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(Review Article)

# Identification of potential aquifer zones by applying multi-criteria analysis in the department of Abtouyour, Guéra province (Republic of Chad)

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## Abstract

The study was conducted in order to highlight that making a positive drilling borehole in the base area is a very difficult course and which requires the contribution of several complementary disciplines, namely geology, geomorphology, geophysics, the Topography, rainfall etc.

Multi-sectoral analysis is necessary to solve a complex problem of a successful implantation of boreholes in the basement area.

The analytical approach for the search for aquifers in the basement area and especially in a semi-arid area such as the province of Guéra.

Nowadays the research and the management of groundwater requires the contribution of several related disciplines in order to produce decision -making information.

The GIS thanks to spatial analysis allows rapid analysis with its spatial analysis component and offers a powerful spatial modelling tool.

In this perspective, remote sensing allowed us to make an extraction of the lines from satellite images, the multi -criteria analysis was applied, and it allowed the development of thematic maps.

The approach was made with the analysis of the characteristics of the boreholes carried out in the area, in particular the flow rate, the depth and the thickness of alteration.

This allowed us to make a following observation on 295 forges made 195 flows rate belong to the very low class or 50.08%, 85 flows rate belonging to the middle class or 28.8% and 60 flows rate correspond to the strong class or 20.03%.

Thus, the multi -criteria analysis by uttering at each element which enters the implantation a weight which has been of great use to us in the development of the Aquifer potential map of the study area.

For this study in we used software such as Excel for drilling data, ArcMap 10.8 for GIS, PCI Geomatica software for the extraction of lineaments.

**Keywords:** Lineaments; Remote sensing; Satellite images; Abtouyour; Multi -criteria analysis; Flow

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## 1. Introduction

In Chad, the problems of the shortage of drinking water and the difficulties of access to water have always made water a rare commodity.

The main donors in the water, sanitation and hygiene sector are: the European Union (the largest in terms of budget), the French Agency for

Development (AFD), the African Development Bank (ADB), the World Bank (WB), the United Nations, the Swiss Cooperation, the German Cooperation.

Village water programs have been developed with the aim of reducing the rate of water inaccessibility; this approach has enabled the rural population to benefit from water boreholes which are not in sufficient quantity because the demand is always growing given the increase in it.

Given the strong enough demand there is always a shortfall in relation to the needs. Local problems of the unavailability of water resources arise more and more frequently, especially in the dry season when ponds and temporary streams dry up.

Even in urban areas with large populations, namely Mongo, Bitkine, Mangalmé, and Melfi, which are the capitals of departments, most of the water supply is carried out by surface water supplies.

But the current severe shortages mean that groundwater is a necessary contribution to the increased needs generated by the expansion of cities in general.

Current urban hydraulics programs have a low success rate for high-flow drilling given the province's geology, which is a basement zone.

Traditional geophysical methods are today the main methods for prospecting and detecting underground aquifers in basement areas.

However, they could not solve the problem of the relatively high failure rate in the area.

It is in this perspective that we wanted to apply the multi-criteria analysis which had given us satisfactory results, this method will allow us to locate and map favorable areas for future water well drilling.

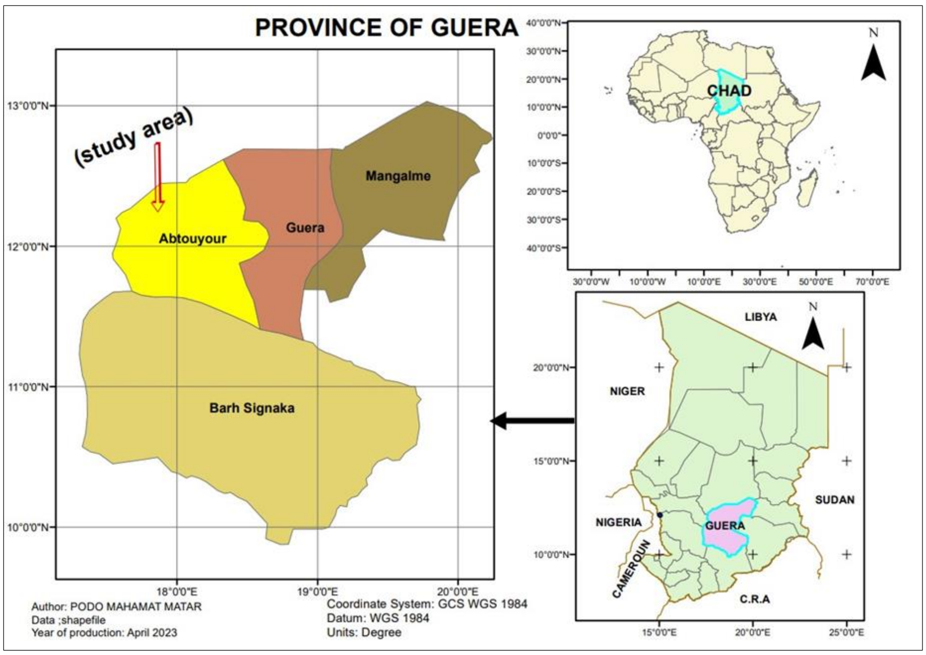


**Figure 1** Location of the study area

### 1.1. Physical and hydrogeological context

According to the geologist[1] said that the province of Guéra is located in a Sahelo-Sudanian zone and on the edge of the Saharan zone and with a dry continental climate. The annual rainfall varies between 600 and 900 mm.

