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Using Remote Sensing and GIS-Multicriteria decision Analysis for Groundwater Potential Mapping in the Middle Atlas Plateaus, Morocco

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Abstract

The remote sensing technology and GIS tools have been developed recently for planning and management of water resources. In This study, the groundwater potential zones were delineated by integrating various thematic maps generated from remote sensing data (Landsat ETM+, Aster DEM) along with the existing maps. All the thematic layers combined with a GIS environment, were then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the Saaty's analytical hierarchy process. The groundwater potential zones demonstrates that the highest recharge potential area is located in the northern plateaus and towards the down streams in the region because of the high infiltration rates caused by the importance of fracturing within dolomitic limestone in these regions is an attempt to map groundwater potential zones in the Middle Atlas Plateaus and could help the concerned decision-makers to identify areas suitable for circulation of vital groundwater.

Keywords: Mapping, groundwater potential, remote sensing, GIS, MCE, middle atlas plateaus, Morocco.

Introduction

Groundwater is an essential part of the hydrologic cycle and a valuable natural resource of earth that sustains all human activities. It is essential not only for sustenance of the human life but also for the economic and social progress of a region. Middle Atlas Platform consists essentially of dolomites and dolomitic limestone's of the Lower and Medium Lias, favoring a large groundwater above the impermeable substratum formed by Triassic red clays. These groundwater karstic origins play a crucial role for both the drinking water supply of the major cities of Meknes, Fes and irrigation of surrounding areas. Remotely sensed data can provide useful information to understand the distribution of groundwater. In the present study, remote sensing and GIS techniques were used to generate groundwater potential zones in the Middle Atlas plateaus in Morocco. Recently, Integrated Geographic information System (GIS) and remote sensing are efficient techniques in groundwater studies; in facilitate better data analysis and their interpretations of groundwater potential controlling parameters[1-7]. The combination of remote sensing, GIS and multi-influencing factor techniques has been proved to be a successful and a powerful tool to understand the behavior of groundwater in any area[8]. Thus, multi-criteria evaluation (MCE) approach using raster based GIS may provide more and better information about decision making situations[9,10]. The analytical hierarchy process (AHP) developed by Saaty[11,12] is a method of MCE consists to organize spatial problems and to decides which alternatives are most suitable for the defined problems[13]. It's calculated the weights of different thematic layers and each feature of the individual thematic layers.

For creating the pair wise comparison matrix, Saaty[14] has employed a system of numbers to indicate how much one criterion is more important than the other. These numerical scale values and their corresponding intensities are stated in table-1. The aim of this study is to utilize the factors influencing a potential recharge of groundwater in the Middle Atlas Plateaus, such as: lithology, structural, land cover, slope, drainage and overly karstic conditions in using GIS-MCE environment to evaluate the groundwater potential and to help the concerned decision-makers to identify areas suitable for circulation of groundwater of the region.

Study Area: The region of Middle Atlas Plateaus (figure 1) is located between latitudes 32°55' North and 34° south, 4°30' and 5°10' longitude west. The northern limit is the plateaus itself that stops its fallout on the Sais basin, between El Hajeb and Bhalil cities. Structurally, the limestone formations of the plateaus extend well beyond. To the north, in the furrow South Rifain until contact thereof with pre-Rif wrinkles along a line, longhead a river of Inaouen in the east, extends to mountain of Zerhun in the west. The southern boundary is ridgeline left bank of the watershed of the Oum -er- Rbia in Khenifra. This limitation extends to the northeast by the heights of the ridges bordering the right bank of Guigou valley (mountain of Ben- Ij, Tadja). Beyond national road N°20 which goes to Fez-Boulmane boundary bends more to the north-east and follows the ridgelines overlooking the Plateaus. The western boundary on the contrary, is marked by the sudden interruption of the plateau that dominates the primary land Meseta (cliff Ito, Azrou and Ain Leuh). To the east, the boundary is marked by the cliffs of the Platform, overlooking the buttonhole primary fields of Bsabis[15]. The area of this study part of the Middle Atlas Plateaus as defined in GIS is about 3394 km^2.

Geology and Geomorphology: Middle Atlas Plateaus, consists mainly of dolomitic limestone's of the Lower Jurassic (Lower and medium Lias), which overcome the series consisting of Triassic red clay, shale and basalt[16-19]. It is characterized by a tabular structure, more faulted and folded as a monotone relief. It's a large karst plateaus variously staged, overlooking the plain of Sais, at altitudes above 1000 m. It's crossed by the Fault NE-SW of Tizi n'Tratten and separates, South East of Middle Atlas Plateaus, by North Middle Atlasic Fault. The limit North and Northwest is determined by the tertiary and quaternary overburden of the Rif south corridor. The elevations are ranging from 473 m in contact with Platform - Sais basin to about 2420 m summits of the mountains of Tizi n'Tretten accident in the middle of the Platfom. Climatically, we can say that the area receives annual rainfall on average between 450 mm and 950 mm, while temperatures on the plateaus are significantly influenced by altitude. The annual mean values are between 10.9°C and 15.2°C for Ifrane, Immouzer, and El Hajeb stations[20].

