used, that combines the factors and constraints maps according to the following formula:

$$S_j = \sum W_i X_i \prod C_k, \qquad (2)$$

where S_j represents the suitability for pixel j, W_i represents the weight of factor i, X_i represents the standardized criterion score of factor i and C_k represents the constraint k. More specifically, each factor layer is multiplied by its respective weight and the weighted factor layers are summed in order to provide a total performance score for each cell. The constraints maps are thus merged and used to mask unsuitable areas, which are excluded from the analysis. Only the cells with value ‘1’ in each input layer will have non-zero value in the constraint

Table III. Criteria description and standardization

	Criteria	Description	Standardization
CONSTRAINTS	Ground water depth	Areas with ground water depth between 0 and 3 m are excluded from the analysis.	Depth ≤ 3 m is standardized to 0; all other values are standardized to 1.
	Flood areas	Flood areas with return period less than 50 years are excluded from the analysis.	Flood areas with return period ≤ 50 years are standardized to 0; the remaining areas are standardized to 1.
	Protected areas	Protected areas are excluded from the analysis.	Natural protected areas are standardized 0; the remaining areas are standardized to 1.
	Elevation	Areas with elevation higher than 1000 m are excluded from the analysis.	Areas with altitude ≥ 1000 m are standardized to 0; all other values are standardized to 1.
	Slides	Active slide areas are excluded from the analysis.	Active slides are standardized to 0; the remaining areas are standardized to 1.
	River Basin Watershed Protection Plan	Riparian buffer protections are excluded from the analysis.	Riparian buffer protection is standardized to 0; the remaining areas are standardized to 1.
FACTORS	Distance to surface waters	The criterion represents the distance to surface water bodies.	Distance ≤ 150 m (protection buffer provided by PPGR, 2006) is standardized to 0; distance >150 m is standardized according to the linear maximum function (the higher the distance, the higher the score).
	Ground water depth	The criterion maps the ground waters depth in order to avoid contamination.	Linear standardization (the higher the depth, the higher the score).
	Water quality index	The criterion maps the distance to the best perfoming classes of water quality index.	Linear standardization (the higher the distance from the high quality classes, the higher the score).
	Index of naturalness	The index of naturalness is calculated by assigning a value between 0 and 1 to each patch in the area under consideration (the higher the natural value of the area, the higher the score) and by multiplying this value for the area of the considered patch (OCS, 2002).	Linear standardization (the higher the index, the lower the score).
	Lithology	The criterion classifies the area in 15 classes according to the composition of the soil.	Linear standardization (the higher the clay percentage, the higher the score).
	Slope of the land surface	The criterion maps the percentage of slope of the land surface.	Slopes between 0 and 10% are standardized to 1 (Gemitz *et al.*, 2007; Nas *et al.*, 2010); slopes ≥ 10% are

Table III. (Continued)

Criteria	Description	Standardization
		standardized according to the linear function (the higher the slope, the lower the score)
Land use	The criterion classifies the area in five classes: urbanized areas, agricultural areas, forests, wetlands, and hydrological network.	Linear standardization (the higher the natural value of the area, the lower the score).
Distance to human settlements	The criterion considers the effects of siting a waste incinerator on the surrounding population in terms of noise, odours, traffic, and visual impacts.	Distance ≤500 m (protection buffer provided by PPGR 2006) is standardized to 0; distance >500 m is standardized according to the maximum function (the higher the distance, the higher the score).
Distance to protected areas	The criterion maps the distance to protected areas.	Linear standardization (the higher the distance, the higher the score).
Distance to roads	The criterion represents the road network system inside the area under examination.	Distance ≤60 m (protection buffer provided by PPGR 2006) is standardized to 0; distance >60 m is standardized according to the linear function (the higher the distance, the lower the score).
Distance to the existing landfills	The criterion maps the distance from the already existing landfills within the area under analysis.	Linear standardization (the higher the distance, the higher the score)
Residential real estate	The criterion assigns to each Municipality the real estate value expressed in €/m^2 (Agenzia del Territorio, 2010) in order to provide a representation of the real estate property.	Linear standardization (the higher the real estate values, the lower the score).
Distance to the waste production centre	The criterion maps the distance to the waste incinerator where the waste has to be collected.	Linear standardization (the higher the distance, the lower the score).
Slides	The criterion classifies the area according to the following three classes of geological risk: medium, medium/ high, and very high.	Linear standardization (the higher the geological risk, the lower the score).
Flood areas	The criterion classifies the area according to the floods return period.	Linear standardization (the higher the return period,the higher the score).
Distance to dangerous industries	The criterion considers the presence of dangerous industries inside the area under examination.	Linear standardization (the higher the distance, the higher the score).
Population density	The criterion assigns to each Municipality the population density value (Comuni Italiani, 2010).	Linear standardization (the higher the population density, the lower the score).
Distance to contaminated areas	The criterion maps the distance to the contaminated sites needing reclamation within the area under analysis.	Linear standardization (the higher the distance, the higher the score).

