# Mapping Potential Areas for Groundwater Storage in the Middle Moulouya Basin (Morocco): Contribution of Remote sensing and Geographic Information System.

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## ABSTRACT

The main objective of this study is to identify groundwater storage areas in the middle Moulouya Basin by using Geographic Information System (GIS) and Remote Sensing (RS) methods. Five thematic maps of lithology, slope, rainfall, rock fracture and drainage were respectively categorized and weighed, and then used to create the map of potential groundwater storage areas. The results have shown that the area of very low to low potential surfaces represents approximately 10% of the total area, indicating that the middle Moulouya Basin is rich in groundwater, where more than 2200 wells and boreholes have been drilled. The obtained results have been validated with specific yield of springs in the study area. It indicates a clear correlation between the groundwater potential zones and the specific yield, this correlation is particularly obvious in light of flows of water points and their locations, indeed, most of water points with high flows are located in excellent potential zones while poor potential zone includes the majority of water points with low flow.

## KEYWORDS

Moulouya; Groundwater; Remote Sensing; Geographic Information System.

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## 1 Introduction

In Morocco, Access to water is a human right and a basic requirement for economic development due to the growing importance of water in the fields of environment, health and mainly agriculture. 65% of water for irrigation comes from groundwater [1 2 3], and therefore the groundwater is strongly needed. This has required evolving efficient and economic methods of groundwater exploration, assessment and development. In this regard, integrated geological methods, remote sensing and GIS have proven to be interestingly effective [4].

Moreover, some authors used one parameter (i.e. lineaments) for determining groundwater, others integrated two parameters (i.e. lineaments and drainage density) [5], while others combined more than two parameters (i.e. geology, geomorphology, vegetation, lineaments, elevation and slope) [6 7].

Indeed [8] managed recap several studies by indicating the quality of the results obtained according to the parameters used (Figure1).

| Author | Year | Parameter | Result |
|---|---|---|---|
| Meisler | 1963 | Lineaments | Unsatisfactory |
| Rauch and LaRiccia | 1978 | Lineaments | Unsatisfactory |
| Taylor | 1980 | Lineaments and fracture traces | Unsatisfactory |
| Seelan | 1983 | Lithology, morphology, soil and land use | Unsatisfactory |
| Salman | 1983 | Drainage characteristics | Assumption |
| Ahmed *et al.* | 1984 | Lineaments and drainage intensity | Assumption |
| El-Baz | 1992 | Topography, lineaments and drainage | Satisfactory |
| Gustafsson | 1994 | Lineaments and vegetation | Satisfactory |
| Teeuw | 1995 | Lineaments | Satisfactory |
| Sander *et al.* | 1996 | Vegetation, drainage, lithology and lineaments | Satisfactory |
| Savane *et al.* | 1996 | Lithology and lineaments | Satisfactory |
| Edet *et al.* | 1998 | Lineaments and drainage | Satisfactory |
| Robinson *et al.* | 1999 | Drainage and lineaments | Assumption |
| Das | 2000 | Geology, geomorphology, soils, land cover /land use and lineaments | Assumption |
| Bilal and Ammar | 2002 | Lineaments, drainage and lithology | Satisfactory |
| Sener *et al.* | 2005 | Geology, lineaments, land use | Satisfactory |
| Kumar *et al.* | 2007 | Geomorphology, geology, fractures, slope | Satisfactory |
| Ganapuram *et al.* | 2008 | Morphology, geologic structures, drainage, slope, land cover /use | Assumption |

**Figure 1: A selection of studies using remote sensing for groundwater exploration**

In this work, special attention has been given to determining the groundwater storage sites in the middle Moulouya Basin, which will be used to provide a database for hydrogeological decisions such as action plans for groundwater protection or hole-drill positioning.