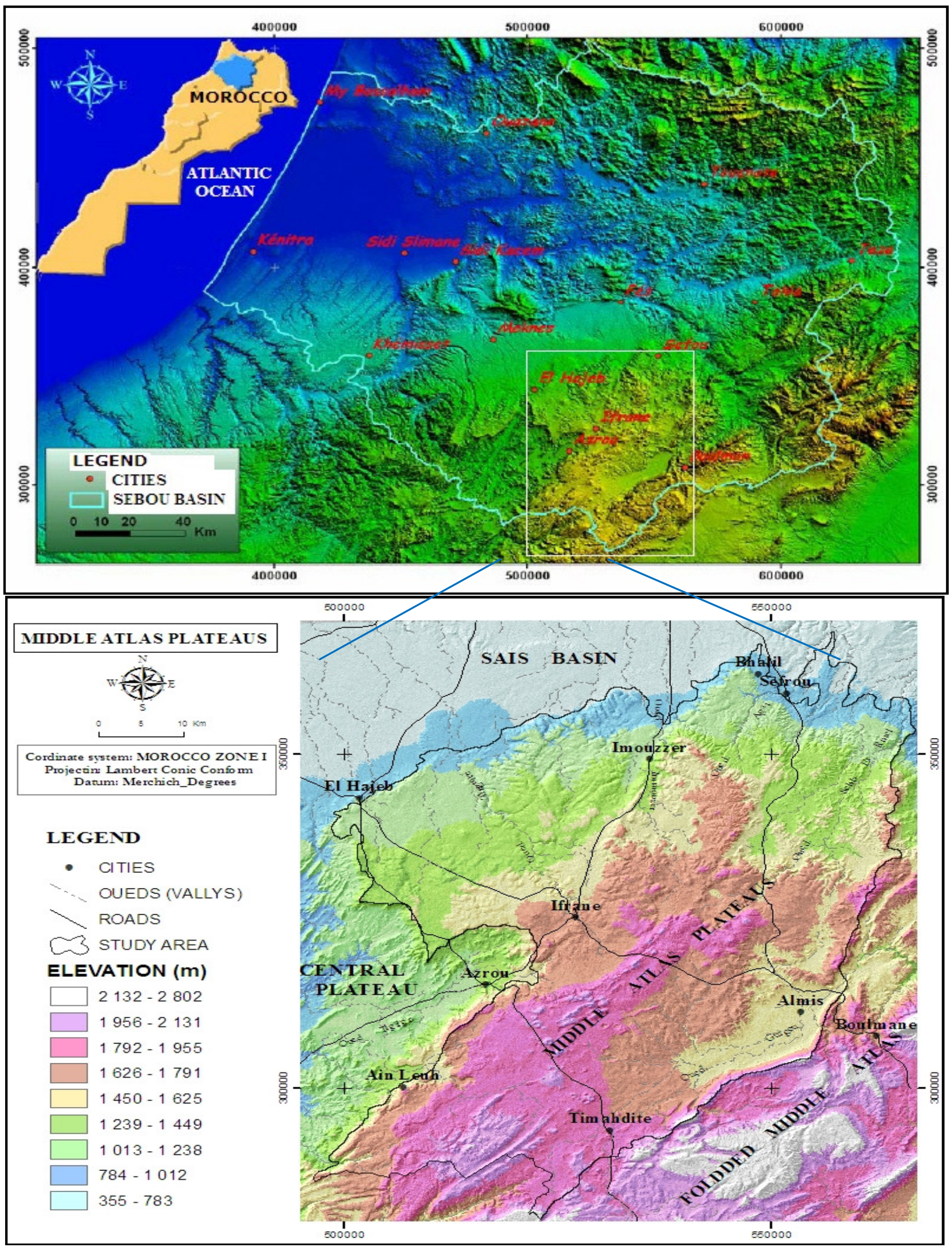

Figure-1
Study Area of Middle Atlas Plateaus

Methodology

The methodology includes generation of thematic maps such as lithology, structures, land cover, slope, drainage and karstic domains using GIS-MCE techniques merged satellite data and other collateral information. Lithological Map is derived from published geological maps on 1:100 000 of El Hajeb, Ifrane, 1: 50 000 of Azrou and 1:200 000 of Septentrional Middle Atlas. Land cover and lineament maps were interpreted from satellite imagery (Landsat ETM+). Slope and drainage maps are prepared from Digital Elevation Model (ASTER DEM) made with ASTER satellite radar on NASA's Terra posted June 29, 2009. Depending upon the perceived importance of their role in occurrence and movement of ground water, weightage has been assigned for individual themes using AHP[11,12]. A paired comparison matrix was prepared and individual class weights and map scores were worked out. Acrding to Saaty, an index of consistency, known as the CR (Consistency Ratio), is used to indicate the probability that the matrix judgments were randomly generated, the consistency is acceptable if the value of the CR is smaller or equal to 10%, , but if it's greater than 10%, the subjective of judgment needs to be revised. The paired comparison matrix was prepared for each criterion using Saaty's nine point scale. The rating used for paired comparison is as follows:

Table-1
Rating Scale used in Saaty's AHP Model

Weight	Definition
1	Equally likely occurrence
3	Moderately likely occurrence
5	Strongly likely occurrence
7	Very strongly likely occurrence
9	Extremely strongly likely occurrence
The values 2,4,6 and 8 can be used to denote intermediary values	

All the maps were integrated by overlay techniques using GIS to delineate ground water potential zones. During weighted overlay process, each individual parameter was classified in each thematic map, and weights were assigned based on the relative importance of each factor on the supply of groundwater in the study area[21] (figure 2).

The final map was produced by Weighted Linear Combination (WLC) where each class individual's weight was multiplied by the map scores and then adding the results[22]:

$$S = \sum W_i X_i \quad (1)$$

Where: S = Suitability, Wi = Weight for each map score, Xi = Individual map

Results and Discussion

Lithology (Lt): Groundwater inevitably occurs in geological formations that require knowledge of how these earth materials formed and the changes they have gone to understanding the distribution of geologic materials of varying hydraulic conductivity and porosity[23]. The type of lithology, structure and weathering grade implies different hydraulic conductivity, transmissivity and storage coefficient for diverse geological formations and affects the groundwater infiltration[24]. Higher porosity contributes to higher Groundwater storage, and also higher permeability contributes higher groundwater yields. In the present study, geological map was prepared using previous data from different studies. These formations were classified into three infiltration categories (table 2, figure 3)

Table-2
Classes Infiltration Rocks

Geological Age	Litholgy	Infiltration
Quaternary	Alluvim, Limon Basalt	Low Moderate
Miocene	Marl	Low
Paleocene	Marly-limestone	Moderate
Turonien	Limestone	High
Cenomanien	Marly-limestone	Moderate
Midium to upper Bajocien	Marl	Low
Toarcien to Low Bajocien	Limestone	High
Midium Lias	Limestone	High
Low Lias	Dolomite	High
Permo-Trias	Red clay, shale	Low

Karstic domains (K): The criterion used to assess the potential karst in a particular polygon is: The probability that the karst forms on the beds of soluble minerals (eg limestone mountains and thick beds, dolomite). The proportion of beds soluble rocks is based on lithology, thickness, information about the stratigraphic unit and its position. Of course, there are other important factors that control the karst potential (eg secondary porosity, mineralogical composition, etc.), but this information was not available at this scale of mapping and data collection. Are distinguished according to lithology and studies and interpretations made in this region[20], three main types, there (figure-4): i. Land of high karst limestone and dolomitic limestones of the Lower and medium Lias with separate sinkholes, and other surfaces of lapies dissolution ii. land of medium karstification of limestone-marl of Toarcian - Bajocian - Cenomanian to Senonian and iii. non- karst areas of the quaternary (Alluvium, basalts) and Permo-Triassic terrains (shales, clays.). High karst area were classified a very high capacity for groundwater potentiality and vis-versa.

Lineaments (Li): O'Leary et al.[25] define lineaments "as the simple and composite linear properties of a surface such as faults, cleavages, fractures, and various surfaces of discontinuity, that are arranged in a straight line or a slight curve, as detected by remote sensing". Many previous authors have been considering that lineaments extracted from remote sensing data indicated fractures in the Earth's crust. Lattman and Parizek[26] were adopted a lineaments map to exploit groundwater. In recent years, many countries have achieved higher success in many groundwater exploration projects conducted when drilling sites were guided by lineament mapping[27]. In this study, lineaments density is classified into five categories (figure-5): very high, high, moderate, low and very low. Very high density is considered as a very high capacity for groundwater potentiality and vis-versa.

