Technical Note

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Enhancing the success of new dams implantation under semi-arid climate, based on a multicriteria analysis approach: Case of Marrakech region (Central Morocco)

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Abstract: Water management has become one of the major interests in arid and semi-arid regions. Scientists have suggested different criteria and methodologies for the identification of suitable dam sites. According to our literature review, we have used two major methodologies for the selection of suitable dam site location: geographic information system and remote sensing (GIS/RS) and multicriteria analysis (MCA) integrated with GIS/RS. The most common criteria used for the selection of suitable dam sites were slope, rainfall, land use land cover, soil type, lithology, lineament density, and hydrographic typology. All the factors were superimposed to prepare the synthesis map of water-harvesting structures, each thematic layer's weight was determined, and storage water potential indices were calculated using water accumulation conditions. According to the water-harvesting location map, where the spatial distribution of the excellent (5%), very good (9%), and good (17%) aptitude classes is established in the northeast and central parts of the westward zone, the average located in the center of the zone. Study and weak are located south of the map; the area of moderate (25%) to poor (44%) suitability

is situated in the south and southwest zone. The MCA was validated using an existing dam across the study area, where the MCA provides for the dam located in the good and moderate zones. The approach adopted in this study can be applied for any other location globally to identify potential dam-construction sites. From the point of view of the literature of multicriteria analyses of water recovery, areas unsuitable for surface water harvesting and dam projects are suitable for groundwater recharge.

Keywords: multicriteria analysis, geographic information system and remote sensing, dam, water-harvesting structures.

1 Introduction

Surface water is generally limited in arid and semi-arid regions due to low rainfall and high evaporation ruling over such regions [1]. Arid and semi-arid climatic environments are undergoing an increasing surface water deficit across the world [2,3].

Increasing population and modern industrial and agricultural activities are creating increasing demand for water resources due to the inadequate availability of surface water resources. In addition, climate-related hazards have ultimately resulted in decreasing surface water supplies. Consequently, these activities have led to an increase in research, not only with regard to surface water resources but also with an emphasis on locating surface water of good quality for human consumption [1,4].

In Morocco, the period of drought at the beginning of the 1980s, considered the longest ever observed, was the starting point for a policy of building small dams and hill lakes using a highly labor-intensive practice. These dams are designed mainly for irrigation, livestock watering, and protection against floods or for the supply of drinking water in rural areas that have no groundwater resources.

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In this context, we chose the Tensift region, located in the central part of Morocco, to assess the possibilities of enhancing the successful implantation of new dams based on a method requiring less field investigations and heavy and expensive tools.

The Tensift region belongs to an arid zone with an annual rainfall ranging between 160 and 350 mm, an annual evaporation reaching 2,640 mm. The decrease in rainfall caused by climate change on a global scale is clearly observed in the Tensift basin. The intensification of modern irrigation techniques (with a mechanized pumping system) and the growth of the urban population are the origin of a strong increase in water needs. These phenomena lead to several issues in the management of water resources. Historically, the Tensift region area has exploited groundwater as its main water resource. But the pressure on this groundwater has clearly increased over the last years, particularly due to the development of large-scale irrigation, for recreational activities (tourism) and population growth. This increase is now leading to a drop in the level of the water line, hence the importance of building dams in this region.

Generally, dam site selection is conducted by traditional methods, such as conventional decision-making techniques or according to political interests [5]. However, remote sensing (RS), geographic information systems (GIS), and multicriteria analysis (MCA) techniques are recently emerging as some of the most appropriate approaches to understand dam sites. In recent years, the advance in satellite and computational power has enhanced the opportunity to manage different hydrological factors and terrain characteristics. RS and GIS are of high adaptability in joining spatial information with different progressed numerical, factual, and decision-making strategies, such as fuzzy logic, weighted overlay analysis, multicriteria evaluation techniques, and artificial intelligence [6].

However, the success of rainwater harvesting (RWH) yet depends on the site selection and its construction technical design [7]. Appropriate selection of sites for different RWH technologies in larger areas is a great challenge [8]. In the literature, several methodologies for the selection of suitable sites for RWH have been developed [9–11]. The most conventional method of selecting suitable sites for dam/reservoir construction is the field survey, but the main disadvantage of this technique is that we cannot concentrate on larger areas, which may result in some wrong conclusions. Nowadays, the appropriate data for the purpose can be made available from GIS and RS data, and this will allow the selection of sites for different RWH technologies [8].

