

Landfill site selection using GIS, remote sensing and multicriteria decision analysis: case of the city of Mohammedia, Morocco

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Abstract In Morocco, as in most developing countries, landfill is still the only solution for the disposal of municipal solid waste. Choosing the appropriate site for waste elimination is a very complex process that depends on several criteria and regulations. To this end, many environmental, social and economic requirements have to be met. For the city of Mohammedia, which is the subject of this study, the choice of the landfill site was performed using multi-criteria decision analysis (MDA), a geographic information system (GIS), and remote sensing. Several criteria were discussed, such as waste production, distance from houses, surface and ground water, land use, slope of land, transport network, etc. A final map was produced by overlaying the criteria map layers, which enabled us to propose three potential sites for the establishment of the landfill. Our study also showed the need to rehabilitate the current landfill site, which represents a major nuisance in terms of air, water and soil pollution, and affects the health of city residents.

Keywords GIS · Landfill siting · Multi-criteria · Solid waste · Site selection · Mohammedia

Introduction

The amount of solid waste generated in Morocco, as is the case in all developing countries, poses a serious threat to the environment and to public health, given the fact that the current conditions of collection, transportation, landfilling or recycling of this waste are clearly insufficient.

In order to comply with national sustainable development policy, solid waste management has been considered and several mechanisms have been put in place. Thus, the legal arsenal has been strengthened by the adoption of Law 28–00, which lays down the rules and basic principles relating to waste management and disposal. Solid waste must be disposed of in controlled and monitored landfills to limit the impact of waste on the environment.

The rapidly changing socio-economic environment has fostered the emergence of production and consumption patterns without much concern for environmental issues. This has resulted in significant changes in the quantity and quality of solid waste generated, which has increased to more than 6 million tons per year at present. In terms of composition, household waste in Morocco is very wet (water content varies between 60 % and 70 %), and most of the wet weight (65–70 %) consists of organic matter (60–70 %). Paper and cardboard account for 5–10 % and plastic for about 6–8 % (Enda Maghreb 2003).

Given the importance of this sector, the government has made considerable efforts to ensure a satisfactory level of effectiveness in the various services relating to waste management. However, the management of such waste is now facing a set of constraints: institutional, legal, technical, social and financial.

First, most of the municipal waste is disposed of in landfills without prior treatment that would reduce the impact of this waste on the surrounding environment

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(leachate, odour, biogas, etc.). Secondly, and more importantly, the quantities of recovered and recycled waste remain minimal, and far from reflecting the potential of the composition of municipal waste in Morocco.

Interest in landfills, the implementation of which up to now has been random and spontaneous, has grown considerably, and reducing the impact of the proliferation of these uncontrolled landfills is now a priority action. Thus, several landfill sites have been subject to environmental impact assessments, rehabilitation operations, and transfer requests in order to reduce the nuisance caused by lack of good management and proper location.

The identification of a landfill site is based on a multi-sectoral analysis where different players are involved. The goal is to find the best site for which favorable conditions are met, where the following criteria are evaluated:

- Geological and hydrological criteria, especially water protection
- Area utilization criteria, including housing and transport
- Nature conservation criteria.

In this context, our contribution combines geographic information system (GIS) technology and multi-criteria analysis in order to achieve an objective search for a better match between capacity, life expectancy, location and nuisance for the location of a suitable site for the new landfill of the Prefecture of Mohammedia.

Thanks to its ability to store, manipulate and produce spatial information, GIS is considered an excellent analysis tool for planning and management. Such systems are used to study the natural environment and human activities distributed over a territory, enabling planners to make strategic decisions about regional planning, urban planning, environmental protection, economic development, etc. (Dadras et al. 2010; El Morjani 2002; Mansour 2009).

Presented as a methodological guide for landfill site selection, this document is aimed specifically at municipalities and communities, which are called on to engage in the new dynamics within a favorable and evolving institutional, administrative and political environment.

This guide is also a basic technical and methodological support tool that will help with matters relating to pollution caused by landfill sites chosen only in the light of land available. It is hoped it will be a valuable tool to help policymakers and players involved in the management of solid waste grasp the challenges of the draft law on waste and the texts of application in the process of being approved.

Methods

We began by gathering all the data required to meet all criteria. In this study, we identified six criteria for the selection of a suitable site for a new landfill. All parameters were identified on the basis of guidelines for the selection of a favorable site for solid waste produced by the German Technical Cooperation (GTZ 2004) and on the basis of information relating to the selection of landfills, considered by international organizations such as the United States Environmental Protection Agency (US EPA). These criteria include: waste generation, surface water, land use, slope of land, transport network and geology.