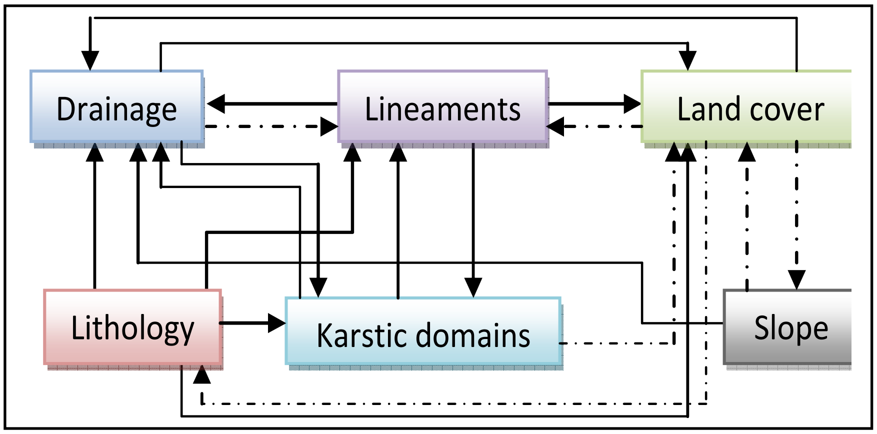

Figure-2
Interaction of the factors affecting the property of recharge[21]