The objective of this study is to identify and make an inventory of RWH possible sites to enhance the availability of water by storing rainwater over the Tensift basin

to partially mitigate the problems of water shortage in this region. All water-harvesting systems consist of the following components [12]:

- A catchment: The area of the catchment varies from a few square meters to several square kilometers and can take the form of a rock, a paved road, a piece of farmland, or a roof. It is also known as a runoff area.
- A storage facility: This is where collected runoff accumulates and can be used for various purposes.
- A target: The end user of the water-harvesting system when the harvested water is used for agriculture or domestic use.

Each parameter is firstly studied independently, and then all parameters are integrated and compiled to derive a synthetic map aiming at the choice of the hill dam site. RS and GIS are important tools to enable appropriate surface water management [13]. Recent studies showed that RS satellite imagery and GIS are widely used for hydrological and hydrogeomorphological studies.

2 Study area

The study area, the Tensift watershed, lies within the central part of Morocco over an area of about 20,500 km² extending between latitudes 31° and 32° 30' N and longitudes 7° and 10° W. The region presents strong geographical and climatic variations with three distinct areas: the plain of Marrakech Al Haouz and Chichaoua in the east, the coastal plain of Essaouira in the west, and the piedmont of the High Atlas in the south [14] (Figure 1).

The climate is arid to semi-arid characterized by an annual average temperature of 20°C, an irregular rainfall and long periods of drought. The monthly rainfall pattern showed a highly temporal variability with an average of approximately 300 mm/year mainly received in November (Tensift Water Basin Agency data).

On the geological side, the study basin offers different types of facies. The plain of Marrakech-Al Haouz and Chichaoua presents detrital formations (alluvium) of Tertiary and Quaternary age. In the western part, the overlying sedimentary sequences comprise epicontinental and marine sediments from the Cretaceous and Eocene largely dominated by limestone, calcareous sandstones, and marls [15].

3 Methodology

The current study uses a compilation of RS and GIS databases for preparing the dam potential zones. A hill dam is a reservoir created by a small earthen dam containing a

Figure 1: Location map of the study area.

few tens of thousands to 1 million m^3 of water collected in watersheds of a few hectares to a few square kilometers. They are integrated naturally into the landscape without creating any particular nuisance. They are able to regulate the water flows and, therefore, likely to maintain the populations in place by ensuring them the real possibilities of development.

RS offers data that can be used to gain insight into hydrological and morphological knowledge over large regions at different spatial and temporal scales such as merged satellite rainfall estimate, tropical rainfall measuring mission, the global precipitation measurement, advanced space borne thermal emission and reflection radiometer, LANDSAT satellite, and several others. For the past 20 years, researchers have put up their efforts on satellite imagery applications in hydrology [16–20] using GIS for collecting, storing, managing, and analyzing spatial and nonspatial data [21]. Various thematic layers can be generated by applying spatial analysis with GIS. These layers can then be integrated to identify suitable sites for hill dams. The integration of GIS and MCA is a privileged and indispensable way to make GIS become real decision support

systems. Coupling of GIS and MCA puts the concepts of decision support with spatial reference within the reach of nonspecialists; it clarifies the notions related to GIS and MCA and presents a set of conceptual and methodological solutions and methodological solutions for their integration.

The criteria used were defined both qualitatively and quantitatively. Qualitative criteria refer to the identification of suitable valleys, river physical characteristics, based on satellite images interpretation mainly a digital elevation model (DEM) and large-scale available cartography; other qualitative selection criteria concern the distance from settlements and infrastructures. Quantitative criteria were based on indexes for synthesizing the effectiveness and feasibility of the possible operations such as the alluvial plan index and the hydrological index.

A model based on geographic information system (SIG) and RS and an MCA of parameters was applied to identify sites suited in the zone of study. The methodology is summarized and well explained in Figure 2. Five steps were followed to reach this goal:

In the first stage, different types of required data were collected (Table 1), and then the second stage was focused

Figure 2: Flowchart showing the adopted methodology.

Table 1: Slope classification according to the SOTER model

Slope (%)	Description	Storage water potentiality
<2	Flat	Very high
2–8	Undulating	High
8–15	Rolling	Moderate
15–30	Moderately steep	Low
30–60	Steep	Very low

application of RS in ephemeral streams is limited compared to permanent rivers [26].

3.1 GIS approach

This study adopted seven parameters for determining suitable sites for dam implantation:

on maps reclassified with different suitable weights. In the third stage, all maps were harmonized to the same cell size, and finally, a weighted overlay tool was run with different weights according to its relation to a suitable location for a small dam construction.