## 2 Study area

The middle Moulouya Basin is located in the Southeast of Morocco, geographically between X=580000, X=7760 000 and Y=220 000, Y= 370000 (UTM geographical projection system). Its surface area is approximately 16800 km$^2$ (Figure 2), and its geomorphology has 6% mountains (middle and High Atlas); 55% plateaus (Rekkam) and 39% plains that constitute the valley proper area, which is studied here.

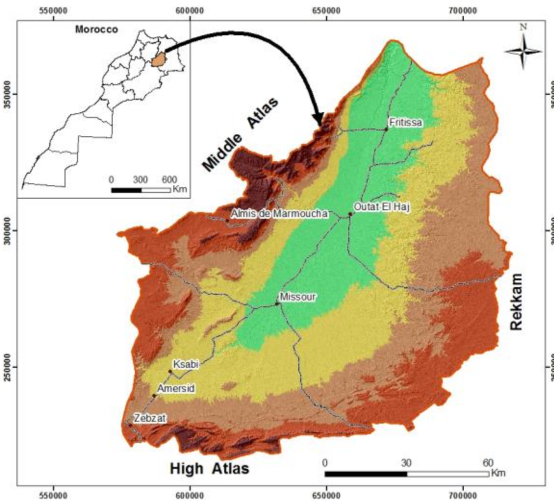


**Figure 2: Location map of the study area.**

According to [9] the geology of the middle Moulouya Basin, the latter includes distinct structural domains that range from the Mesozoic to the Quaternary and is divided into five steps: 1- during the Upper Triassic, 2- During the lower and middle Liassic, 3- During the Upper Liasic p.p-Dogger, 4- During the Cretaceous 5-During the Cenozoic.

## 3 Material and methods

In order to determine the groundwater storage sites in the middle Moulouya Basin, the proposed methodological approach according to [8] is based on the collection, processing and analysis of all the data related to the following parameters (Rainfall, slope, rock fracture, lithology, and drainage), which affect the groundwater storage. Their integration in a model will be reflected in an empirical model which will be used to assess groundwater storage potential areas. (Figure3) depicts the detailed methodology. The validation process was based on the flows of water springs.

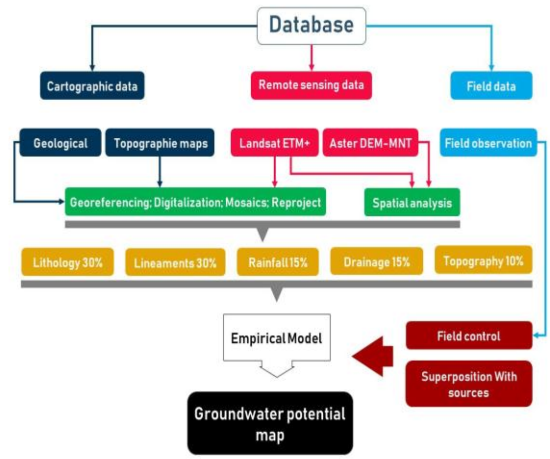


**Figure 3: Simplified functional approach to characterize potential groundwater storage.**

### 3.1 Precipitation (Rainfall).

In our study area, we have concluded that precipitation generally decreases in the Southern part of the study area, and gradually decreases from North to South.

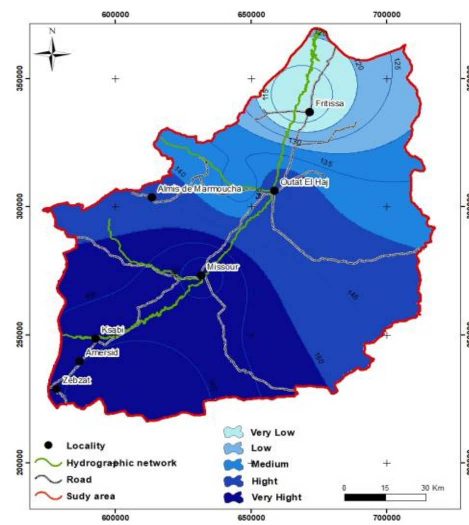


**Figure 4: Rainfall map classes of the middle Moulouya Basin.**

The map obtained was classified into five main classes (Figure 4): <120 mm/year (Very low), 120-130 mm/year (Low), 130-140 mm/year (Medium), 140-150 mm/year (High), and over 150 mm/year (Very high).

