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| RESEARCH ARTICLE

Contribution of Remote Sensing and GIS to Identify the Potential Area for Artificial Recharge in Fractured Area in the Talmakent Region, Western High Atlas, Morocco

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| ABSTRACT
In view of the progressive retreat of groundwater due to rarity, continuous depletion and overexploitation of water, especially in mountainous areas, which are a major source of water, there is a need for artificial recharge for better management of these resources to ensure their long-term sustainability. The approach used is a contribution of new geomatic technologies; Remote Sensing coupled with Geographic Information Systems, for the mapping of potential areas of artificial recharge in the fractured medium of the Talmakent region, which is located in the western high atlas and is characterized by the presence of impermeable rocks. This study requires the consideration of different factors influencing the recharge potential, which are the characteristics of the land surface such as geology lineaments, geomorphology and drainage system. All these criteria are grouped in a GIS prototype in which a multi-criteria overlay analysis has been done for the cartographic restitution of the potential areas for artificial groundwater recharge. The existing basins in the area revealed that only 6% of the total area was identified as having a high potential for groundwater recharge, hence suitable for the implementation of new artificial recharge structures. While 94% of the area has a low to moderate recharge potential, hence unsuitable for groundwater recharge processes.

| KEYWORDS

Geographic Information System, Remote Sensing, Lineaments, DEM, Drainage System, Artificial recharge. Groundwater, Western High Atlas.

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1. Introduction

In recent decades, Morocco has been under pressure from water stress due to the decreasing frequency of water resources and the increasing need for water, especially in arid to semi-arid regions. The problem of this precious source is worsening due to the imbalance between groundwater recharge and exploitation. Most rainwater is wasted through surface runoff (CGWB, 2014), hence the need for artificial recharge to ensure sustainability (Chinnasamy and al., 2015). Artificial recharge is the increase of water to groundwater reservoirs via artificial devices (Todd, 1959).

To map potential areas for such recharge, this study focuses on the choice of remote sensing techniques and GIS tools as effective tools to designate the most favourable sites for artificial recharge without resorting to expensive geophysical techniques (Hoffmann and Sander, 2007; Elmahdy and Mohamed, 2013). To this objective, the approach adopted requires the consideration of different factors controlling groundwater dynamics that are supposed to be adequate such as geological, geomorphological and hydrological parameters (Kanohin and al., 2012; Magesh and al., 2012; Ndatuwong and Yadav, 2014; Oikonomidis and al., 2015). To detect these different factors, we used DEM, with a spatial resolution of 30 m, as a data source for the automatic extraction of lineaments from shading maps on the one hand (Saadi and al., 2011) and on the other hand to understand the topographic and hydrological parameters of the area such as the spatial distribution of slopes and elevations and the drainage system (Wise, 1998; Wise, 2000).

Whilst the rocks in the study area are impermeable but when fractured, they present opportunities for karst flow. The first relevant step in the selection of potential sites is to detect the areas of intersection of the fractures with the drainage network. These sites correspond to areas suitable for groundwater storage. The second step is a dynamic and frequency study of the physiographic characteristics of the sub-basins in the area, which will be associated with the intersection result to achieve a complete theoretical understanding of the hydrological events which will be used to identify the sites for artificial groundwater recharge and their spatial distributions (Khadri and Kanak, 2015; Goyal and Arora, 2004; Suja Rose and Krishnan, 2009).
The result of this study is useful for defining the most appropriate sites for the implementation of groundwater augmentation measures for the long-term maintenance of natural groundwater sources in the Talmakent region.

2. Description of the study area

The study area is located in the Western High Atlas; it belongs to the latitude of 8.45° to 9° N and the longitude of 30.45° to 31° E (Fig.1). It is a high mountainous area with an elevation of more than 3000m (Adrar-n-Dern 3025m, jbel Tinergwet 3434m), its average annual temperature is 23° degrees, the average annual precipitation exceeds 500mm in the mountainous area and 300mm in the foothills and snow regularly falls above 1000m each year but only persists on slopes above 1500m on the northern flank and 2000m on the southern flank.