For the digital GIS database development, various maps were used as separate information layers (Table 1).

Landsat of the US space agency (NASA) is at an average altitude of 705 km on circular nearly polar orbits characterized by an inclination of 98.2°. To produce the land use map, we worked with a multispectral satellite image, Landsat georeferenced without cloud cover (El Hadraoui 2013).

The final map was prepared using the layer technique (superposition procedure) according to the criteria and sub-criteria selected. This technique is an approach that includes the different characteristics of the study area and makes comparison possible through ARCGIS10.2 software (Lunkapis 2010; Delgado et al. 2008; Nishanth et al. 2010).

In our study, we used more specifically the “Weighted Overlay” method by Arcgis software. This tool applies one of the most used approaches for overlay analysis to solve multi-criteria problems such as site selection and suitability models.

Table 1 Sources of different maps used

| Map type | Source |
|---------------------------------------|---|
| Topographic map | National Agency of Land Conservation, Cadastre and Cartography, Mohammedia |
| Map of slopes | http://srtm.csi.cgiar.org/selection/inputcoord.asp |
| Surface water map | Hydraulic Basin Agency of Bouregreg, Chaouia and Ben Slimane |
| Land cover map | http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp |
| Development and regional planning map | Prefecture of Mohammedia |
| Geological map | http://www.neogeo.unisi.it/IWSViewer/egeo.php?s=cama&c=CAMA044 |

The weighted overlay tool lets us implement several of the steps in the general overlay analysis process within a single tool.

The tool combines the following steps:

- It reclassifies values in the input rasters into a common evaluation scale of suitability or preference, risk, or some similarly unifying scale.
- It multiplies the cell values of each input raster by the rasters' weight of importance.
- It adds the resulting cell values together to produce the output raster.

The tool accepts only integer rasters as input, such as a raster of land use or soil types. Continuous (floating-point) rasters must be reclassified to integer before they can be used.

Since the input criteria layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion must be reclassified into a common preference scale such as 1–10, with 10 being the most favorable.

For the surface water map, the road map and the waste production map, we used the ArcGIS “Euclidian Distance”

Table 2 Calculations of the required area for the future landfill

| Total waste tonnage (in tons) | Total waste volume (in m ³) | Burial area (ha) | Landfill area (ha) |
|-------------------------------|---|------------------|--------------------|
| 3,884,338 | 2,913,253 | 29.13 | 39.3 |