### 3.2 Lineaments.

Landsat data has been one of the most valuable datasets for mapping the Earth surface for more than 40 years [10]. Therefore, Landsat 8 Oli acquired on December 31$^{st}$, 2018 with path/row 200/36 is used for automatic lineament extraction. The satellite data uploaded from http://earthexplorer.usgs.gov the USGS earth explorer website. In our methodological approach, lineaments have automatically been extracted from the bands with the LINE module of PCI Geomatica 2018©.

The results of LANDSAT 8 Oli are used to analyze lineaments for middle Moulouya Basin. The lineament map (Figure 5) and the directional rosettes (Figure 6) show that major direction of lineament is ENE-WSW. The directional rosettes are generated on the basis of total length and frequency of the lineaments [11].

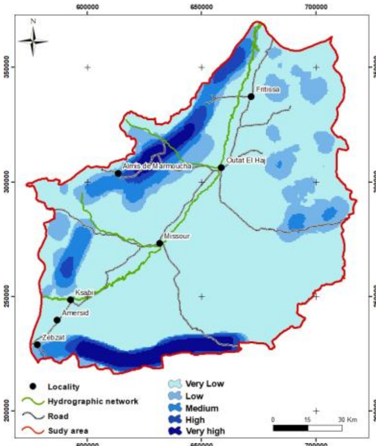


**Figure 5: Lineaments map of the middle Moulouya Basin.**

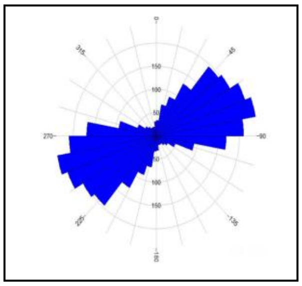

**Figure 6: Directional rosettes.**

## 3.3 Drainage.

Drainage density is an inverse function of permeability. So , its role is extremely important in the delineation of the groundwater potential zone [12].Drainage density is obtained by dividing the total length of all the rivers in a drainage basin by total area of the drainage basin [13].The drainage density was reclassified and categorized as Very high (> 0.5 km/km$^2$), high (0.4– 0.5 km/km$^2$), moderate (0.3–0.4 km/km$^2$), low (0.2–0.3 km/km$^2$) and Very low (< 0.2 km/km$^2$) (figure 7).

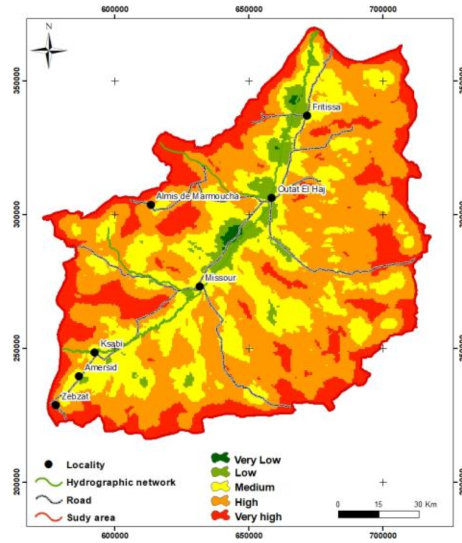


**Figure 7: Map of drainage density classes (km/km$^2$).**

## 3.4 Topography (slope).

The slope parameter is represented by the percentage slope degrees, reflecting the ability of surface water to flow and infiltrate into the groundwater [14]. This factor is very significant for the identification of favorable sites to groundwater recharge because it directly affects surface water infiltration [15]. Interestingly, the bigger the slope is, the lower the runoff is. Consequently, the water has enough time to infiltrate, which makes groundwater recharge easier due to the high retention of rainwater [16] (figure 8).