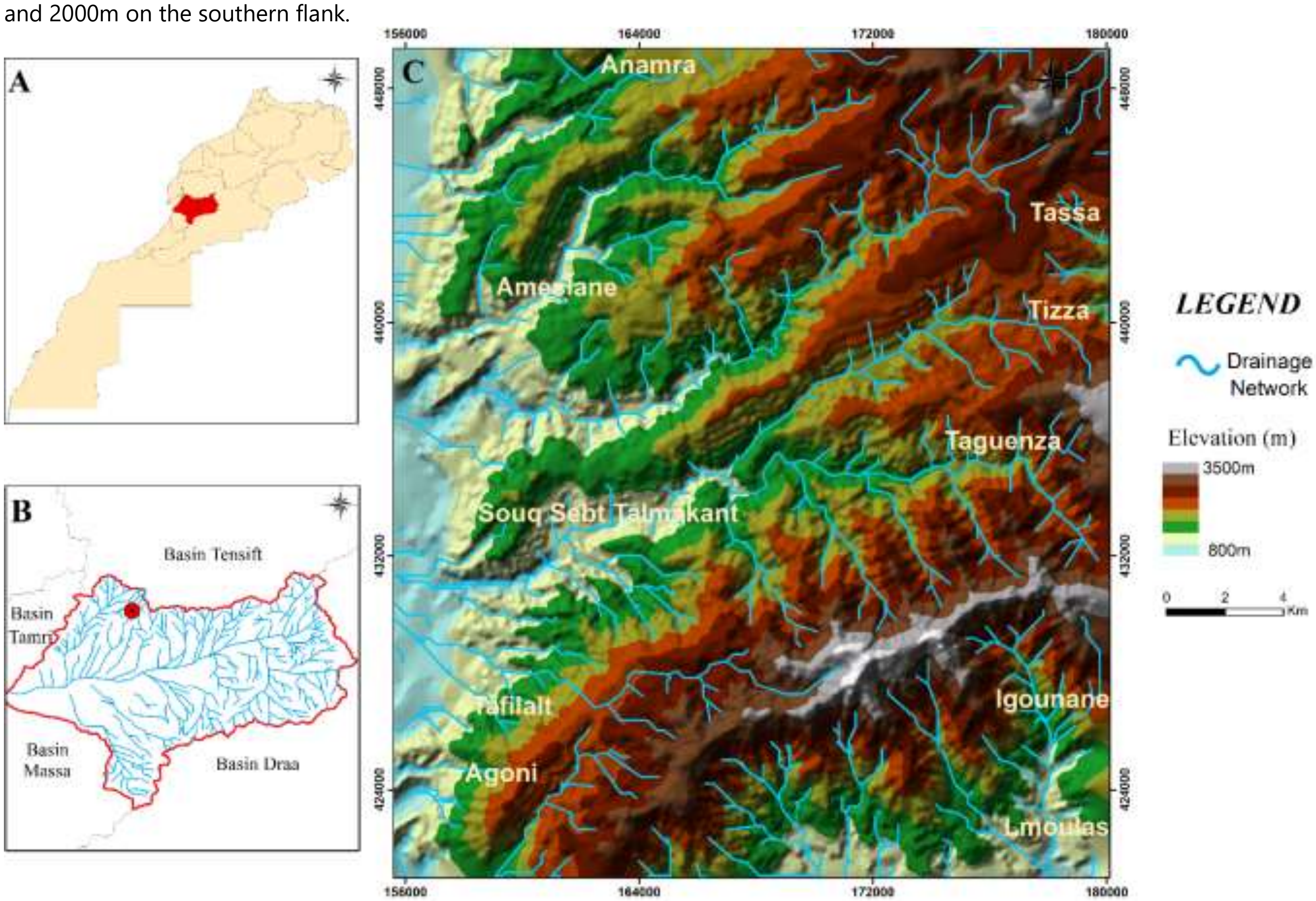

Fig.1: Location of the study area: A) Morocco, B) situation basin Souss area and C) a topographic map of the study area.

The territory covered by this zone is part of the ancient High Atlas massif, in which the axial zone of the Atlas chain is developed composed of volcanic and volcano-sedimentary rocks, but also of sedimentary formations from the Paleozoic and Permo-Triassic. Hercynian tectonics is predominant in the basement with preferential NE-SW directions.

The area is part of the Souss watershed. It is mainly drained by the tributaries of the left bank of the Oued Issen, these tributaries are Oued Aït Bkhayr, Oued Aït Chaïb, Oued Aït Tounart, Oued Aït Driss and Oued Amlal, and the southern part of the area is drained by the tributaries of the Oued Aït L'Haj which flows directly into the Oued Souss.

The area in question is mainly formed by rocks of low permeability, and from a hydrogeological point of view, it is not of great interest insofar as the prolonged snow cover makes it possible to maintain throughout the year a generally very limited reserve of water in reservoirs that are often not very extensive and of mediocre porosity (generally superficial alteration zones and fissured formations). Due to the climate, these small water tables are drained annually by springs with generally very modest flows. Due to the climate, these small aquifers are drained annually by springs with generally very modest flows. The water points are essentially constituted by springs or perennial rivers.

3. Methodology

In this study, the focus will be on the determination of artificial groundwater storage areas through an analysis of the geological, hydrological and geomorphological criteria of the area to show the impact of tectonics, slope and relief on surface water circulation (Fig. 2).

The data sources adopted to achieve this objective are; the Digital Elevation Model (ASTER DEM) with a spatial resolution of 30 m which has been exploited for the extraction of lineaments, which allow the increase of the permeability and porosity of the rocks in order to facilitate water infiltration. It is also adopted for hydrographic analysis of the drainage network and delimitation of watersheds. The second source of data is the cartographic data, namely the geological map at a scale of 1:50,000 covering the study area, which allows the structural characteristics to be understood, and the topographic map at a scale of 1:50.000 for the extraction of anthropogenic lineaments.

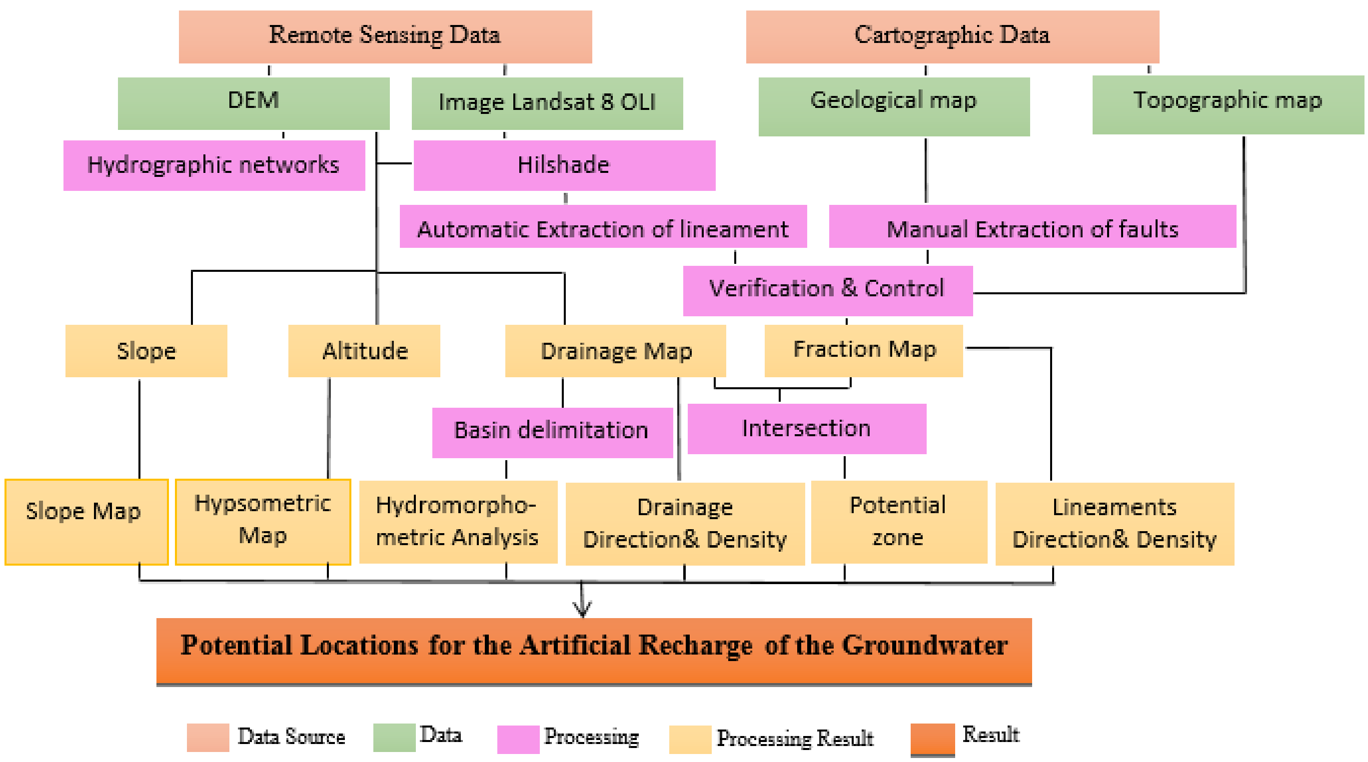

Fig.2: The approach followed during this study

3.1. *Geological characteristic: Linear mapping*

The importance of lineaments is paramount in the selection of potential sites for groundwater management and storage (Subba and al., 2001), it is an essential parameter that allows water to flow through the aquifers as the river system often uses weak areas to minimize the energy required for flow (Deffontaines, 1990) and according to the study by (Verma and Patel, 2021), lineaments based on hard rocks create secondary types of porosity and permeability that play a vital role in the occurrence of groundwater.

