# Application of remote sensing and GIS for groundwater potential modeling in the crystalline basement of Tamanrasset area, Southern Algeria.

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**Abstract**

**The study area is part of the crystalline basement in the South of the country, which is characterized by a Saharan climate and field with a very complicated hierarchy of relief structures. These structures imprint a multilayer aquifer system (alluvial aquifer, cracked rock aquifer....). The aquifer during exploitation is the alluvial deposits, but the amount of water exploited does not meet the needs of the population.**
**The cracked rock aquifer, despite its large distribution and the importance of reserve point in the study area, remains poorly known due to the complexity and heterogeneity of the fracturing network and the difficulty of estimating the degree of evolution of this system. Thus, the evaluation and calculation of the hydrodynamic parameters of this aquifer remain relative and imprecise.**
**To deal with this problem, we chose to work on the Tamanrasset sub-basin. This study aims to explain, on the one hand, the relationship between morphology and fracturing in association with groundwater flow and, on the other hand, to identify probable zones with high aquifer potential. This requires a variety of knowledge while using modern methods of remote sensing and GIS, where the analysis and processing of data is done using special software. This remote sensing method is based on photo interpretation of satellite images and automatic extraction of lineaments. All information layers have been integrated through GIS analysis and the main axes of groundwater flow have been delineated. The reliability of the results of this method is verified by in situ tests.**

**Keywords: -Aquifer potential, crystalline basement, fracturing, GIS, remote sensing, Tamanrasset sub-basin.**

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## Introduction

Water is an essential element, indispensable to human life where all related activities (drinking water supply, industry, irrigation, etc.) are mainly based on this resource. However, water scarcity has become a crucial problem experienced by all societies and particularly those in developing countries. In Algeria, the exploitation of underground water has made it possible to face the problem of scarcity, especially in the Northern part of the country. The major part of the national territory is essentially occupied by sedimentary grounds, which represent more than 90 % of its total surface area and the rest is the crystalline basement.

The study area is part of the crystalline basement in the South of the country; it is characterized by water scarcity and very rare precipitation [Sekkoum et al. 2012; Cherchali 2001]. Currently, the water resources available in the study region are mainly provided by the underflow aquifers located in the wadis [Nefis et al. 2018; Cherchali 2001]. They are small and fail to meet the needs of a growing population. To solve this problem, it has become necessary to seek additional resources.
Aquifers in the crystalline basement have been the subject of numerous studies [Grillot et al. 1990; Diouf 1999; Tweed et al. 2011; Roques 2013]. However, the major constraint in the study area is the complex and erratic nature of groundwater occurrences and circulation in the crystalline basement, due to the complexity and heterogeneity of the existing fracturing network [Cherchali 2001].
The problem of groundwater occurrences and circulation in the crystalline basement has been approached from several points of view. To name a few, Taylor and Howard [2000] used a tectono-geomorphic model to study the hydrogeology of deeply weathered crystalline rock. Srivastava and Bahattacharya [2006] have integrated a geophysical data with spatial data, to delineate and assess groundwater potential zones. Nowadays, modern techniques combine various conventional methods with satellite imaging techniques and geographic information systems to delineate zones with height aquifer potential in fractured rocks [Olutoyin et al. 2014; Chenini et al. 2010; Machiwal et al. 2011; Talabi and Tijani 2011].
It should be noted that the Remote Sensing (RS) and Geographic Information System (GIS) offers many advantages in terms of spatial, spectral and temporal availability of data covering wide and inaccessible areas, making them an excellent tool for evaluating, tracking and conserving natural groundwater resources [Tolche 2020; Dasho et al 2017; Naghibi SA et al. 2017; Nagaraju A &al. 2016; S. K. Nag et al. 2012; Jackson 2002; Jenson and Trautwein 1987; Burrough 1986].
The objective of this study is to delineate and assess groundwater potential zones in the weathered and fractured rock aquifer of the study area; using data provided from RS techniques and GIS technology. The efficiency of this result is verified by field tests using Electrical Tomography Resistivity (ETR) and Pumping Tests (PT).

## 1. STUDY FRAMEWORK AND GEOLOGICAL CONTEXT

The study area is part of the Wilaya of Tamanrasset, which is located in the South of Algeria, nearly 2000 km from the Algerian capital. It covers an area of 550,000 $Km^2$ or about 23% of the total Country area with an estimated population of 205,220 inhabitants. It is immensely; influenced by the desert-type climate with low to scarce rainfall and almost no vegetation cover (Fig. 1).
Geologically, the study area is part of the Hoggar domain, which is composed of a junction of terranes, characterized by a strong, highly tectonized basement [Dautria 1988; Caby 2003; Gaci et al 2014], basaltic in nature upstream [Fabre 2005] and granites, gneiss, schist downstream [Briedge 1993] (Fig. 2). The latters are characterized by a weathered upper part extending over 10 to 40 m followed by a sandy alluvial covering ranging from 10 to 30 m.