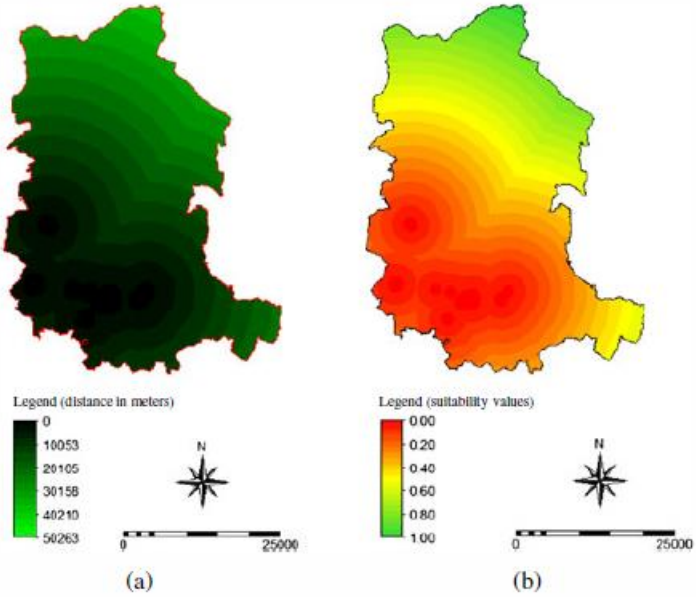


Figure 3. Source map and standardized map for the factor 'distance to dangerous industries'.

map, meaning these cells meet all constraints and are eligible for further consideration. The final suitability map is derived from the multiplication of the constraint map by the composite factors map. This operation is equivalent to removing the restricted areas out of the evaluation map.
The aggregation procedure plays a crucial role on the degree each factor influences the final suitability determination (Gemitzi et al., 2007).
The resulting suitability map for siting the landfill shows the overall attractiveness of each point (pixel) presented in the scale between 0 and 1 for the whole area under analysis (Figure 6).

4.4. Detailed analysis and implementation phase: sensitivity analysis

In most MCDA, a 'what if' sensitivity analysis is recommended as a means of checking the stability of the results against the subjectivity of the expert judgements and the uncertainty in the factors' scores. The information available to the DMs is often uncertain and imprecise because of measurement and conceptual errors. Sensitivity analysis considers how and how much such errors affect the final result of the evaluation (Geneletti, 2005).
Carrying out a complete sensitivity analysis is quite a complex and difficult process to implement in spatial multicriteria evaluation, especially with respect to error margins in each score, which corresponds basically to a pixel in the map.
As a matter of fact, sensitivity analysis is not a common practice in the field of spatial MCDA. It is still largely absent or rudimentary for most of the studies. Delgado and Sendra (2004) conducted a review on how sensitivity analysis has been applied to GISbased MCDM models, and they founded that little attention has been paid to the evaluation of the final results from these model simulations. The most frequently used sensitivity analysis method is based on the variation of the criteria weights considered in the process in order to test whether these changes significantly modify the obtained results.
In this study, the performed sensitivity analysis considers the effect of changes in the clusters weights upon the overall suitability index. To this aim, the following five sets of weights (Table V) were considered, so as to simulate the presence of different perspectives during the decision-making process:

• Scenario I (neutral perspective): all criteria have
equal weights;
• Scenario II (biophysical environment oriented perspective): in this case, the ‘biophysical environment’ cluster dominates the others;