To map the lineaments that invaded the study area, we used the Hillshade method by exploiting the DEM (Alshayef and Javed., 2018; Akram and al., 2019), which is a technique used to create new lineaments through shadow maps or shaded reliefs made at different illumination angles (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) with a solar elevation of 30° and an ambient light level).

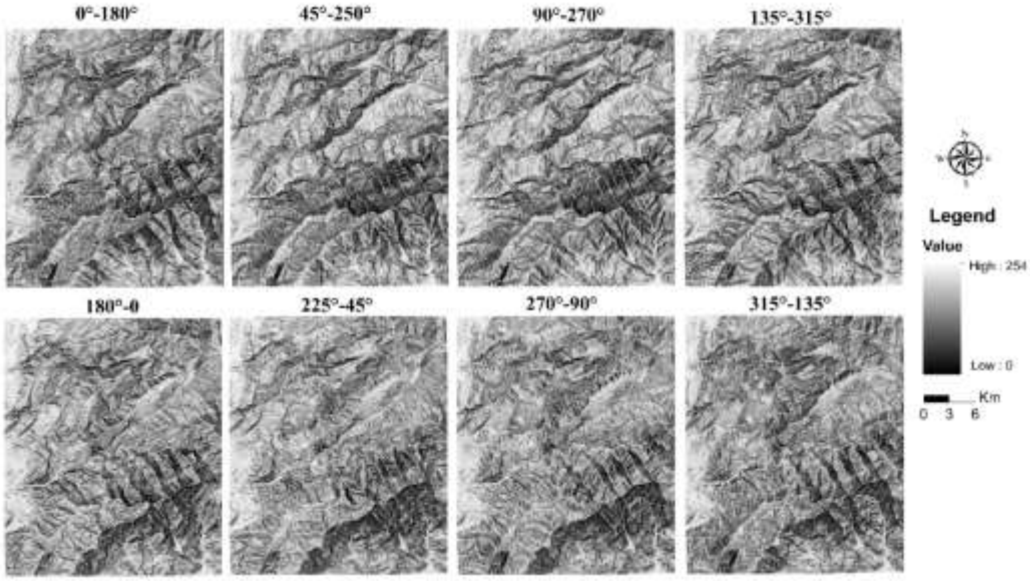

Fig.3: The images are eight shaded relief illustrations from the DEM with various sun angles (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) and a solar elevation of 30°. An ambient light setting of 0.20.

The cartography of the linear features that show up in the results of the filtered image (Hashim and al., 2013; Sedrette and Rebai, 2016) was done in an automatic way using the LINE algorithm of the PCI Geomatica software (Hubbard and al. 2012) which allows the translation of these linear features into vector form using six parameters (RADI, GTHR, LTHR, FTHR, ATHR, and DTHR) explained briefly by (Sarp, 2005).

The density of lineaments is the accumulated lineaments length by unit area. (Edet and al., 1998), a high density of lineaments is considered one of the fundamental factors for the identification of favourable areas for groundwater storage, and the intensity of groundwater decreases with the distance of lineaments (Ibrahim Bathis and Ahmed, 2016).

The result shows that the density is classified in five classes of equal intervals that vary from 0.5 km/km^2 to 2.7 km/km^2 (Fig. 4), most of the area (41%), which represents an area of 392 km^{2,} has very low linear density, 22% represents (213 Km^2) has low density, 18% (168 Km^2) moderate, 11% (102 Km2) high and just (8%) which covering 79Km^2 represents very high density >2 km/km2 which was considered as potential areas for groundwater.

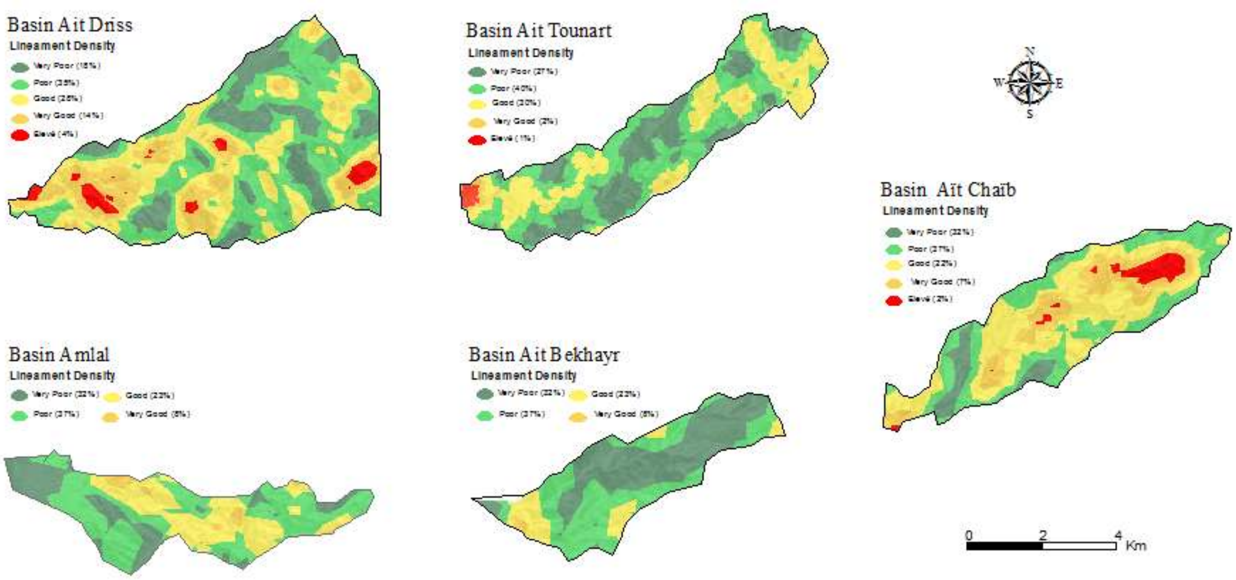

Fig.4: Lineaments density map of the basins

3.2 *Hydrographic Characteristic*

All the tributaries of the study area are like gorges carved in hard rocks. Most of them are drained by the Oued Issen river, except the small SE part of the area, which is drained by the tributaries of the Oued Aït L'Haj. Their hierarchy is defined according to the SHUMM-STRAHLER method, which was originally presented by Horton in 1945 and modified by Strahler in 1952 (Fig.5A). This method makes it possible to classify the branches of the outcrops by attributing to each one a value that qualifies its importance, which makes it possible to identify the main wadis that are from North to South:

- Oued Aït Bkhayr, which has blunt meanders in the Middle Cambrian silty shales with a slope of 7%.
- Oued Aït Chaïb with a very steep slope of 9%, which meanders through tight gorges in the Lower Cambrian sandstones and quartzites and widens in the Ordovician mudstones and silstones.
- Oued Aït Tounart, its valley is dug in hard rock formations of the Lower Cambrian of the Ordovician or in soft grounds of the Middle Cambrian with a slope of 4%.
- Oued Aït Driss is much stronger than the other rivers of the oued Issen because it is longer and much more fed by the numerous streams that descend from the high mountains. Upstream, its valley is quite wide because it is excavated in the soft rocks of the Devonian and is suddenly transformed into a gorge dug in the volcanic andesitic sandstone and quartzite rocks. Its slope is 9%.
- Oued Amlal, which is a small wadi with a slope of 12%.

