

# Integration of ELECTRE III and AHP—Multicriteria Decision Analysis for Identification of Suitable Areas for Artificial Recharge with Reclaimed Water



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**Abstract** The present study represents a coupling between the geographic information system (GIS) and the multicriteria analysis, leading to the selection of an artificial recharge site with reclaimed water for the Ariana Governorate, Tunisia. Based on the regional characteristics, bibliography, and available data on artificial recharge, 13 constraints and 5 factors were hierarchically structured for the adequacy of artificial recharge. The factors are subdivided into two main groups: environmental factors and economic factors. The adopted methodology allows a preliminary assessment of a recharge site, by combining the weighted linear combination (WLC) and the Analytical hierarchy process (AHP) in a GIS. The results of this study show three potential candidate sites that are based on environmental factors, which in turn are more important than the economic factors. These sites are ranked in descending order using the ELECTRE III method.

**Keywords** Multicriteria decision analysis · Analytical hierarchy process · The weighted linear combination · Artificial recharge · Reclaimed water

## 1 Introduction

Tunisia is a country characterized by an arid to a semiarid climate, with an area of about 164,000 km<sup>2</sup>. The estimated available freshwater is only about 450 m<sup>3</sup>/citizen/year, which is relatively low compared to the international standards

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(1000 m<sup>3</sup>) [1]. On the other hand, the over-exploitation of groundwater has resulted in lowering the groundwater levels. In such areas, artificial recharge has been practiced for the recovery of groundwater levels, the improvement of groundwater quality, and the storage of surface water in the sub-surface, as well as a barrier to salinity intrusion [2]. The artificial recharge of groundwater also allows an additional polishing of the reclaimed water through soil aquifer treatment or geo-purification since the water moves through soils and aquifers [3].

In recent years, several studies have been implemented using new and different methods such as remotely sensed data, Geographic Information System (GIS) approaches as well as geophysical methods, in order to identify suitable sites for artificial groundwater recharge, taking into account different geological and hydrogeological criteria.

## 2 Methodology

The selected study area is the region of Ariana. It is located in the far northeast of Tunisia and extends to 482 km<sup>2</sup>. The climate is semiarid with about 460 mm of annual precipitation and 19 °C yearly mean temperature. The wastewater in the study area is treated by two wastewater treatment plants, namely Chotrana I and Chotrana II. To quantify the organic pollutants, all the analyses and measures are standardized in accordance with the Tunisian Norm (NT 106.002 and NT 106003), similar to the French Norm (AFNOR).

For the selection of the suitable area for artificial recharge with reclaimed water, an Analytic Hierarchy Process (AHP), combined with a GIS, was used. All criteria were selected according to the regional characteristics and were based on consults with national experts and literature reviews [2, 4, 5]. In fact, this methodology involves the following main steps:

- Selection of the decision criteria: factors and constraints;
- Dealing with constraints, the Boolean criterion is applied to differentiate areas considered as suitable for an artificial recharge site from those which are not, taken into unsuitable under any conditions;
- Normalizing factor layers to make their combination possible using fuzzy functions and calculating the consistency ratio (CR);
- Weighing and combining the criteria using the AHP method;
- Aggregating spatial layers criteria using a Weighted Linear Combination (WLC);
- Creating two scenarios for the determination of the best/most appropriate sites;
- Applying the ELECTRE III method to rank the best/most suitable site.

### 3 Results and Discussions

In the present study, the generated suitability map for artificial recharge was developed using the AHP method in the ArcGIS environment. The pairwise comparison method was used to assign weights and establish the importance of environmental and economic criteria, using the experience and knowledge of local experts and literature reviews.

#### 3.1 Scenario Design

The WLC alternatives are applied for two scenarios, generated by different weights that are assigned to the environmental and economic factors. The first scenario assigns a weight of 0.75 to the environmental factors and 0.25 to the economic ones. For the second scenario, weights are of 0.25 and 0.75, respectively, for environmental and economic factors.