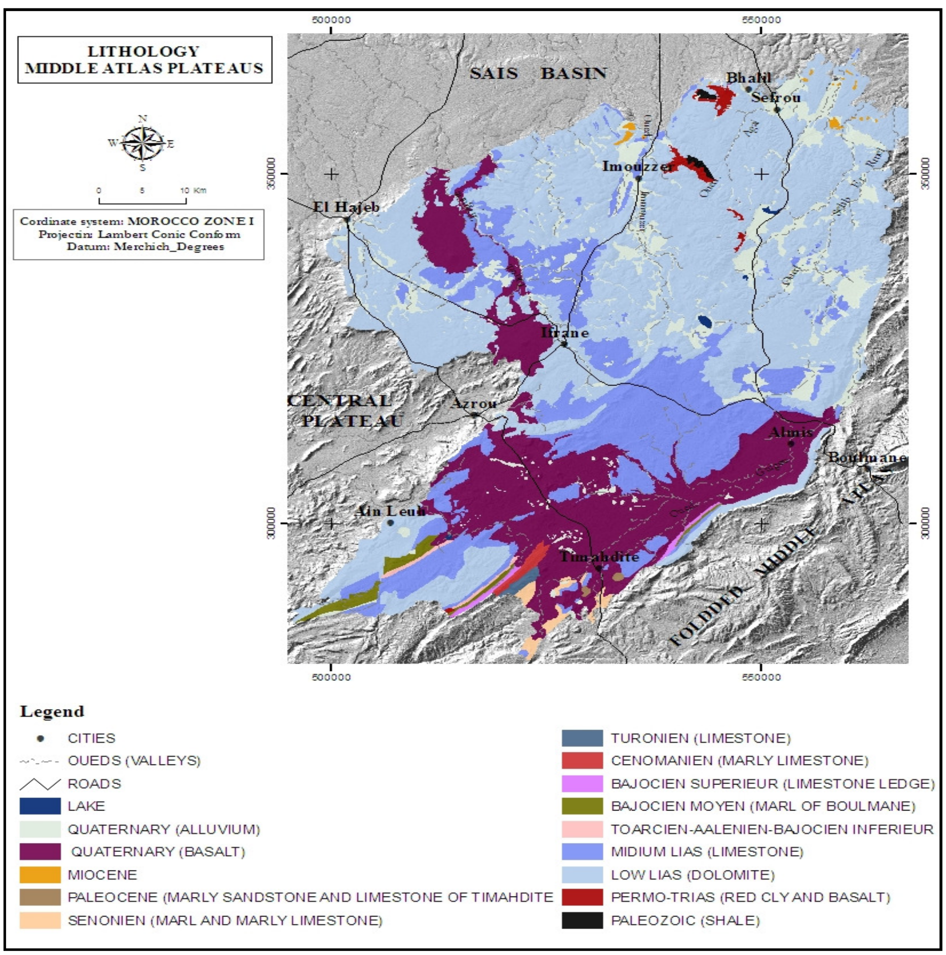

Figure-3
Lithology Thematic Map of Middle Atlas Plateaus

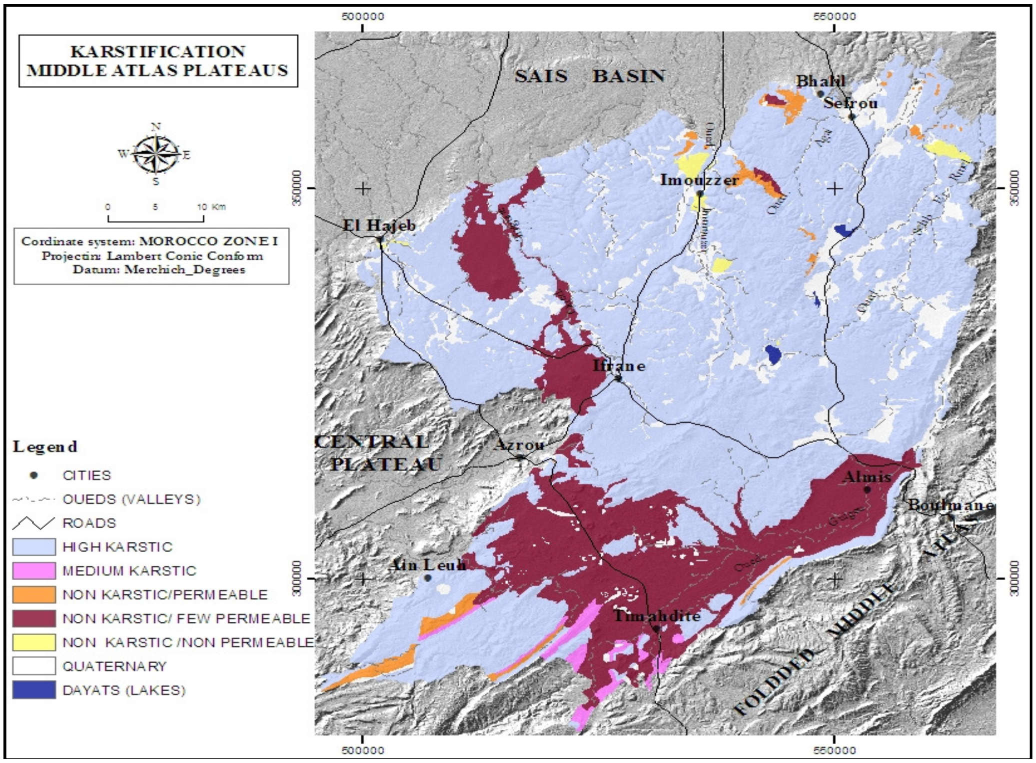

Figure-4
Karst potential Map of Middle Atlas Plateaus

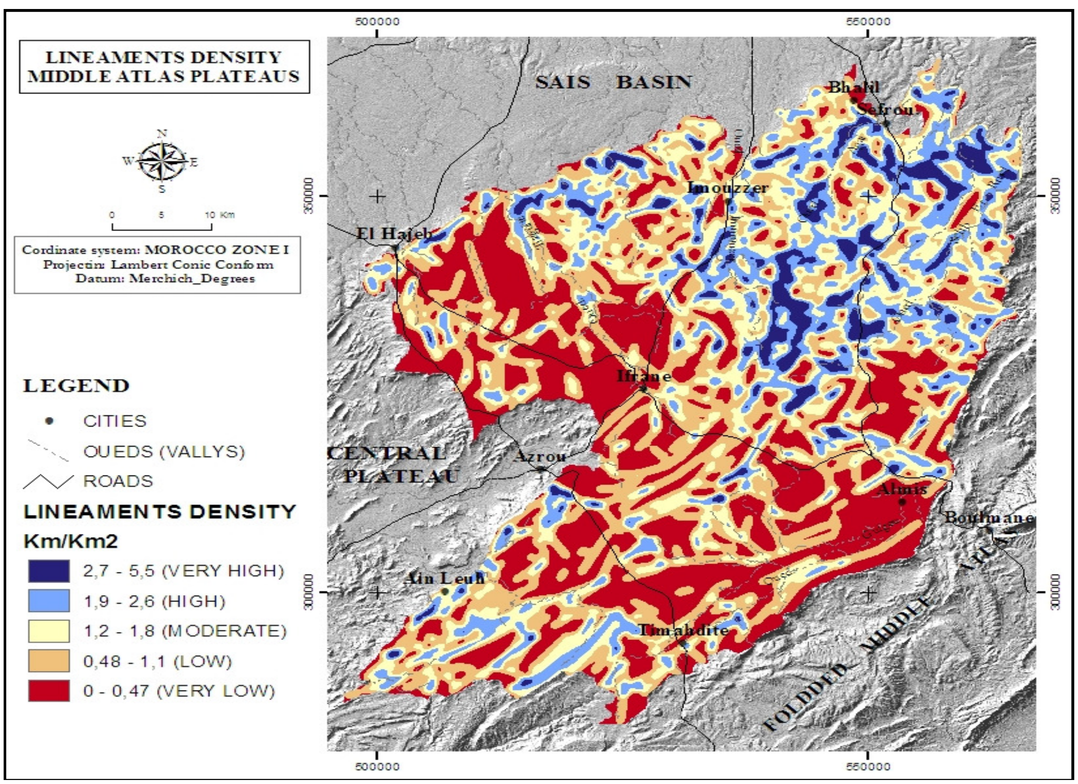

Figure-5
Thematic Map of Lineaments Density

Drainage (Dr): The drainage density is calculated as a ratio of the sum of streams lengths to the size of area of the grid considerated[28]. This criterion favoring drainage basins reduces the duration of infiltration favoring runoff[29]. The higher the infiltration rate, the lower the density of surface-water drainage, which is a major control on groundwater recharge[30]. This thematic layer was extracted from the Aster DEM image. Then, very high density is considered as a very low capacity for groundwater potentiality and conversely (figure-6).