A statistical analysis of the drainage network was carried out to compare the distribution of the different orders throughout the study area (Fig. 5B). The analysis of the frequencies of the cumulative lengths of each order of the drainage network shows that these decrease from the least important tributaries to the highest order, orders 1 and 2 are the best represented with a total percentage of 74%, order 3 is scarce with frequencies lower than 21%, while order 4 represents a rate close to 5%.

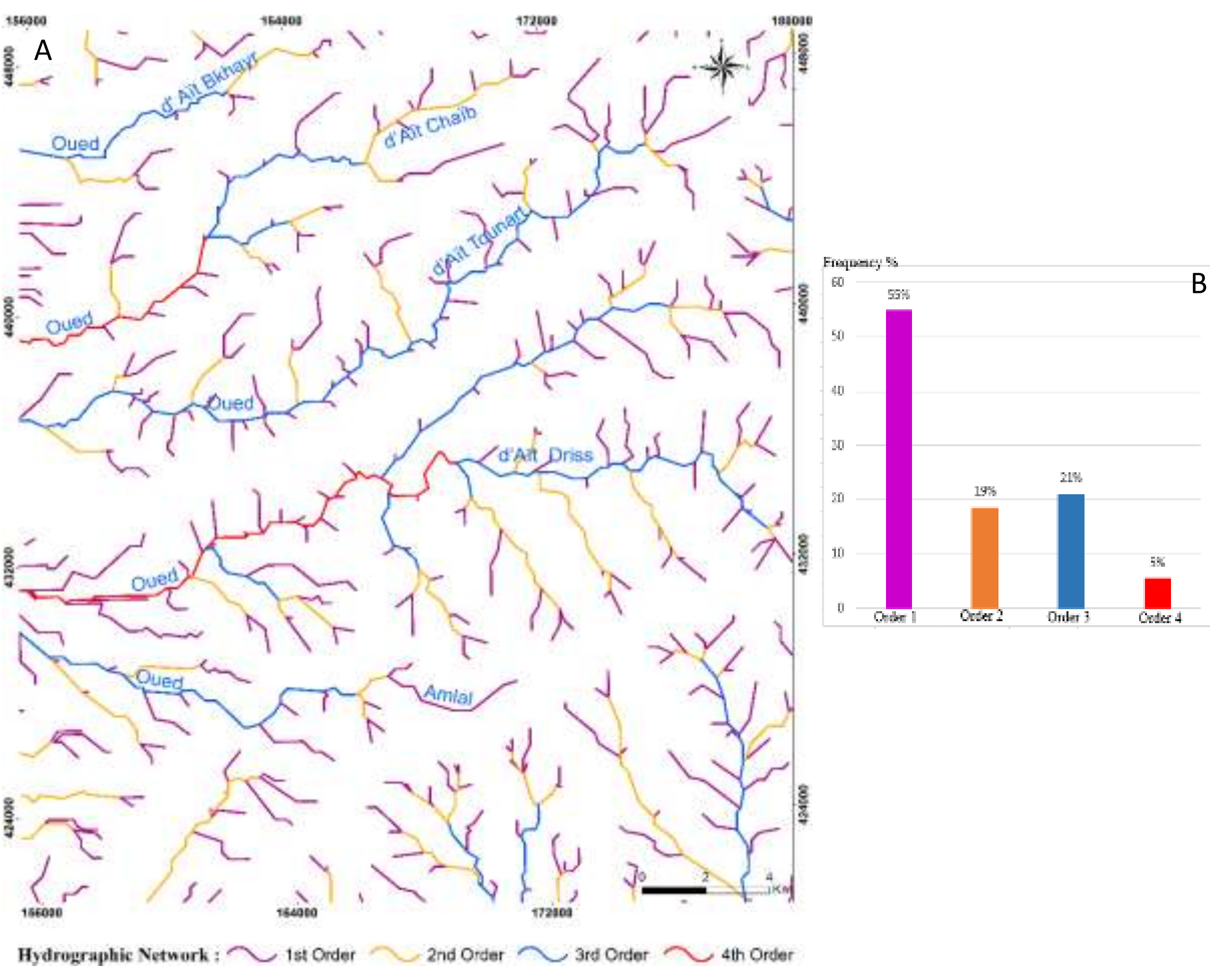

Fig.5: A Map of the drainage network classified by order. B Frequencies of the different orders of the river system.

3.3 Analysis of sub-basins characteristics

The river sub-basins to which the wadis of the study area belong are delimited by a ridge made up of a succession of carbonate rocks and tuffs from the Lower Cambrian. It dominates from very high up, a foreland slumped along an EW fault and cut by transverse ridges into a series of compartments giving fairly wide and shallow basins (Fig.6).

The study area contains five sub-basins which are very distinct by their physiographic characteristics; they extend in a main NE-SW direction, with an elongated shape (Table 2). This shape has a primordial impact on the global flows of the watercourses; it favours important times of routing of the water to the outlet as well as it informs on the course of the hydrographs at the outlet of the basins (Roche, 1963).

The shape of the basin is defined by the equation :

$$Kg = \frac{\mathrm{P}}{2 * \sqrt{\pi * \mathrm{A}}} = 0.28 * \frac{\mathrm{P}}{\sqrt{\mathrm{A}}}$$