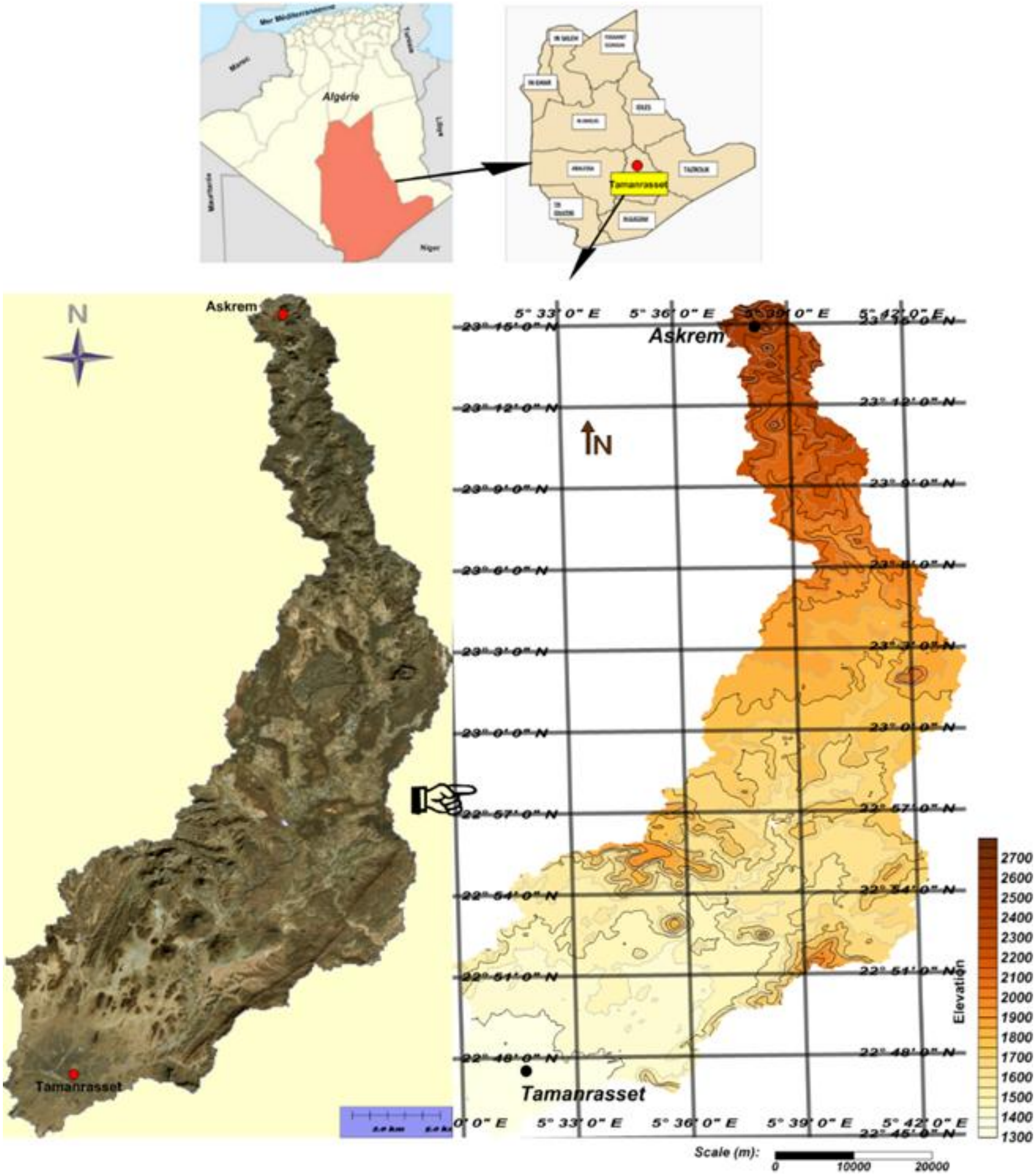


**Fig. 1.** Geographical location of the study area.

From a hydrogeological point of view, crystalline rocks, in normal conditions, have very low porosity and permeability. However, the tectonic and physico-chemical phenomena that affect these rocks induce so-called secondary porosity and permeability, allowing these formations to serve as aquifers, which are often highly productive [Greenbaum 1992]. The presence of two types of aquifers should be noted, weathered rock aquifers and fractured rock aquifers (Fig. 3).

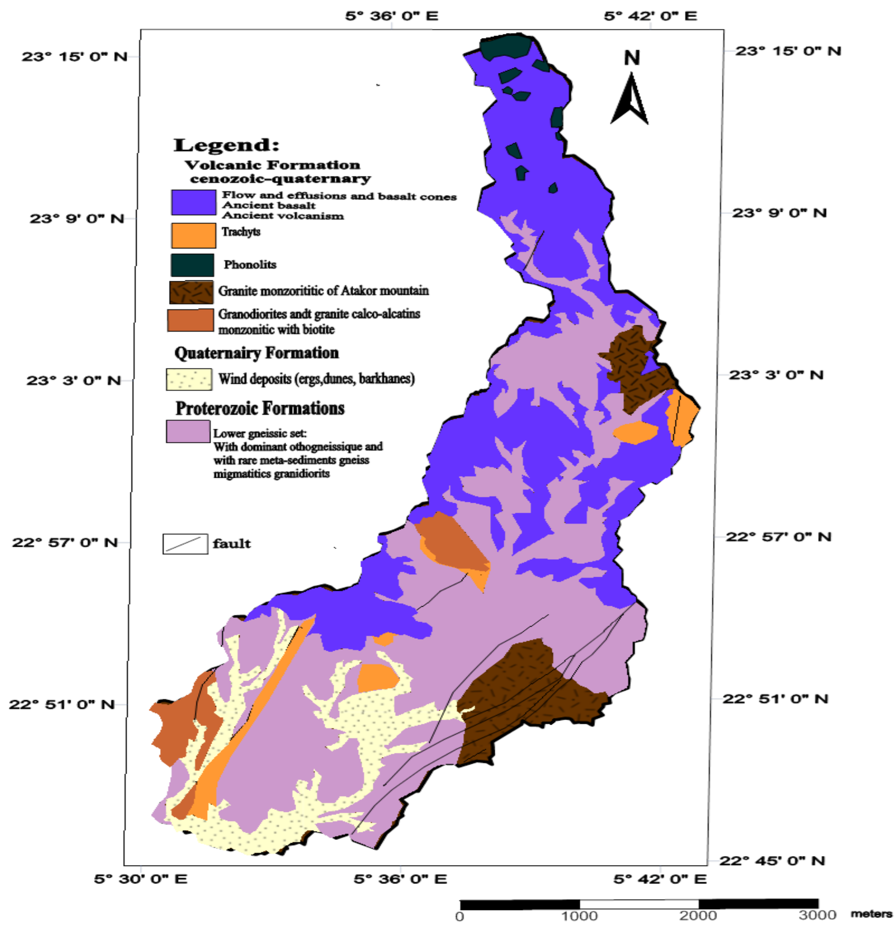


**Fig. 2.** Geological map of the study area.

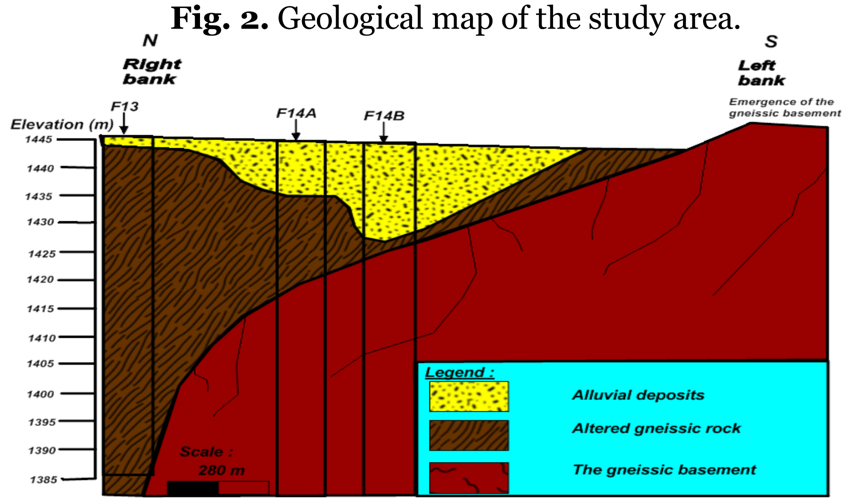


**Fig. 3.** Hydrogeological section along the Tamanrasset wadi.

## 2. MATERIAL AND METHODS

The analysis of a physical environment in terms of characterizing the state and the evolution of fractured rocks is based on the use of modern techniques (RS, GIS) for surveying and processing structural data. We can analyze the fracturing of an environment when outcrop conditions are favorable. The interpretation of RS data has been used for several studies in hydrogeological investigations [Sander et al 1997; Gustafsson 1993].

The methodologies carried out in this study use RS and GIS. The extraction of lineaments from a satellite image is established by following continuous processes, all based on specialized software. Each of these latters used, are part of the work.

The methods used for image processing include principal component analysis (PCA) provided from land-sat 7EMT + processing and spatial filtering resulting from SRTM DEM processing. The result of this phase will be used by other software to automatically extract lineaments. The organization chart below (Fig. 4) summarizes the main lines of all these operations.

