MULTICRITERIA ANALYSIS TECHNIQUES FOR SAND AND GRAVEL EXTRACTION SITE SUITABLE LOCATION IN THE SURROUNDINGS OF ZARAGOZA

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I. INTRODUCTION

European legislation calls for a well-planned sustainable development. **The overall objective is to provide information for the improvement or the restructuring of land-use decision processes including the consideration of socio-economic and environmental issues, as well as public participation.**

In this sense, any planning process must focus on a mix of hard (objective) and soft (subjective) information. The former are derived from reported facts, quantitative estimates, and systematic opinion surveys. The soft information denotes the opinions (preferences, priorities, judgments, etc.) of the interest groups and decision makers. The idea of combining the objective and subjective elements of the planning process in a computer based system lies at the core of the concept of SDSS (*Spatial Decision Support System* SDSS) (Booty *et al.*, 2001; Malczewski, 2004; Shim *et al.*, 2002).

SDSS can be defined as the combination of sophisticated decision support methodologies (e.g. in terms of multicriteria analysis techniques - MCE) and GIS (Gómez-Delgado y Barredo, 2005; Jankowski, 1995; Malczewski, 2004; Marinoni, 2005), and are therefore suitable to manage sustainable development of urban areas.

Zaragoza city and its surroundings are located in the Ebro corridor, a highly dynamic economic area within the Iberian Peninsula. The Quaternary materials deposited by the Ebro river are an important source of sand and gravel material which is needed for civil engineering purposes and hosts important groundwater reservoirs, used for domestic, industrial and agricultural purposes. The availability of these resources has been one of the reasons of the fast development of the city in the last decades. But this fast development has also led to negative interactions with the environment and man-made infrastructure. Thus, a research project was initiated to develop a methodological workflow which will facilitate the sustainable development in the surroundings of a growing city. Our main objective was to perform a

land-use suitability analysis to identify the most appropriate future land-use patterns, taking into consideration the geo-resources and geo-hazards of the study area.

II. METHODOLOGY

In the context of a land-use suitability analysis, it is important to differentiate between the site selection problem and the site search problem. The aim of site selection analysis is to identify the best location for a particular activity from a given set of potential (feasible) sites. Where there is no predetermined set of candidate sites, the problem is referred to as site search analysis (Malczewski, 2004). In this chapter, we compare the results obtained by the application of both approaches. During the site search analysis, performed using the SAW method, each pixel was considered a potential location alternative. The site selection analysis has been performed by the implementation of PROMETHEE-2 which belongs to the 'family' of outranking techniques. For a more detailed description of both methodologies see Saaty (1977), Brans *et al.* (1986), Lamelas *et al.* (2010) y Lamelas (2007).

In order to perform both site search and site selection, several steps needed to be covered:
- Definition of alternatives (decision options): feasible location areas.
- Definition of constraints: areas with land-use restrictions.
- Definition of important factors in the decision process: identification of criteria.
- Determination of criteria weights

A problem in the application of multicriteria analysis is the definition of weights for a given set of criteria. A variety of approaches does exist (Malczewski, 1999), but the probably best known weight evaluation method is the AHP, which we have used in our case as well.

Another problem is the specification of the criteria performance scores which are often subjective in their determination. Data which have been measured directly will certainly be regarded as more reliable than data which have been estimated, interpolated, taken from a map or simply interpreted. Thus, the method of criteria data collection plays a central role (Marinoni, 2005). A stochastic approach which takes account of the uncertainty of input values and which is presented at a last step in this chapter could be a way out of this dilemma.

1. Site search analysis for sand and gravel extraction sites

Constraints depict the areas where sand and gravel extraction is and will not be allowed. These are:
- Natural protected areas: the Nature Reserve of Los Galachos de La Alfranca, Pastriz, La Cartuja y El Burgo.
- Urban areas: information extracted from the topographic maps, scale 1:25,000, from the National Geographical Institute (IGN), imported to ArcGIS and updated.
- Infrastructures: Imperial Canal and other canals, roads and train rails (infrastructure and area of protection as defined by the Spanish roads law and Spanish railway sector law). Information also taken from the topographic maps.
- Planning: land management planning from Zaragoza city (PGOUZ) and Natural resources management planning of the Ebro river (PORN del Ebro).