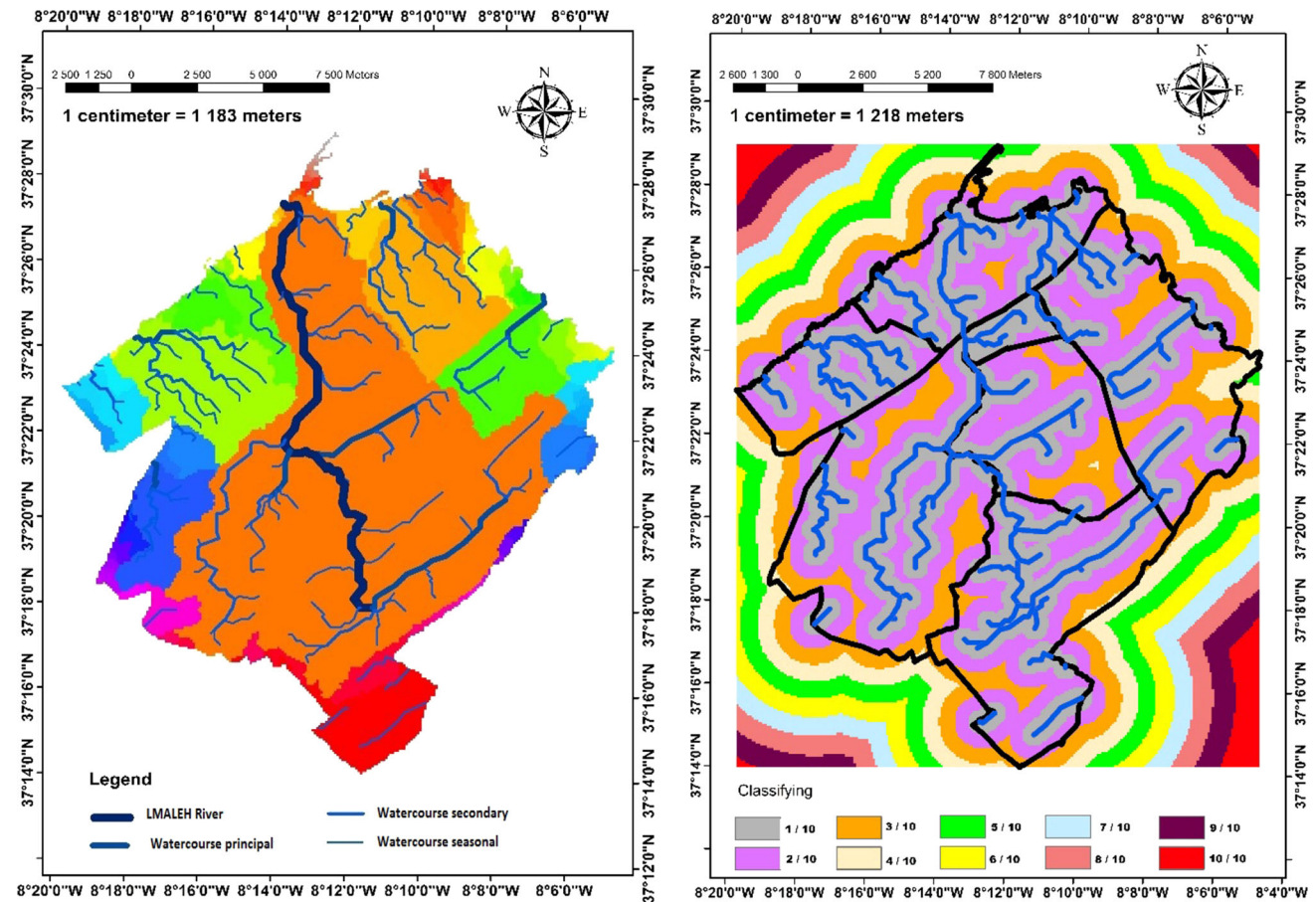


Fig. 1 Surface water map, Mohammedia

Table 3 Monitoring parameters of surface water at a sanitary landfill

| Frequency | Parameter |
|-----------|--|
| Quarterly | Temperature, pH, conductivity, TSS, total nitrogen, NH ₄ , COD, BOD5, dissolved oxygen, total hydrocarbons, fecal coliforms |
| Annual | Heavy metals (zinc, lead, arsenic, chromium, mercury, nickel, chloride, total iron, etc.) |

tool in order to calculate, for each cell, the Euclidean distance to the closest source. The resulting rasters are continuous rasters. To be used, they have to be reclassified to integer into a common preference scale such as 1–10, with 10 being the most favorable; idem for the slope map, which is a continuous map.

For the land use map, water areas, woods and building areas were excluded for any plans of landfill construction. We used the “Reclassify” tool to rule out such areas. This tool also allowed us to grade the other areas.

For the geological map, each land type was graded according to its impermeability, 10 being 100 % impermeable.

The grades in both cases are shown in the maps’ legends.

Each of the criteria in the weighted overlay analysis may not be equal in importance. The input criteria are multiplied by the weights and then added together. In our case, all the criteria have the same weight of importance.

As we used the Weighted Overlay tool for suitability modeling (to locate suitable areas), higher values indicate that a location is more suitable.

Results and discussion

The prefecture of Mohammedia is part of Great Casablanca and consists of six collectivities. The prefecture covers an area of 277 km² and is bounded on the north by the Atlantic Ocean, on the south by the province of Ben Slimane and on the west by the city of Casablanca. The prefecture of Mohammedia produces about 444 t municipal waste daily. The estimate of the area required for the burial of waste is carried out with some assumptions:

- The amount of waste produced by the year A_I is estimated using the relation: $Q_{A_I} = Q_{2014} (1 + T_c)^{(A_I - 2014)}$, T_c is the average annual growth rate of waste estimated in our study at 1.3 %. The study considers an operation of the landfill over a period of 20 years, let it be 2034.
- Waste compaction is around 75 %, a required ton 0.75 m³ of the landfill (DE 2013).
- The height of the landfill is 13 m. This height includes the thickness of the waste, which is 10 m, and the thickness of the intermediate cover.