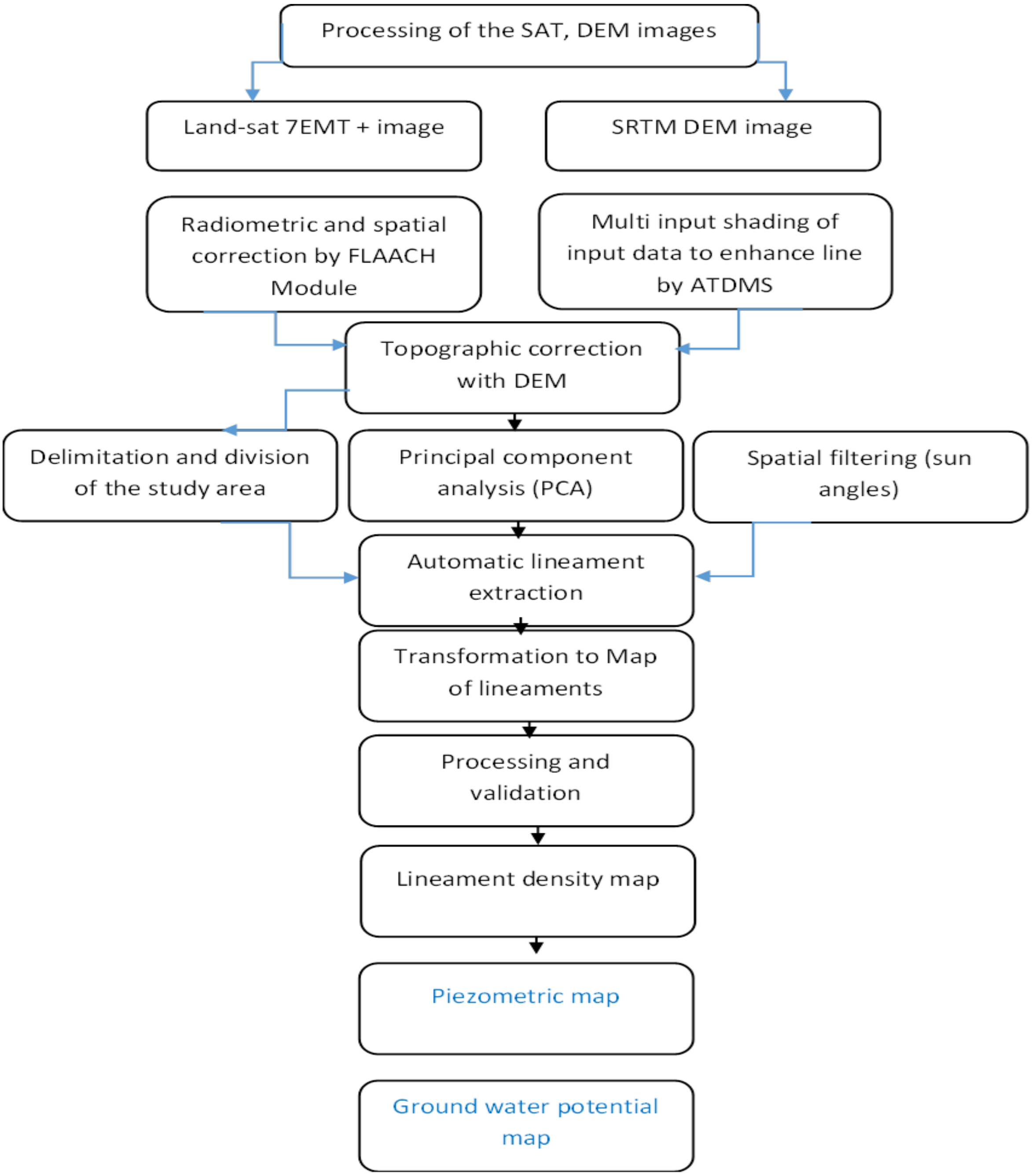


**Fig. 4.**Cartography Flowchart: shows the integration of multi thematic maps to produce Groundwater potential map. ATMDS: adaptive-tilt multi-directional shading, FLAASH: Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes.

The geometric structure of the basement aquifer is controlled by fracture evolution and orientation, where visible surface fracturing and the geometry of this type of aquifer are closely related. For this reason, fracturing analysis has become a major element in the hydrogeological study of these environments.

To answer the problem in question, the method used is based on:

- Lineament maps,
- Lineament Density maps,
- Piezometric maps.

This study required the use of several types of data, emerging from geological, topographical maps and satellite images (Land-SAT 7, SRTM DEM). These data were used to map linear networks.

To obtain the data, it is essential to use specific software to visualize, display the satellite map and automatically extract the lineaments. Then, the result of this phase is processed and analyzed to highlight fracturing density maps and consequently the orientation of the main drains for underground flows. The resulting maps are overlying on piezometric maps to highlight the relationships between fracturing and underground flows. Finally, the results of these steps are used to determine the probable zones, which have good productivity for the installation of future collection structures.

**2.1 Lineament map:**

For this study, the lineament extraction is carried out by using the land-sat 7 (EMT+) image of the study area, which was obtained from the global land cover facilities. The image used had 30 m of resolution for the reflective band. The SRTM DEM 30 m resolution of the study area was acquired from USGS's Earth Explorer. To obtain results, a series of digital image processing procedures were applied to the Landsat-7 ETM+ image (Tab. 1):

**Tab. 1**: Landsat-7 ETM+ Processing

| Steps | Description |
|---|---|
| Spectral enhancement | Optimum Index Factor 3.3. |
| Resolution enhancement | The Landsat-7 ETM+ FCC image is of 30 m resolution. |
| Radiometric enhancement | The FCC image was enhanced by linear stretching. |
| Spatial enhancement | Application of edge enhancement filters on the stretched image. |

The SRTM DEM is used to produce geomorphology with the aid of principal components analysis (PCA) produced from Landsat-7 ETM + (Tab.2):

**Tab. 2**: Digital elevation map (DEM) processing.

| Steps | Description |
|---|---|
| Fill sink | free of sink error a process carried out on it in the ArcGIS 10.3 |
| Shaded relief | 4 shade relief images (0°, 45°, 90°, and 135°), sun elevation angle of 30°. |

The result of this processing is imported into the PCI Geomatica 2014 software for automatic lineament extraction. The lineament extraction process in PCI Geomatica software utilizes the line algorithm, which involves edge detection, thresholding, and curve extraction steps [Geomatica 2014]. During the initial stage, the line detection algorithm is employed to generate an image highlighting the strength of the edges.

The line detection algorithm in the first step involves three sub-steps. Initially, the input image undergoes filtering using a Gaussian function with a radius determined by the filter radius (RADI) parameter. Next, the gradient is computed based on the filtered image. Finally, pixels whose gradient does not represent a local maximum are suppressed, resulting in their edge strength being set to zero.

**Tab. 3**: PCI Geomatica line extraction parameters

| Parameter name | Values (Landsat-7) | Values (SRTM) |
|---|---|---|
| Radius of filter in pixels (RADI) | 12 | 12 |
| Threshold for edge gradient (GTHR) | 80 | 90 |
| Threshold for curve length (LTHR) | 30 | 30 |
| Threshold for line fitting error (FTHR) | 10 | 10 |
| Threshold for angular difference (ATHR) | 30 | 30 |
| Threshold for linking distance (DTHR) | 15 | 20 |

In the second stage, the edge strength image is thresholded to generate a binary image. Each pixel in the binary image represents an edge element. The threshold value is determined by the edge gradient threshold (GTHR) parameter.

In the third stage, curves are extracted from the binary edge image, involving multiple sub-steps. Firstly, a thinning algorithm is applied to the binary edge image, resulting in pixel-wide skeleton curves. Then, a sequence of pixels is extracted from the image for each curve. Any curve with a pixel count below the curve length threshold (LTHR) parameter is discarded from further processing. The default parameter values of PCI Geomatica [2001] were used for these processes (Tab. 3).

