Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2019, Volume 10, Issue 5, Page 411-421

http://www.jmaterenvironsci.com

Application of Remote Sensing Techniques and GIS-Multicriteria decision Analysis for Groundwater Potential Mapping in Souss Watershed, Morocco

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Received 09 April 2019,
Revised 30 May 2019,
Accepted 01 June 2019

Keywords
- ✓ Groundwater potential,
- ✓ Mapping,
- ✓ GIS,
- ✓ remote sensing,
- ✓ Souss watershed,

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Abstract
Planning and management of groundwater resources requires modern techniques and scientific principles. Remote sensing and geographic information system based multicriteria and analytic hierarchy approaches are used to identify promising areas for groundwater potential in Souss river basin. In this study, seven parameters that affect groundwater occurrences are derived using Saaty's analytic hierarchy approach. Those parameters are geology, slope, lineaments density, soil, elevation, drainage density and land cover. The thematic maps were integrated using ArcGIS 10.3 software to generate the overall groundwater potential map for the study area. The result revealed that the study area can be categorized into five different groundwater potential zones: areas of very good groundwater potential are estimated to cover 3547.48km^2 (20.97% of the study area), good potential 1923.44 km^2 (21.6 %), moderate potential 3578.05 km^2 (21.16%), poor potential 4217.21 km^2 (24.93%), and very poor potential 3646.75 km^2 (21.56 %). The classes of groundwater potential map were independently tested against the distribution of the groundwater wells, results of such verification proved that the groundwater potential zones are reliable and representative.

1. Introduction
Water is a vital natural resource for human life, necessary for its economic activities, a scarce resource characterized by irregularities in time and space. It is very sensitive to the harmful effects of human activities, the control of this resource in Morocco is essential because of the vulnerability of the climate and the hydrological framework in the country, as well as the uneven distribution of the precipitation system. The desire for water resources is the most important challenge that Morocco faces due to the disruption of seasonal rainfall and its reflection on water resources.

The Souss Basin is Morocco's second most important economic region due principally to its high-value agricultural production, tourism industry, and fishery development[1]. The agricultural sector is the main source of water demand in this region, Groundwater is a most important resource in Souss Watershed because 64% of the total water use in the basin are produced from aquifers and 36% from surface water [2], But due to fast urbanization and the increased population and its associated agricultural and industrial expansion, the demand for water supply increases rapidly[3], These increased usage leads to overexploitation of various sources of groundwater and thereby creates a condition of water scarcity, up to 2008,water deficiency caused the abandonment of at least 11,900 ha of cultivated land in the Souss Valley, and particularly around the city of El-Guerdane[1] , the location of groundwater potential zones, monitoring and conserving this vital resource has become highly crucial[4], the possibility of Groundwater existence in an area is controlled by many factors such as physiography, geology, hydrogeology, geomorphology, drainage, slope, depth of weathering, presence of fractures, surface water bodies[5-6], these factors can be interpreted in GIS using remote sensing data. The objective of this study was to define the groundwater potential zones in Souss Basin in Morocco using integrated approach of geographic information System techniques and remote sensing. Recently, Integrated Geographic information System and remote sensing are efficient techniques in groundwater studies[7], Many researchers have used remote sensing and GIS techniques for groundwater exploration and identification of groundwater potential zones with successful results through different methodologies[8]. Remote sensing and geographic information System techniques have been effectively utilized as a tool to delineate groundwater potential zones in various parts of Morocco. Aouragh et al. [7] applied multicriteria decision analysis within GIS environment in order to produce a groundwater potential map in the Middle Atlas Plateaus (Morocco), Nouayti et al.[9]used remote sensing and GIS to identify the potential areas for the groundwater storage in the high Ziz Basin (Morocco). Aouragh et al. [10] applied fuzzy logic approach, GIS and remote sensing to map the groundwater potential of Middle Atlas plateaus (Morocco). Ait El Mekki et al. [11] applied a similar method to map groundwater recharge potential in the Haouz Plain, Morocco.

The combination of GIS, remote sensing and Multi-criteria decision analysis techniques has been proved to be a successful tool to appreciate the behaviour of groundwater in any area, consequently, multi-criteria analysis approach using raster based GIS may provide more and better information about decision making situations[7]. The mathematical method of analytical hierarchy process (AHP), which was developed by Saaty [12] has been applied in many hydrogeological studies by integrating multi-criteria decision analysis(MCDA) with remote sensing and GIS techniques[12], the method of MCDA consists to organize spatial problems and to decide which alternatives are most suitable for the defined problems, It's calculated the weights of different thematic layers and each feature of the individual thematic layers[7].

Saaty[12] has employed a system of numbers to specify how much one criterion is more important than the other. The main objective of the present study is to use the factors influencing the groundwater potential zones in the Souss basin, such as: Rainfall, lithology, Potential recharge, density of lineaments, slope, density of drainage networks and depth to groundwater in using remote sensing, GIS, Multi-Criteria Decision Analysis techniques and the Analytic Hierarchy Approach, this last is used to determine the weights of different factors for identifying the groundwater potential zone based on weight assignment and normalization with respect to the relative contribution of the different factors to groundwater occurrence[6].