For the two scenarios, the CR is less than 0.1. Hence, consistency is acceptable. For the environmental aspect of our project, the environmental factors are given precedence over the economic factors.

#### 3.2 Results of the Outranking of Candidate Sites Using the ELECTRE III Method

According to the environmental scenario, the selected sites are classified in a predefined category using the ELECTRE III method. The evaluation criteria used are the distance from roads, the geometric form of the site, the cost of cover soil, and the distance from wetlands.

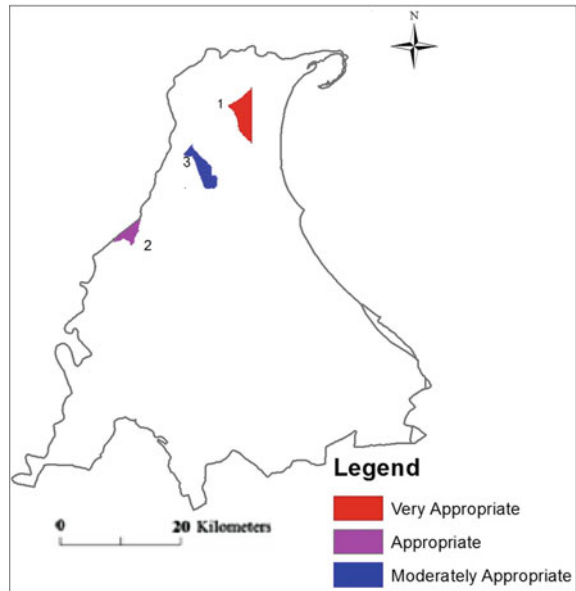
Then, this evaluation makes it possible to generate a classification of these sites according to the sites of the ascending and descending distillation.

The final ranking of the selected sites is presented in Fig. 1. The outranking of these candidate sites using the ELECTRE III method, according to both distillations, were divided in appropriate, moderately appropriate, and very appropriate sites.

### 4 Discussions

This method creates an easy way to understand what works best with continuously distributed data. Three candidate sites (1, 2, and 3) were recommended for an artificial recharge site because these regions were determined to be high-suitability regions by the AHP and GIS techniques. The weighting process was carried out using the

**Fig. 1** Final artificial recharge suitability map showing the selected sites based on the environmental scenario



Analytic Hierarchy Process (AHP) method. The selected weights are used with their corresponding individual standardized criteria as inputs for the WLC aggregation method. It is important to note that the most suitable sites are concentrated in the northern and northwestern parts of the study area, which contain permeable and halomorphic soils as well as poor land use and no residential inhabitants.

The method that we applied in the current study, using the AHP and GIS techniques, is of great significance and helpful for water resource management. However, the selection of the final artificial recharge site requires geotechnical studies and hydrogeological analyses focused on the protection of groundwater.

## 5 Conclusions

The present study describes an innovative methodology to rank suitable sites for artificial recharge with reclaimed water—using the fuzzy set theory, AHP, and WLC based on the GIS—in the region of Ariana (Tunisia), selected as the target area. Many criteria are selected, taking into account geological, environmental, and economic aspects. Literature reviews and expert knowledge are used for the selection of the appropriate fuzzy functions and their control points. The proposed method considers 13 constraints and 5 factors. The constraints criteria used in this study include soil permeability, slope, coastal zone, forest, groundwater depth, water supply wells, wetlands, distance from rivers, proximity to irrigation, urban area, distance from roads, soil salinity, and depth of vegetation cover. The combination of different sets

of factors according to the environmental scenario indicates three possible artificial recharge sites. The most suitable sites are concentrated in the N and NW parts of the study area. These zones contain permeable and halomorphic soils and are characterized by poor land use and lack of residential activity, and by slopes at less than 15%. The ELECTRE III method has been applied to classify the candidate sites and to identify the best option. This work constitutes a helpful technical support for decision-makers, for a better-integrated water management policy in the region of Ariana.

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