- Cattle tracks: tracks traditionally used by the seasonal migration of livestock which are protected by law (LEY 10/2005, de 11 de noviembre, de Vías Pecuarias de Aragón). Information provided by the Aragon Gobernment.
- Industrial areas: the source is a database of industrial areas from the Aragon Institute of Public Works (IAF, Instituto Aragonés de Fomento).
- Areas already extracted: the information about old and present-day extractions was obtained from the Zaragoza Council and the Department of Mines in the Provincial Industrial Service from the Aragon Government.

A variety of social, economic and environmental factors were taken into consideration:

- Distance to other natural protected areas: Special Protection Areas for birds, Special Areas for Conservation, habitats, sites of geological interest, wetlands, hydraulic public domain, etc., which are not strictly restricted, but require environmental impact assessment prior to their utilization.
- Groundwater vulnerability: a model developed in the project implementing Hölting *et al.* (1995) methodology within Gocad was introduced in the process (Lamelas, 2007). Since sand and gravel exploitation implies the reduction of the aquifer protection cover, areas with higher groundwater vulnerability should be protected from being exploited.
- Agricultural capability of the soils: a model developed by Lamelas (2007), using the Cervatana model (de la Rosa y Magaldi, 1982), was used. Soils with good agricultural capability should be avoided for extraction site location in order to preserve the resource.
- Distance to roads: according to the EIA law extraction sites should be more than 2 km distance from roads.
- Distance to nuclei with population over 1,000 inhabitants: extraction sites should be more than 2 km distance, according also to EIA law.
- Distance to existing extraction sites: no less than 5 km distance from present-day extractions, according to EIA law.
- Groundwater level: it is forbidden to exploit sites where the aquifer reaches surface. Also, areas with deeper water table are better, since the capacity of the resource can be higher. A model developed in the project has been applied (Lamelas, 2007).
- Geo-resource location: the sand and gravel thickness model was extracted from a 3D geological model developed in Gocad in the project (Lamelas, 2007; Lamelas *et al.*, 2010). Deposits with a high thickness imply a higher exploitable volume of the deposit so that the surface area of the area that is mined can be reduced.
- Overburden: developed according to the 3D geological model previously cited. This factor is introduced since the removal of the overburden to get access to the deposit causes costs.

Many multicriteria methods, as the SAW methodology, require criteria standardization to bring all of them to a common scale. The classification ensures that the weights properly reflect the importance of a criterion. The standardization method used here may be classified as a subjective scales approach (Malczewiski, 2004). These ranges have been selected following standards, legal requirements, or the classes already determined in the geo-resources and geo-hazards models used as criteria in the decision process. For more details on the standardization approach see Lamelas, (2007) and Lamelas *et al.* (2010).

Weights for criteria are assigned with the help of an AHP extension specifically developed for the ArcGIS environment at the Institute of Applied Geosciences of the Technische Universität Darmstadt (Marinoni, 2004). In this case study, preference values have been defined after conversations with different stakeholders from the Zaragoza Council, Aragon Government and Ebro River Authority. The highest preference values (and therefore the highest weights) were given to the resource location (value 0,286 = 28%), groundwater protection (0,187), distance to natural protected areas (0,187), as well as the agricultural capability of the soils (0.111) and groundwater level criteria (0,111).

In addition, in order to test the robustness of the results, a sensitivity analysis of the model has been performed where higher weights were given to economic aspects. In this sense, the highest preference values were given to the overburden material (0.187) and groundwater level (0.157). In a last step all classified raster files (criteria) are multiplied by its corresponding weight and summed up.

2. Site selection analysis for sand and gravel extraction sites

The main objective of a site selection analysis is the ranking of feasible alternatives. Here, location alternatives are represented by twelve future extraction sites, provided by the Environmental Department in Zaragoza council. Geometrically, these alternatives represent a polygon each.

As alternatives are directly compared along their criteria values, the application of outranking methods does not require a standardization of criteria. The restrictions (constraints) and criteria are the same used for the site search analysis. It is important to notice that there exist some extraction sites, representing one alternative, located partially in restricted areas, as these polygons are partially occupied or crossed by a road or a cattle track. It has implied the inclusion of the constraints as an additional criterion in the decision process.