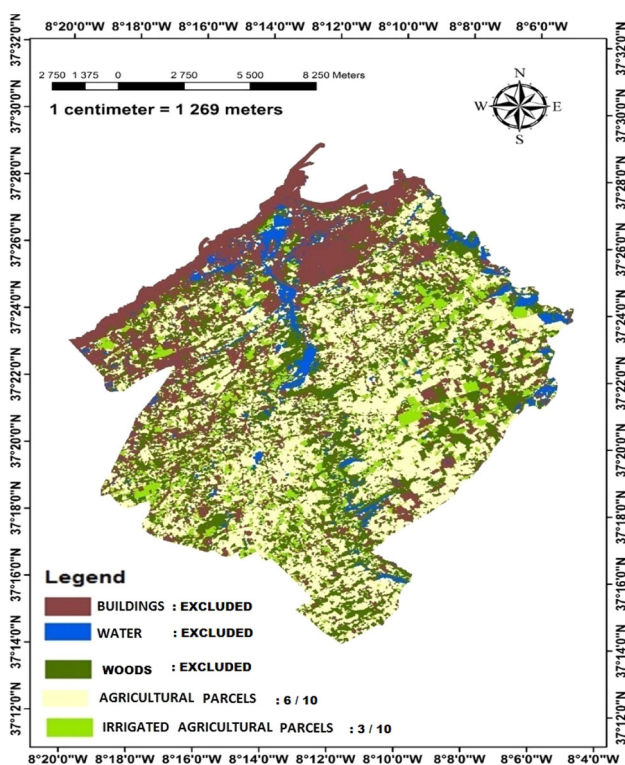


Fig. 2 Land use map, Mohammedia

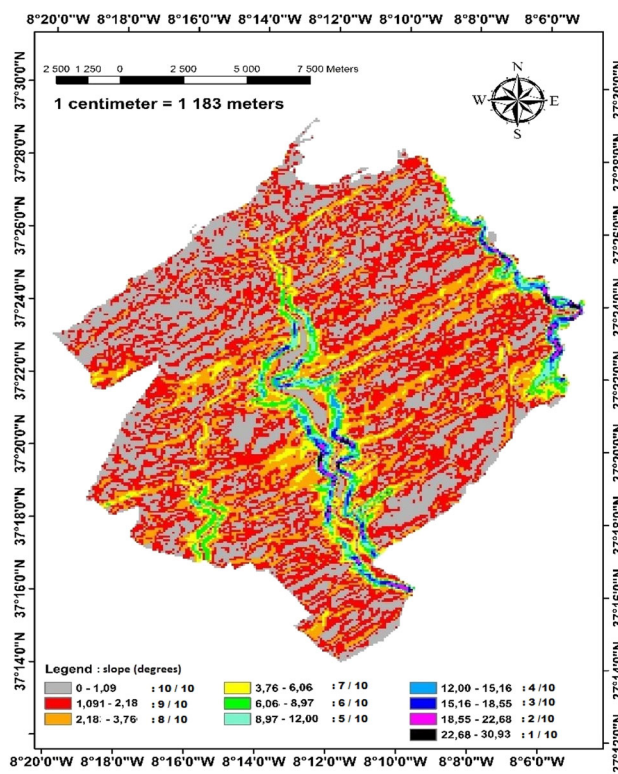


Fig. 3 Slope map, Mohammedia

- The area of the associated infrastructure (storage platform, buildings, trails, leachate collection basins, etc.) is about 35 % of the landfill area.

The land sought to establish the new inter-communal landfill requires an area of about 40 ha as stated in Table 2.

Surface water map

The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate (see Fig. 1 for surface water map). Safe distances from meandering and non-meandering rivers should be achieved to prevent waste from eroding into rivers and major streams.

Monitoring surface waters is to periodically check, at representative locations, the quality of these waters and to detect any anomaly or incident on the receiving environment that is linked to the landfilling activities, such as an accidental leachate spillage in streams (Sarptas et al. 2005; Al-Khatib 2007). The main objective is to help decision-makers choose and implement, as soon as possible, the necessary

measures to remedy any anomalies detected. The design of the monitoring program will depend, among other things, on the nature of the pipeline, water levels and flow, and on the soil permeability. There should be at least two monitoring points by stream, one upstream and another downstream of the landfill. Moroccan law provides devices for preserving the quality of surface water via Decree No. 2-97-787 of 4 February 1998 on water quality standards and on the water pollution inventory. Monitoring of the physicochemical and biological parameters is required (Table 3).

Land use map

The land use map (Fig. 2) develops primarily on the basis of remote sensing data, from satellite or plane, and is supplemented by information obtained from the topographic map and the proposed or underway planning, and from various infrastructure intended for development planning or regional urban planning.