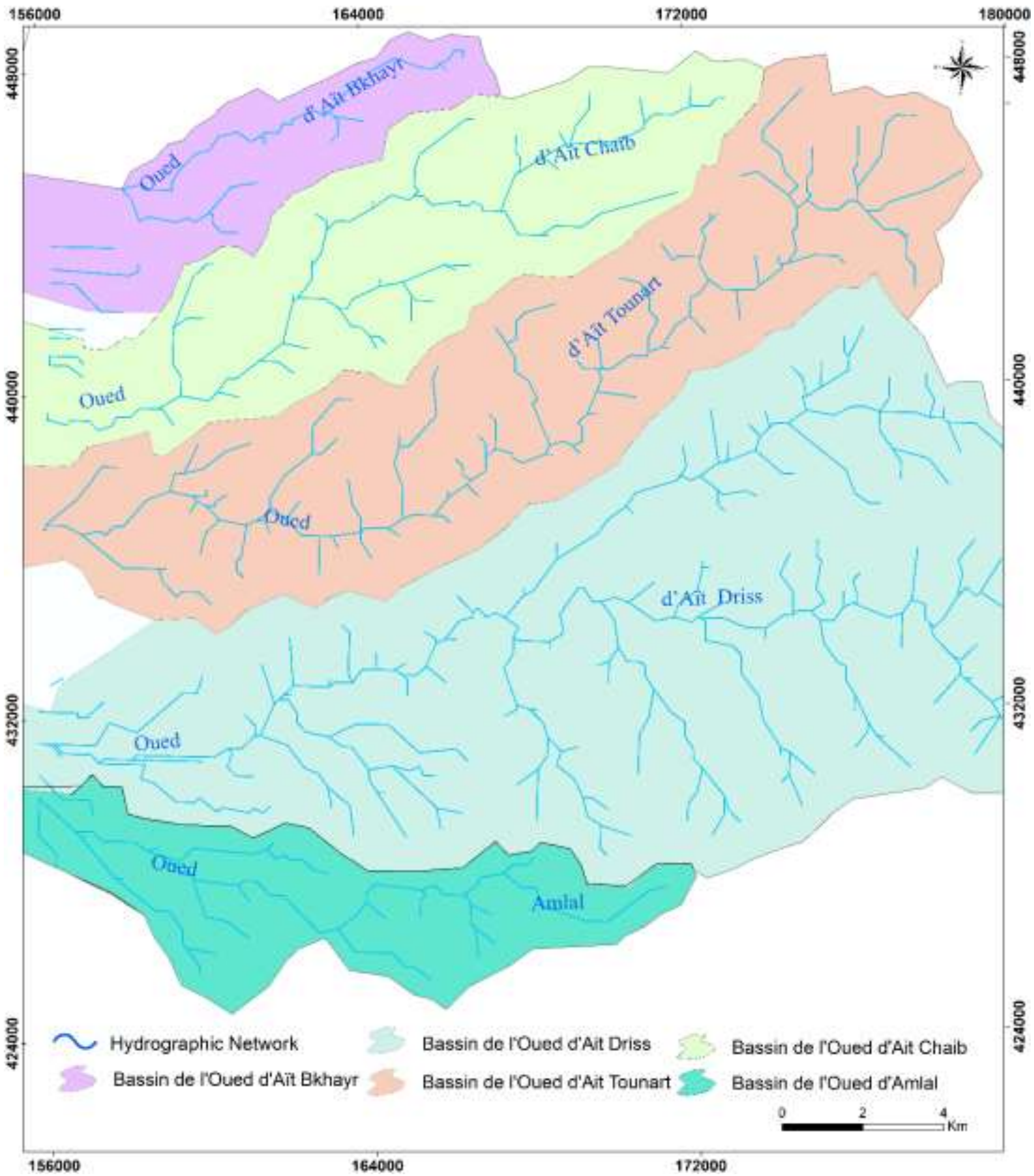

Fig.6: delimitation of the study area's basins.

3.3.1 Relief

The relief is very important in the hydrological behaviour of the basin; it influences the runoff, infiltration and evaporation of water because many hydrometeorological parameters vary with altitude.

The hypsometric maps of the basins (Fig. 7) determine the altimetric distribution, which informs the morphology of the basin. It ranges from 3500 m upstream to 883 m downstream, which translates to a rugged morphology with high average altitudes that vary from one basin to another; for the basins of Ait Driss, Amlal, Ait Tounart, Ait Chaib and Ait Bkhayr, their average altitudes are respectively 2037m, 2140m, 1877m, 1811m and 1619m (Table. 2).

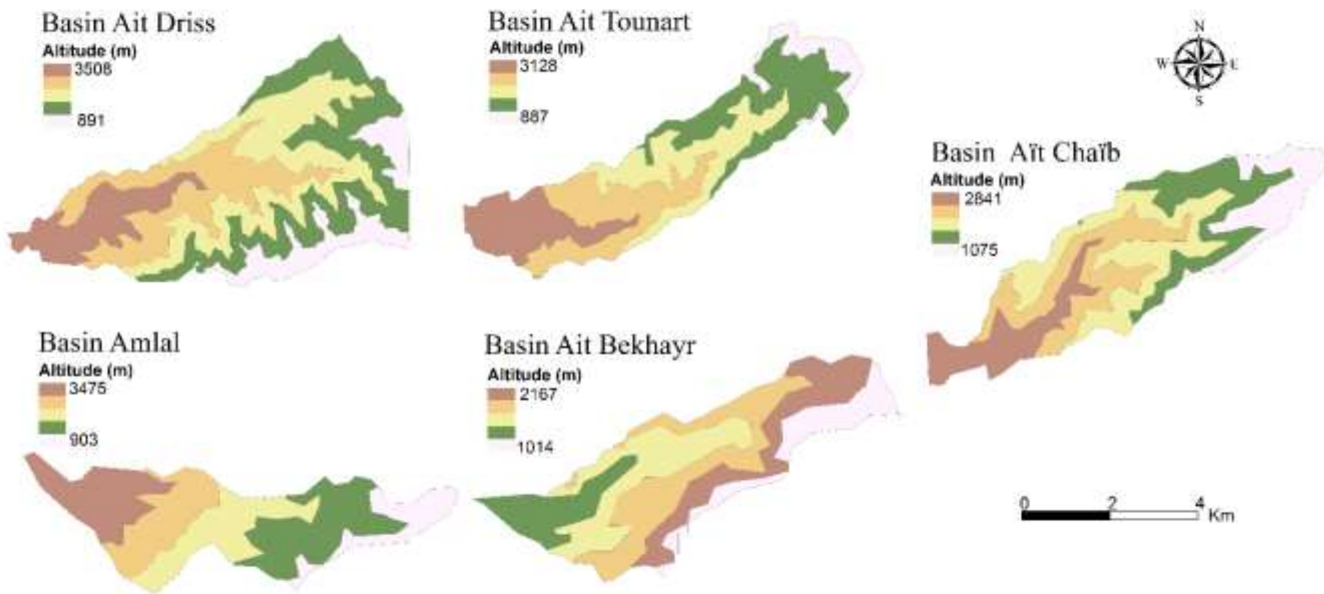

Fig.7: Representation of the maximum and minimum altitudes of the basins.

3.3.2 Slope of basins

The slope is one of the parameters that influence the groundwater recharge process and affects the direction of water flow and distribution (Gupta & Srivastava, 2010).

The slope of the study area varies from 0 to 70% (Fig.8), which translates that all sub-basins belong to a hilly relief with important average slopes in the order of 42%, 36%, 37%, 39% and 35% for the sub-basins Ait Driss, Ait Tounart, Amalal, Ait Chaib and Ait Bkhayr respectively (Table.2) For the gentle slope which is an indicator of the presence of areas with high potential for groundwater recharge are respectively 11%, 16%, 13%, 13% and 18%.