From the hydrogeological point of view, the province of Guéra does not contain a general aquifer. Hydraulic resources are linked to alluvium, alterity and fissured and/or fractured rock constituting major aquifers with potentially high productivity and cover aquifers, alluvium and fluvial sands[2].

The Ouaddis, which are intermittent watercourses, feed the shallow aquifers in this semi-arid region, which constitutes a precious and renewable water resource[3].

The rainy season generally lasts from June to September with most often brief and intense rainfall.

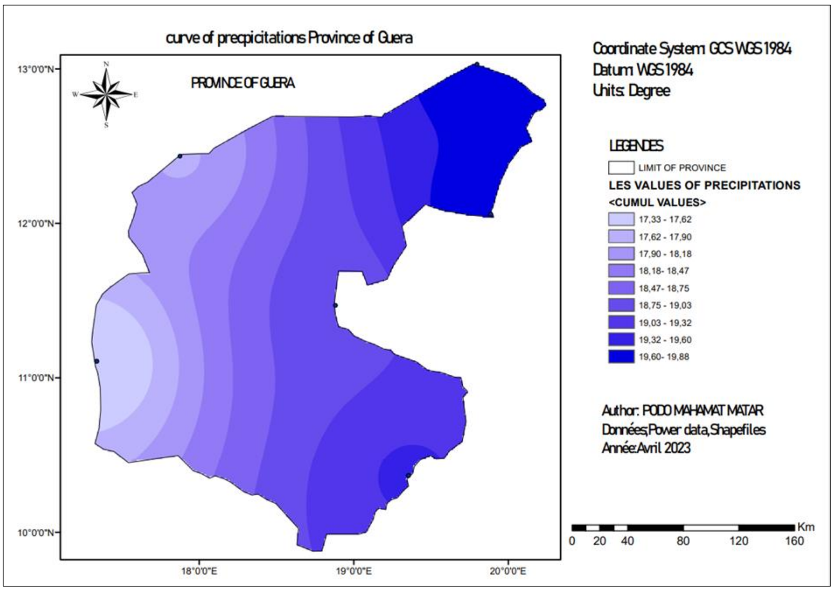


**Figure 2** Rainfall map of Guéra province

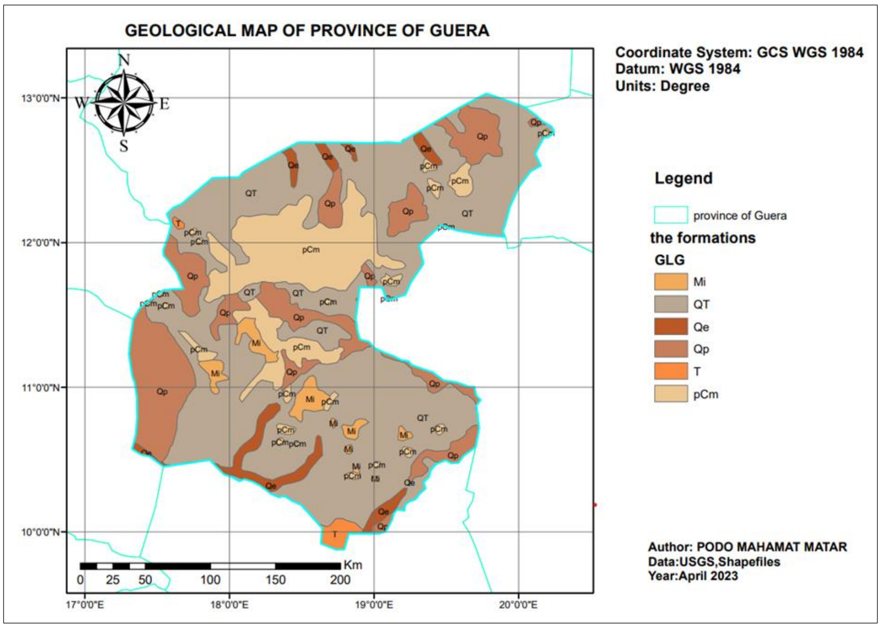


**Figure 3** Geological map dominated by Quaternary formations

The alluvial deposits in the bed of the oasis consist in most cases of coarse sediments such as gravel and sandy-clayey [4].

These deposits have a high porosity thus making it possible to recharge and store a relatively high water productivity. The nature of these current alluvium is essentially sandy in a relief zone resulting from leaching materials, resting directly on the base [4].

