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# Potential sites determination of for boreholes implementation in basement zones (N'zi-Comoé region, Côte d'Ivoire): Contribution of a multi-criteria analysis and a Spatial Reference Hydrogeological Information System (SIHRS)

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## Abstract

The high failure rate recorded during village water campaigns has led the authorities to mainly capture surface water for water supply in certain areas, as is the case in the south of the former N'zi-Comoé region (central-eastern Côte d'Ivoire). The objective of this study is to identify areas favorable to the installation of high-flow boreholes that can guarantee the supply of drinking water to the population over a long period. The slope, induced permeability, thickness, depth of the structure, fracturing density and drainage density constituted the database. Their processing and assembly thanks to a multi-criteria analysis made it possible to obtain a Spatial Reference Hydrogeological Information System (SIHRS). Thus, the identification of potential sites was made possible by the adoption of the weighted aggregation method for the cross-referencing of the selected criteria. The implementation of the SIHRS led to the map of potential groundwater sites. This map shows that only 63% of the study area has good groundwater reserves with good accessibility and easily exploitable that can lead to very good flows at the catchment structures. The SHIRS is a tool capable of facilitating decision-making in groundwater prospecting.

**Keywords:** Basement aquifers; Groundwater; Multi-criteria analysis; Spatial Reference Hydrogeological Information System; N'zi-Comoé region

## 1. Introduction

Water, source of life, is an essential factor in any development. Its importance in daily life is no longer to be demonstrated. Like the important issues of this millennium, the problem of water is acute. It therefore seemed imperative to search for water, wherever it was found, and to make it available to the population [1]. In Côte d'Ivoire, according to the Master Plan for Integrated Water Resources Management, of the 77 billion m3 of the volume of water resources that can be mobilized in an average year, the underground fraction is 38 billion m3, or nearly 49.35% [2]. Essentially made up of basement (about 97%), Côte d'Ivoire suffered from a shortage of drinking water that affected 70% of its population in 1964 [3]. Therefore, the Ivorian State, in order to deal with this situation, launched in the 70s vast national hydraulic programs (NHPs) which focused on the groundwater reservoirs of the fissured environments of the basement. Despite the considerable resources available, these programs experienced difficulties and a high failure rate linked to a lack of serious feasibility studies and a lack of knowledge of the fracture system that drained almost all the groundwater from the crystalline and crystallophyllian basement [3]. The N'zi-Comoé region, central-eastern Côte d'Ivoire, is no exception to this situation. It also has problems with the supply of drinking water to its rural populations.

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It is becoming necessary to carry out remote sensing studies and GIS, which are decision-making tools in order to locate fractures and map groundwater resources [4]. The present study was conducted to propose a solution to this situation, which affects many regions such as Dimbokro. It mainly aims to locate sites favorable to the establishment of catchment structures that can facilitate decision-making in groundwater prospecting. Specifically, these included:

- To select the factors or criteria for the design of hydrogeological indicators;
- To carry out the weighting of the factors used for the multi-criteria analysis;
- To draw up maps of availability, accessibility, exploitability and the map of potential groundwater sites in the n'zi-comoé region.

## 2. Materials and methods

### 2.1. Study area

Figure 1 shows the study area with the geographical coordinates of 3°30' - 4°30' W and 6°30' - 8°00' N. It covers about 4,200 km² and is located in the forest-savannah transition zone (central-eastern Côte d'Ivoire). It offers sufficient lithological and demographic homogeneity to analyze fissured aquifers in crystalline basement, in a representative framework allowing the development of transposable models and the optimization of catchment infrastructures.