The intensity of the slope varies from one sector to another. The drained areas upstream of the wadis have a very steep to steep slope with a very low infiltration rate due to the fast-flowing tributary runoff, and for the drained area downstream, the slopes are gentle, which allows more retention time for infiltration, which favours the accumulation of water and the increase of groundwater recharge (Van der Hoven and al., 2003).

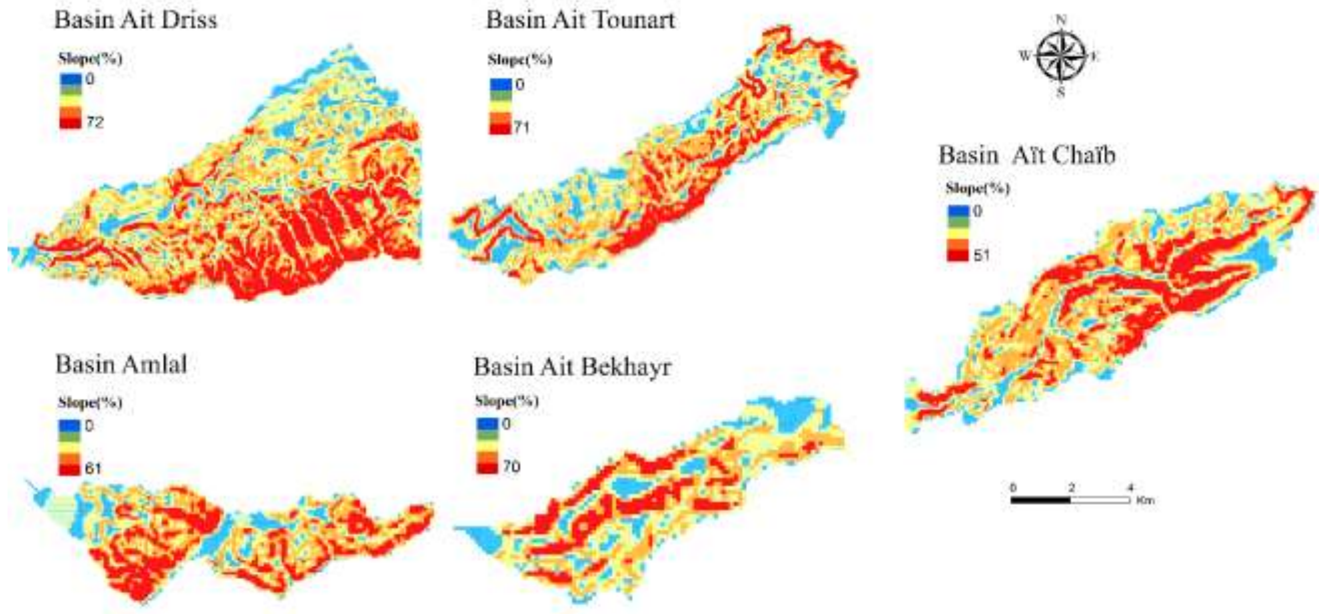

Fig.8: Representation of the maximum and minimum slopes of the basins.

3.3.3 Concentration time

The time of concentration of Tc reflects the time necessary for the water to travel its hydrological path, coming from the part of the basins that is the furthest hydrologically from the outlet to reach the latter. The basins that react most quickly to heavy rainfall are the Ait Driss and Ait Chaib basins with average concentration times of 6h49 min and 6h95min, which implies the implementation of effective works in these two basins to artificially recharge these areas. Table 1 summarises the various values of time of concentration obtained by different formulae. The value of the time of concentration selected is the average of the values.

Basin	Californienne $60*0,1452*(\frac{L}{I^{0.5}})^{0,77}$	Espagnole $0,3*(\frac{L}{(\frac{I}{100})^{0.25}})^{0,77}$	Turazza $\frac{0,108\sqrt[3]{(A*L)}}{\sqrt{I}}$	US Corps $16,682*(\frac{L}{I^{0.25}})^{0,77}$	Moyennes des Tc (h)
Ait Driss Basin	5,53	6,87	7,18	6,37	6,49
Ait Chaib Basin	6,41	7,26	7,42	6, 72	6,95
Ait Tounart Basin	3,89	5,04	4,08	4,67	4,42
Amlal Basin	3,01	4,16	2,71	3,86	3,43
Aït Bkhayr Basin	2,833	3,47	2,70	3,22	3,05

Tableau.1: Time of concentration calculated by different formulas.

3.3.4 The drainage density

The drainage density is introduced by Horton as the total length of the hydrographic network per unit area of the nas; it is one of the most important indicators of hydrogeological characteristics. It's calculated (Table.1) shows that this density is almost similar for the sub-basins of Ait Chaib (0.6) and Amalal (0.4), low compared to the sub-basins of Ait Driss (1.8) and Ait Tounart (1.02) and high compared to the sub-basin of Ait Bekhayr (0.2).

The drainage density is defined by equation (1) :

$$Dd = \frac{\sum L}{A}$$

For the spatial representation of drainage density, it is classified into five classes with values varying between 0.5 and 2.6 km/km2 (Fig.9), in which the concentration rate is high around the crossing of tributaries and decreases when moving away from the watercourses; the high drainage density represents 17% for the Ait Driss sub-basin, 5% for Ait Tounart, 24% for Ait Chaib, 4% for Amalal and just 2%, Ait Bekhayr.

Potential areas for artificial groundwater recharge are closely related to drainage density; a high storage rate occurs in environments with dense drainage systems; hence potential areas will be best located in basins with high drainage density, such as Ait Driss, Ait Chaib and Ait Tounart.