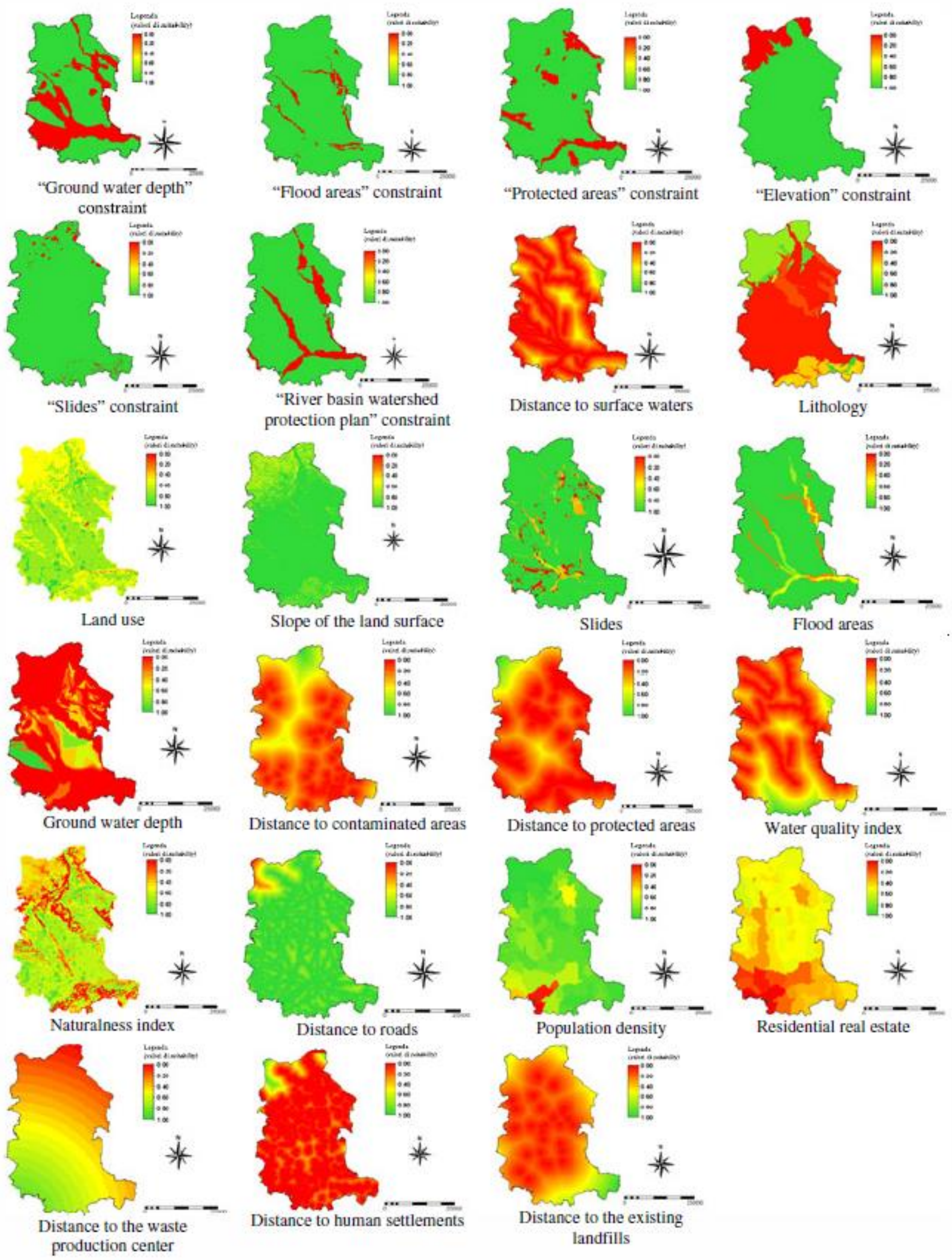


Figure 4. Standardized maps for the constraints and the factors considered in the analysis.

Table IV. Priorities of all the elements considered in the network

Elements of the network	Normalized priorities
Biophysical environment (0.073)	
Flood areas	0.014
Slope of the land surface	0.005
Ground water depth	0.014
Distance to surface water	0.009
Slides	0.020
Lithology	0.013
Land use	0.009
Distance to contaminated areas	0.009
Biotic environment (0.019)	
Distance to protected areas	0.118
Water quality index	0.016
Naturalness index	0.040
Location (0.426)	
Distance to human settlements	0.201
Distance to the waste production centre	0.127
Distance to existing landfills	0.049
Socio-economic aspects (0.311)	
Distance to dangerous industries	0.060
Population density	0.114
Distance to roads	0.123
Residential real estate	0.060

• Scenario III (biotic environment oriented perspective): in this case, the 'biotic environment' cluster dominates the others;
• Scenario IV (location oriented perspective): in this case, the 'location' cluster dominates the others; and
• Scenario V (socio-economic aspects oriented perspective): in this case, the 'socio-economic aspects' cluster dominates the others.