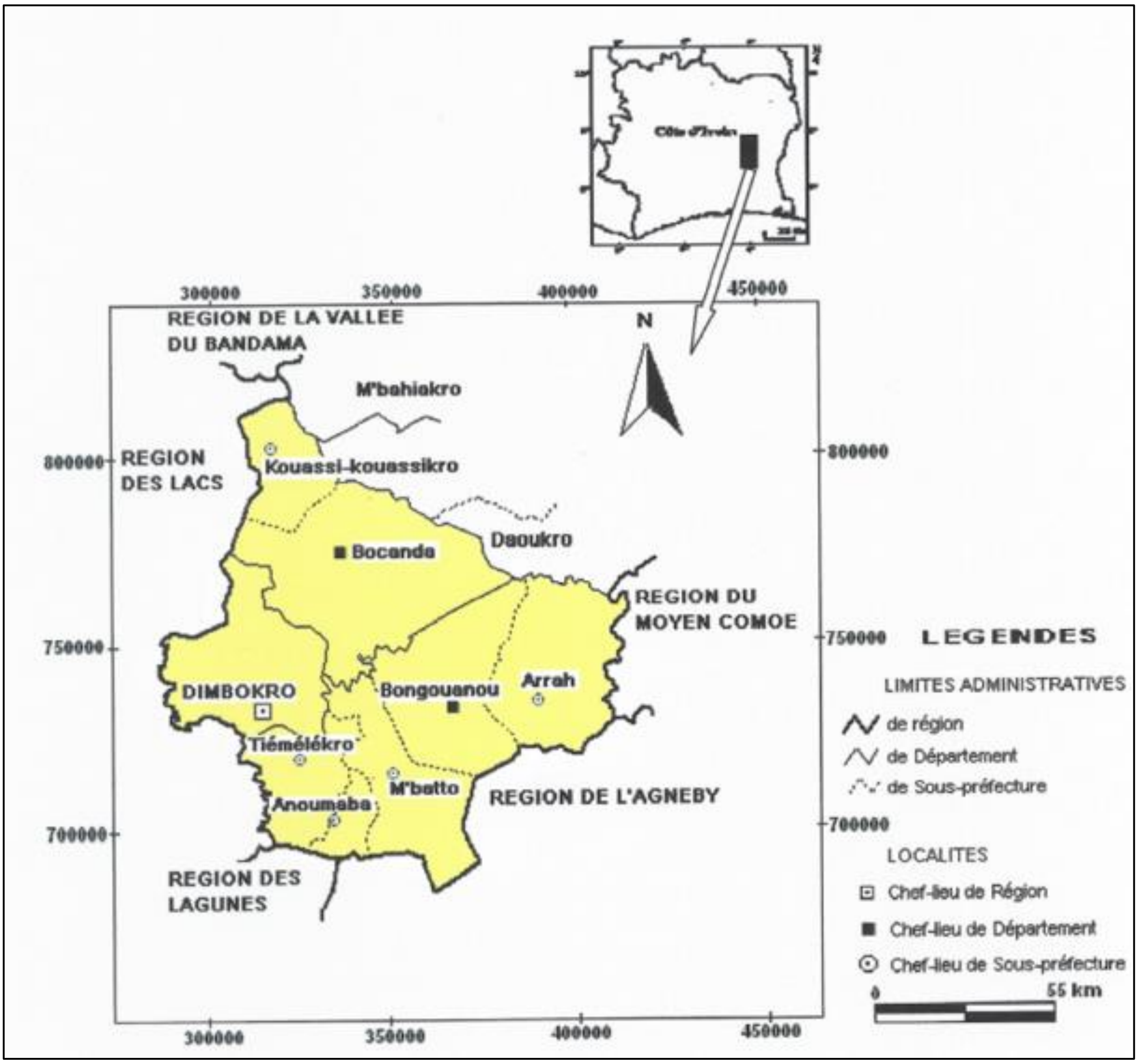


**Figure 1** Presentation of the study area

## 2.2. Materials

The diverse and varied data are made up of hydrogeological, cartographic and satellite elements. The geological and topographic maps at 1:200,000 provided a structural framework for interpreting lineaments and correlating formations and boreholes. Landsat 7 ETM+ scenes facilitated manual lineament extraction and fine spatial analysis. The induced permeabilities were obtained by applying the method of [5] to the fracturing map. The digital processing was carried out with MapInfo 12, ArcGIS 10.8, Envi 5.3 and the R software version 4.4.3.