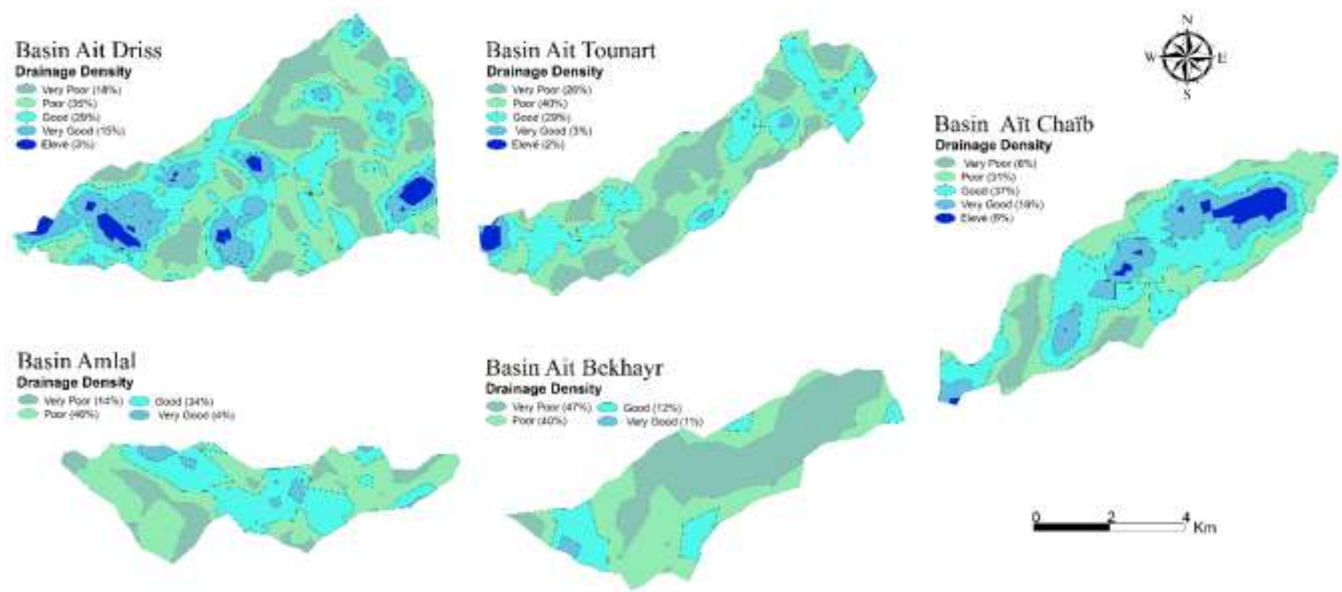

Fig.9: Drainage density map of the study area

4. Results and discussion

Drainage is integrated with lineaments to propose potential areas for groundwater storage (Edet and Okereke 1997; Robinson and al., 1999). The simultaneous influence of the two factors, fracturing and drainage network, can result in better artificial recharge sites in the area.

4.1. Identification of water concentration zones in fractured areas

Overlaying the fraction and hydrography data in a GIS environment will be used to locate areas where lineaments and the water network are evident and important (Fig.10). Most of the region has moderate (22%) to low (75%) potential for water storage in fractured areas, and just 3% corresponds to areas suitable for water storage to artificially recharge the water table in these broken areas.

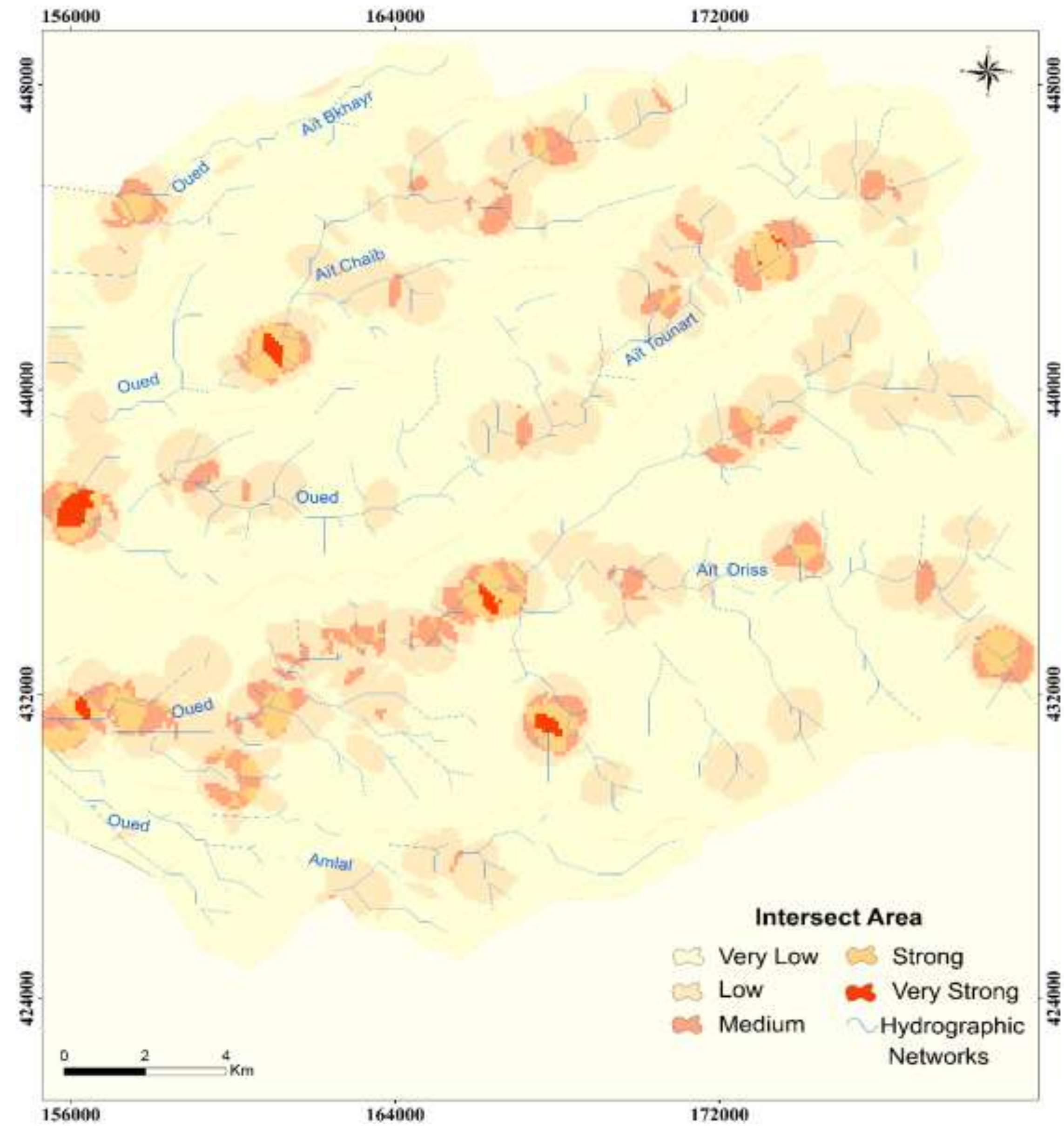

Fig.10: Identification of water concentration zones in fractured areas

The results obtained from the intersection map of the drainage network with the fraction were combined with other criteria that characterize the study area, such as geology, geomorphology and slope of each basin (Table.2), in order to explicitly take into account the factors influencing the artificial recharge process.

4.2. Basin characteristics

The different sub-basins of the study area are very distinct in their geometric (surface area, shape, etc.) and physiographic (concentration-time, average runoff speed, etc.) characteristics, which influence the hydrological behaviour of the basins. The high altitudes concern the sub-basins of Aït Driss, Aït Tounart and Amlal with average altitudes above 1870m and with slopes of about 42%, 40% and 37%, respectively. The basins of Aït Chaïb and Aït Bkhayr are lower in altitude with an average altitude around 1811m with minima below 1619m and with average slopes of around 36% and 35%, respectively (Table.2). The higher altitude basins deliver more water to the outlet than the lower ones, and a low slope area represents a high potential for the implementation of artificial recharge devices, while a high slope area represents a low potential (Nampak and al., 2014; Andualem and Demeke, 2019).