Land Cover (Lc): Land cover of the study area is characterized by the presence of forest cover, agriculture, water and bare soil. These were interpretable from Landsat ETM+ satellite images (resolution 30m) after supervised classification. From Land cover mapping identified importance of vegetation in this area (about 40%) and bare soil (about 60%), for that we are considered NDVI (Normalized Difference Vegetation Index) in calculate of groundwater potential (figure-7). The NDVI involves a non-linear transformation of the visible or red and near-infrared bands of satellite images. It is calculated using formula:

$$\mathbf{NDVI = (NIR\text{-}R) / (NIR+R)} \qquad (2)$$

Where NIR and R are the observed reflectance in the near infrared and red portions of electromagnetic spectrum, respectively. NDVI can be regarded as a rough measure of vegetation amount in terms of biomass, leaf area index, and percentage of vegetation cover. Its values range from -1 to 1 (pixel values 0 - 255). -1 is considered very low and 1 is very high for groundwater prospect landforms.

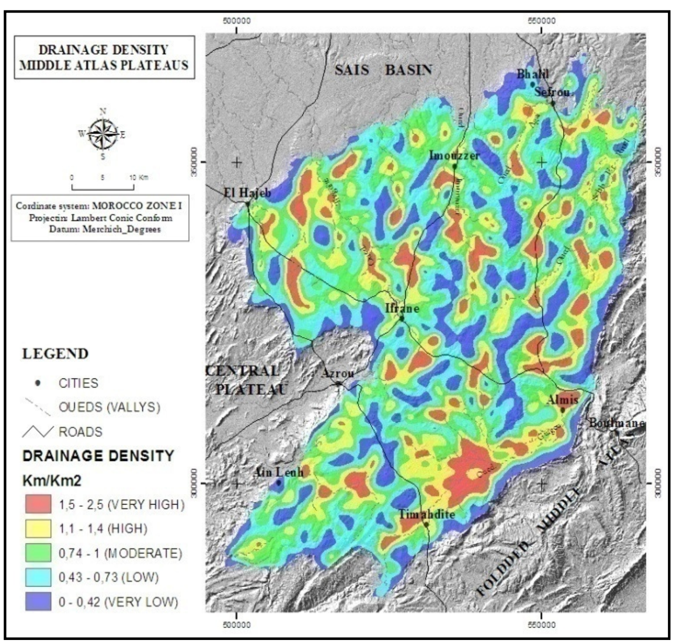

Figure-6
Thematic Map of Drainage Density

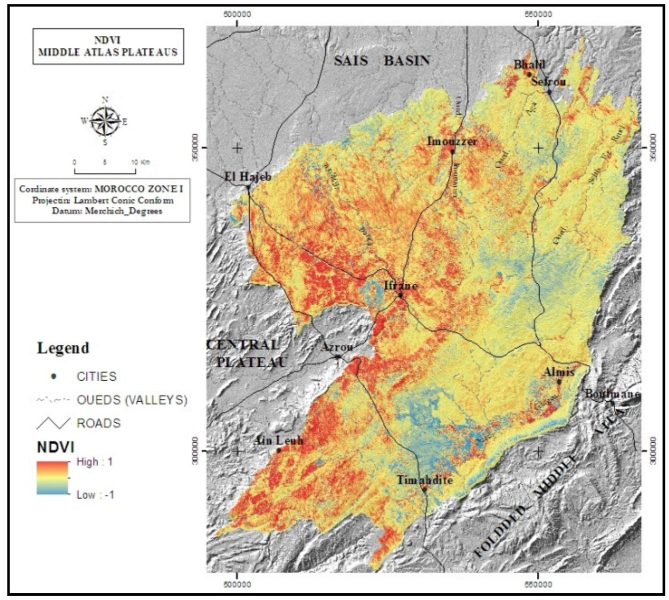

Figure-7
NDVI Thematic Map

Slope (Sp): Slope may be defined as the loss or gain in altitude per unit horizontal distance in a direction. Slope may be dependent on lithology, climate, meteorological parameter, runoff, vegetation, geological structure and the process of denudation. The classification was adapted from the SOTER (Soils and Terrain) model[31] where the maximum slope that influences terrain is 60%. Table-2 shows the slope classification and the descriptions according to the SOTER model. Very gentle slope is considered as a very high capacity for groundwater potentiality and conversely (figure-8).