2. Material and Methods

2.1. Study Area:

The Souss river basin (figure 1) is located in the middle western Morocco, approximately between 9.6 and 7.47 degrees west longitude and between 29.70 and 31.11 degrees north latitude, which is bounded on the north by the High Atlas Mountains, on the west by the Atlantic Ocean and on the south and east by the Anti-Atlas Mountains, covers approximately 17186km^2, The surface elevation of the area ranges from 0 m (Atlantic Ocean) to 4,168 m (Toubkal summit in the High Atlas Mountains).Elevations in the basin range from 0 m (Atlantic Ocean) to 4,168 m (Toubkal summit in the High Atlas Mountains).

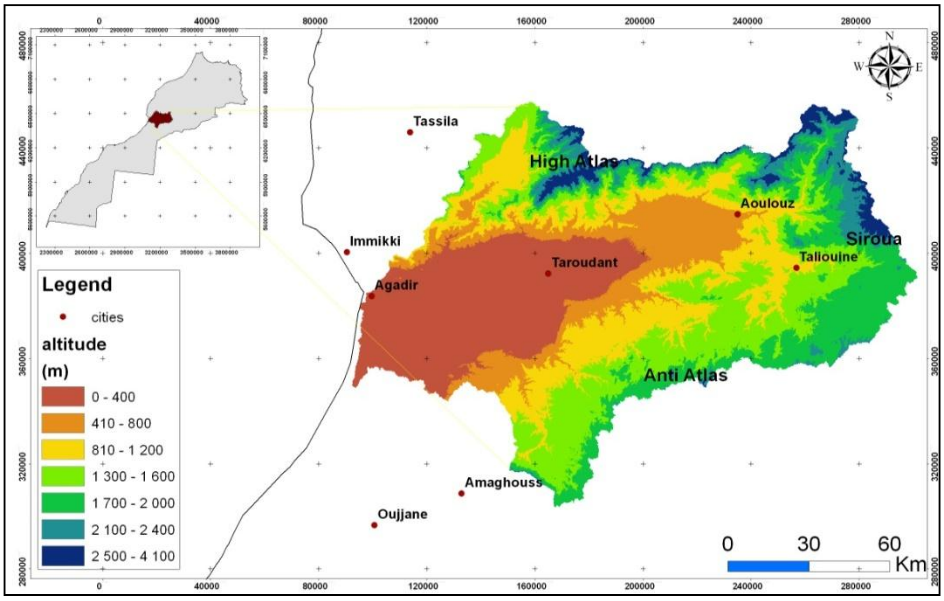

Figure 1 : Geographical situation of Souss river basin.

2.2. Methodology

The methodology includes development of thematic layers such as geology, slope, lineaments density, soil, elevation, drainage density and land cover using GIS-MCDA techniques, The data layer for each of these factors was generated and classified using a series of satellite data, existing maps, and data from related governmental organizations, all these thematic layers were integrated using GIS and MCDA methods.

GIS-based analysis offers a powerful tool for suitability analysis due to its capability to process and analyze different layers of spatial data, the relations of these influencing factors are weighted according to their reaction to groundwater occurrence. A factor with a higher weight shows a larger effect and a factor with a lower weight value show a minor effect on groundwater potential[13]. Integration of these factors with their potential weights is computed through analytical hierarchy process in GIS environment to determine groundwater potential zone.

The individual groundwater potentiality factors were given values according to their importance, all the factors were paired with each other and following that, each factor was given an arithmetic value between 1 and 9(table 1), where 1 represents equal importance between the two factors and a score of 9 indicates the extreme importance of one factor compared to the other one[14].

Table 1 : Saaty's 1–9 scale of relative importance

Scale	Importance
1	Equal Importance
2	Weak
3	Moderate Importance
4	Moderate Plus
5	Strong importance
6	Strong Plus
7	Very Strong Importance
8	Very, very Strong
9	Extreme Importance

A pair wise comparison matrix is derived using Saaty's nine point importance scale based on thematic layers used to determine the groundwater potential zone.

The Analytical Hierarchy Process (AHP) captures the idea of uncertainty in judgments through the principal eigenvalue and the consistency index [15]. Saaty gave a measure of consistency called Consistency Index (CI) as deviation or degree of consistency using the following equation (1)[16]

$$CI = \frac{\lambda_{max} - n}{n-1}$$

Where λ_{max} is the largest eigenvalue of the pairwise comparison matrix (table 2**)** and n is the number of classes. The value of λ_{max} is given by the equation (2) [17]. Based on the principal eigen value, obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix

$$\boldsymbol{\lambda_{max}} = (2.59 \times 0.386) + (5.2 \times 0.193) + (7.78 \times 0.129) + (10.38 \times 0.096) + (12.96 \times 0.077) + (15.55 \times 0.064) + (18.15 \times 0.055) = 7.01$$

$$CI = \frac{7.01 - 7}{7 - 1} = 0.0016$$

Consistency ratio (CR) is a measure of consistency of pairwise comparison matrix and is given by the equation (3).

$$CR = \frac{CI}{RI}$$

Where RI is the ratio index, the value of RI for different 'n' values is given in Table 2.