To accomplish the first phase in lineament extraction, SRTM DEM images with different filter angles (0°, 45°, 90° & 135°) were imported into the PCI Geomatica 2014 software to perform automatic lineament extraction, following the previously described method.

The parameter values employed, as indicated in Table 3, were carefully selected to ensure optimal threshold values for identifying lineaments, as recommended by Abdullah et al. in 2013. This phase is so important to carry out lineament correction by emerging errors that are mainly from anthropogenic structures [Mallast et al. 2011].

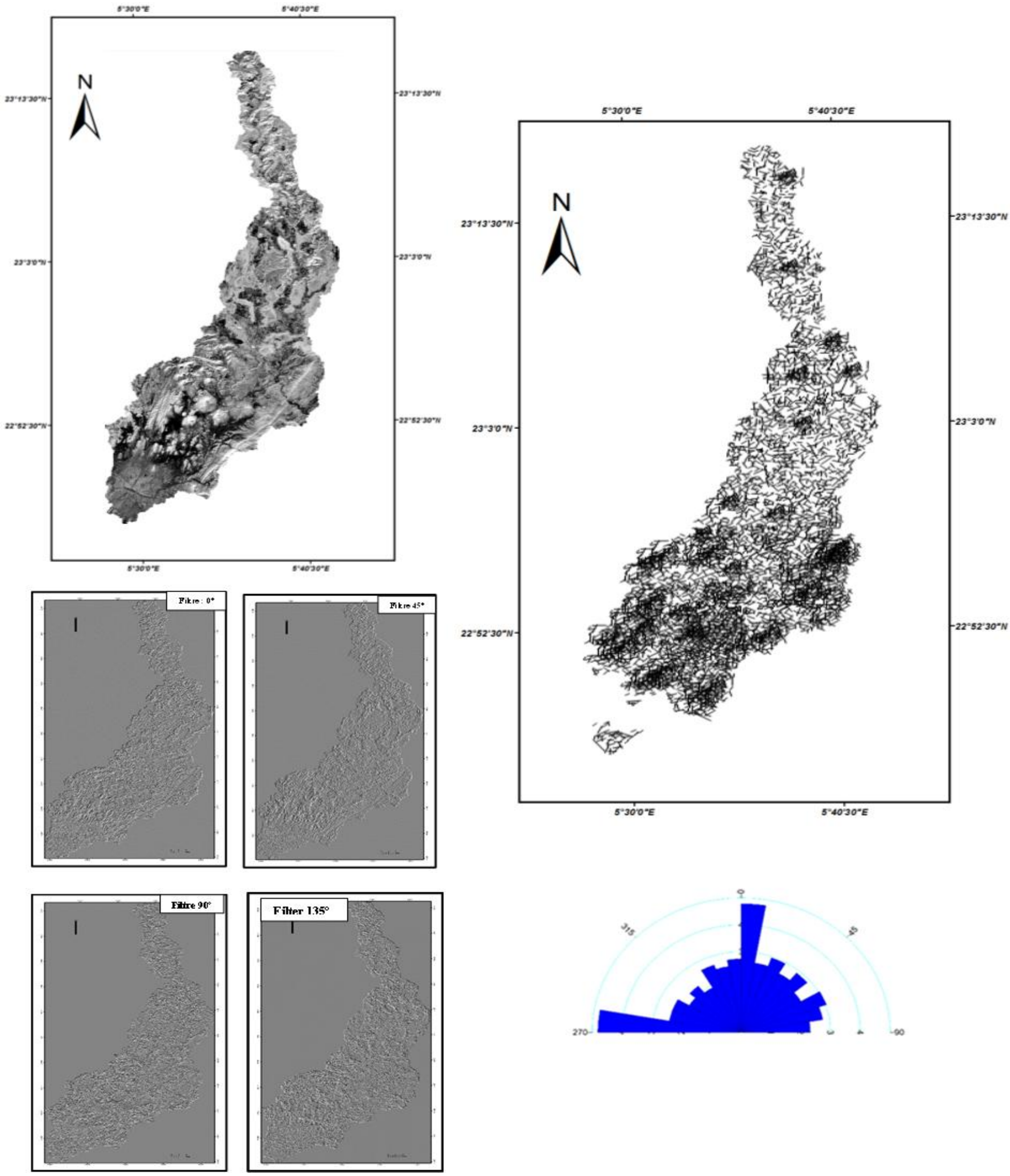


**Fig. 5.**Lineament map

## 2.2 Lineament density map:

The result obtained by PCI Geomatica 2014 software processing is imported to Arcgis 10.3 to calculate and map lineament density . The calculations of lineament density lead to determining the frequency of lineaments within a given area. Lineament density also noted as lineament frequency [Greenbaum, 1985], provides a measure of the clustering of linear features in a specific region. This analysis resulted in the generation of a map that highlights concentrations of lineaments across the study area (Fig. 6).