Table-2
Classification of regional slope based on Soil Terrain (SOTER) Model.

Slope (%)	Classes	Groundwater potentiality
0–2	Flat	Very high
2–8	Undulating	High
8–15	Rolling	Moderate
15–30	Moderately steep	Low
30–60	Steep	Very low

All these factors are integrated to obtain a Groundwater Potential Map (GPM). Since the factors do not have the same degree of influence on the recharge potentiality, a weighting approach is incorporated and the effect of the factors on each other is presented as schematic sketch (figure-2). According to the above sketch, and to arrive at a relative value for comparison in the rate evaluation, 1 major avenue of effect was given 1 point, while the minor avenue effect was given 1/2 of a point. It reveals that the lithology was the most influential one having four major effects, it has an effect on lineaments, karst domains, drainage and land cover. Accordingly, the relative rates for each influencing factor as expressed in degrees as follows:

Lithology: 4 major = 4x1 = 4 degree, Lineaments: 3 major = 3x1 = 3 degree, Karst: 2 major + 1 minor = 2x1 + 1x0.5= 2.5 degree, Drainage: 2 major + 1minor = 2x1 + 1x0.5 = 2.5 degree, Land cover (NDVI): 1 major+3 minor=1x1+3x0.5=2.5 degree, Slope: 1 major + 1minor = 1x1 + 1x0.5 = 1.5 degree

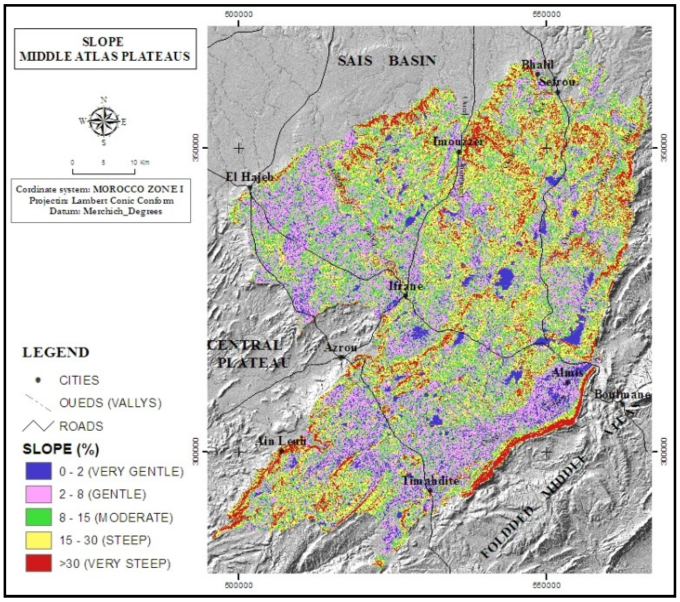

Figure-8
Slope Thematic Map

Using AHP (table-3), based on the number of major and minor effect we are considering lithology has a rank 1, lineament 2, karst domains, drainage and land cover rank 3 successively and slope has 5. GPM were computed by using equation-1. From the calculation, it was found the GPM had a minimum value of 0.078, and a maximum value of 0.56, with an average value of 0.32 and a standard deviation of 0.11. These GPM values were the divided into five classes based on the natural breaks range, which represent five different zones (figure-9). These are very high, high, moderate, low and very low potential zones (figure-10). Natural Breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values.

Table-3
A matrix of pair-wise comparisons of 6 criteria for the AHP process

	Lt	Li	K	Dr	Lc	Sp	Weight
Lt	1	2	3	3	3	5	0.35
Li	1/2	1	2	3	3	3	0.24
K	1/3	1/2	1	2	3	3	0.16
Dr	1/3	1/3	1/2	1	2	3	0.12
Lc	1/3	1/3	1/3	1/2	1	2	0.08
Sp	1/5	1/3	1/3	1/3	1/2	1	0.05

Consistency ratio: 0.0376

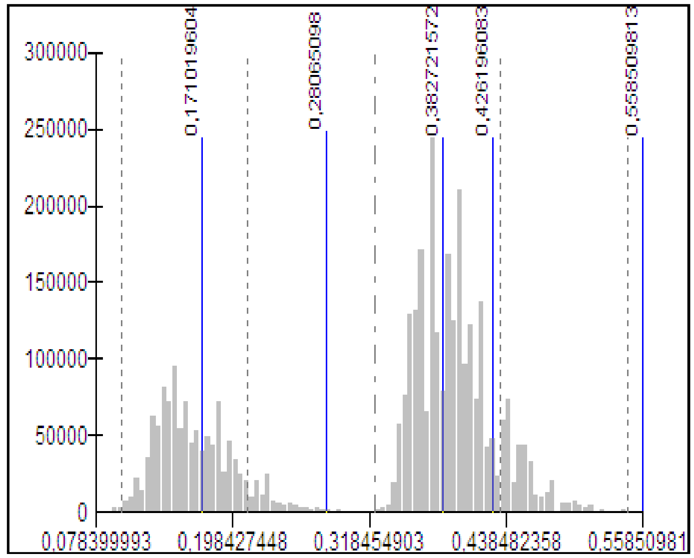

Figure-9
GIS-Classification with Natural Breaks (Jenks) method for GPM of study area