Table 2: Saaty's ratio index for different values of N

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45

$$CR = \frac{0.0016}{1.32} = 0.0012$$

According to Saaty, if the value of CR (Consistency Ratio) is smaller or equal to 10%, the inconsistency is acceptable, if CR is greater than 10%, we need to revise the subjective judgment. Since 0.12 %< 10%, it implies that there is a high level of consistency in the pairwise comparison and hence the weights 38.60 %, 19.30 %, 12.93 %, 9.65 %, 7.72 %, 6.41 % and 5.50 %, respectively can be assigned to geology, slope, Lineament's density, soil, elevation, drainage density and land cover, respectively. The values for different thematic are shown in Table 3.

Table 3 : Pair wise comparison of the factors that affect groundwater potentiality

	Geology	Slope	Lineament density	Soil	Elevation	Drainage density	Land cover	Weights	Weights *100
Geology	1	2	3	4	5	6	7	0.3860	38.60
Slope		1	3/2	2	5/2	3	7/2	0.1930	19.30
Lineament density			1	4/3	5/3	2	7/3	0.1293	12.93
Soil				1	5/4	6/4	7/4	0.0965	9.65
Elevation					1	6/5	7/5	0.0772	7.72
Drainage density						1	7/6	0.0641	6.41
land cover							1	0.0550	5.50

After determining relative weights for each of the factors, the criteria for groundwater potential for each pixel were calculated using the mathematical equation (4):

$$GWPI_i = \left(\sum_{n=1}^{7} W_i \times X_i\right)$$

where GWPI is the Ground Water Potential Index, i is pixel number in the raster, n is the number of the factors, Wi is the weight assigned to each factor and Xi the groundwater potentiality raster file of each factor:

$$GWPI = (0.386 \times \text{Geology}) + (0.193 \times \text{Slope}) + (0.129 \times \text{Lineament density}) + (0.096 \times \text{Soil}) + (0.077 \times \text{Elevation}) + (0.064 \times \text{Drainage density}) + (0.055 \times \text{land cover})$$

The seven factors for groundwater potentiality mapping (geology, slope, lineaments density, soil, elevation, drainage density and land cover, are examined separately in the following paragraphs. The thematic maps represent the seven factors that are extracted for the calculation of the final map. The values' range was reclassified into five classes, based on the weighted spatial probability modelling, with equal intervals. The reclassification was performed based on the potentiality of groundwater existence.

2.3. Geology

The geological factor (weight 0.386) is associated with the water permeability and the capacity of the formations to host groundwater, according to Hssaisoune et al.[1] the age of the geological formations of study area ranges from Paleozoic to Quaternary, the plain is composed of Plioquaternary sediments (sands, gravels, and lacustrine limestone), which covers a Cretaceous syncline in the north of the basin and a Paleozoic schistose basement in the south, the High Atlas shows an alternation of permeable and impermeable Mesozoic formations, Some layers contain evaporate minerals (gypsum in Jurassic and Cretaceous and halite in Triassic formations). The Anti-Atlas Mountains are characterized by carbonate and crystalline formations; the geologic map of the study area is shown in (Fig.2)

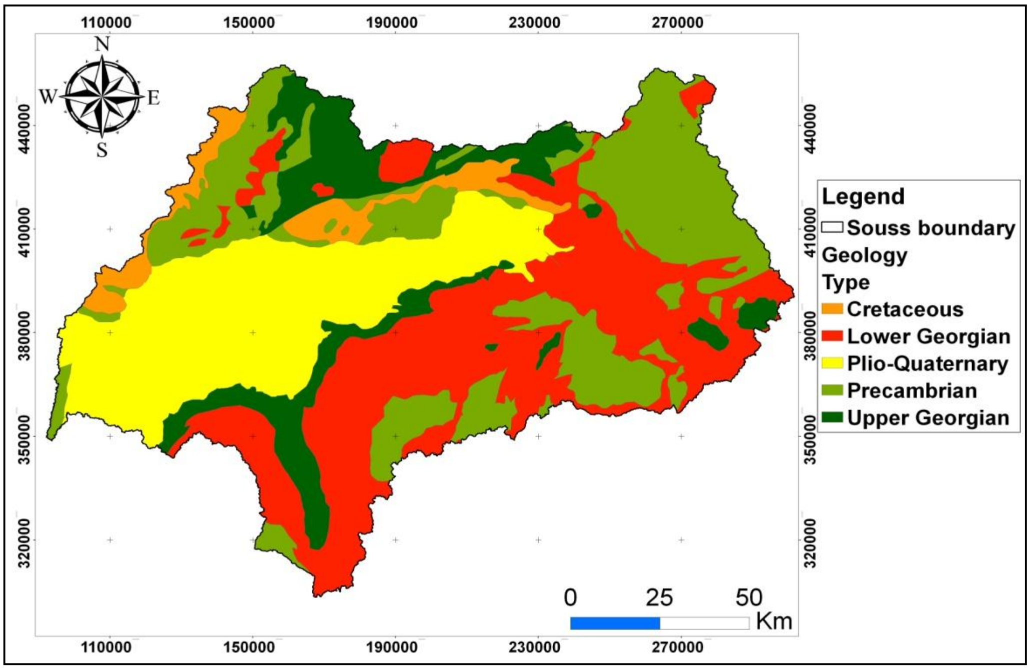

Figure 2 : geological map of Souss river basin

2.4. Slope

Slope is an important factor in groundwater potential mapping, slope determines the rate of infiltration and runoff of surface water, the plane surface areas can hold and drain the water inside the ground, which can augment the ground water recharge whereas the steep slopes increase the runoff and decrease the infiltration of surface water into ground[18]. The slope of the study area has been calculated in degrees based on the DEM model which was based on the SRTM data. The slope ranged from 0o to 72^{o} (figure 3). The steep slope was found mainly in North-south part of the region. In the central part of the area has flat topography.