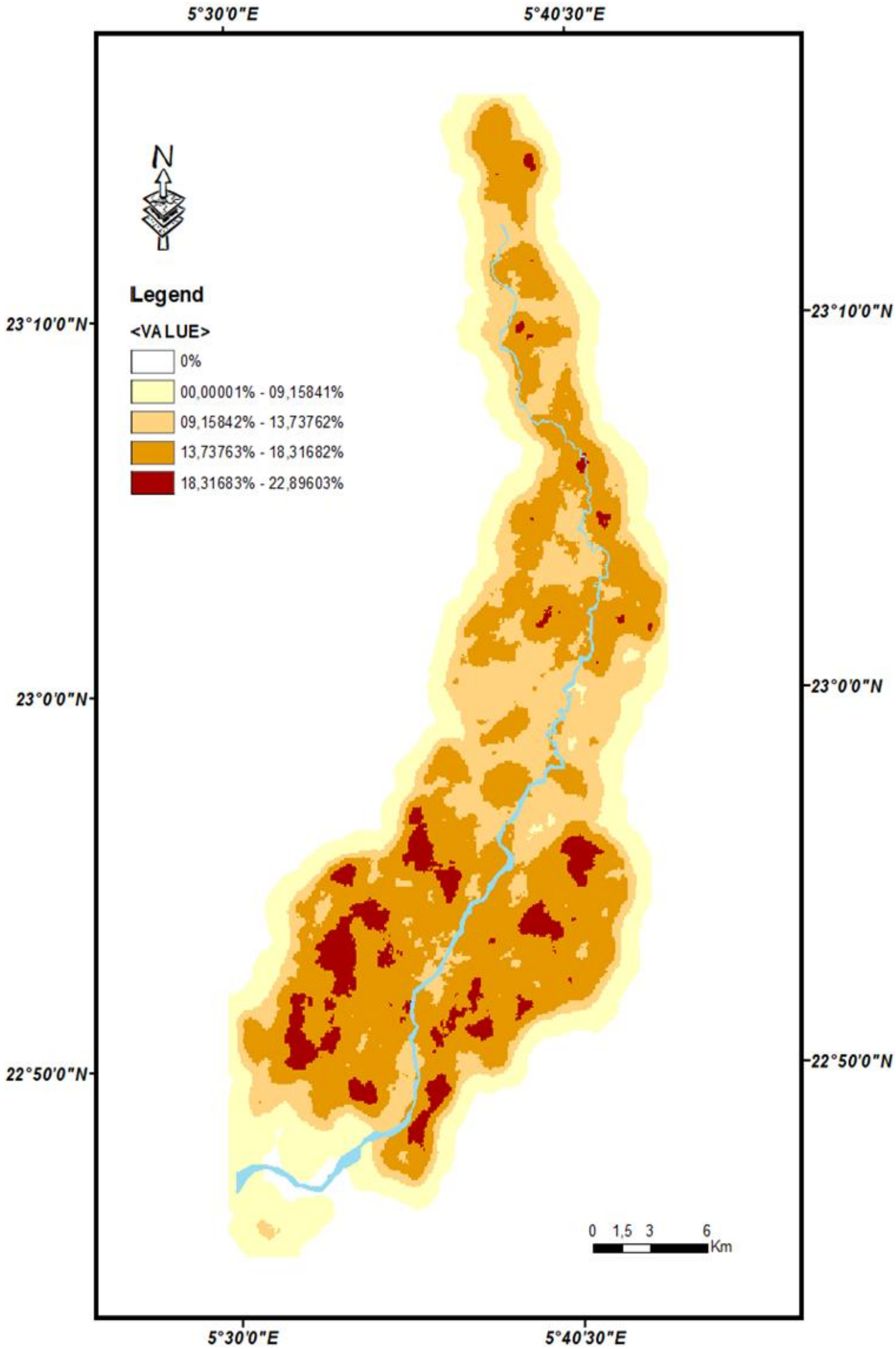


**Fig. 6.**Lineament density map

According to Edet et al. (1998), zones exhibiting relatively high lineament density indicate a greater degree of rock fracturing, which serves as a prerequisite for the development of groundwater conduits in that particular area. Areas characterized by high lineament density, are very favorable for future groundwater supply development [Haridas et al., 1994; Sander, 2007; Dasho et al 2017].

## 2.3 Piezometric map:

To highlight the mode of flow of the groundwater and monitor the evolution of the piezometric level during the year, monthly piezometric measurements have been taken, at approximately thirty wells that capture the fractured rock aquifer along the wadi; we chose to take two examples to demonstrate the reliability of the method (Fig. 7). The figures below show that the direction of groundwater follow had the same direction as it is in sub surface.

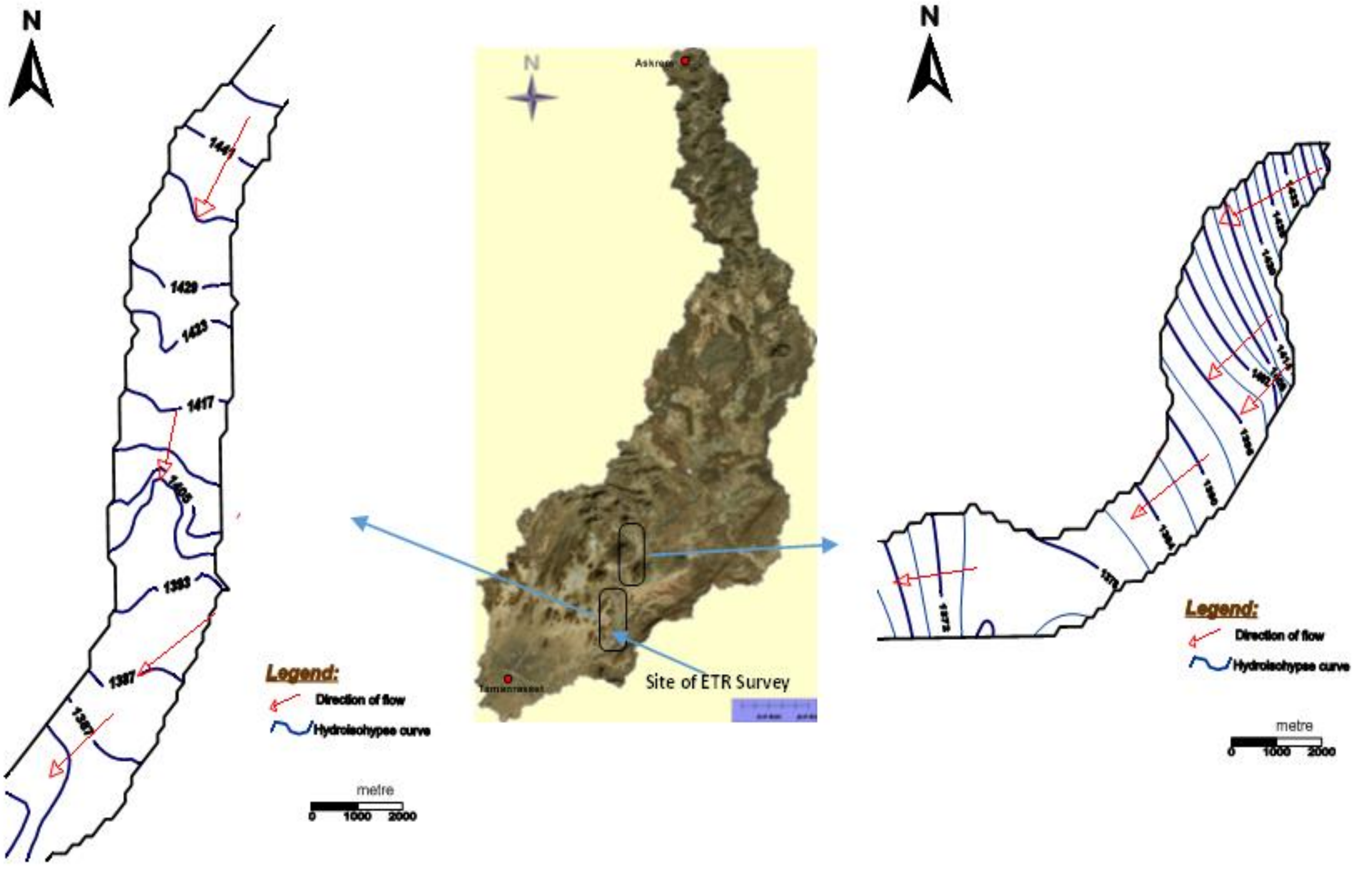


**Fig. 7.**Piezometric maps.

The maps obtained during this study (Fig. 7) show the same general flow pattern that coincides with the wadi pattern. The piezometric level ranges from 1450 m in the north to 1370 m in the south. In the north, the direction of the flow is northeast - southwest and the flow is uniform. It converges downstream as it approaches the town where exploitation is significant. The hydraulic gradient is 0.0067 and rises to 0.02 in the middle and south of study area.

## 2.4 FIELD TEST

In the study area, previous studies indicated that the region is characterized by multiple aquifer system in which ground water is confined in alluvial sediments and poorly known in the crystalline basement object of this study. To verify the reliability of the results obtained by RS, GIS and superimposed piezometric map over density maps, field tests are executed to illustrate the efficiency of methods applied in this study. Tow technics are used:

- Geophysics methods by using; Electrical Resistivity Tomography (ERT).
- Hydrodynamics methods using; Pumping Tests (PT).

The ERT survey (Fig. 7, 8) covered a 2 D horizontal profiling length of 240 meters, reaching a depth of 40 meters below ground level carried in high density lineament zone in the study area. The parameter of the survey lines (TE1) addressed in Figures 8 below.