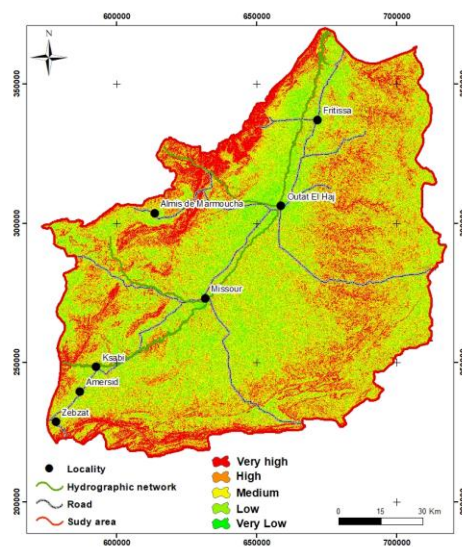


**Figure 8: Slope map classes.**

## 3.5Lithology.

The type of lithology determines the aquifers where groundwater is stored because it impacts potential groundwater storage by monitoring the percolation of water flow [1, 17], and it is also associated with permeability and porosity of a formation which defines its quality as an aquifer [18]. The geological maps of Morocco, sheet Oujda, at 1/500 000 were used for extraction of lithological formations of our study area. Moreover, a supervised classification of these, was generated from ETM+ satellite images. So, a map with five classes of rock formations with similar hydrological properties was generated (figure 9).

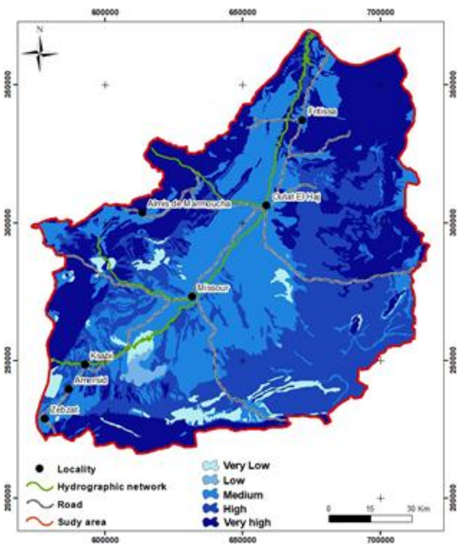


**Figure 9: Map of lithology classes.**

The lithology map classified into five categories was served as one of the GIS layers.

## 4 Model and data validation

Five thematic maps of lithology, rainfall, drainage, lineaments and slope, were respectively categorized and weighed (figure 10), and subsequently used to generate the map of potential groundwater storage zones (figure 11).

| Factor /Class | Subclass | Rating | Weight |
|---|---|---|---|
| Lithology | Quaternaire | 3 | 30% |
| | Domérien | 5 | |
| | Turonien | 4 | |
| | Trias & Low Crétceous | 1 | |
| | Aléno-Bajocien | 5 | |
| | Mio-Pliocene | 4 | |
| Lineaments | Very high (1.12-2.2 km/km²) | 5 | 30% |
| | High (0.8-1.12 km/km²) | 4 | |
| | Medium (0.4-0.8 km/km²) | 3 | |
| | Low (0.2-0.4 km/km²) | 2 | |
| | Very low (< 0.2 km/km²) | 1 | |
| Drainage density | Very high (> 0.6 km/km²) | 5 | 15% |
| | High (0.4-0.5 km/km²) | 4 | |
| | Medium (0.3-0.4 km/km²) | 3 | |
| | Low (0.2-0.3 km/km²) | 2 | |
| | Very low (< 0.2 km/km²) | 1 | |
| Slope | Very low (0-2°) | 5 | 10% |
| | Low (2-8°) | 4 | |
| | Moderate (8-15°) | 3 | |
| | High (15-30°) | 2 | |
| | Very hight (> 30°) | 1 | |
| Rainfall | Very High (>155 mm/an) | 5 | 15% |
| | High (145-155 mm/an) | 4 | |
| | Medium (136-145 mm/an) | 3 | |
| | Low (124-136mm/an) | 2 | |
| | Very low (<124 mm/an) | 1 | |