## 2.3. Methods

### *2.3.1. Conceptual framework*

The study adopts a multi-criteria analytical approach to establish a Spatial Reference Hydrogeological Information System (SIHRS) which is a special case of Geographic Information System (GIS). It is a GIS applied specifically to water-related data and processes, enabling in-depth analysis and management of water resources through its spatial capabilities.

### *2.3.2. Approach strategy*

The implementation of the SIHRS, which follows a procedure already implemented by several authors [6, 7, 4], can be summarized in the following steps (Figure 2):

- The production of the database;
- Data integration;
- Data management;
- Data processing and analysis;
- Data display.

For the processing and analysis of the data, the first question was the selection and classification of the various data, the design and weighting of the factors leading to the indicators. Then there was the stage of cross-referencing the maps of the indicators, the final result of which gave the map of potential groundwater sites. Thus, the factors retained in the framework of this study are the slope, the induced permeability, the thickness, the depth of the structure, the fracturing density and the drainage density.

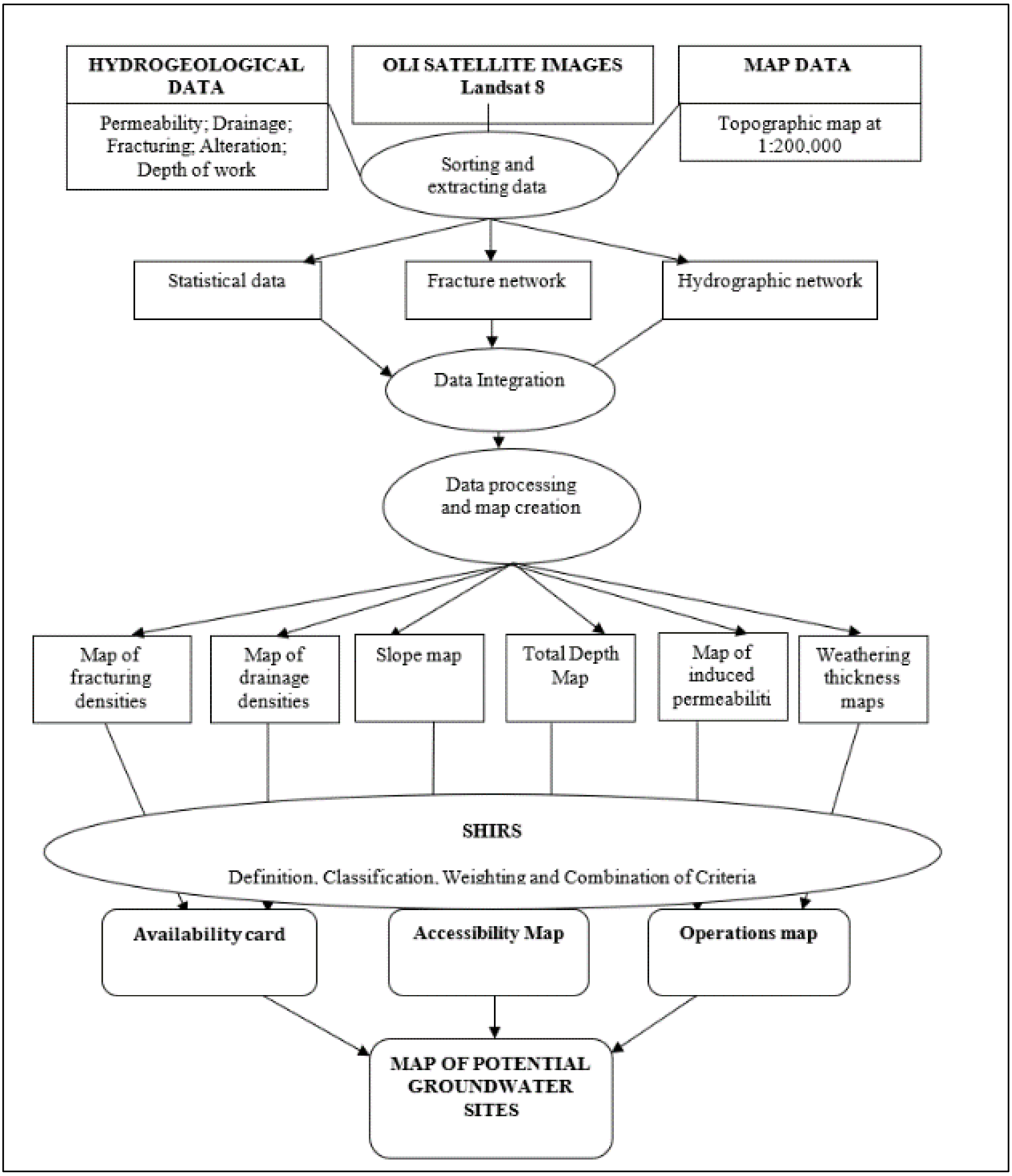


**Figure 2** Schematic of the development of the SIHRS

Classification of factor or criteria

The definition of classes responds to a concern to facilitate the interpretation of the maps. To this end, 5 classes (Table 1) have been defined as factors based on the classification proposed by the Inter-African Committee for Hydraulic Studies (CIEH): very low; low medium; strong and very strong. The boundaries of these classes are set by the operator based on the available data and are not fixed. These classes make it possible to evaluate each criterion in relation to a given indicator.

**Table 1** Classification of Factors

| Classes / Factors | Very Low | Weak | Average | Strong | Very strong |
|---|---|---|---|---|---|
| Slope (%) | < 0.1 | 0.1 - 1 | 1 - 3.5 | 3.5 - 5 | > 5 |
| Induced permeability (x10-7 m/s) | < 0.013 | 0.013 - 3.86 | 3.86 - 7.99 | 7.99 - 9.98 | > 9.98 |