A review by Singh et al. [22] used several RS imageries to identify dam sites including the following parameters:

- Slope (less than 15%)
- Soil infiltration rate (less)
- Land use (shrubs and riverbeds)
- Soil type (sandy clay loam)

According to Sanyal and Lu [23], the application of RS in flood management stated that the DEM model is the main part of flood hazard mapping. Slope data derived from DEM can be used for many hydrological studies and can be used for the dam location selection. Furthermore, a limited effort has been devoted in recent years to determine the capability of these techniques in assisting the engineering dam design by allowing efficient, quick, and economic data collection [24,25]. However, the

3.1.1 Lithological map

Lithology has a major impact on the occurrence and movement of water storage as it highly controls the infiltration and flow processes [27]. The lithological map of the basin was obtained from the geological map (Marrakech 1/500,000) digitized and presented in (Figure 3). Lithological categories classification done according to the criteria of geological facies (Table 2) and permeability which control the rate of accumulation of surface water, and the rate of runoff from the study area [28].

3.1.2 DEM and slope

The slope factor affects the increase of water flow speed with the reduction of the subsequent vertical percolation and so in the assignment of the accumulation process. It is an effective factor for spatial prediction [29]. It also helps to determine the direction of the drainage surface. Low slope areas show more precipitation accumulation

Figure 3: Permeability map of the study area.

than steeply sloping areas. Spatial distribution of slopes (Figure 4) was established from a DEM at a 25 m resolution under ArcGis® Spatial Analyst Tools® using the hydrology ArcGis extension and grouped into five classes. The classification is based on the SOTER model (European Commission Soil Terrain Database 1995; Table 1).

3.1.3 Rainfall

Water storage is controlled by various factors with rainfall playing a key role as it represents the main source of surface water recharge [30,31]. The annual mean rainfall for the period from 1998 to 2018 in the study area is obtained from the Tensift Hydraulic Agency data sets (ABHT). It is varying from 100 to 550 mm/year. The

rainfall data were interpolated through the tools spatial analyst tools interpolation based on inverse distance weighted (IDW) [32] of 47 rainfall stations to obtain a rainfall map (Figure 5).

3.1.4 Lineament density

A lineament is a linear property that expresses the underlying structural features such as fractures, faults, cleavages, and discontinuity surfaces. Lineaments represent the simple and complex linear features of structures, with parts that are arranged in a rectangular or moderately curved mode, and which differ from the arrangement of the adjacent features and reflect some subsurface features [33]. Lineament densities in the basin vary from

Table 2: Main facies constituting the study area

Facies type	
Very permeable	Recent formations (Quaternary), gravel, and sand
Permeable	Silt, pink silt, conglomerates, and sandstone
Low permeable	Evaporites, sandstone limestone, lake limestone, sandstone marl, and shale
Impermeable	Solid noncracked limestone, marl, silt, and clay
Very impermeable	Quartzite, basalt, granite, and rhyolites

Figure 4: Map of slope gradient.

Figure 5: Map of average annual rainfall.

Figure 6: Map of the lineament density of the study area.

<3 to 40 km/km² (Figure 6). The lineaments were digitized from the structural map of Morocco [34] and the geological map of Tensift [35]. The obtained map was then added to ArcGIS, and the lineament density was estimated using Spatial Analyst Tools (density and line density).

3.1.5 Land use – land cover

LULC map (Figure 7) was prepared using Landsat 8 OLI/ TIRS C1 Level-1 available online from <https://www.usgs.gov/special-topic/water-science-school/science/infiltration-and->

Figure 7: Map of LULC.

water-cycle?qtscience_centerobjects=0#qt-science_center_objects. A supervised classification was performed using the maximum likelihood classifier, which is one of the most popular supervised classification methods used with RS image data.

This parametric classifier depends on the second-order statistics of a Gaussian probability density function model for every class [36]. This classification considers that the statistics for a particular class in each band is normally distributed and calculates the probability that a given pixel corresponds to a precise class [37].

3.1.6 Soil types

Soil has a significant control on the infiltration and accumulation rates [38]; soil grain size, shape, and arrangement and the corresponding pore system can highly affect the vertical and lateral water movement [31]. The soil map (Figure 8) was obtained from the digital soil map of the Tensift region; the map was then classified and reclassified into five main classes.