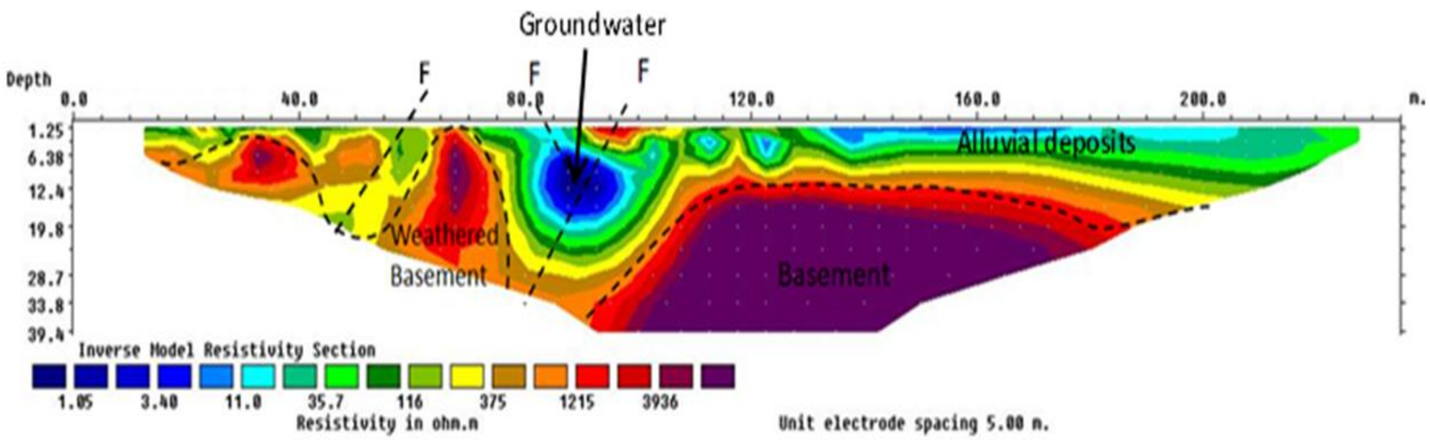


**Fig. 8.**The result of 2D inversion of Dipole–Dipole electrode array data from the study area (TE1).

In the study area the depths of wells vary between 5 m and 30 m, and the static water levels range from 6 m to 18 m indicating that the wells in the region are shallow in the crystalline basement of the Tamanrasset wadi sub-basin.

Four pumping tests were conducted in chosen wells, where these tests are intercepting weathered rock aquifers and the density of lineaments in these locations are variable.

A pumping test is a field experiment in which a well is pumped at a controlled rate. The response of the water level (drawdown) is determined in one or more nearby observation/monitoring wells. Pumping tests are essential to provide dynamic aquifer parameters, and to determine the response of the groundwater table at each point of test.

The results indicate (Fig. 9) that for the same discharges (Q m3/s) the water table has been stabilized at various depths in the four wells:

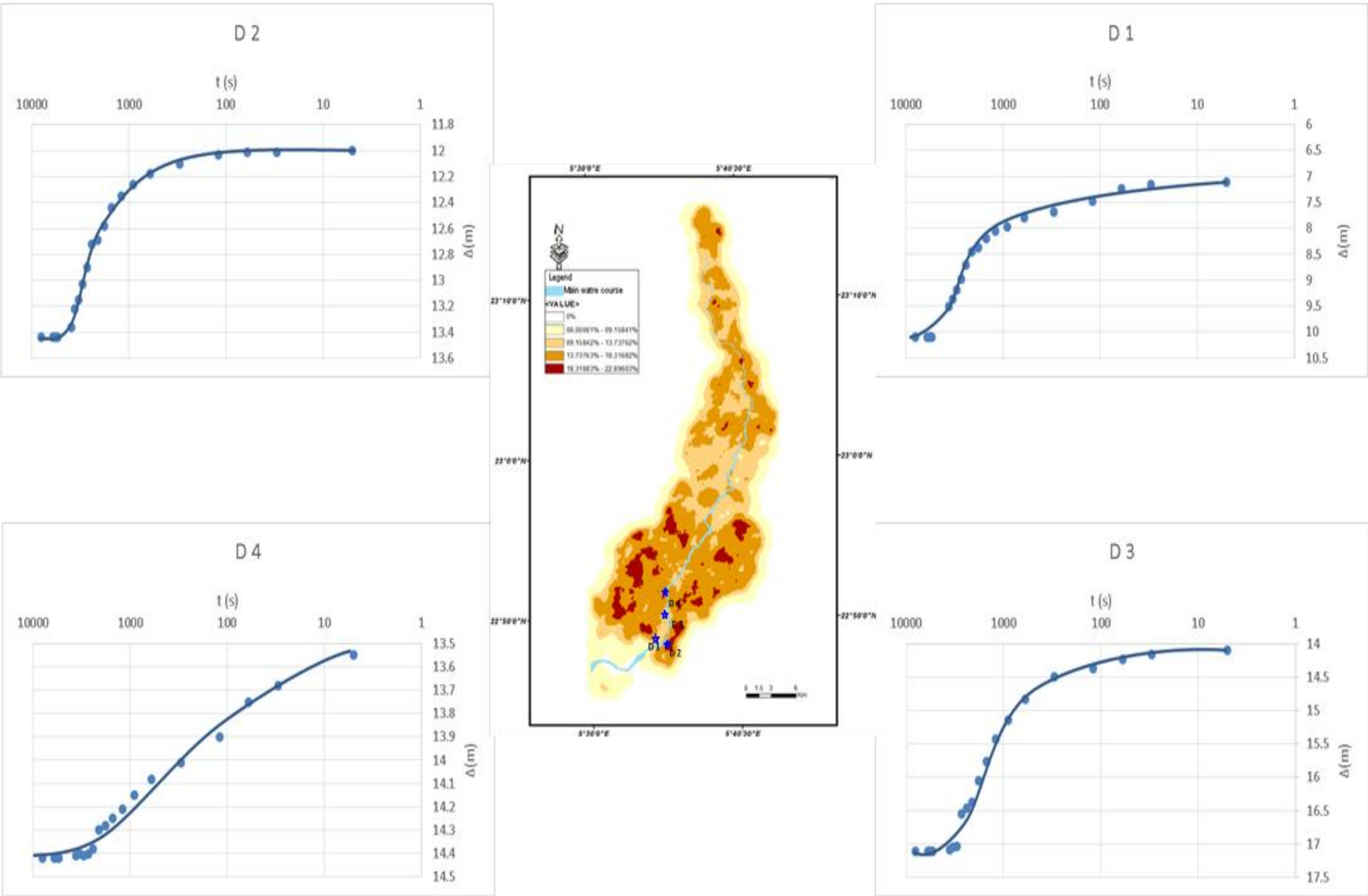


**Fig. 09.** Pumping test in Tamanrasset wadi sub basin.

## 3. Results and discussion:

### *3.1 Characterization of lineament distribution:*

Digital processing carried out on satellite images made it possible to draw up two maps, highlighting the state of fracturing in the study area. The sequence of digital processing operations applied to the satellite images allowed us to produce a lineament map and a fracture density map. Thus, we were able to create rosettes of distribution of the lineament directions in the Tamanrasset wadi sub-basin (Fig. 6), making it possible to account for the major dominant directions as well in the basement. The main directions obtained from this map are NNE-SSW, NE-SW, EW. The results detected from these maps (Fig. 6) show that the high fracturing density aligned along well-distinguished axes, where these axes constitute preferred drains for groundwater.

3.2 Overlaying piezometric map on the lineaments density map.

The overlay maps in the figure below showed significant concordance between lineament density and groundwater flow axes in the crystalline basement. These flow directions align well with the families of fracturing and fissuring indicated by the directional rose diagram (fig.5). It should be noted that the lineaments adapt well even with the main wadi flows, further supporting the consistency between lineament orientations and groundwater flow patterns.