| Weathering Thickness (m) | < 10 | 10 - 15 | 15 - 20 | 20 - 25 | > 25 |
| Depth of work (m) | < 25 | 25 - 35 | 35 - 45 | 45 - 70 | > 70 |
| Drainage density (km/km2) | < 0.16 | 0.16 - 0.36 | 0.36 - 0.52 | 0.52 - 0.72 | > 0.72 |
| Fracking Density (km/km2) | < 0.12 | 0.12 - 0.28 | 0.28 - 0.40 | 0.40 - 0.60 | > 0.60 |

Then, following the work of certain authors [8, 7], the method of aggregation by codification (Table 2) was adopted for the cross-referencing of criteria.

**Table 2** Distribution of factors by indicator class

| Indicator / Factors | Bad | Mediocre | Good | Excellent |
|---|---|---|---|---|
| Slope (%) | 5 > | 3.5 - 5 | 1 - 3.5 | < 1 |
| Induced permeability (x10-7 m/s) | < 3.86 | 3.86 - 7.99 | 7.99 - 9.98 | < 9.98 |
| Weathering Thickness (m) | < 10 | 10 - 20 | 20 - 30 | > 30 |
| Depth of work (m) | > 70 | 40 -70 | 30 - 40 | < 30 |
| Drainage density (km/km2) | > 0.72 | 0.52 – 0.72 | 0.36 – 0.52 | < 0.36 |
| Fracturing density (km/km2) | < 0.28 | 0.28 - 0.40 | 0.40 - 0.60 | > 0.60 |

Design and Weighting of Indicators

Weighting consists of assigning "weights" to the different factors in order to allow the manipulation of the cards. The assignment of weights was done according to the multi-criteria hierarchical method (MHM) mentioned by [9]. Thus, this assignment results from the comparison, two by two, of the criteria of the same level while taking into account the general context of the study [6]. The numerical value, between 0 and 1, of the weight assigned to a criterion depends on its importance and is a function of the objective. This value can be low or high depending on the elements considered for the definition of a given indicator (Table 3). This is what constitutes a limitation for this method and at the same time somewhat undermines the reliability of the expected results. In addition, there are still several sources of inaccuracies in the proposed method due to errors recorded during data collection on the one hand. And on the other hand, during the weighted sum of the criteria, which sometimes masks a negative evaluation on a criterion, as underlined [6].