**Figure 10: Classification of weighted factors influencing the potential zones in the study area.**

The model obtained reveals that the area of very low potential is absent in our study area; however, the zone of the highest recharge potential reaches 2% of the total area (3360 km$^2$) while the area of high potential corresponds to 14%, and the area of moderate potential reaches 76%, indicating that the middle Moulouya Basin is generally rich in groundwater. Furthermore, the high number of wells and boreholes (>2200) used for domestic and irrigation purposes has corroborated our results.

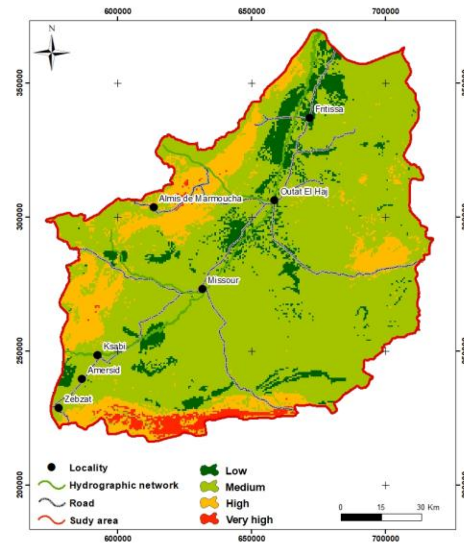


**Figure 11: Empirical model showing groundwater potential zones of the study area.**

The validation process of the model was based on the flow of water points, from 33 water springs. The productivity of water points was classified into five classes (figure 12): Very low (0-0,3 L/s), low (0,3-5 L/ s), moderate (5-20 L/s), high (20-90 L/ s), and very high (>90 L/s).

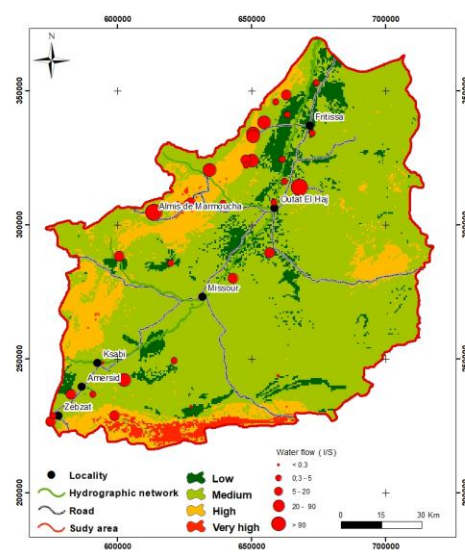


**Figure 12: Location of water springs and their productivity in the potential model storage of groundwater.**

Interestingly, the water springs with very low flow to low flow, which most of them belong to Mio- Pliocene-Quaternary unit, both lower than 5 L/s are at the level of the areas with medium to high potential, this is because most of them are seasonal, and they depend to wet season, and they are related to the underflow of streams. While the moderate flow sources are located perfectly at the class of medium potential areas, among eight water points with moderate flow, seven are located in area of medium groundwater storage potential.

The results show a coincidence of about (figure 13): 55% of the springs water with very low flows are located in areas of low groundwater storage potential, 86 % of the springs with low flow are located in areas of low to medium groundwater storage potential, 87% of the springs water with moderate flow are located in areas of medium groundwater storage potential, 80% of the springs water with high flow are located in areas of high groundwater storage potential, 50% of the springs water with very high flows are located in the areas of high groundwater storage potential.

