GIS-based Selection of Appropriate Landfill Sites: The Case of Communal Grouping in Batna, Algeria

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ABSTRACT

The choice of a landfill site is a complex process that includes various, social, environmental, and technical, parameters which require the processing of a large amount of spatial data. The Geographic Information System (GIS), integrated with its functionalities, represents a powerful and well-adapted tool to solve this problem. This study uses the Analytic Hierarchy Process (AHP) to solve the problem of quantifying qualitative features. It enables users to make intuitive judgments about the relative eight of different predetermined criteria or options in Batna, northeastern Algeria and its neighboring municipalities. The superposition of data related to several characteristics, such as geology, hydrology, and land use, allowed us to overcome several difficulties in evaluating the location of sites suitable for establishing landfills. Results show that 88.498km^2 in total meets the specified exclusion factors, of which 34.098% represent areas of very excellent suitability and 33.741% appropriate areas. Finally, low appropriateness applies to 32.161%.

Keywords-GIS; Analytical Hierarchy Process (AHP); landfills; communal grouping; Batna

I. INTRODUCTION

Implementing an environmental management strategy requires detailed, reliable, and well-organized information on the state of the territory and the spatial distribution of socio-environmental problems. Geographic Information System (GIS), Multi-Criteria Analysis (MCA), and statistical methods are robust and well-adapted tools for solving the problem of illustrating the multidisciplinary approach in the selection of favorable sites for public landfills. This approach proposes, on one hand, the GIS approach [1-3] which, through its spatial analysis functions, contributes to the study of a large number of potential sites according to the evaluation criteria (exclusion and appreciation), and on the other hand, the AHP approach, which is one of the most popular and widely employed MCA methods, which is used to rank these alternatives. [4-6].

Rapid urbanization and rapid and erratic population growth have generated huge amounts of municipal waste. Several techniques and methods have been used for solid waste management, such as collection, transportation, recycling, physical treatment, and landfilling [6, 7]. The latter has been used for many years and is the most common method for the disposal of urban solid waste. The choice of the landfill site is a complex process that includes various social, environmental, and technical, parameters and regulations. This requires processing a massive amount of spatial data [6]. GIS and MCA are widely used tools and methods [8, 9]. GIS specializes in capturing, storing, and analyzing databases and allows the integration of multiple layers of information with different combinations. MCA is designed to produce synthetic information [10] that provides a list of candidate sites based on a combination of selection criteria.

The wilaya of Batna produces about 188 thousand tons of solid waste annually, including 169 thousand tons of household waste. This quantity is expected to increase due to population growth, economic development and, changing lifestyle [11]. Nearly 70% of this waste is concentrated in urban areas, while managing household waste as it is currently conducted is unfavorable to the socio-economic development of Wilaya due to the significant increase in demography and to the change in consumption patterns. The implementation of a GIS prototype as a decision support tool in the field of environmental management is a tool that should allow managers to analyze the information necessary for the selection of appropriate sites for the storage of household waste. It will thus contribute to the protection of the environment and public health and reduce the obligations imposed on future generations by limiting the proliferation of illegal dumpsites [12]. The selection of a suitable site for a landfill consists of a compilation of data related to several disciplines, such as geomorphology, geology, hydrology, climatology, and demography. In the present study, several thematic maps were used, namely the topographic map, the geological map, and the piezometric map adding the use of the digital terrain model extracted from the SRTM image. All these data have allowed the establishment of a database with a spatial reference under a GIS whose purpose is the selection of appropriate sites for the establishment of landfills in Batna and neighboring municipalities.

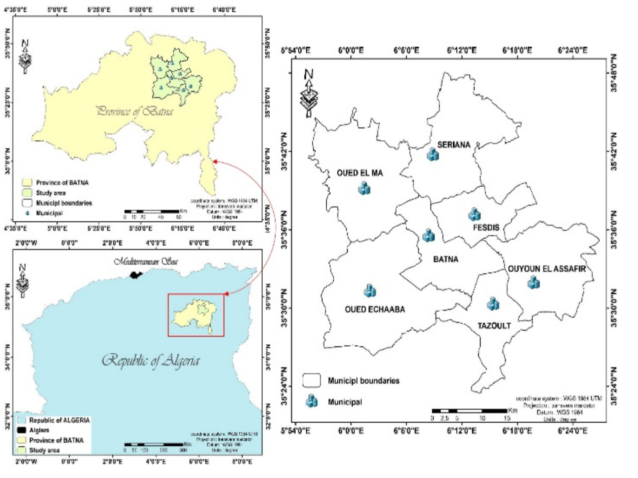

Fig. 1. The study area.