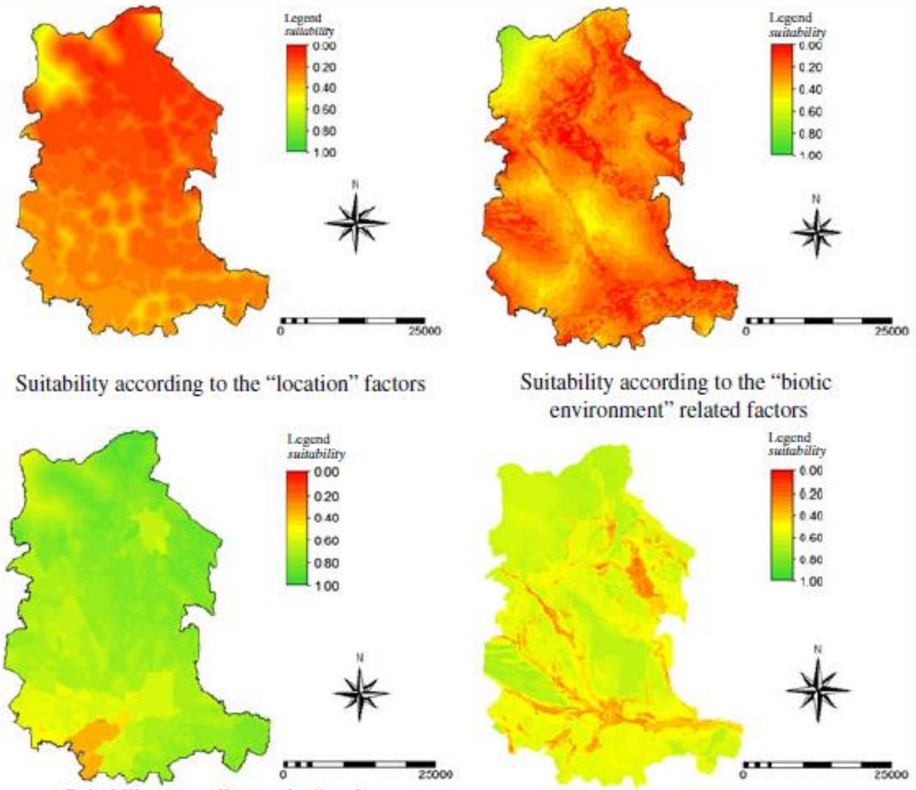
Table V summarizes the combination of weights associated to each scenario, whereas Figure 7 illustrates the suitability maps obtained from each perspective. As it can be seen in Figure 7, the final suitability of the area under analysis is sensitive to the clusters weights. The sensitivity analysis thus allowed to draw some interesting conclusions. First, it can be noticed that, while increasing the weight of the 'biotic environment' cluster or of the 'location' cluster results in an increase of the areas with low suitability values, increasing the weight of the 'biophysical environment' cluster or of the 'socio-economic aspect' cluster results in an increase of the areas with high suitability values. Secondly, the map obtained by the equal factor weightings analysis showed an increase in the areas with low suitability values.

It is noticeable that, although the resulting maps for the five scenarios of the sensitivity analysis demonstrate modifications in the suitability index, Figure 7 shows that the most suitable sites for the location of the Municipal Solid Waste landfill remain relatively stable in all cases and concentrates in the middle East portion of the area under analysis.

5. DISCUSSION OF THE RESULTS AND CONCLUSIONS

The present paper illustrates the development of an MC-SDSS based on the ANP technique with the aim of studying the land suitability to host a waste landfill in the Province of Torino (Italy).

The objective of the study was to find suitable sites for waste landfill construction, taking into account a number of emerging economic, social, environmental and technical criteria. The processing was supported by the ILWIS' GIS software and its spatial multicriteria evaluation module, that has demonstrated to be an effective tool for managing and combining a large amount of spatial and non-spatial information. The application has highlighted that a site is suitable for hosting a landfill because of its position, which can maximize the positive factors that derive from the location and thus create added value. The negative drawbacks can in fact be minimized for all the alternative sites through the use of the best available technologies (Bottero and Ferretti, 2011). The final suitability map shows that a large portion of the area under analysis is unsuitable for effect of one or more constraints. This was largely expected, due to the intensity of current land uses in the area, the complex morphology, and the high number of features that acted as constraints. Nevertheless, the results obtained in the present application are aligned with those coming from the study developed by the Provincial Administration (TRM, 2010), thus confirming that the most suitable areas for the location of the landfill overlaps with the feasible locations highlighted in the aforementioned study.The main drawback in the practical application of the ANP is a consequence of the complexity of the decision-making issue that has to be analysed. To this end, the ANP prescribes a high number of comparisons that occasionally become too complex for DMs to understand if they are not familiar with the method. Hence, a great deal of attention should be devoted to the writing up of the questionnaires and the comparison process should be helped by a facilitator (Gomez- Navarro et al., 2009; Aragonés-Beltrán et al., 2010).



Suitability according to the "location" factors

Suitability according to the "biotic environment" related factors

Suitability according to the "socio-economic" factors

Suitability according to the "biophysical environment" related factors

Figure 5. Intermediate suitability maps.

The sensitivity analysis has resulted to be an explanatory process by which the DMs achieve a deeper understanding of the structure of the problem (Khan and Faisal, 2008). As a matter of fact, knowledge of uncertainty factors is bound to increase the awareness of the DMs about the merit of the different alternatives, and, consequently, to orient their strategy better (Geneletti *et al.*, 2003). The role of MCDA is to convey this information to the DMs

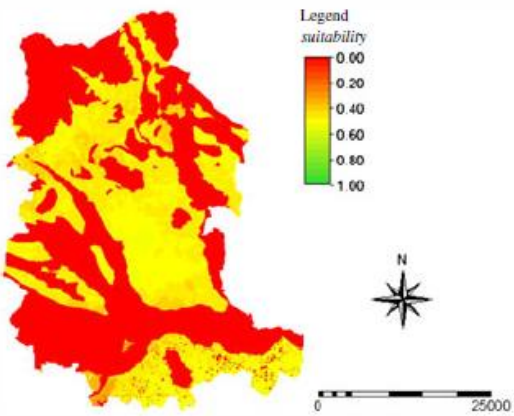


Figure 6. Overall suitability map.