It is important to ensure the wellbeing of the people living around the landfill and to protect them from harm

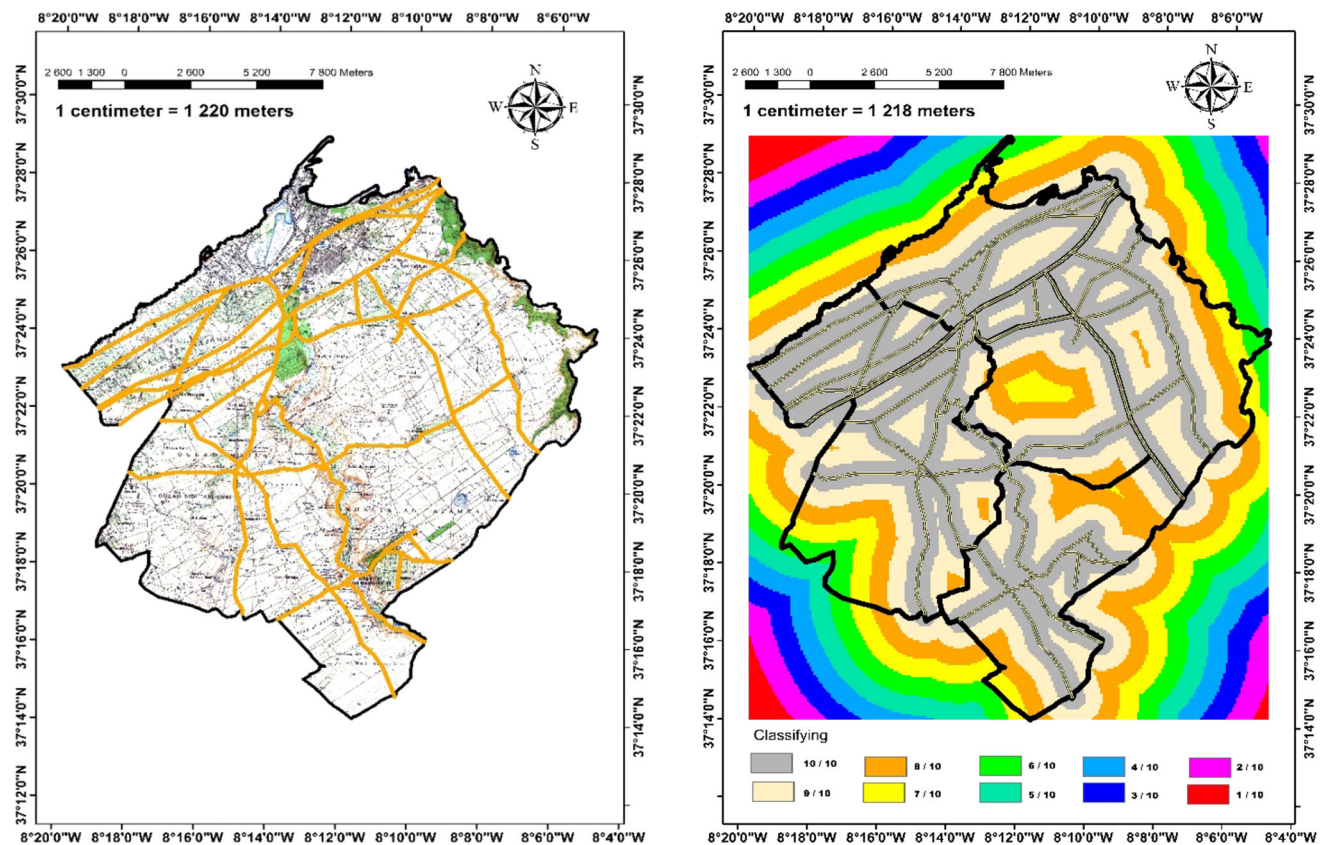


Fig. 4 Road map, Mohammedia

that can be caused by the landfill: the smells, the flights of plastic bags and paper, animals (birds, rodents and insects), fire, the noise of trucks and compacting machines, etc.

In addition, the site excludes protected areas such as local woods and conservation areas of wildlife or plants. In order for the land to not have other conflicting uses, it is best to choose bare land that can be used after the completion of the landfill (Delegado and Tarantola 2006; Higgs 2006).