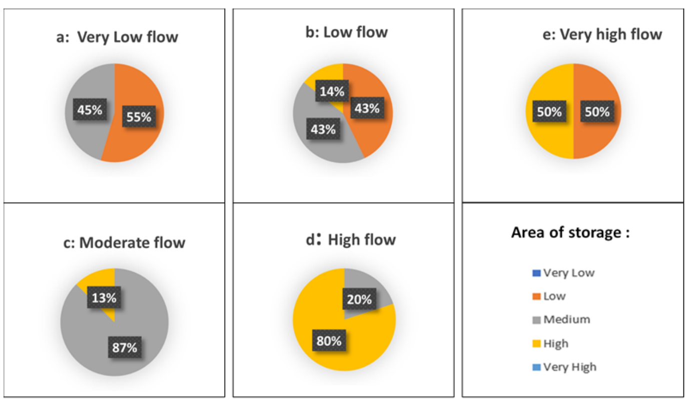


**Figure 13: Diagram showing the situation of water points in the Model; a) Water points with very low flow; b) Water points low flow; c) Water points with moderate flow; d) Water points high flow; e) Water points with very high flow.**

Based on the validation test by the flows of water springs, we have concluded that the model developed is quite satisfactory and operational.

The obtained results were validated with specific yield of the water points (water springs) in the study area. It indicates a clear correlation between the groundwater potential zones and the specific yield springs; this correlation is particularly obvious in light of flows of water point and their locations. Actually, most of water points with high flows are located in excellent potential zones while poor potential zone includes the majority of water points with low flow (figure 14).

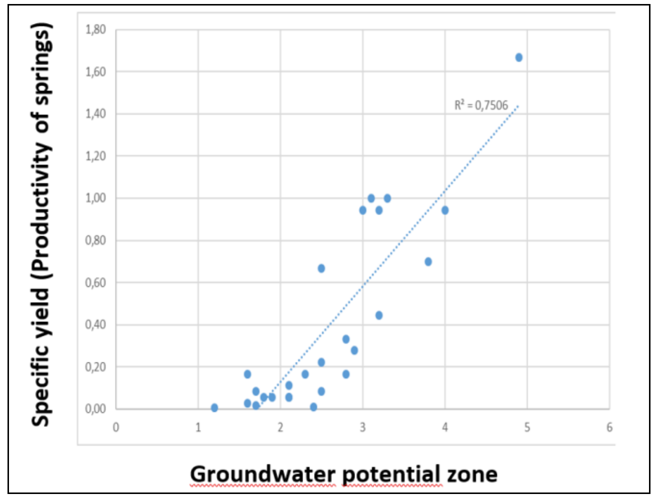


**Figure 14: Relationship between specific yield and groundwater potential zone.**

Based on the model and the statistical study between the specific yield and the storage area, which are considered appropriate in solving complex problems related to water resources of the middle Moulouya district, the managers will primarily be able to use these results to determine the recharge areas for the improvement of groundwater condition, and they will also have the opportunity to fill the gaps regarding the clever choice of the dam construction site, determination of agricultural area and location of irrigation boreholes, which are the basis of all socio-economic development.

## 5 Conclusion

Groundwater exploration has become in demand more than ever before. Classical methods for groundwater haven't often been able to identify promising areas for groundwater storage. In this regard, GIS and remote sensing techniques have become of paramount importance to many researchers worldwide. The main concern of this study is to identify areas that are favorable for drilling by determining areas favorable to groundwater storage. In doing so, we used GIS and remote sensing techniques, which proved to be effective to cover large areas such as the case study (16800 km$^2$) and proven to be less consuming with regard to time and money.

The results show that the middle Moulouya Basin is potentially rich in groundwater namely in areas with intense fracture systems. As far as decision support and pre-prospection are concerned, the current model can be an effective tool and it can also be used to avoid heavy, slow and expensive research phases.

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