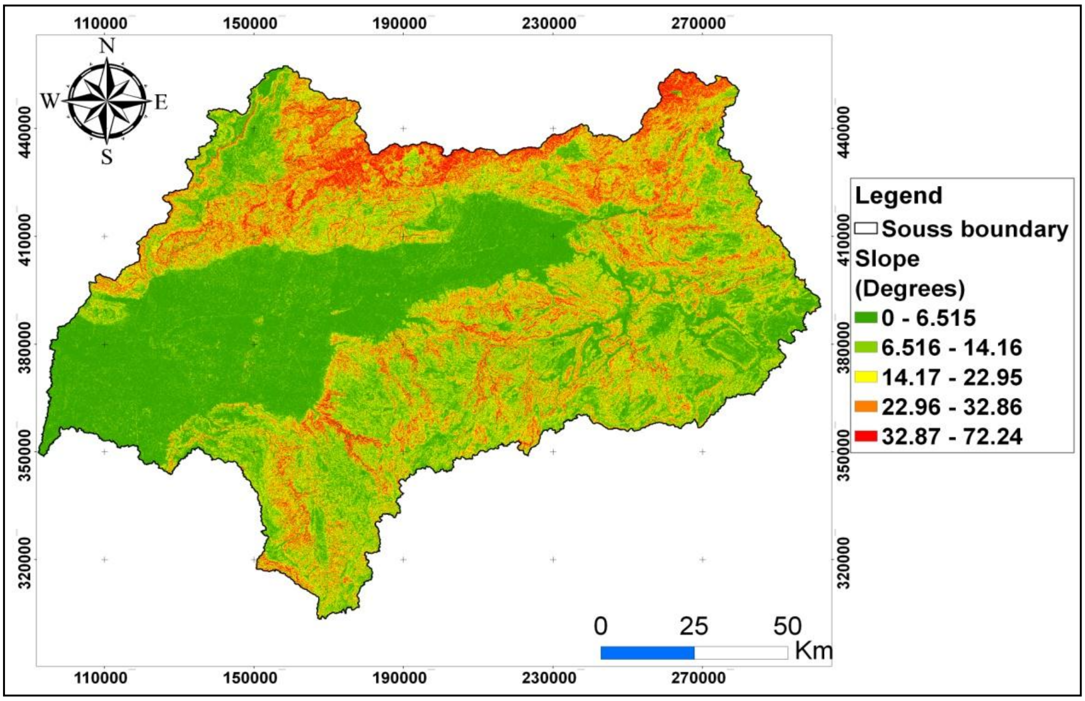

Figure 3 : Slope map of Souss river basin

2.5. Lineaments density

The lineaments play a significant role in the occurrence and movement of groundwater[19], Lineaments are any observable geomorphic linear feature that can be attributed to geological structures, notably fractures, or lithologic contacts[20], the remote sensing data help in understanding and mapping the lineaments of regional and local scale. Use of remote sensing technique is quite easy to analyze the lineament with different spectral bands [18].The lineaments occurring in the study area was extracted from the Landsat 8 OLI image using Geomatica 2016 . Lineament is extracted and then getting lineament density map using ArcGIS10.3 (figure 4).