Table V. Combination of weights for the sensitivity analysis

	Clusters weights			
Scenarios	Biophysical environment	Biotic environment	Location	Socio-economic factors
I	0.25	0.25	0.25	0.25
II	0.55	0.15	0.15	0.15
III	0.15	0.55	0.15	0.15
IV	0.15	0.15	0.15	0.55
V	0.15	0.15	0.55	0.15

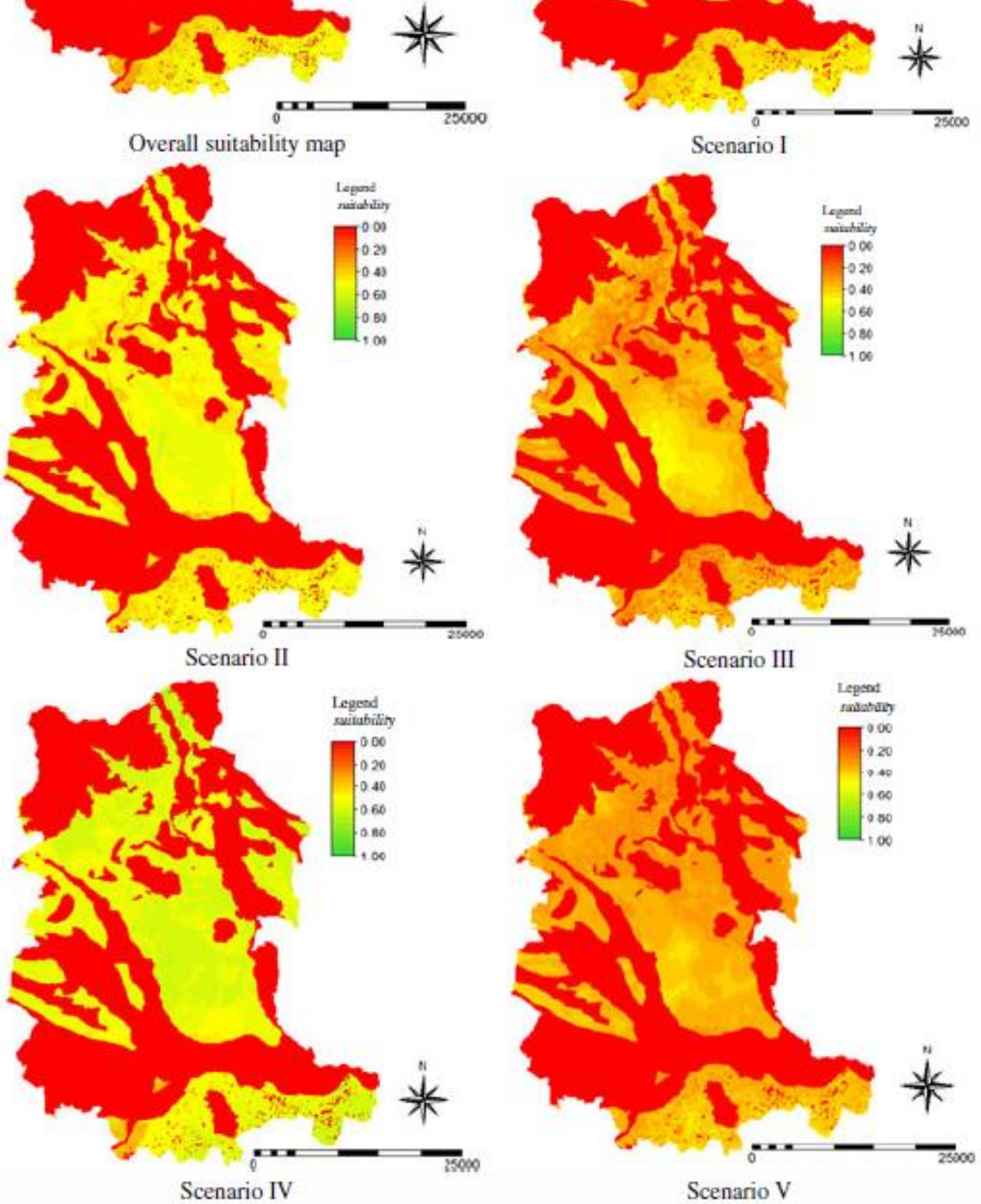


Figure 7. Sensitivity analysis.

so that they can take a decision according, for instance, to their risk awareness. Furthermore, the results of the performed analysis show that the use of the spatial ANP is suitable to represent the real problems of a territorial system and the complexity of the decision under examination, leading towards an integrated assessment. Moreover, the performed analysis provided a robust and transparent decision-making structure, making explicit key considerations and values and providing opportunities for stakeholders participation. The procedure followed in the application seems to be suitable for dealing with real world problems from a practical point of view, showing a way for considering the whole range of available information and for taking into account experts opinions.