3.1.7 Hydrographic typology

The hydrological parameters from the spatial analysis tools were derived to produce the stream order map

prepared from DEM data, and the watershed system is a hierarchical and structured group of permanent or temporary streams that provide drainage from upstream to downstream. The main surface water is watershed. In the dry season, water gathering is used for human life, livestock, and other purposes. This order is a way of identifying and classifying types of watercourses according to their number of tributaries. Certain characteristics of watercourses can be easily guessed from their order. The hydrographic network was modeled using ArcHydroTools and ArcMap using an eight-step protocol [39,40] (Figure 9).

3.2 Factors influencing the potential choice of dams

When various criteria need to be considered, one of the most commonly used methods is MCA, which has been based on soft-computing technique for identifying a suitable dam site. One of the main rules of MCA is to estimate a relative weight for each criterion, rather than assuming the same weight for all criteria [41] and then compares two or more alternatives. The main procedures most commonly used in achieving multicriteria evaluation, known

Figure 8: Map of soil of the study area.

Table 3: Assignment of weight for the feature classes of individual parameter

Parameters	Rating (C_i)	Weight (W_i)	Rating $\times$ weight	Accumulation index	Percentage of contribution (Tx_i)
Lithology	10	5	50	130	23%
	8		40		
	6		30		
	4		20		
	2		10		
Lineaments	10	2	20	60	10%
	8		16		
	6		12		
	4		8		
LULC	2	5	4	130	23%
	10		50		
	8		40		
	6		30		
	4		20		
Slope	2	4	10	120	21%
	10		40		
	8		32		
	6		24		
	4		16		
Rainfall	2	1.5	8	45	8%
	10		15		
	8		12		
	6		9		
	4		6		
Soil type	2	3	3	90	16%
	10		30		
	8		24		
	6		18		
	4		12		
Hydrographic typology	2	4.5	6	135	19%
	10		45		
	8		36		
	6		27		
	4		18		
	2		9		

3.2.2 Integration of thematic layers

The thematic maps showed the rating of the various factors and each map was multiplied by the contribution of each factor [46]; the map of a suitable site for surface water in Tensift watershed is produced using the following equation (equation (4)):

$$MpD = \sum CpF_i \times W_i \times Tc_i, \quad (4)$$

where MpD is the map of factor i ; CpF_i is the map of parameter i as a function of its ratings; Tc_i is the contribution of factor i ; and W_i is the weight of factor i .

All the thematic maps or factors were integrated applying weighted overlay analysis in a GIS environment (Arc Map 10.7 software) to produce the resultant map.

4 Result

Table 3 shows the recommended final weights to generate the MCA after revising and moderating the weights of seven maps. The revised weighting attempted to balance and mitigate any over- or underestimation of the thematic layers that influence the dam suitability location. Figure 10 shows the synthesis map of suitability sites for surface water harvesting structures was divided into five classes: poor, moderate, good, very good, and excellent suitability.

To exploit the approach set out in Table 3, the layers prepared with their weight are superimposed in the GIS to identify the applicable water harvesting sites. The resulting layers are in vector format; the first step in the data conversion is “rasterization” to convert the various

Figure 10: Synthesis map of the potential dam sites classification.

lines and the coverage of the polygons into a matrix format. Then, the reclassification of all raster files is processed, as well as the scale value of each unit.

The factors influencing accumulation were initially studied individually and then integrated and compiled using GIS to obtain a synthesis map of the potential water harvesting.

The lithology thematic map illustrated different lithological facies; Table 4 shows the geological data for the study area extracted from various sources: metamorphic rocks, acids plutonic rocks, carbonate sedimentary rocks, mixed sedimentary rocks, and siliciclastic sedimentary and unconsolidated sediments (Figure 3).

The overall characteristics of the average annual rainfall are that it has the highest levels on the southward

parts; the interval defined in this study is <100–550 mm/year (Figure 5).

Five soil categories were adopted: uneroded soils, young alluvial deposits, mollisols aridisols, isohumic soil, and vertis (Figure 8).

Water, vegetated area, urban area, barren soil, and relief are the main land use and land cover (LULC) types in the study area (Figure 7). However, the barren soil/relief use represents only the biggest percentage of the LULC types.

The lineament density in the basin varies from <3 km/km² to >40 km/km² (Figure 6), and high lineament densities are situated at the southeast and north parts of the study area. The presence of fractures usually involves a permeable zone. A high density of lineaments is likely to promote water infiltration [47] (Figure 6).