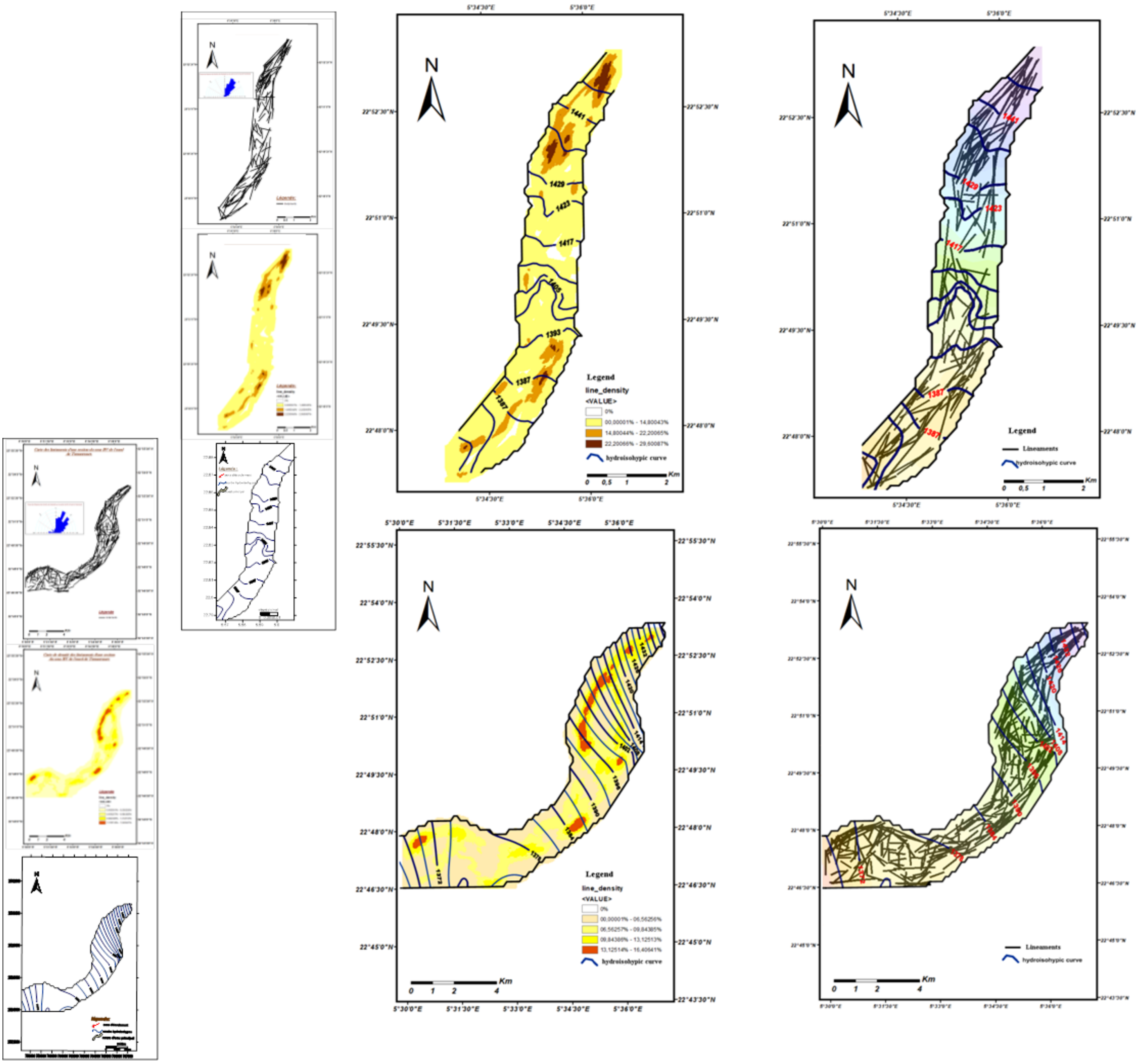


**Fig.10.**Overlay map Results (examples of Ground water potential maps).

## 3.3 Field test

### 3.3.1 ETR survey:

The measurements collected in the field after processing and 2D inversion is presented in the following figure (Fig. 8):
The results obtained at a depth of approximately 40 m show variations in resistivity at both horizontal and vertical scales. The examination of the inverted section on the profile reveals that resistivity varies over a wide range, from a minimum of 1.05 Ω·m to a maximum of over 3936 Ω·m.

The geoelectric models derived from 2D electrical imaging profiles allowed us to distinguish three different zones on the profile. The main characteristics of these sections are described as follows:
On the left side of the profile, between the electrodes (120-160 m) at the surface there is a zone with resistivity values ranging from 116 to 3936 Ω·m, which is interpreted as a mix between weathered basement and alluvial deposits.
In the middle part to the right side of the profile, between the electrodes (100-190 m) at surface, there is a zone with high resistivity more than 3936 Ω·m (violet color), which can be interpreted as crystalline basement, with a depth ranging from 12.4 to 40 m. this structure is covered by alluvial deposits.
Between the electrodes (80-100 m) at the surface, there is a humidified zone that is characterized by low resistivity values (1.05-11 Ω·m). The interpretation of these low resistivity anomalies suggests the presence of water flow through fractures affecting the rocks (indicating a water-saturated zone in this horizon).

### 3.3.2 Pumping test

The water discharge from the 04 wells under test in the study area provokes various drawdown of water level, ranging from 1 to 3.5 m. Among the 04 boreholes, two had stabilized in depth ranging from 1 to 1.4 m, while two had stabilized in depth ranging from 3 to 3.5 m. The lower drawdown of water level wells is situated on a highly weathered basement reflecting that the wells are more prolific and associated with saturated fractures.
These results showed good concordance between lineament density and groundwater flow axes in the cracked crystalline basements.

## CONCLUSION

Satellite remote sensing is coupled with a geographic information system to extract automatically fracture network in the Tamanrasset wadi sub basin. The completed maps are transformed into density maps and then superimposed on piezometric maps to show the relationship between underground flows and fracturing networks. The result obtained by these methods shows that the high fracturing density aligned along well-distinguished axes, where these axes constitute preferred drains for groundwater. The reliability of the results obtained by RS, GIS and piezometric map overload are verified by ETR and pumping test methods at chosen point in the study area. The field test confirms that sites with a high density of lineaments are potential zone for groundwater supply. The principal result of this study shows that the major axes of fracture density are preferred directions for groundwater flow, which will allow in the future to easily locating groundwater refilling and catchment areas in the study region.

References

[1] Briedge, M. (1993) Etude géologique de la région de Tahifet (Hoggar centrale, Algérie). Implication géodynamique. Thèse de Doctorat, université de Nancy 1 (France).

[2] Burrough PA (1986) Principals of geographical information systems for land resources assessment. Clarendon Press, Oxford.

[3] Caby R (2003) Terrane assembly and geodynamic evolution of central-western Hoggar: a

synthesis. J Afr Earth Sci 37:133–159.

[4] Chenini I, Mammou AB, May ME (2010) Groundwater recharge zone mapping using GIS-based multi-criteria analysis: a case study in Central Tunisia (Maknassy Basin). Water Resour Manage 24(5):921–939.

[5] Dasho, O.A., Ariyibi, E.A., Akinluyi, F.O. et al. Application of satellite remote sensing to groundwater potential modeling in Ejigbo area, Southwestern Nigeria. Model. Earth Syst. Environ. 3, 615–633 (2017). https://doi.org/10.1007/s40808-017-0322-z.