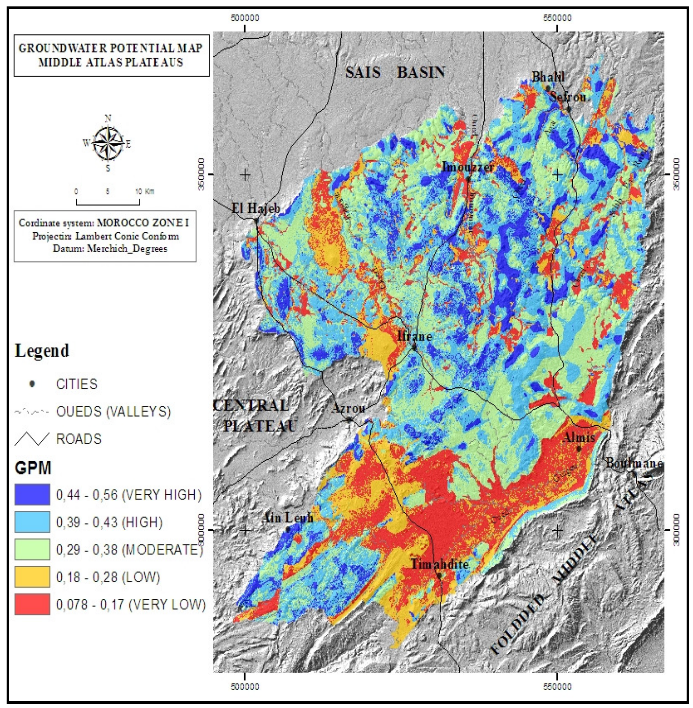

Figure-10
Groundwater Potential zones of study area

From data seen in figure-11, that 11, 24% of the total area (3394 Km^2) has very high recharge potentiality, 29,19% high potentiality, 28,44% moderate potentiality, 12,46% low and 18,66% very low recharge potentiality of groundwater in the study area.

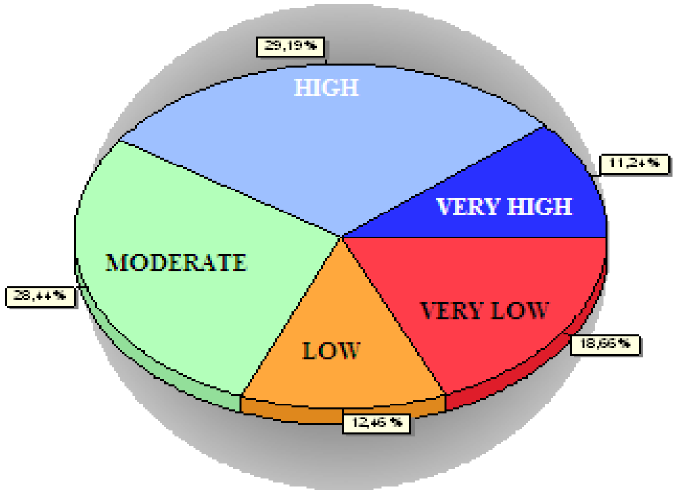

Figure-11
Diagram showing % of various groundwater zones

Conclusion

Remote sensing, GIS and multicriteria analysis using AHP technique has facilitated to delineate the groundwater potential zones by combination a various thematic maps of phenomena related to land and water resources. The results of this study show that the region is potentially rich in groundwater resources, which represents 41% (high to very high) of the total area. Occurrence of groundwater has a direct relationship with the karst lithologic formations, influenced by the presence of lineaments. Study area is dominated by a limestone and dolomitic limestone of low and medium Lias, represents about 75% of the total area. The very low to low potentialities located in the basalts area along the Guigou plain and volcanic cones of Outgui-Kodiate in El hajeb-Ifrane plateaus.

To better understand the potential of groundwater in this area, it is necessary to improve the type of karst units, discrimination of soil types and thickness, analyze flows and logs of boreholes, distribution of springs. Adopted other approaches in the future, by using remote sensing and GIS integrated may play an important role for investigation of relevance groundwater, especially for karst systems.

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