### 1.2. Hydrogeological settlements

The analysis of the several geophysical implantations made in the province of Guéra with the classic methods of photo interpretation as well as the detailed geomorphological and hydrogeological studies enabled us to note that the results were mixed. And the success rate has remained within a not very acceptable standard [5].

### 1.3. The failure rate in the province of Guéra

In the study for the implantation of drilling sites made in 6 provinces of Chad, only the province of Guéra has a high failure rate given the geological situation because most of the implantations must take into account geomorphological and hydrogeological studies.

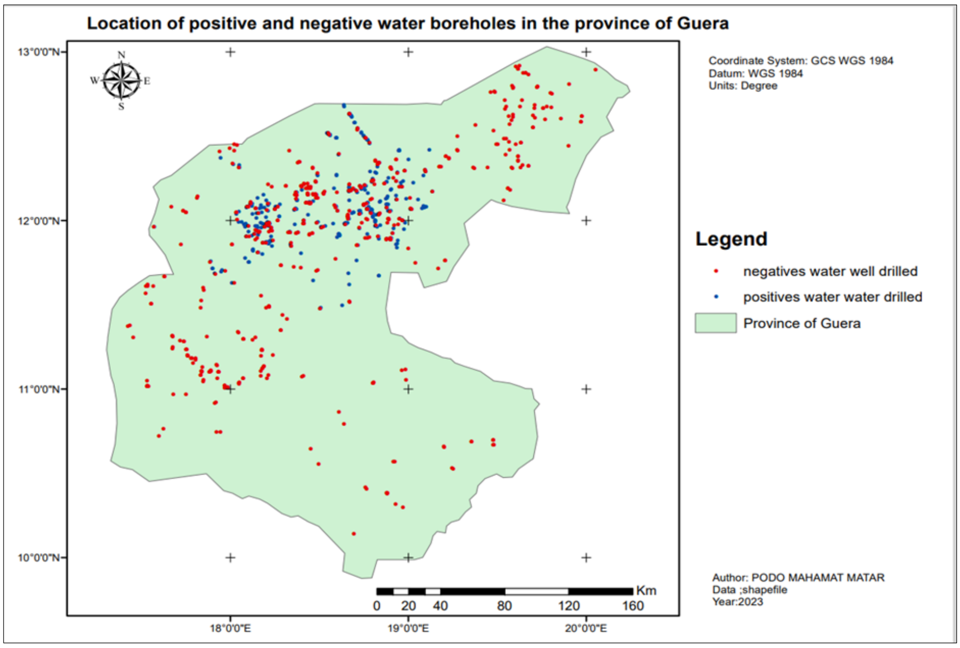


**Figure 4** Illustrating a high failure rate in the execution of water boreholes (In red positive borehole and in blue negative borehole

So Table 1 gives us an idea of the relatively high failure rate.

**Table 1** Summary of failure rates in selected provinces of Chad

| Provinces | Total | Positives | Negatives | Rate of failure | percentage% |
|---|---|---|---|---|---|
| Kanem | 76 | 74 | 2 | 0,02 | 2% |
| Bahr El Gazal | 63 | 63 | 0 | - | 0 |
| Guéra | 161 | 88 | 73 | 0,45 | 45% |

## 2. Methodology

We used the weighting consists of assigning numbers to the criteria to describe its influence on the definition of the phenomenon studied[6].

This is a delicate phase because it consists of making judgments based on the numbers between several criteria.

To determine the weight of the criteria in the study of a phenomenon, the method (the method of complete aggregation by hierarchy) was chosen, because it makes it possible to evaluate the judgment and to give the possibility of correcting it by case of inconsistency[7].

The index and the coherence ratio make it possible to assess the reasoning.

Consistency of judgment becomes difficult when the number of criteria becomes large. For the determination of the weights of the criteria, the approach is based on the comparison by pair of the criteria to build the matrix of comparison[8].

This comparison is materialized by the attribution of scores according to the importance of one criterion compared to another.

### 2.1. Materials, Software, and Data

#### *2.1.1. Materials*

To identify favorable areas for drilling, a collection of data was made for this purpose, all the drillings carried out in the province were listed and identified with their depth and static level for the productive ones.

We processed this data from these geographical coordinates to split the two types of positive and negative drilling.

These are: a database of water points with more than 744 wells and boreholes was obtained from the CDIG (Centre for Documentation and Geographic Information) carried out by the Ministry of Urban and Rural Hydraulics. For each water point, information such as the type of water points, the depth, the piezo metric level and the characteristics of the well or the positive or negative boreholes were available;

A database of 150 borehole logs from the province of Guéra was obtained from the RESEAU project.

Digital terrain models of the terrain, developed from SRTM images, 30 m resolution, downloaded from the USGS "Earth explorer" web application (https://earthexplorer.usgs.gov) in the system UTM projection zone 34. Scene Images (Path: 182/Row: 51 and 52. These images were acquired on January 23, 2023.

So as we can see in the image of figure: 3 scenes 51, and 52 in the map of Chad.