II. GEOGRAPHIC LOCATION OF THE STUDY AREA

The wilaya of Batna is located in northeastern Algeria, 435km from the capital Algiers. The study area is situated in the northeast of this wilaya, between 5°5' and 6°2' E longitude and 35°24' and 35°48' N latitude. It extends over the city of Batna (capital of the wilaya of Batna) and neighboring communes, namely Tazoult, Oued Elma, Seriana, Ouyoun El Aassafir, Fesdis, and Oued Echaaba (Figure 1).

III. METHODOLOGY

The proposed model for optimizing the location of waste storage sites consists of an overlay of geographic data from several disciplines in a GIS that will serve as a decision support tool. Each information theme used various spatialization techniques to create basic spatial documents in raster or vector format (slope, land use, hydrographic network, road networks). Finally, a set of decision criteria was developed (i.e. exclusion and evaluation criteria). Exclusion criteria are constraints that aim to limit the search for sites in the domain that do not tolerate competition [13]. These criteria are applied to create a constraint map. Six criteria were considered in this study:

- Exclude areas with 500m of proximity to the hydrographic network, with the purpose to avoid the pollution of the aquatic environment.
- Exclude the road network with a proximity of 500m.
- Exclude the urban areas with a proximity of 2000m.
- Exclude wells, springs, reservoirs, and water towers with a proximity of 1000m
- Exclude the protected areas (forests, agriculture) with a proximity of 1000m.
- Exclude areas with a slope greater than 12%.

ModelBuilder is an application to create, modify and manage models. Models are workflows that allow concatenating sequences of geoprocessing tools and injecting the output of one tool into another tool. ModelBuilder can be compared to a visual programming language for creating workflows [14, 15]. Furthermore, ModelBuilder has a simple interface with drop-down menus, toolbar tools, and contextual menu options. The layout of the tools and variables connected is called the model diagram. Figure 2 illustrates the sequences of geoprocessing tools used to determine suitable sites for implementing a public landfill in Batna and the bordering municipalities.

The next step is to examine and evaluate suitable sites for the landfill, considering geo-environmental (soil permeability) and socio-economic (proximity to the road network, slopes) factors. The results of the AHP correspond to scores that sum to 1. The construction of the hierarchy and the structuring of the priorities should ensure the consistency of the homogeneity and relevance of the groupings and the proportional relationship between the important parameters.

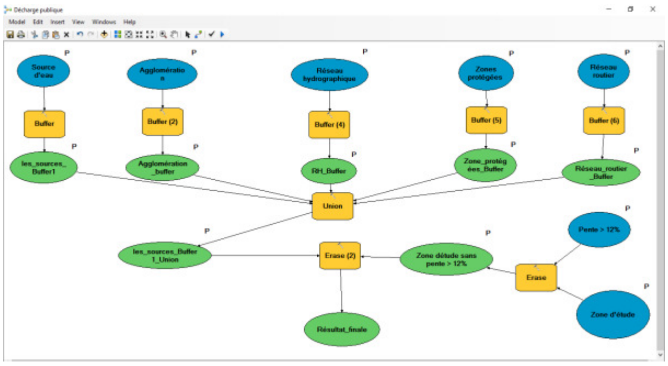

Fig. 2. The model determining suitable sites for landfill siting.

TABLE I. DETERMINATION OF THE RELATIVE IMPORTANCE OF FACTORS BY A SCALE OF 1 TO 9 [16]

Degree of importance	Definition	Explanation
1	Equal importance	Two characteristics contribute equally to the goal
3	Low importance of one characteristic in relation to another	Experience slightly favors one characteristic over another
5	Strong or determining importance	Experience strongly favors one characteristic over another
7	Very strong or proven importance	A characteristic is strongly favored, and its dominance is evidenced in practice
9	Absolute importance	Evidence favoring one characteristic over another is as convincing as possible
2, 4, 6, 8	Values associated with intermediate judgments	When a trade-off is necessary

IV. RESULTS AND DISCUSSION

The results clearly show that most of the study area is excluded according to the previously established model (Figure 3). The results of the AHP method show that the factor of soil permeability has an influence of 55.84% on the final result, and the factor of distance to main roads is 31.96%. Finally, the factor of slope influences 12.19%. Note that CR (Coherence Ratio) must be less than 0.10. A higher CR indicates a higher level of inconsistency. In our case, the CR is equal to 0.018. The weighted overlay scales the input data on a defined scale (graduated by default from 1 to 9), weights the input rasters and groups them. The most favorable locations for each input criterion are re-ranked based on higher values.

In the weighted overlay tool, the sum of the weights assigned to the input rasters must equal 100%. The layers are multiplied by the appropriate factor, and each cell's resulting values are grouped. Weighted overlay assumes that more favorable factors result in higher values in the output raster, thus identifying these locations as the best. As with all weighted overlay analyses, we defined the problem by rendering it into submodels and then identified the input layers. In the case of our study, the input information layers are soil permeability, road proximity, and slope. In our study's case, and after considering the problem, we explicitly focused on the permeability factor (Figure 4).