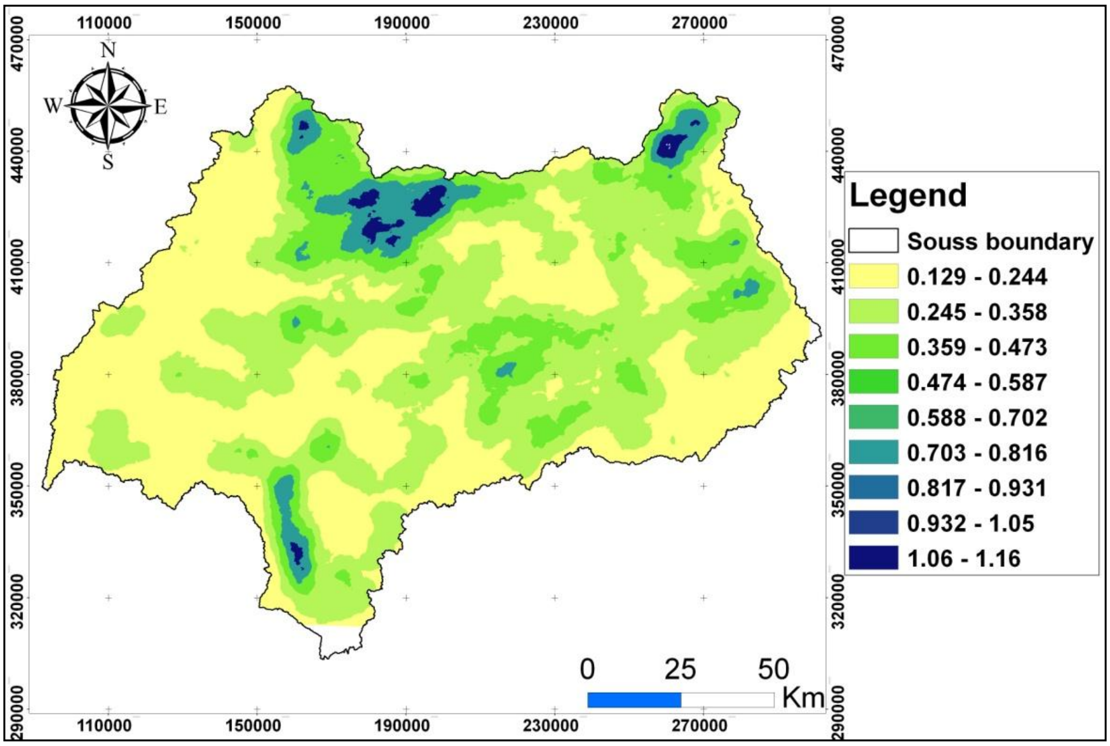

Figure 4 : Lineament density map of the study area

2.6. Soil

Soil is the most important parameter that determines the infiltration capacity of the region, it's one of the natural resources, which is an important factor to delineate potential groundwater zones and it plays a critical role in groundwater recharge[21] , soils play an essential role in encouraging or discouraging the recharge of groundwater and determining the quality parameters of groundwater[18], The soil type layer for the study area has been compiled from the Harmonized World Soil Database (HWSD) version 1.21, HWSD was produced in 2012 [22]by the International Institute for Applied Systems Analysis (IIASA) in partnership with ISRIC–World Soil Information, the Food and Agriculture Organization of the United Nations (FAO), the European Soil Bureau Network, and the Institute of Soil Science, Chinese Academy of Sciences, Study area mainly underlined by calcic xerosols, calcic cambisols, leptosols , fluvisols and luvisols. The Figure 5 shows major part of the area covered by leptosols (6670.32km^2). These five soil classes can be categorized into four classes— 'very good', 'good', 'moderate' and 'poor' according to their influence on groundwater occurrence.

2.7. Elevation

Elevation played an important role in determining the infiltration rate of the rainfall, flow accumulation, transit and dissipation zone, areas with low relief was closed associated with groundwater accumulation[19], The water infiltration increases with the decrease in value in altitude[23], The elevation parameter used in this study is derived from SRTM global elevation data distributed by the US Geological Survey with 1 arc-second spatial resolution (approx 30 m), the altitude map was grouped into six classes: 0 – 503 m, 503.5 – 1 023m, 1 024 – 1 494m, 1 495 – 2 079m, and 2 080 – 4 141m based on the Natural Breaks classification method.