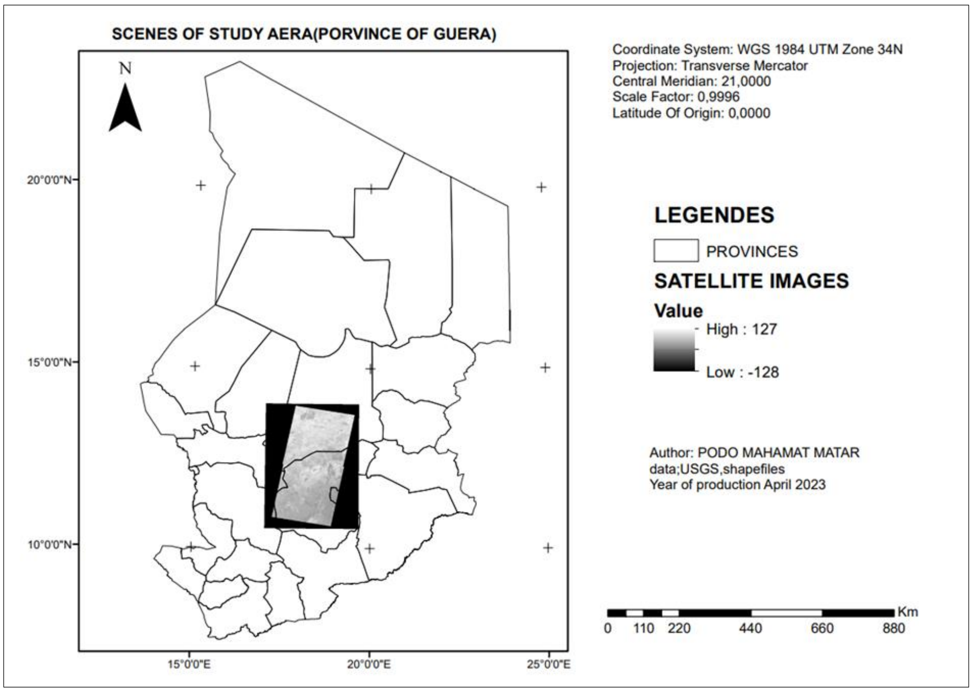


**Figure 5** Scenes 51 and 52 that served as a working basis

*2.1.2. Software used*

The software used are:

- ARCMAP 10.8 software.
- The ROCKWORK software.
- PCI Geomatica software.
- ROCKWORKS software
- Rose diagram
- Google Earth.
- Garmin GPS.
- Excel software.

*2.1.3. Drilling data*

These data come from drillings carried out by the 9th EDF and those carried out by UNICEF, the UNDP, and certain NGOs. The first category of data will be used for interpolation during the thematic mapping of water resources and the second will be used for the validation of the results. This database was compiled by the Ministry of Urban and Rural Hydraulics. It includes the localities, the geographical coordinates, the thicknesses of alteration (m), the depths of the structures (m), the flows (m3/h), the piezo metric levels, etc. It will allow the production of thematic mapping of water resources.

*2.1.4. Climate data*

Hydro climatic data are monthly and annual rainfall data, Piche evaporation data, humidity data, sunshine data, and temperature data. The latter will allow statistical analysis to highlight their fluctuations. They come largely from the POWER | Data Access Viewer (nasa.gov).

### 2.2. Qualification criteria for multi-criteria analysis

**Table 2** Classification criteria

| **Value** | **Comparison** |
|---|---|
| 1 | Equal importance |
| 3 | Moderately important |
| 5 | significant |
| 7 | Very Important |
| 9 | Extremely Important |
| 2, 4, 6,8 | Intermediate values |

**Table 3** Classification and standardization of criteria for the groundwater potential indicator

| **Indicator** | **Criteria** | **Qualifier criteria** | **Classes** |
|---|---|---|---|
| WATER POTENTIALITY | SLOPE in % | Very low | < 2 |
| | | low | 2-5 |
| | | average | 5-15 |
| | | strong | >15 |
| | Fractures density km/km$^2$ | Very low | > 25 |
| | | low | 25-55 |
| | | medium | 50-75 |

| | | | |
|---|---|---|---|
| | | strong | >75 |
| | Drainage density | Very low | 6-65 |
| | | low | 65-95 |
| | | medium | 95-119 |
| | | strong | 119-178 |
| | | | |
| | Weathering thickness | Very low | <10 |
| | | low | 10-15 |
| | | medium | 15-25 |
| | | strong | >25 |
| | Vegetation density | Very low | 0,0024 – 0,1352 |
| | | low | 0,1352 - 0,2679 |
| | | medium | 0,2679 - 0,4006 |
| | | strong | 0,4006 – 0,666 |

### 2.3. Comparison matrix and determination of criteria weights

Or to study the groundwater potential, made up of the following criteria: slope, drainage density and fracturing density[9]. The comparison of these criteria is done two by two. The principles for developing the matrix are as follows: Determine[10] the eigenvectors VP of each criterion using the following formula: $Vp = \sqrt[k]{W1\ x \ldots\ldots xWK}$

**Table 4** Accessibility indicators

| Indicator | Criteria | Qualifier criteria | classes |
|---|---|---|---|
| ACCESSIBILITY | PROBABILITY OF SUCCES DE SUCCESS % | Very low | < 25 |
| | | low | 25-50 |
| | | medium | 50-60 |
| | | strong | 60-100 |
| | STRUCTURE DEPTH (m) | Very low | < 20 |
| | | low | 20-30 |
| | | medium | 30-40 |
| | | strong | >40 |

With k the number of criteria to be compared, and Wk the scores assigned to the criteria.