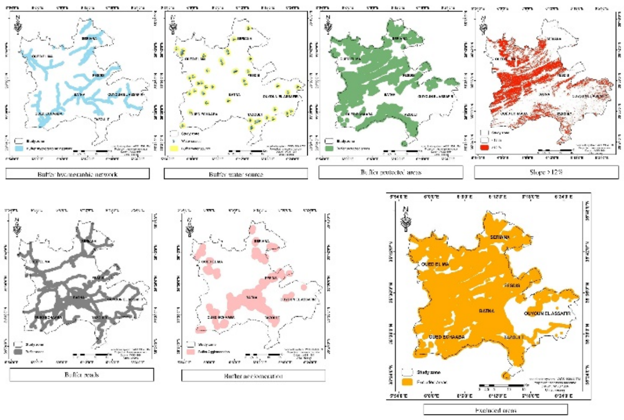

Fig. 3. Results of the implementation of the exclusion criteria.

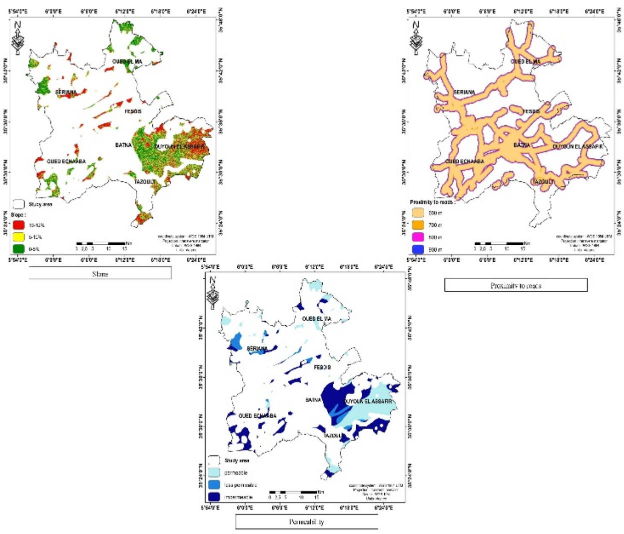

Fig. 4. Thematic maps representing the evaluation criteria.

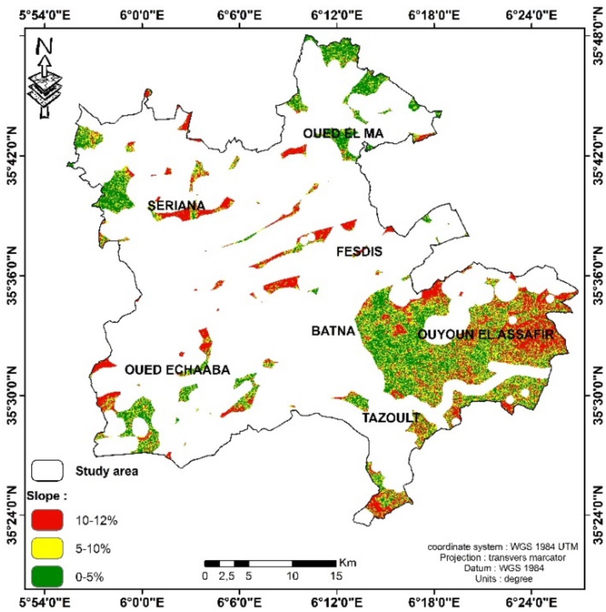

Fig. 5. Final map of suitable sites for landfills.

The following percentages of influence were assigned to the ability cards. The values in parentheses are the percentage produced by division by 100 to normalize the values. These are assigned to each suitability map: soil permeability (50%), road proximity (30%) and slope (20%). As with the assignment of suitability scales, the assignment of weights is a subjective process that depends on the goals of our study. After the spatial analysis of suitability and appreciation, it can be noted that the total area that meets the committed exclusion factors is 88.498km², with 34.098% of that area representing areas of very good suitability, and 33.741% of the area is suitable areas. Finally, 32.161% of the area falls under the low suitability class (Figure 5).

V. CONCLUSION

Site selection is a critical issue in installing a landfill site. The objective of this work was to develop a site selection methodology that will allow the selection of the most suitable areas for installing a landfill. The core of this study is based on the processing of geospatial data related to the study area using a GIS. For this purpose, a set of factors was classified and two categories (exclusion factors and appreciation factors) were defined. A siting methodology for the area is provided by the current study. It can support the decision-makers in solving the waste management problem. The selection criterion of permeability was considered as the most important in this study.

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