Slope map

The proper slope on which to build a landfill is about 5–15 % (see Fig. 3 for slope map). If the slope is too steep, it would be difficult to build and excavate the landfill components, and would also impact the water drainage. Slopes steeper than 15 % would increase the rain flow. Contaminants can therefore travel a greater distance from the containment area (Higgs 2006).

Road map

Aesthetic considerations would be good practice for good planning, and on the basis of this principle, landfills should not be located within 300 m of main paved roads. However, the landfill should not be placed too far from the existing road network in order to avoid the high cost of feeder roads construction (Sener et al. 2006; Nas et al. 2010). Figure 4 shows a road map of the study area.

Table 4 Daily production of Mohammedia collectivities

| Collectivity | Production (t/day) |
|----------------------|--------------------|
| Mohammedia | 213 |
| Ain harrouda | 72 |
| Bni ikhlef | 56 |
| Ech'chellal | 62 |
| Sidi moussa ben ali | 18 |
| Sidi moussa Imajdoub | 23 |

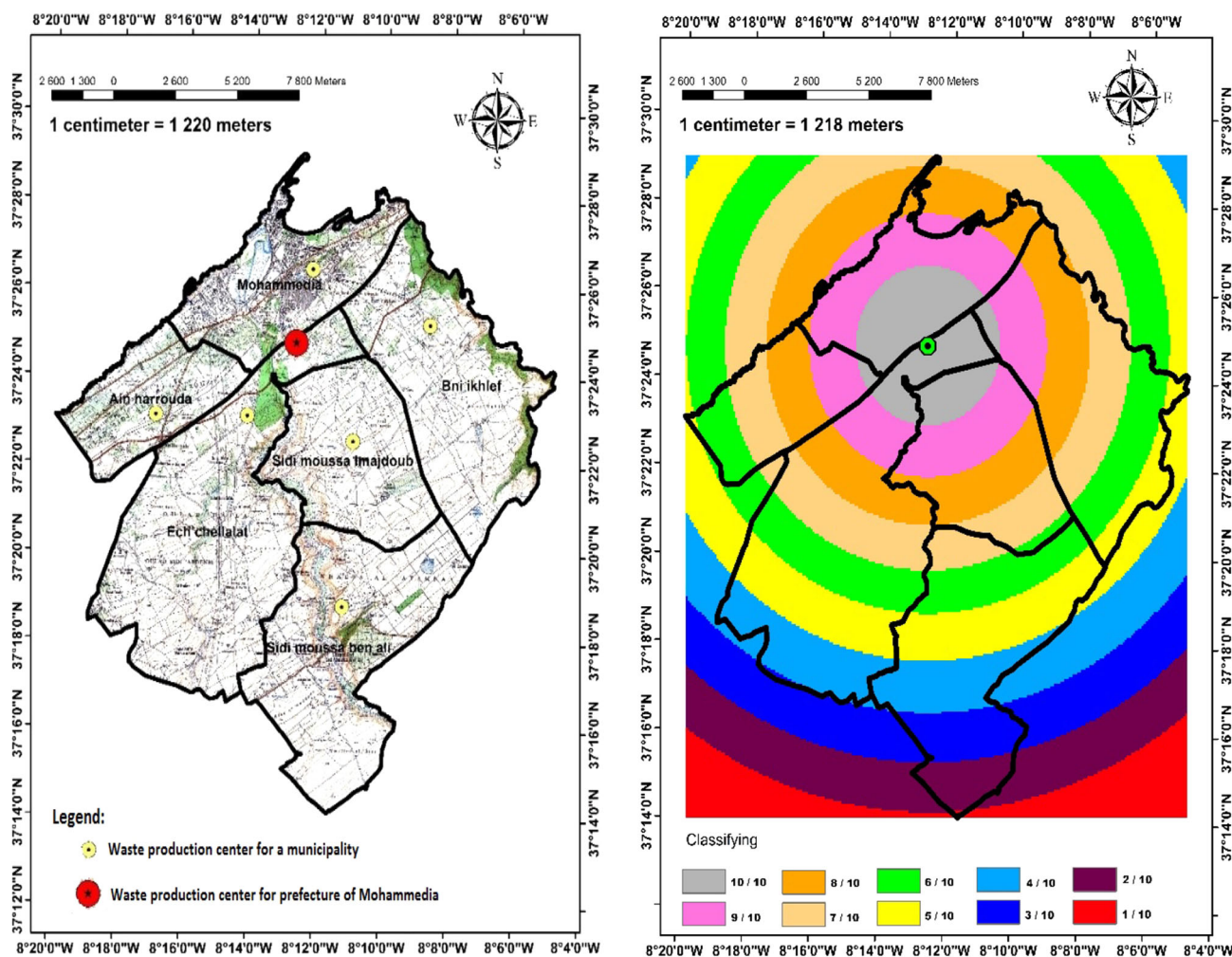


Fig. 5 Waste production map, Mohammedia

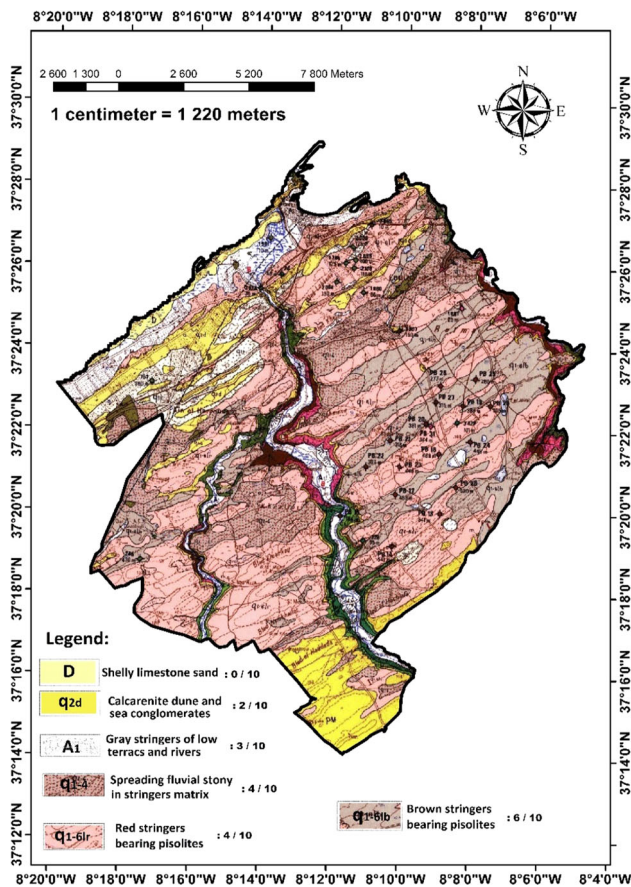


Fig. 6 Geological map, Mohammedia

Waste production map

Selecting a site near the source of waste generation reduces transport costs, which are partly related to the distance from the landfill (Fig. 5). Compliance with this factor would decrease the time and distance of waste collection, which improves service quality (Karadimas 2008; Sumathi et al. 2007; Mahini and Gholamalifard 2006) (Table 4).

Geological map

Choosing a site with a good impermeability protects the soil and aquifers against contamination from leachate. The geological environment can be classified according to the nature and degree of permeability of the land (Fig. 6).

Below are examples of different types of land:

1. Alluvial materials