We can calculate the weighting coefficient Cp by the formula:

$$CP = \frac{VP}{VPl + \cdots .. + VPk}$$

The sum of the weights must be equal to 1.

The elements of the vector Cp having been determined, it is now a question of calculating the elements of the matrix making it possible to generate the index and the coherence ratio.

**Table 5** Exploitability criteria

| Indicator | Criteria | Qualifier criteria | classes |
|---|---|---|---|
| EXPLOITABILITY | STRUCTURE FLOW (m3/h) | Very low | 0,5-1 |
| | | low | 1-2 |
| | | medium | 2-5 |
| | | strong | 5-10 |
| | DEPTH OF DRILLINGS | Very low | > 10 |
| | | low | 5-10 |
| | | medium | 10-15 |
| | | strong | >15 |

The elements of each criterion at the column level are multiplied by the weight of that criterion at the row level[11]. Then the sum S1… SK of the elements of each row is made and these different sums are related to the weights of each criterion (S1/Cp1… Sk/Cpk).

Then the average of (S1/Cp1+… +Sk/Cpk)/k is calculated and constitutes λmax. Finally, the coherence index Ic is determined by the following formula:

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Then the average of (S1/Cp1+… +Sk/Cpk)/k is calculated and constitutes λmax. Finally, the coherence index Ic is determined by the following formula:

$Ic = (\lambda max - k) / (k-1)$

The judgment is consistent when the consistency index is less than 10%. If it is higher, the analysis should be revised[12].

The judgment is also evaluated from the coherence ratio RC which is considered as the probability that the matrix is completed randomly. RC must also be less than 10%, if necessary the reasoning must be reviewed[13].

It is calculated as follows: RC = Ic/Ia with IA random index.

**Table 6** Weight of criteria for the underground potential indicator

| Indicator | Criteria | Weight |
|---|---|---|
| WATER POTENTIAL | Vegetation density | 0,12 |
| | Drainage density | 0,1 |
| | Fractures density | 0,2 |
| | slope | 0,5 |
| | Weathering thickness | 0,08 |

The groundwater potential map will be made according to the following formula: Potential map = (Dd map x 0.1) + (DF map x 0.2) x (P map x 0.5) x (Ea map x 0.08) + (Dv map x 0.12)

The same approach will be adopted for the determination of the weights of the accessibility and exploitability indicators of the resource. Tables 7and 8 highlight the weights of the accessibility and exploitability indicators of the resource.

**Table 7** Weight of accessibility indicator criteria

| Indicator | Criteria | Weight |
|---|---|---|
| ACCESSIBILITY | DRILLING DEPTH | 0,75 |
| | PROBALITY OF SUCCESS | 0,25 |

**Table 8** Weight of criteria for the accessibility indicator

| Indicator | Criteria | Weight |
|---|---|---|
| EXPLOITABILITY | Rate Flow | 0,75 |
| | piezometric level | 0,25 |