A multicriteria GIS extension was developed to draw site specific values (minimum, maximum, mean, etc.) for raster cell populations that lie within the polygonal outline of a location alternative. For our analysis the mean value was used for all criteria since, in our opinion, this value better symbolizes all alternative values.

PROMETHEE-2 methodology uses preference function, which is a function of the difference between two alternatives for any criterion (Brans *et al*., 1986). We used the «usual criterion» preference function that is based on the simple difference of values between alternatives.

The pair comparison of alternatives produces a preference matrix for each criterion. Having calculated the preference matrices along each criterion, a first aggregation is performed by multiplying each preference value by a weighting factor w (expressing the weight or importance of a criterion), and building the sum of these products (Marinoni, 2005). This results in a preference index, Π.

The final ranking of alternatives is performed by calculating the net flow Φ (a1) for every alternative, a, which is a subtraction between the leaving flow (how a1 is outranking all the other alternatives) and the entering flow (how a1 is dominated by all the other actions).

3. Stochastic PROMETHEE-2

The stochastic PROMETHEE-2 approach requires the assignment of theoretical distribution types to every criterion of the available alternatives. Distribution models were inferred based upon the criteria value populations (pixel values) within each location alternative (polygon) along all criteria.

In a next step the distribution models were used within a Monte Carlo Simulation (MCS). The number of iterations n was set to 5000 (Marinoni, 2005). The results may then be used to establish a rank distribution for a specific alternative or a distribution of alternatives for a specific rank. However, the alternative possessing the highestnumber of first ranks may not necessarily be the best (Marinoni, 2005). Therefore, it was suggested calculating a dimensionless mean stochastic rank MSR for every alternative. Finally, in order to compare mean stochastic ranks of simulations with different iteration counts, the MSR value must be standardized which leads to the stochastic rank index SI. The more the SI value approaches 0, the better the alternative.

III. RESULTS AND VALIDATION

The validation of a model consists in checking whether the structure of the model is suitable for the purpose and if it achieves an acceptable level of accuracy in predictions. In the case of land-use suitability analysis, in order to validate the model, a common practice is to verify that the result follows the preferences in the assignation of the weights to the criteria.

Figure 1 shows the final results of the site search analysis for new sand and gravel extraction sites. The lefthand side of figure 1 shows the suitability map under sustainability. The white sections indicate the areas where extraction site location is not possible due to the constraints. The areas more suitable to sand and gravel extraction are located in the high terraces, and in those terraces covered by pediments where the thickness of resource is relatively high. Besides, these areas are far from valuable natural areas, outside areas most vulnerable to groundwater contamination, and beneath soils with poor irrigation capability. In addition to areas without resources, the less suitable are located in the low terraces were groundwater vulnerability is higher and water table level is nearer to the surface. The righthand side of figure 1 shows the results of this last approach, where the best locations for sand and gravel extraction sites have been increased in surface and are identified to be in the low terraces as groundwater protection is less important in this last analysis. In fact, in order to measure the correlation between both results the Pearson coefficient of correlation between both raster images has been calculated giving a value of 0.713, significant at a 0.01 level, implying a high agreement between both results.

The preference indices and the leaving and entering flow generated after the application of PROMETHEE-2 methodology are presented in Table 1. Figure 1 shows the location of the alternatives of the site selection analysis. The best alternatives, number 10, 9, 1 and 2, match the more suitable areas in the site search analysis and are located in the high terraces, in some cases covered by pediments, giving evidence of the robustness of the model.

The results of the site selection suitability analysis based on stochastic PROMETHEE-2 can be seen in Table 1.In general, there are few differences in the SI values and total flows.

In fact, in both approaches alternative 10 present the first ranking. The change in ranking in alternatives 1 and 2 (third and fourth ranking), can be due to the fact that a part of alternative 1 is located in a restricted area. Thus, alternative 1 and 2 present a value higher than 1 and 0, respectively, in PROMETHEE-2, being alternative 1 less suitable than alternative 2. On the opposite, in the stochastic approach, as the probability of 0 values (no restricted area) in alternative 1 is much more higher than the 1 values (restricted areas), and the rest of criteria are better, alternative 1 is better ranked than alternative 2.