However, there are still a number of opportunities for expanding the study and for validating the obtained results. First, it will be interesting to develop the present model according to the fuzzy sets theory (Zadeh, 1965) in order to properly deal with preference relations and uncertainties. As a matter of fact, uncertainty can be associated with fuzziness concerning the criterion weight assessment (Malczewski, 1999). In this context, DMs may specify their preferences with respect to the weights of the evaluation criteria using a set of linguistic terms such as 'low', 'medium', and 'high'. The linguistic terms possess a natural and human capacity to deal with ambiguity inherited in spatial problems (Boroushaki and Malczewski, 2010).

Moreover, it would be interesting to further develop the present study through investigation of different standardization procedures in order to test the robustness of the obtained results. In order to refine and optimize the siting process, further analyses are deemed appropriate. Based on the suitability values provided by the present study, alternative locations for the landfill could be proposed. By developing a more detailed analysis at the municipal scale, it will be possible, for instance, to assess site visibility through view shed analysis in a GIS which generates a map of the portions of landscape visible from each potential site. Furthermore, given the public opposition risk associated with undesirable facilities location, it would be of scientific interest to develop an online collaborative MC-SDSS.

Implementing GIS on the Internet and integrating its capabilities with MCDA procedures provides a system that can potentially fill the gap between the general public and experts (Malczewski, 2006). Web-based GIS (WebGIS) addresses the issue of democratization of spatial data and spatial decision-making process by offering open accessibility and effective distribution of geospatial information. It enables the public to gain access to dynamic online maps and spatial decisionmaking processes via online communication tools, where they can express and exchange their preferences and opinions regarding the decision problem. WebGIS thus contributes to greater participation in democratic decision-making procedures (Carver, 1999; Dragićević and Balram, 2004; Miller, 2006; Jankowski, 2009; Boroushaki and Malczewski, 2010).

Nevertheless, it is worth underlying that developing a web based MC-SDSS is only one part for easing the participation. For an effective feasibility study, it is also necessary to consider and redesign such components of a public participation project as (i) advertising methodology (informing the general public of the spatial decision-making), (ii) incentives for participation, and (iii) accessibility to the system (the computers and the Internet). Within this context, the sustainability of development projects depends, to a large extent, on the integration of local knowledge with scientific inputs from the experts (e.g. planners) in the decision-making process (Dunn, 2007; Geneletti and Abdullah, 2009). In conclusion, it can be stated that the integration of GIS and MCDA constitutes a very promising research line in the broad field of sustainability assessments of territorial transformation projects and, particularly, in that of undesirable facilities location problems, thanks to the greater effectiveness and efficiency gained by the spatial decision-making process.

REFERENCES

Aerts JC, Esinger E, Heuvelink GB, Stewart TJ. 2003. Using integer linear programming for multi-site land-use allocation. Geographical Analysis 35: 148–169.

Agenzia del Territorio. 2010. www.agenziadelterritorio.it, accessed on 20/10/2011.

Alumur S, Kara BY. 2007. A new model for the hazardous waste location- routing problem. Computers and Operations Research 34: 1406–1423.

Andrienko G, Andrienko N, Jankowski P. 2003. Building spatial decision support tools for individuals and groups. Journal of Decision Systems 12: 193–208.

Aragonés- Beltrán P, Pastor- Ferrando JP, Garcìa- Garcìa F, Pascual- Agullò A. 2010. An Analytic Network Process approach for siting a municipal solid waste plant in the Metropolitan Area of Valencia (Spain). Journal of Environmental Management 91: 1071–1086.