We have here a table which allowed us to establish the thematic map

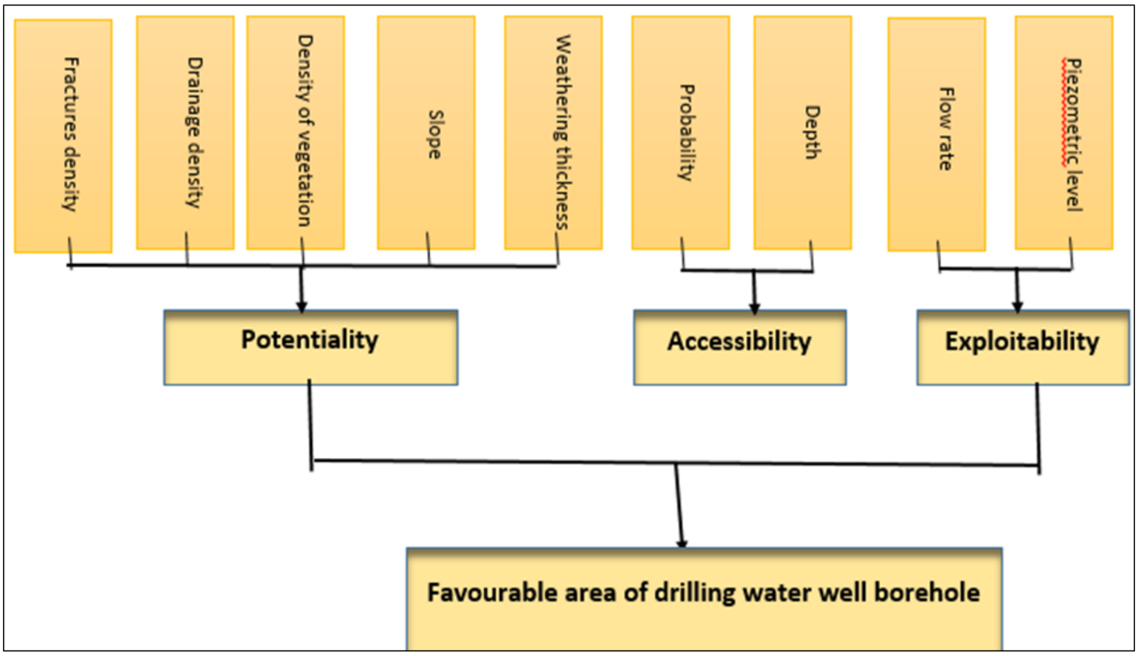


**Figure 6** Methodology for thematic mapping

This methodology has allowed us to draw up the following thematic maps

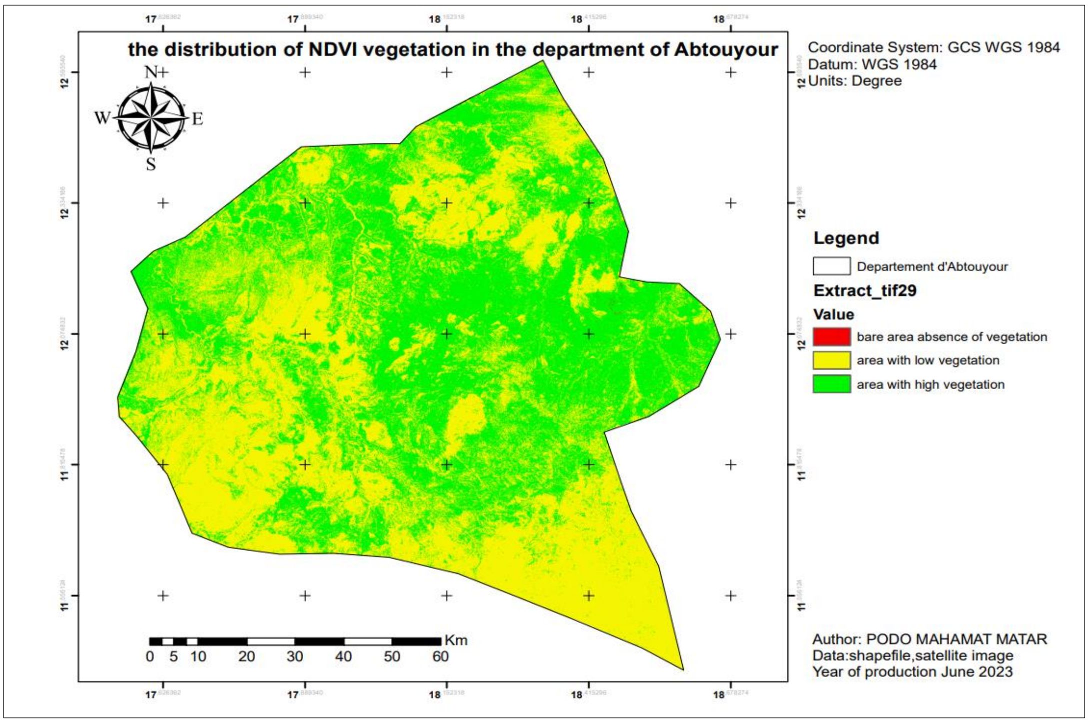


**Figure 7** Map of vegetation distribution (NDVI) in the department

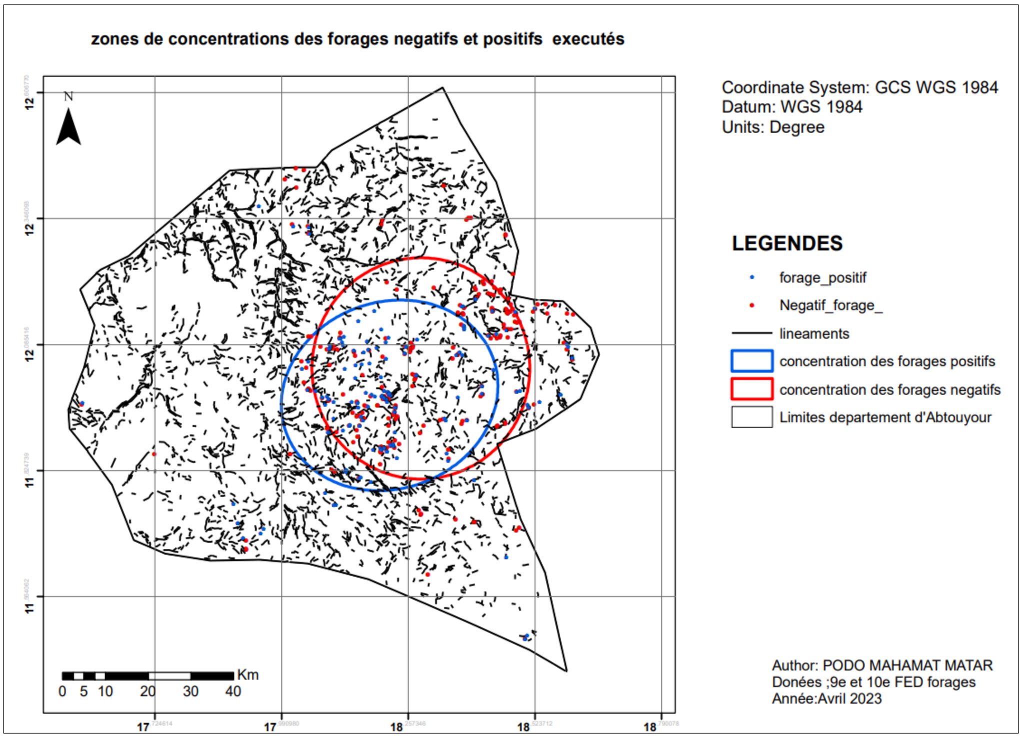


**Figure 8** Positive and negative drilling concentration zone

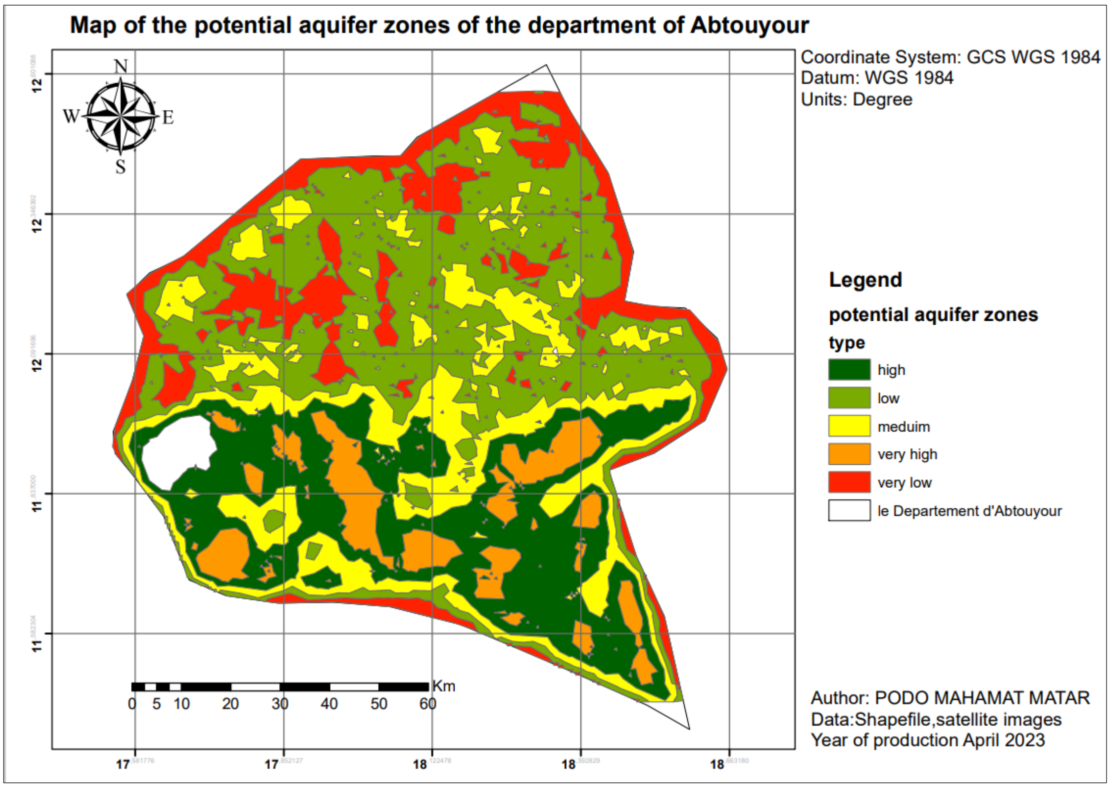


**Figure 9** Zone of aquifer potential of the department of Abtouyour

### 2.4. Analysis of productivity parameters

But in the case of our zone in the province of Guéra, the alteration zone is located at a depth of 60 m, but other authors have shown the existence of productive boreholes at great depths.

They studied the productivity of the aquifers using data from the technical sheets of the boreholes. An analysis between flows and physical parameters (total depths and alteration thicknesses) was established.

We established correlations between the different factors influencing productivity using principal component analysis.

The analysis of the correlation matrix shows a strong correlation between the transmissivity and the specific rate, between the rate and the specific rate.

Average correlations are noted between total depth and basement thickness, transmissivity and flow, weathering thickness and static level.

During the above-mentioned works, important data were used and which made it possible to make a broader analysis of the productivity of the aquifers.