Table 4: Data used in this research and their sources

Data	Source	Thematic layer
Satellite image Landsat 8 Oli/TIRS C1 level-1	USGS	Land use land cove
Existing maps	ABHT	Rainfall
	Geological map of the Tensift (1/500,000)	Lithological
		Lineament density
	Soil map of the Tensift	Soil type
Digital elevation model (DEM)	USGS	Slope
		Hydrographic typology

Table 5: The criteria for selecting areas suitable for water harvesting and groundwater recharge

Water-harvesting structures (dams)	Groundwater recharge
The slope should be less than 15%	The slope should be less than 10%
The land use may be barren land, shrub land, and riverbed	The infiltration rate of the soil should be moderately high
The infiltration rate of the soil should be less	The land use/cover may be barren or scrub land
The type of soil should be sandy clay loam	The type of soil should be silt loam

Five slope classes identified in the present study vary from <2% to >35%. Table 2 shows the slopes with gradients ranging (Figure 4).

The slope, lithology, LULC, rainfall, hydrographic typology, soil, and lineament density were considered as the seven factors influencing water accumulation from the point of view of the literature. These parameters were classified, weighted, and reclassified. The main factors have been considered, and the ratings were assigned on a scale of (0–10). In addition, the characteristic classes of each parameter were weighted quantitatively as low (weight = 2–4), moderate (weight = 4–6), high (weight = 6–8), and very high (weight = 8–10). The ratings are based on the reaction of thematic layers to the accumulation of surface water and on the advice of the experts.

5 Discussion

RS data and GIS data were compiled to compose the thematic layers that were then allocated appropriate weightage through the MCA technique. According to the surface water potential locations map, the results show that the spatial distribution of the excellent (5%), very good (9%), and good (17%) aptitude classes is established in the northeast and central parts of the westward zone, and the average is located in the center of the zone. Study and weak are located south of the map; the area of moderate (25%) to poor (44%) suitability is situated in the south and southwest zone. The moderate potential areas are characterized by permeable geological and quaternary, with high slopes constituting plain and depression

Figure 11: Validation criteria map.

terraces. For areas to be rejected are characterized by a high density of lineaments in these areas favored porosity and increased overall permeability. The characterized soils of areas rejected are of iso-humic class with brown, and Sierozem soils. The nature of this type of soil has increased its permeability. On the other hand, in the north-east and in the centre the terrain is often impermeable with rocky outcrops and low density of lineaments, which induces a strong potential for dam construction.

The criteria have been followed for a selected suitable site for various water-harvesting structures, as mentioned in Table 5 and are different from percolation tanks areas used for groundwater recharge; therefore, the areas are unsuitable for RWH and dam projects are suitable for groundwater recharge.

The approach followed in this study allows to carry out an empirical model to determine the areas favorable to RWH selected by a specialized MCA based on the choice of parameters governing the precipitation accumulation, their degree of influence, and their possible relationships. Water-harvesting structures are a major component of the watershed development and store water, but they can also be used to recharge groundwater [48]. Storage structures require a substantial investment, and it is, therefore, important to define the appropriate location of these structures before their construction. Decision making and planning regarding the number and type of water storage structures assembled using RS and GIS approach are extremely important to avoid huge investments [22].

Validation of the model consisted of comparing observed data with the simulated data. The study was conducted using a preexisting dam to analyze the accuracy of model MCA adapted to rain water harvesting (RWH). The principal objective is to use this new approach in long term, as a decision-support tool in planning future small dam projects and groundwater recharge.

The Lalla Takerkoust dam, located about 35 km southwest of Marrakech, was built between 1929 and 1935 for irrigation and hydropower production. It is built on the N'fis river, which has its source in the High Atlas chain and is a tributary of the Tensift river.

As confirmation, XY coordinates of the Lalla Takerkoust dam (Figure 11) fall under high and moderate zones, thereby validating the approach and the study. This study was conducted and validated and fulfils the water needs in light of sustainable development.

6 Conclusion

Generally, the hydrological context of Morocco is mostly influenced by an annual irregularity and a very marked

interannual variability in the rainfall characterized by a heterogeneous distribution. Given this variability in water availability both within and between years, there is no alternative but to control and store surface water during wet periods in order to be able to use it throughout the year to follow an effective policy for the mobilization and management of water resources.

The new approach is a methodological contribution to a research effort to promote a more accurate implantation of small dams through the Tensift system. This approach can be one of the techniques for collecting runoff and sediment in arid to semi-arid regions where the annual average precipitation is low and where crops cannot grow without additional water. In this regard, the study has contributed to define suitable dam sites in the Tensift region, helping decision makers choose the best sites to build dams. The suitable dam site will be decided mainly based on the environmental conditions while irrigation water supply is put as the main usage of these dams.

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