Armstrong MP. 1993. Perspectives on the development of
group decision support systems for locational problem
solving. Geographical Systems 1: 69–81.
Armstrong MP, Densham PJ, Rushton G. 1986. Architecture
for a microcomputer-based decision support system. Proceedings
of the 2nd International Symposium on Spatial
Data Handling, Williamsville New York, International
Geographical Union; 120–131.
Bedard Y, Merrett T, Han J. 2001. Fundamentals of spatial
data warehousing for geographic knowledge discovery.
In Geographic Data Mining and Knowledge Discovery,
Miller H, Han J (eds). Taylor and Francis: London.
Boroushaki S, Malczewski J. 2010. Measuring consensus
for collaborative decision-making: a GIS-based approach.
Computers, Environment and Urban Systems 34:
322–332.
Bottero M, Ferretti V. 2011. An Analytic Network Processbased
approach for location problems: the case of a waste
incinerator plant in the Province of Torino (Italy). Journal
of Multicriteria Decision Analysis 17: 63–84. DOI:
10.1002/mcda.456, ISSN: 1057–9214.
Bottero M, Lami IM, Lombardi P. 2008. Analytic Network
Process. La valutazione di scenari di trasformazione
urbana e territoriale.Firenze: Alinea.
Bouyssou D, Marchant T, Pirlot M, Tsoukiàs A, Vincke P.
2006. Evaluation and Decision Models: Stepping Stones
for the Analyst. Springer Verlag: Berlin.
Buenrostro Delgado O, Mendoza M, Lopez Granados E,
Geneletti D. 2008. Analysis of land suitability for the siting
of inter-municipal landfills in the Cuitzeo Lake Basin,
Mexico. Waste Management 28: 1137–1146.
Burstein F, Holsapple WC (eds). 2008. Handbook on Decision
Support Systems. Springer-Verlag: Berlin.
Carver S. 1991. Integrating multi-criteria evaluation with
geographical information systems. International Journal
of Geographical Information Systems 5: 321–339.
Carver S. 1999. Developing Web-based GIS/MCE: improving
access to data and spatial decision support tools. In
Spatial Multicriteria Decisionmaking and Analysis, Thill
JC (ed.). Ashgate: Aldershot, England; 49–75.
Changa NB, Parvathinathanb G, Breedenc B. 2008. Combining
GIS with fuzzy multicriteria decision making for
landfill siting in a fast growing urban region. Journal of
Environmental Management 87(1): 139–153.
Charlton M, Ellis S. 1991. GIS in planning. Journal of
Environmental Planning and Management 34(1): 20–26.
Cheng S, Chan CW, Huang GH. 2003. An integrated multicriteria
decision analysis and inexact mixed integer linear
programming approach for solid waste management.
Engineering Applications of Artificial Intelligence 16:
543–554.
Church RL, Scaparra MP, Middleton RS. 2004. Identifying
critical infrastructure: the median and covering facility
interdiction problems. Annals of the Association of American
Geographers 94: 491–502.
Colebrook M, Sicilia J. 2007. Undesirable facility location
problems on multi-criteria networks. Computers and
Operations Research 34: 1491–1514.
Comuni Italiani. 2010. www.comuni-italiani.it, accessed on
20/10/2011.
Delgado MG, Sendra JB. 2004. Sensitivity analysis in multicriteria
spatial decision making: a review. Human and
Ecological Risk Assessment 10: 1173–1187.
Delgado OB, Mendoza M, Granados EL, Geneletti D.
2008. Analysis of land suitability for the siting of intermunicipal
landfills in the Cuitzeo Lake Basin, Mexico.

Waste Management 28: 1137–1146.
Densham PJ. 1991. Spatial decision support systems. In Geographical Information Systems: Principles and Applications, Maguire DJ, Goodchild MF, Rhind DW (eds). John Wiley and Sons: New York; 403–412.
Densham PJ, Goodchild MF. 1989. Spatial decision support system: a research agenda. Proceedings of GIS/LIS'89, Orlando FL, 107–716.
Dey PK, Ramcharan EK. 2008. Analytic Hierarchy Process helps select site for limestone quarry expansion in Barbados. Journal of Environmental Management 88(4): 1384–1395.
Dragićević S, Balram S. 2004. A Web GIS collaborative framework to structure and manage distributed planning processes. Journal of Geographical Systems 6: 133–53.
Dunn CE. 2007. Participatory GIS: a people's GIS?. Progress in Human Geography 31: 616–637.
Eastman RJ, Kyen PAK, Toledno J. 1993. In A Procedure for Multiple- Objective Decision Making in GIS Under Conditions of Confl
icting Objectives, Hents J, Ottens HFL, Scholten HJ (eds). Fourth European Conference on GIS (ESIG'93) Proceedings, Genova (IT) 1(2): 438–447.
Erkut E, Karagiannidis A, Perkoulidis G, Tjandra SA. 2008. A multicriteria facility location model for municipal solid waste management in North Greece. European Journal of Operational Research 187: 1402–1421.
Farahani RZ, SteadieSeifi M, Asgari N. 2010. Multiple criteria facility location problems: a survey. Applied Mathematical Modelling 34: 1689–1709.
Feick RD, Hall BG. 2004. A method for examining spatial dimension of multi-criteria weight sensitivity. International Journal of Geographical Information Science 18: 815–40.
Ferretti V. 2011. Integrating multicriteria analysis and geographic information systems: a survey and classification of the literature. Proceeding of the 74th Meeting of the European Working Group "Multiple Criteria Decision Aiding", Yverdon (Switzerland) 6–8 October 2011.
Figueira J, Greco S, Ehrgott M (eds). 2005. Multiple Criteria Decision Analysis. State of the Art Survey. Springer: New York.
Gamboa G, Munda G. 2007. The problem of wind farm location: a social multicriteria evaluation framework. Energy Policy 35: 1564–1583.
Gemitzi A, Tsihrintzis VA, Voudrias V, Petalas C, Stravodimos G. 2007. Combining geographic information systems, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills. Environmental Geology 51(5): 797–811.
Geneletti D. 2005. Multicriteria analysis to compare the impact of alternative road corridors: a case study innorthern Italy. Impact Assessment and Project Appraisal 23(2): 135–146.
Geneletti D. 2010. Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Management 30(2): 328–337.
Geneletti D, Abdullah A (eds). 2009. Spatial Decision Support for Urban and Environmental Planning. A Collection of Case Studies. Academic Press: Kuala Lumpur.
Geneletti D, Beinat E, Chung CJ, Fabbri AG, Scholten HJ. 2003. Accounting for uncertainty factors in biodiversity impact assessment: lessons from a case study. Environmental Impact Assessment Review 23(4): 471–487.
Gomez-Navarro T, Garcia-Melon M, Acuna-Dutra S, Diaz-Martin D. 2009. An environmental pressure index proposal for urban development planning based on the analytic network process. Environmental Impact Assessment Review 29: 319–329.