- Sand, gravel and pebbles: domain of alluvial reservoirs where groundwater vulnerability is greatest because of the risk of rapid spread of pollution from leaching by rainwater.

- Silts, marine vessels: generally shielding between buried gravel or sand where the captive reservoirs fairly well protected from surface pollution are created.

2. Limestone, chalk, and in general, all the cracked land: where pollution spreads very rapidly and can spread over large distances.
3. Heterogeneous and less permeable land: where pollution spreads more slowly but stays longer (fine sand, clayey sand, etc.)
4. Impermeable land: where pollution cannot affect groundwater, and only surface water that can wet these lands.

It is recommended that the lockers of the future landfill are provided with a waterproofing layer at the bottom. The bottom of the locker can be fitted with a compacted clay or silt layer (>60 cm) with a very low permeability (10–8 m/s). It is also recommended to use a geotextile and geomembrane. In addition to these precautions, a monitoring program should be developed to monitor the quality of groundwater in and near the landfill, and thereby prevent possible contamination (Yılmaz and Atmaca 2006; Gemitzi et al. 2007; Chang et al. 2008). The monitoring should be done using a periodic collection of representative samples of groundwater followed by laboratory analysis.

It is necessary to provide two piezometers, one upstream and another downstream of the landfill. Piezometers must be well equipped and enable monitors to easily take representative samples of the water quality and to measure the level of the groundwater. Such samples will be used in the monitoring of the physicochemical and biological parameters as shown in Table 3.

Potential sites for future landfill

An analysis of the resulting map leads to the pre-selection of the three most appropriate pieces of land for the establishment of a solid waste landfill (Fig. 7). The final site validation depends primarily on the results of study of land tenure.