[6] Dautria J-M (1988) Relations entre les hétérogénéités du manteau supérieur et le magmatisme en domaine continental distensif. Exemple des basaltes alcalins du Hoggar (Sahara central, Algérie) et de leurs enclaves. Ph.D. thesis. Université de Montpellier 2, 421 p.

[7] Diouf, S. (1999) Hydrogeology in the crystalline and crystallophyllian basement zone of eastern Senegal Ph.D. Postgraduate degree University CHEIKH ANTA DIOP of Dakar, Senegal.

[8] Edet AE, Okereke CS, Teme SC, Esu EO (1998) Application of remote-sensing data to groundwater exploration: a case study of the Cross River state, Southeastern Nigeria. Hydrogeol J 6:394–404.

[9] Fabre, J. (2005) Géologie du Sahara Central et Occidental. Tervuren African Geosciences Collection, MRAC, Tervuren, Belgique.

[10] Greenbaum, D. (1992) Structural influence on the occurrence of groundwater in SE Zimbabwe. In Wright, E.P. and Burgess, W. G. (1992). Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society Special Publication, n°66, London, 264 p.

[11] Greenbaum D (1985) Review of remote sensing applications to groundwater exploration in basement and regolith. Brit Geol Surv Rep OD 85/8:36.

[12] Grillot, J.C., Raulet, M., Ferry, L. (1990) Piezometric behaviour of alteration sheets in humid intertropical zones at high altitude (Madagascar high plateau). J. of Hydr. 120(1-4), 271-282.

[13] Gustafsson, P. (1993) High resolution satellite imagery and GIS as a dynamic tool in groundwater exploration in a semi-arid area. Proceedings of the IAHS conference on Journal of Spatial Hydrology 12 Application of Geographic Information Systems in Hydrology and Water Resources Management held in Vienna, Austria, on April 19-22 1993, pp. 93-100. Vienna.

[14] Haridas VR, Chandra Sekaran VA, Kamaraswany K, Rajendran S, Unnikrshman K (1994) Geomorphological and lineament studies of Kanjamala using IRS-A data with special reference to groundwater potentiality. Trans Inst Indian Geogr 16(1):35–41 Jackson TJ (2002) Remote Sensing of soil moisture: implications for groundwater recharge. Hydrogeol J 10(1):40–51.

[15] Jenson SK, Trautwein CM (1987) Methods and applications in surface depression analysis. In: Proceedings of Auto-Carto 8, Baltimore, pp 137–144.

[16] M.E.H. Cherchali (2001) Caractérisation hydrogéochimique et isotopique des eaux souterraines des nappes d'inféroflux et du socle fissuré du Hoggar Central. Thèse de

magister, Université de Science et Technologie de Houari Boumedien, Alger, Algérie.

[17] Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manage 25:1359–1386.

[18] Mallast U, Gloaguen R, Geyer S, Rodiger T, Siebert C (2011) Derivation of groundwater flow-paths based on semi-automatic extraction of lineaments from remote sensing data. Hydrol Earth Syst Sci 15:2665–2678. doi:10.5194/hess-15-2665-2011.

[19] Nabila, Gaci & Assia, Azizi & Mokrane, Kesraoui (2014) Rare Metal Mineralizations Associated To Albitic Granites In Tamanrasset Area (Central Hoggar, Algeria).

[20] Nag, S.K., Ghosh, P. (2013) Delineation of groundwater potential zone in Chhatna Block, Bankura District, West Bengal, India using remote sensing and GIS techniques. Environ Earth Sci 70, 2115–2127. https://doi.org/10.1007/s12665-012-1713-0.

[21] Nagaraju A, Sreedhar Y, Thejaswi A, Dash P (2016) Integrated Approach Using Remote Sensing and GIS for Assessment of Groundwater Quality and Hydrogeomorphology in Certain Parts of Tummalapalle Area, Cuddapah District, Andhra Pradesh, South India. Advances in Remote Sensing 5(02):83.

[22] Naghibi SA, Moghaddam DD, Kalantar B, Pradhan B, Kisi O (2017) A comparative assessment of GIS-based data mining models and a novel ensemble model in groundwater well potential mapping. J Hydrol 548:471–483

[23] Nefis, M., Afrouag, S., Ben Abdelkrim, R. et al. (2018) Physical characterization to estimate the hydraulic conductivity of the aquifer case study: wadi Izerzi (Tamanrasset-Algeria). Arab J Geosci 11, 480. https://doi.org/10.1007/s12517-018-3848-0.

[24] Olutoyin A. Fashae, Tijani, M.N., Talabi, A.O. et al. (2014). Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach. Appl Water Sci 4, 19–38. https://doi.org/10.1007/s13201-013-0127-9.

[25] Dasho, O.A., Ariyibi, E.A., Akinluyi, F.O. et al. Application of satellite remote sensing to groundwater potential modeling in Ejigbo area, Southwestern Nigeria. Model. Earth Syst. Environ. 3, 615–633 (2017). https://doi.org/10.1007/s40808-017-0322-z.

[26] PCI Geomatica (2001) Geomatica user's guide version 9.1. PCI Geomatica, Richmond Hill.

[27] PCI Geomatica (2014) PCI Geomatica user's guide. PCI Geomatica,Richmond Hill.

[28] Roques, C. (2013) Hydrogeology of crystalline basement fault zones: implications in terms of water resources for the Armorican Massif. PhD thesis, University of Renne 1, France.

[29] Sander P (2007) Lineaments in groundwater exploration: a review of applications and limitations. Hydrogeol J 15:71–74.

[30] Sander, P., Minor, T.B., Chesley, M. and Matthew, M. (1997) Ground-Water exploration based on lineament analysis and reproducibility tests. Ground Water, vol. 35, n°5, pp. 888-894.

[31] Sekkoum Khaled, Mohamed Fouzi Talhi, Abdelkrim Cheriti, Younes Bourmita, Nasser Belboukhari, Nouredine Boulenouar and Safia Taleb (2012) Water in Algerian Sahara:

Environmental and Health impact, Advancing Desalination, Robert Y. Ning, IntechOpen, DOI: 10.5772/50319. Available from: https://www.intechopen.com/books/advancing-desalination/water-in-algerian-sahara-environmental-and-health-impact.

[32] Srivastava PK, Bhattacharya AK (2006) Groundwater assessment through an integrated approach using remote sensing, using remote sensing, GIS and resistivity techniques: a case study from a hard rock terrain. Int J Remote Sens 27(20):4599–4620.

[33] Talabi AO, Tijani, MN (2011) Integrated remote sensing and GIS approach to Ground-water potential assessment in the basement terrain of Ekiti area south-western Nigeria. RMZ—materials and geoenvironment, vol 58, no 3, pp 303–328.

[34] Taylor R, Howard K .(2000) A tectono-geomorphic model of the hydrogeology of deeply weathered crystalline rock: evidence from Uganda. Hydrogeol J 8(3):279–294.

[35] Tolche AD (2020) Groundwater potential mapping using geospatial techniques: a case study of Dhungeta-Ramis sub-basin, Ethiopia. Geology, Ecology, and Landscapes, 1–16.
Tweed, S, Leblanc,.M, Cartwhright,.I, Favreau, G, Leduc, C. (2011) Arid zone groundwater recharge and salinization processes; an example from the Lake Eyre Basin, Australia. J. of Hydr., 408, 257-275.