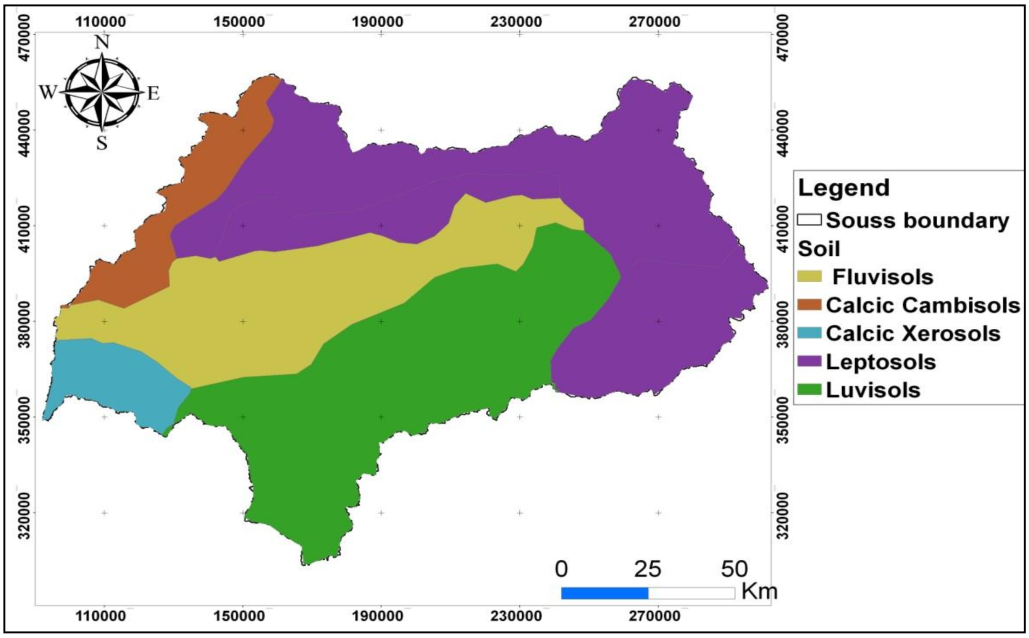

Figure 5 : Soil map of the study area

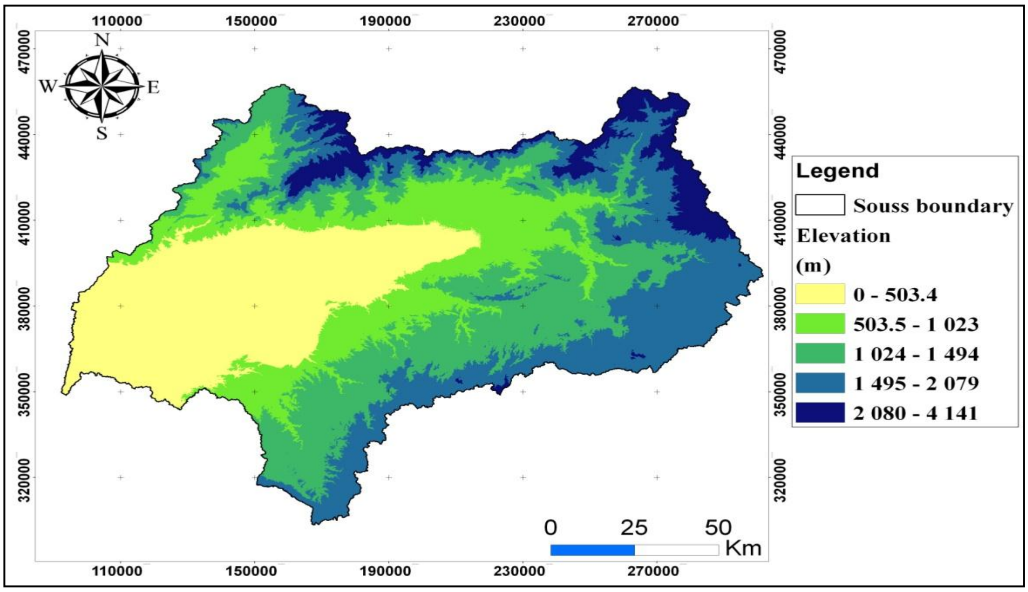

Figure 6 : Elevation map of the study area

2.8. Drainage density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin is calculated as a ratio of the sum of streams lengths to the size of the area of the grid considerate [7], It is one of the most important indicators of hydrogeological features, because drainage network and density are controlled in a fundamental way by the underlying lithology, vegetation type, infiltration rate, slope angle and the capacity of soils to absorb rainfall[20], The drainage network of the study area was created from the SRTM global elevation data through Archydro tools in ArcMap 10.3 and its density was calculated using the Line Density command. Next, the study area was grouped into five drainage density classes from very low to very high.

2.9. Land cover

Land cover studies provide important indicators of the extent of groundwater requirement and groundwater utilization, as well as being an important indicator in the selection of sites for the groundwater potential zone[24], It controls many hydro-geological processes in the water cycle, evapotranspiration, infiltration and surface runoff [21], Land cover of the study area is characterized by the presence of agriculture, forest cover, sparse vegetation, cropland, water and bare soil.

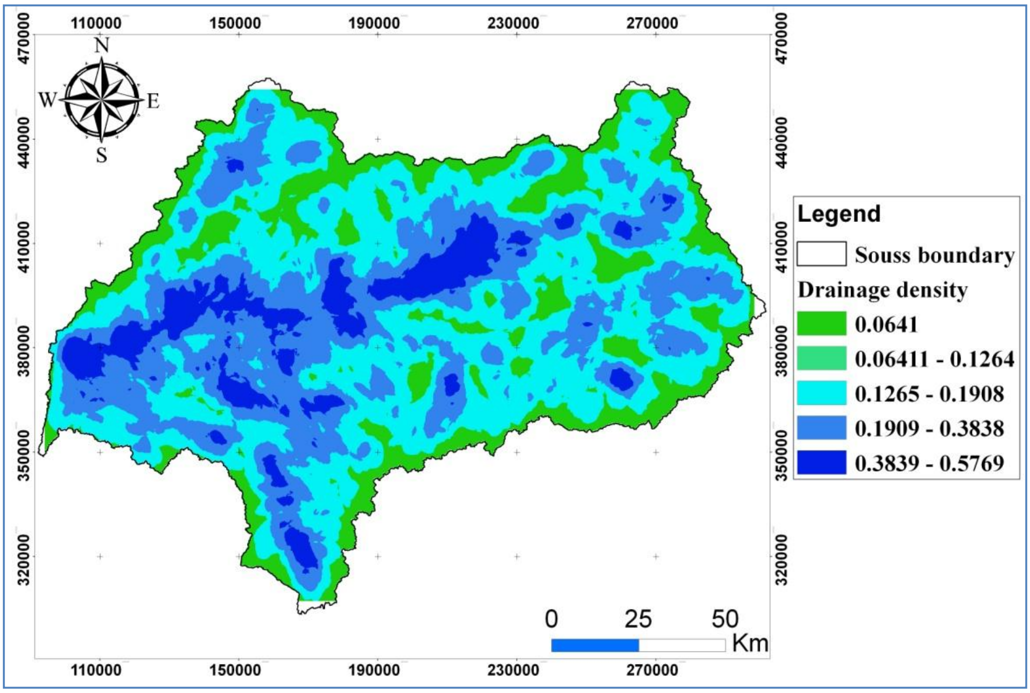

Figure 7 : Drainage density map of the study area

Based on land cover map, made by using the global land cover data from the Food and Agriculture Organization (FAO), shows the presence of 75.26% of the area is equally split between the sparse vegetation and bare soil, 16.84% of the area is mainly cultivated with cereals (35%), citrus fruits (21%), and vegetable crops (14%)[25], for that we are considered NDVI (Normalized Difference Vegetation Index) in calculate of groundwater potential. The NDVI (Fig. 8) involves a non-linear transformation of the visible or red and near-infrared bands of satellite images[7]. It is calculated using the formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. NDVI can be regarded as a rough measure of vegetation amount in terms of biomass, leaf area index, and percentage of vegetation cover[7].