Conclusion

The results confirm that GIS is a powerful spatial analysis tool that can provide valuable assistance to the planning (Rahman et al. 2008). The methodology chosen in the present work is based on remote sensing and GIS, which are increasingly used to study surface phenomena, and form essential tools in interactive decision support systems

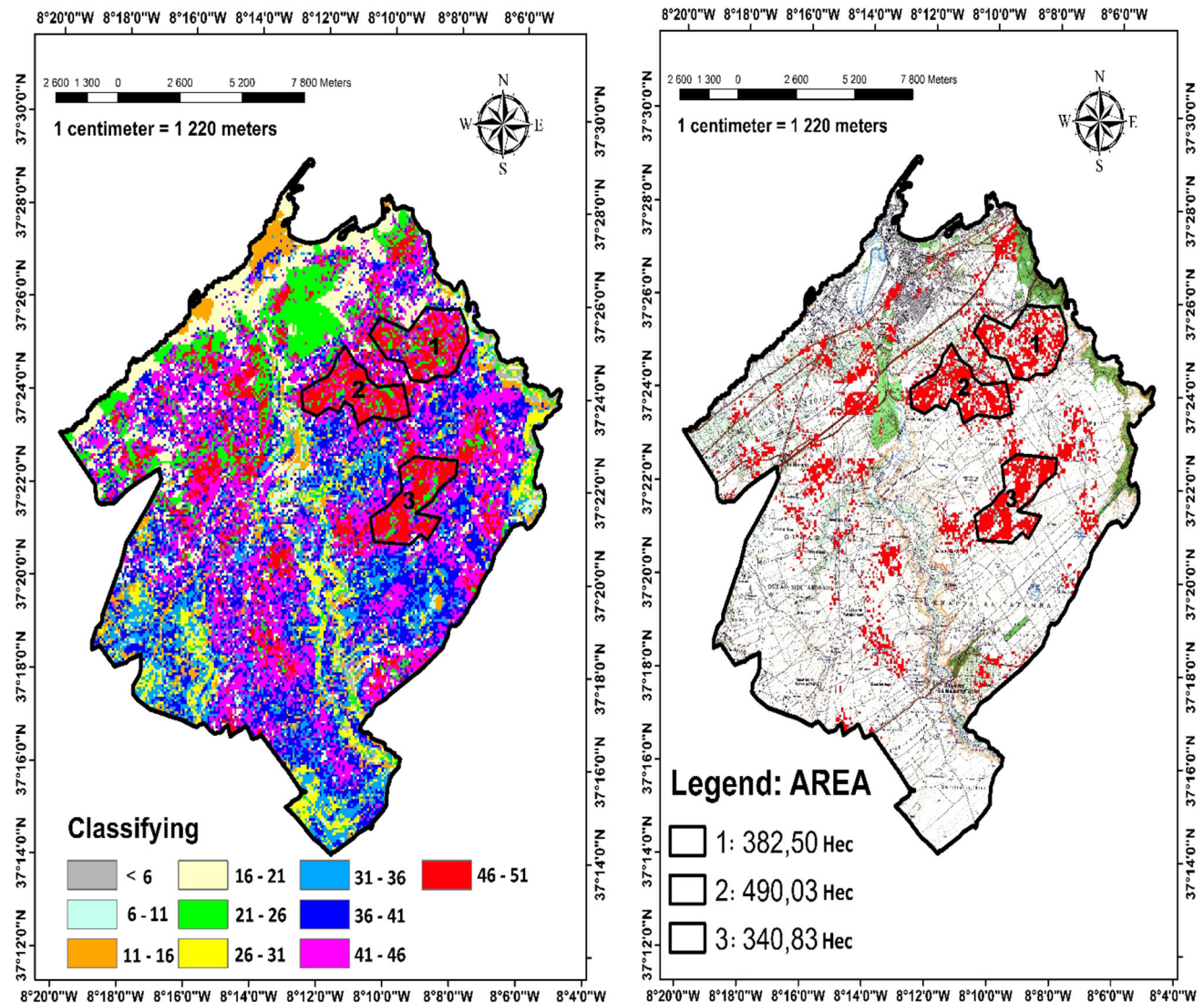


Fig. 7 Map of potential sites for future landfill in Mohammedia

and effective for management operations. The production of thematic maps of different criteria in GIS allowed us to scale up the different regions of the Prefecture of Mohammedia; the superposition of these modules then provided a map of suitable sites to establish a municipal solid waste landfill.

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