Figure 1
a) SITE SEARCH ANALYSIS UNDER SUSTAINABILITY AND b) SENSITIVITY ANALYSIS
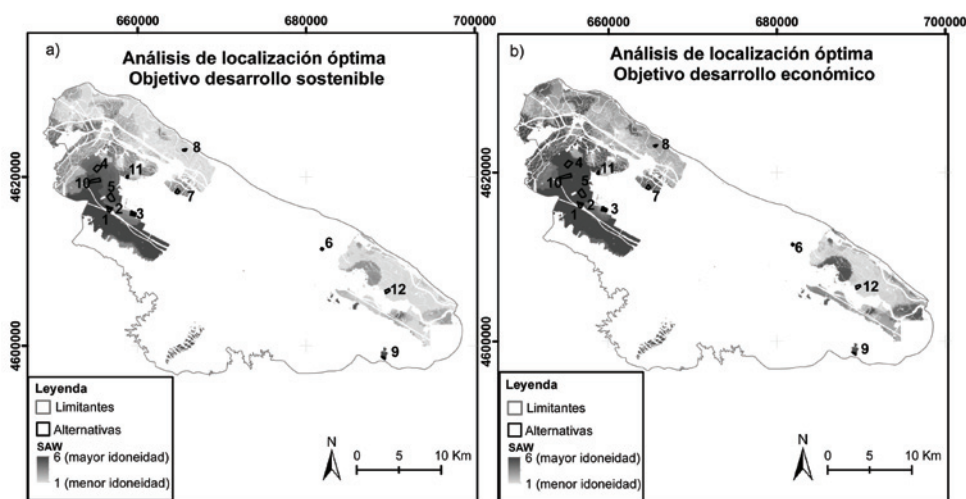
IV. DISCUSSION AND CONCLUSIONS

The extraction site suitability maps developed are a substantial aid in the land-use management, considering the additional benefit of integrating geoscientific aspects, as demanded by Agenda 21.

A fundamental problem of decision theory is how to derive weights of criteria. One disadvantage of the AHP method is the inherent subjectivity of assigning preference values between criteria. The weights derived from these preference values have usually a profound effect on the results of the suitability analysis. However, in our particular case, there were no strong differences between the results of the site search analysis performed under the concept of sustainable development or the site search analysis performed under the concept of economic development.

It is important to notice the similarity of the results after applying the site search analysis and the site selection analysis. In general, the highest rank positions are present in alternatives located in areas where the site search analysis also presented the highest suitability values. Some differences can be observed in alternatives located in areas with restrictions, as in the site selection analysis constrains are included as criteria.

Table 1
ALTERNATIVES (Alt), ENTERING FLOW (Φ+), LEAVING FLOW (Φ-), NET FLOW (Φ), PROMETHEE-2 RANKING, STOCHASTIC INDEX (SI), PROMETHEE-2 STOCHASTIC RANKING, SITE SEARCH VALUE (SAW).

Alt	Φ+	Φ-	Φ	PROMETHEE ranking	SI	Stochastic ranking	SAW Mean value
1	6,07	4,51	1,56	4	0,20	3	4.60
2	5,91	2,33	3,58	3	0,24	4	4.58
3	4,32	3,93	0,39	8	0,62	8	3.00
4	4,50	3,85	0,64	6	0,50	6	3.99
5	5,95	4,73	1,22	5	0,15	2	4.27
6	1,89	8,96	-7,07	12	1,00	12	1.57
7	4,42	3,93	0,48	7	0,54	7	3.30
8	2,07	6,43	-4,36	11	0,89	11	1.81
9	5,99	2,36	3,64	2	0,28	5	4.65
10	6,49	2,17	4,31	1	0,06	1	4.97
11	3,72	4,62	-0,90	9	0,69	9	3.88
12	2,51	6,00	-3,49	10	0,84	10	1.71

Performing a PROMETHEE-2 with the mean values produces a mean result, but the uncertainty in either the input values or the result cannot be quantified. The stochastic approach helps approaching this problem by using probability distributions for the input parameters, instead of single values. For spatial multicriteria analysis in a variable data environment it is our recommendation to use stochastic approaches although, in this case, the process was not absolutely integrated in the GIS, and as a consequence it is very time consuming.