Goodchild MF. 1993. The state of GIS for environmental problem solving. In Environmental Modeling with GIS, Goodchild MF, Parks BO, Steyaert LT (eds). Oxford University Press: New York.
Hale T, Moberg CR. 2003. Location science research: a review. Annals of Operations Research 123: 21–35.
Higgs G. 2006. Integrating multi-criteria techniques with geographical information systems in waste facility location to enhance public participation. Waste Management & Research 24: 105–117.
ITC-ILWIS. 2001. Ilwis 3.0 Academic User's Guide. International Institute for Geo- Information Science and Earth Observation, Enschede.
Jankowski P. 2009. Towards participatory geographic information systems for community-based environment decision making. Journal of Environmental Management 90: 1966–1971.
Jankowski P, Richard L. 1994. Integration of GIS based suitability analysis and multicriteria evaluation in a spatial decision support system for route selection. Environment and Planning B 21: 323–340.
Janssen R, Rietveld P. 1990. Multicriteria analysis and GIS, an application to agricultural land use in the Netherlands. In Geographical Information Systems and Urban and Regional Planning, Scholten HJ, Stillwell JCH (eds). Kluwer Academic Publishers: Dordrecht; 129–139.
Keeney RL. 1992. Value-Focused Thinking. A Path to Creative Decision Making. Harward University Press: Cambridge.
Khan S, Faisal MN. 2008. An analytic network process model for municipal solid waste disposal options. Waste Management 28(9): 1500–1508.
Kontos TD, Komilis DP, Halvadakis CP. 2003. Siting MSW landfills on Lesvos island with a GIS-based methodology. Waste Management & Research 21: 262–277.
Laaribi A, Chevallier JJ, Martel JM. 1996. A spatial decision aid: a multicriterion evaluation approach. Computer Environment Urban Systems 20(6): 351–366.
Leung Y. 1997. Intelligent Spatial Decision Support Systems. Springer-Verlag: Berlin.
Levy JK, Hartmann J, Li KW, An Y, Asgary A. 2007. Multi-criteria decision support systems for flood hazard mitigation and emergency response in urban watersheds. Journal of the American Water Resources Association 43(2): 346–358.
Li Y, Shen Q, Li H. 2004. Design of spatial decision support systems for property professionals using MapObjects and Excel. Automation in Construction 13: 565–573.
Liang C, Li Q. 2008. Enterprise information system project selection with regard to BOCR. International Journal of Project Management 26(8): 810–820.
Liu KFR, Lai JH. 2009. Decision-support for environmental impact assessment: a hybrid approach using fuzzy logic and fuzzy analytic network process. Expert Systems with Applications 36(3): 5119–5136.
Lober DJ. 1995. Resolving the siting impasse: modeling social and environmental locational criteria with a geographic information system. Journal of the American Planning Association. American Planning Association 61(4): 482–495.
Malczewski J. 1999. GIS and Multicriteria Decision Analysis. J. Wiley & Sons: New York.
Malczewski J. 2006. GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science 20(7): 703–726.
McDougall F, White P, Franke M, Hindle P. 2001. Integrated Solid Waste Management: A Life Cycle Inventory. Blackwell Science: London.
McHarg I. 1969. Design with Nature. Natural History Press:

Garden City, New York.
Miller CC. 2006. A beast in the field: the Google maps mashup as GIS/2. Cartographica 41(3): 187–199.
Miller GA. 1956. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychological Review 63: 81–97.
Morrissey AJ, Browne J. 2004. Waste management models and their application to sustainable waste management. Waste Management 24: 297–308.
Nas B, Cay T, Iscan F, Berktay A. 2010. Selection of MSW landfill site for Konya, Turkey using GIS and multicriteria evaluation. Environmental Monitoring and Assessment 160(1–4): 491–500.
Neaupane KM, Piantanakulchai M. 2006. Analytic network process model for landslide hazard zonation. Engineering Geology 85: 281–294.
Nekhay O, Arriaza M, Boerboom L. 2009. Evaluation of soil erosion using analytic network process and GIS: a case study from Spanish mountain olive plantation. Journal of Environmental Management 90: 3091–3104.
Niemura MP, Saaty TL. 2004. An analytic network process model for financial- crisis forecasting. International Journal of Forecasting 20(4): 573–587.
Norese MF. 2006. ELECTRE III as a support for participatory decision-making on the localization of wastetreatment plants. Land Use Policy 23(1): 76–85.
OCS - Osservatorio Città Sostenibili. 2002. Indice del grado di naturalità del territorio. OCS Doc 2/2002, Dipartimento Interateneo Territorio del Politecnico e dell'Università di Torino.