Therefore, the analysis will be limited to the study of the flow relationships with the physical parameters (thickness of alteration, depth of the boreholes) and on the flows provided by the boreholes in the study area on the basis of the CIEEH classification.

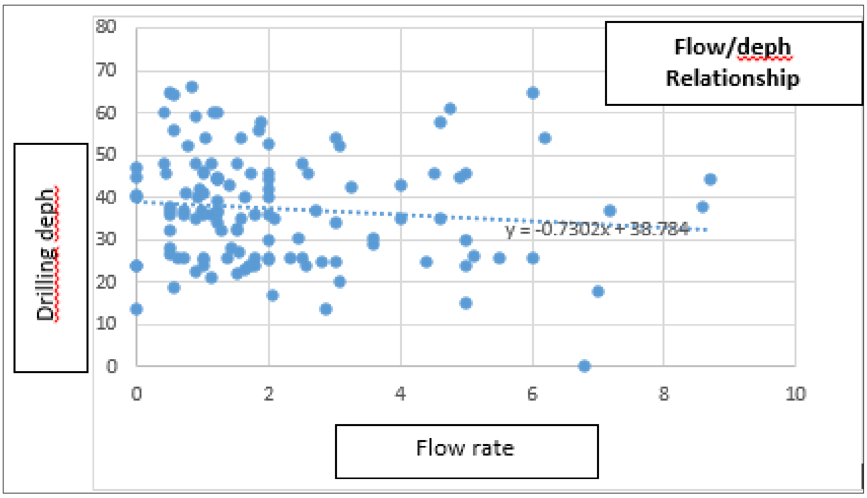


**Figure 10** The existing correlations between the flow rates and the depth

The analysis of the graph shows that the lowest depth is at 20m and the highest reaches 80m. Low flows (less than 2m3/h) are found at all depths, but as some authors have demonstrated, the depths providing high flows are between 30m and 60m deep.

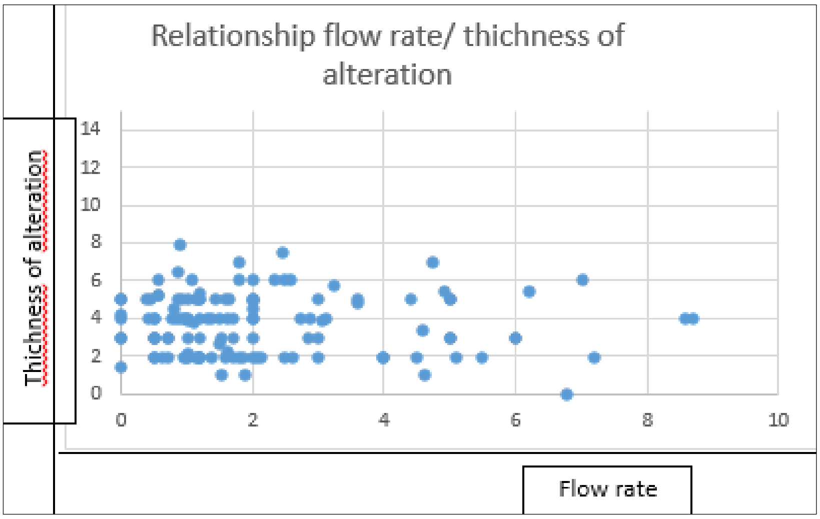


**Figure 11** Flow rate/weathering thickness correlation

The Province's positive boreholes yielded 295 flows which were classified in accordance with the CIEEH classification.

- 195 flows belong to the very low class, i.e. 50.08%,
- 85 establishments belonging to the middle class, i.e. 28.8%
- 60 correspond to the high class, i.e. 20.03%.

So the very low and low flow rates (less than 2.5m3/h) alone represent 50.08% against 48.83% for medium and high flow rates (greater than 2.5m3/h).

This high rate can be explained by the lack of serious studies in the choice of drilling sites.

The solution to this problem must come first from remote sensing and geophysical methods must support the exact identification of sites on the ground[14].

## 3. Conclusion

The multi-criteria spatial analysis method is very well suited to prospecting for basement aquifers because it offers the possibility of integrating and combining several data from various sources in order to make a decision. It allowed us to identify areas favorable to the installation of boreholes and to note that the old boreholes are generally placed for lack of serious studies during their implementation.

The productivity of boreholes was also studied on the basis of a comparison between the flow rates and the physical characteristics of the boreholes. The first comparison has made it possible to establish a correlation between flow and depth.

It was found that the boreholes in the study area provide high flows between 30 and 60 m deep which confirms the conclusions [15].

A second correlation has been established between the thicknesses of alteration and the flow, the drillings productive are those with an alteration thickness between 10 and 35 m.

## Compliance with ethical standards

### *Acknowledgments*

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We also thank Mr. FIDEL DINGAMNODJI engineer at the Center for his help and guidance.

### *Disclosure of conflict of interest*

We affirm on honor that all the authors who contributed to the writing of this article have no conflict of interest.

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