The Aït Chaïb, Amlal, and Aït Bkhayr basins have drainage densities higher than 1.5 while the Aït Driss and Aït Tounart basins have a lower drainage density of 0.97 (Table.2). An area with high drainage density and lineaments is favourable for artificial recharge and vice versa.

	Perimeter (km)	Area (km)	Medium altitude of Watersheds (m)	Medium slope of Watsersheds (%)	Compactness Indice	
Basin Aït Driss	70	202	2037	42	1,37	Elongated Shape
Basin Aït Tounart	64	113	1877	40	1,68	
Basin Aït Chaïb	49	71	1811	36	1,62	
Basin Amlal	40	41	2140	37	1,74	
Basin Aït Bkhayr	28	23	1619	35	1,63	
	Average of Tc (h)	Average runoff speed (km/h)	Length Oued (m)	Medium Slope of Oueds (%)	Drainage density (km-1)	
Basin Aït Driss	6	4,6	30174	7	0,54	
Basin Aït Tounart	7	4,1	28678	4	0,97	
Basin Aït Chaïb	4	4,8	21275	9	1,55	
Basin Amlal	3	5,2	18039	12	2,69	
Basin Aït Bkhayr	3	4	12257	7	4,8	

Table.2: Summary of basins characteristics.

4.3 Potential Areas for Artificial Recharge

To designate the favourable sites for artificial recharge based on the above criteria, two potential zones were defined (Fig.11); 94% of the zone represents a low recharge potential with a surface area of 762 km^2, it is scattered in all the basins, especially in the high relief areas. While just 6% has a medium to high recharge potential with a concentration in the downstream parts of the basins, it occupies 14 km^2 of the study area and is underlain by dolomitic rock formations with a high density of lineaments and drainage and gentle slopes, which favour the storage and filtration of water. The unsuitability of most of the area for artificial recharge is consistent with the geology, geomorphology and slope characterizing the area.

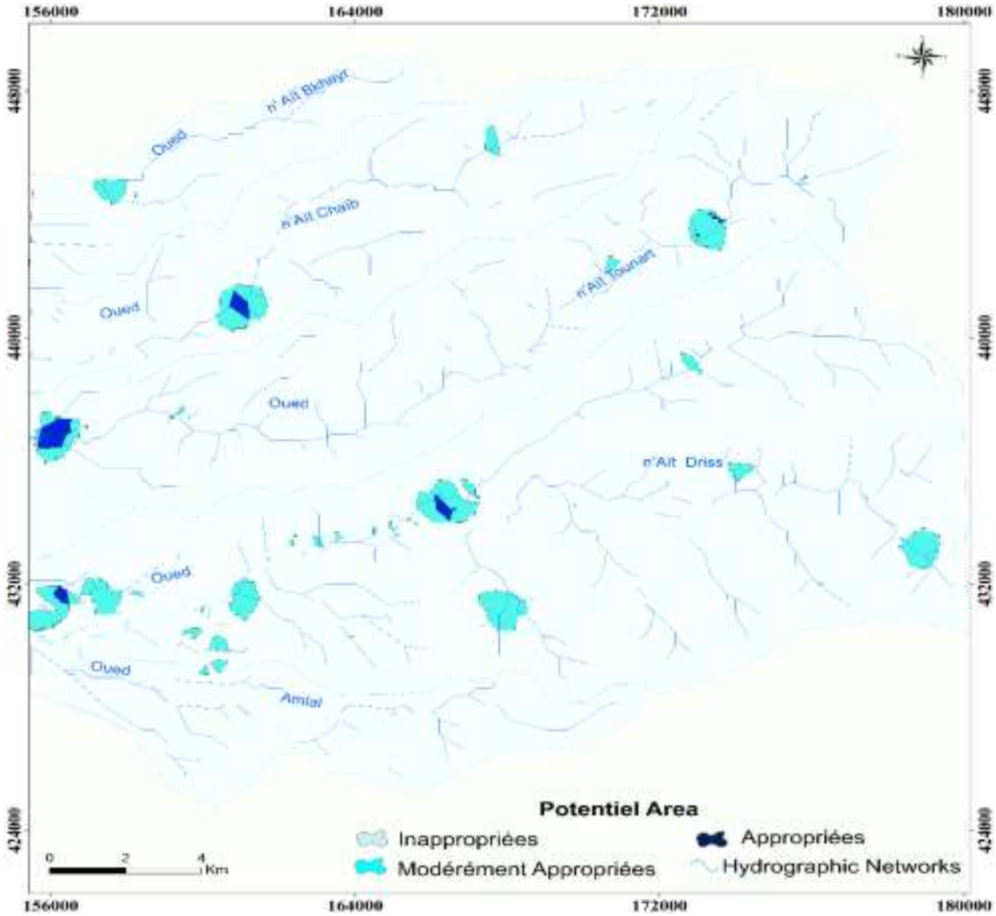

Fig.11: Identification of groundwater potential zones

5. Conclusion

The good governance of water reserves, especially in arid and semi-arid areas, is a real challenge to which it is necessary to find strategies in order to overcome the water insufficiency and to attenuate the piezometric drops of the water table, this is the reason for which this study recommends the artificial recharging of the aquifers by using geospatial GIS and Remote Sensing techniques, as efficient tools to delimit the favourable areas for artificial recharge in the sub-basins of Ait Driss, Aït Tounart, Aït Chaïb, Amlal and Aït Bkhayr, through the integration of the different factors that influence the potential of this recharge such as the density of the lineaments, the density of drainage, the slope, the geology and the geo-morphology of the basins

The interpretation and analysis of statistical data relating to the different basins with the resulting maps (density of lineaments and drainage, fracturing overlay with hydrography, slope, and hypsometry) allowed the designation of potential areas for artificial recharge. In the region of study, three different areas were defined; appropriate areas for recharge represent 2% of the total area, moderately appropriate represents 4%, and inappropriate represents 94% of the study area.

About the structures of this artificial recharge, it is recommended to put hydraulic works on potential sites for artificial recharge mapped, principally on the major watercourses of the Oued d'Ait Driss, Ait Tounart and Ait Chaib, to prevent the water from flowing and to increase its infiltration in the geological formations in order to feed the aquifer and to attenuate its piezometric drops. The map resulting from this study can be used for planning similar artificial recharge projects to ensure effective and sustainable management of these resources. It is recommended that this study be complemented by geophysical and geotechnical studies to ensure the feasibility of the implementation of hydraulic structures.

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