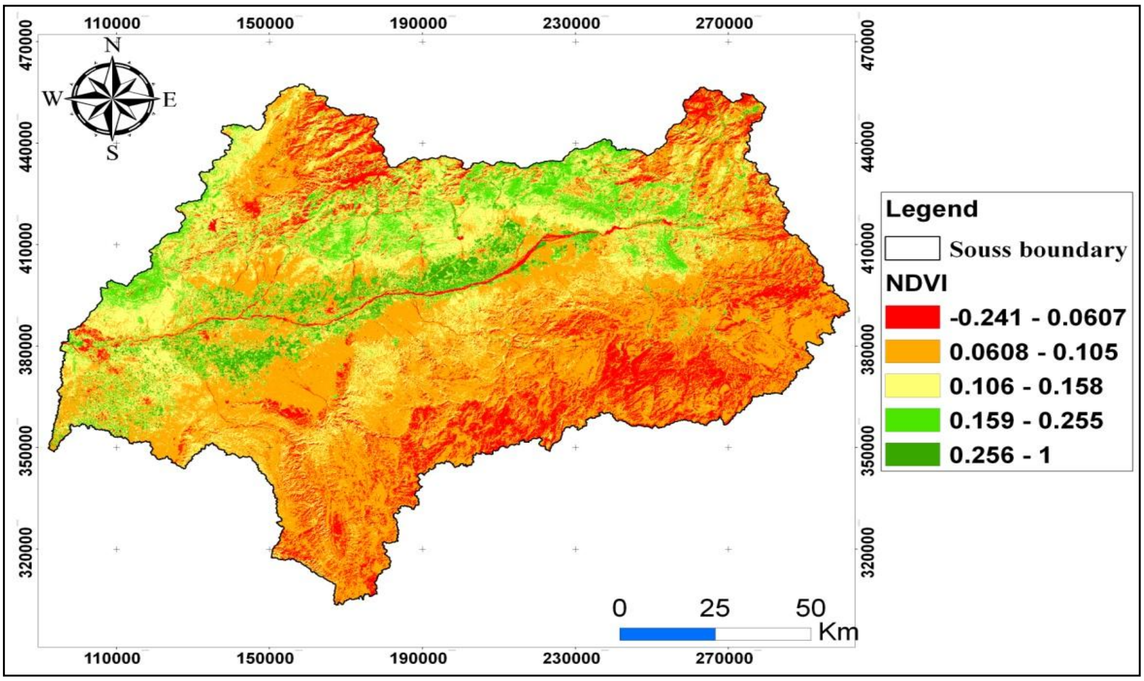

Figure 8 : NDVI map of the study area

3. Results and discussion

3.1. Groundwater potential zones

The delineation of groundwater potential zones for the Souss river basin was generated by integrating the interpreted layers through weighted multi influencing factors and finally assigned different potential zones. The groundwater potential map consists of five major classes including very poor to very good potentiality (Fig. 9). The produced groundwater potentiality map points to the promising localities for groundwater accumulations which are almost always located in areas where the surficial outcropped rocks are highly permeable, which are found in the downstream of Souss River.

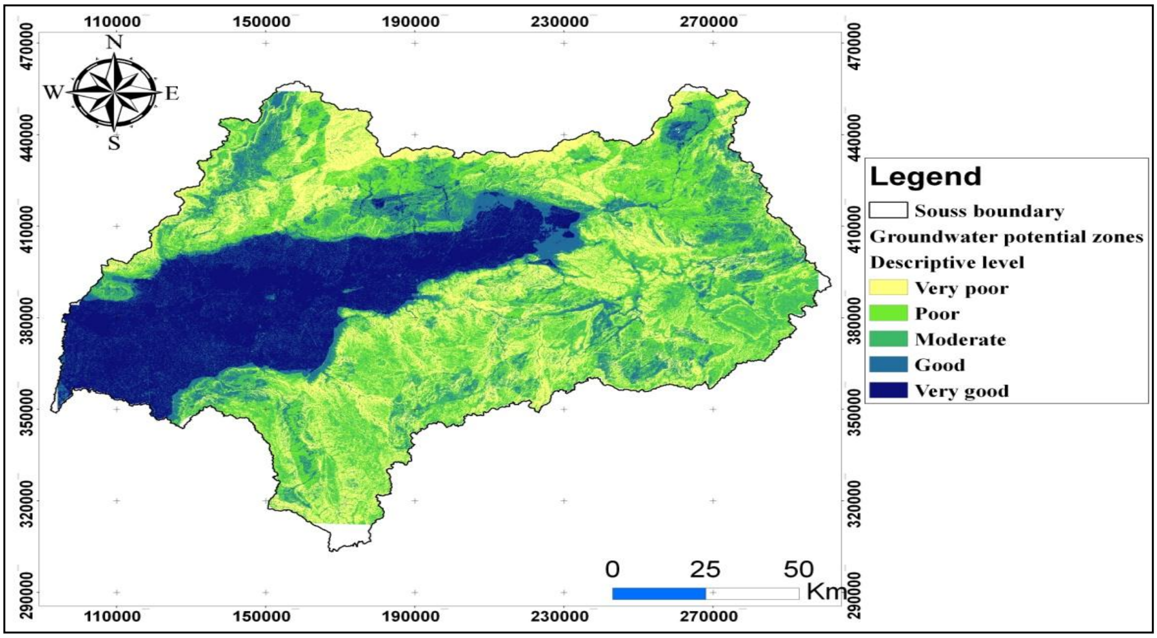

Figure 9 : groundwater potential zones of the study area

The high groundwater potentiality areas are located mainly in the western part of Souss Basin. This indicates that, the geology, slope, lineaments density, soil, elevation, drainage density and land cover affect the infiltration ability of the groundwater system. Regions having very good groundwater potentiality rank cover an area of 3547.48 km2 representing 20.97 % of the Souss basin area, whereas regions characterized by very poor groundwater potentiality rank cover about 3646.75 km^2 areas representing 21.56 % of Souss basin area. The good groundwater potentiality rank occupies 11.37 % of the mapped area, while the poor potentiality rank covers about 24.93 % of the Souss basin area. The moderate groundwater potentiality rank occupies 21.16 % of the mapped area (Table 4).

Table 4: Groundwater potential zones

Groundwater potential zones class	Area(km^2)	Area (%)
Very poor	3646.75	21.56
Poor	4217.21	24.93
Moderate	3578.05	21.16
Good	1923.44	11.37
Very good	3547.48	20.97
Total	16912.93	100

3.2. Validation of Groundwater potential zones

In order to validate the groundwater potential zones in Souss river basin, yield data of the pumping wells for the entire area are utilized. According to Tagma[26], more than 20000 water points were dug in the plain of Souss-Massa, these water points, most of which correspond to irrigation wells, are very dense along the axis of the valley along the river of Souss. They are also dense around the urban centres of Ait Melloul, Taroudant, and Ouled Teima as well as along the Ait Melloul-Massa and Ait Melloul-Biougra roads. Figure 10 represents the groundwater potential zones map along with pumping well locations. It is observed that almost all the existing pumping wells for irrigation purpose are coming under good and very good category of groundwater potential zones area. The groundwater potential zones map also clearly shows the classified irrigation potential of the study area for future planning.

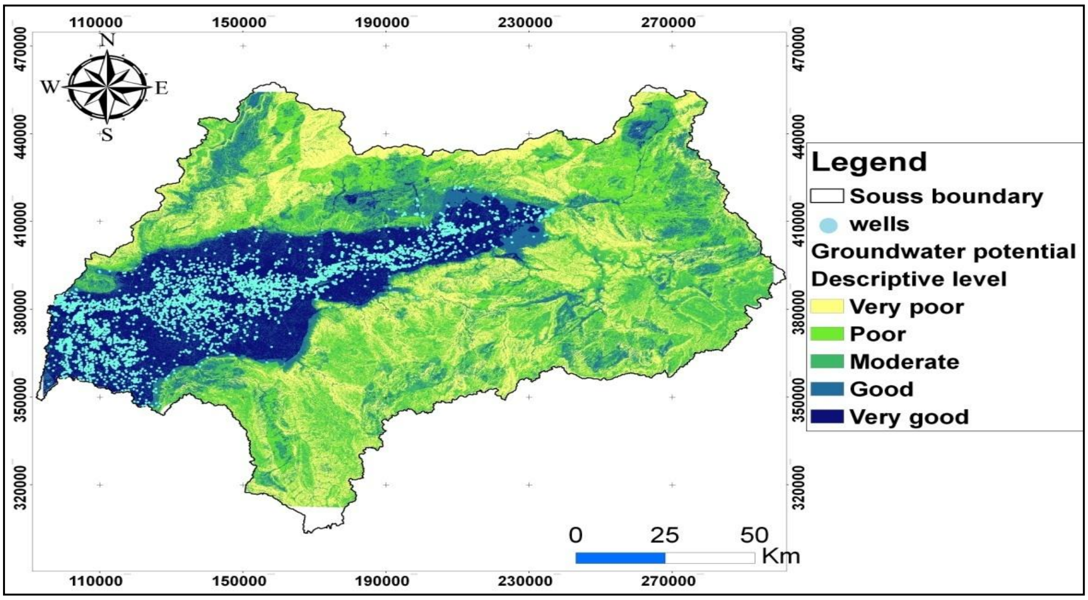

Figure 10 : Distribution of wells in groundwater potential zone map

Conclusions

Remote sensing, GIS and multicriteria analysis have been successfully used for evaluation and delineation of groundwater potential zones by combination of seven parameters related to land and water resources with different weights include geology, slope, lineaments density, soil, elevation, drainage density and land cover. All thematic layers were assigned different ranks and their classes assigned different weight according to their importance for groundwater occurrences. The resulted potential groundwater map showed that the zones with very low, low, moderate, high, and very high groundwater potential cover 3646.75, 4217.21, 3578.05, 1923.44, and 3547.48km^2 of the study area, respectively. In other words, they cover almost 21.56, 24.93, 21.16, 11.37, and 20.97% of the area, respectively. The validity of the illustrated map was also checked by using available drilling data. The maps obtained by this method can be used by local authorities and water policy makers as a preliminary reference in selecting suitable sites for drilling new boreholes. Therefore, the identification of areas where aquifers are developed can contribute to the rational exploitation and sustainable development of water resources.

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