**Table 3** Assignment of factor weights by indicator

| Indicators | Criteria | Weight | Total |
|---|---|---|---|
| AVAILABILITY | Fracturing density | 0.6 | 1 |
| | Drainage density | 0.4 | |
| ACCESSIBILITY | Slope | 0.6 | 1 |
| | Total depth of the structure | 0.4 | |
| OPERABILITY | Induced permeability | 0.6 | |

| | | | |
|---|---|---|---|
| | Weathering thickness | 0.4 | 1 |
| POTENTIAL GROUNDWATER SITES | Induced permeability | 0.2 | 1 |
| | Weathering thickness | 0.2 | |
| | Fracturing density | 0.2 | |
| | Drainage density | 0.2 | |
| | Slope | 0.1 | |
| | Total depth of the structure | 0.1 | |

This approach requires the operator to have a perfect knowledge of the study environment and also a good mastery of the subject. This is in order to be able to work with discernment and in all objectivity.

The user's interpretations depend on this important step above. This step is the indicator development phase. It consists of making different combinations of the maps designed from the classified and weighted physical parameters. This leads to the establishment of summary maps whose names correspond to the indicators set up below [8]:

- The "AVAILABILITY" indicator, which results from the combination of the factors of fracturing density and drainage density. The combination of these two parameters defines the probable existence of an aquifer;
- The "ACCESSIBILITY" indicator gives an idea of the approximate cost of building a catchment structure reaching an aquifer. It combines the slope and the depth of the structure;
- The "EXPLOITABILITY" indicator, combines the induced permeability and the weathering thickness. It reflects the effort to be made in terms of cost for the optimal extraction of a certain volume of water [8];
- The "POTENTIAL GROUNDWATER SITES" indicator, which combines the criteria of fracturing, drainage density, slope, depth of the structure, induced permeability and weathering thickness. It is a summary indicator of those mentioned above. It makes it possible to estimate the overall yield, investment cost and operating cost of a catchment structure.

At the end of the process, the results were validated by a process used by [7]. The choice of an evaluation criterion governed by two principles is guided by the Ombudsman:

- The principle of independence of the criterion, which requires that the reference data have not been involved in the creation of the thematic map to be evaluated;
- The principle of conformity of the criterion, which requires that the reference data be grouped into classes with the same limits (class limits) as those of the thematic maps to be evaluated.

For this study, the criterion chosen is the operating rate of the structures (with a total of 381 boreholes) which made it possible to establish five sensitivity classes (very high, strong, medium, low, very low) to be used for validation. These flows were sorted according to their flow index and then superimposed on the map on the map of potential groundwater sites. The number of boreholes that overlap with the class of the site map is recorded. From this number obtained, the percentage of boreholes that overlap the class of the potential map is calculated.

## 3. Results

### 3.1. Thematic maps of water resources in the N'zi-Comoé Region

These are summary maps obtained from the combination of the various factors and are intended to represent hydrogeological indicators (Availability, accessibility, exploitability and potential groundwater sites) in the SHIRS.

#### *3.1.1. Availability of water resources*

On the whole, the territory has a good disposition for the accumulation of water. With about 70% (63%+7%) of the land favorable for good infiltration given that fracking is generally "good" to "excellent". In addition, there is moderately poor drainage in these areas (Figure 3). In the areas concerned (Arrah and Foutobo in the south; N'zékrenzessou in the east), this indicator reflects the presence of water at very shallow depths in a very fractured environment. These areas are highly sought-after during drilling campaigns because of the low drainage and the pronounced fracturing they reflect.

Moreover, these places are located on the banks of the N'zi and the Agneby, which must probably supply them.

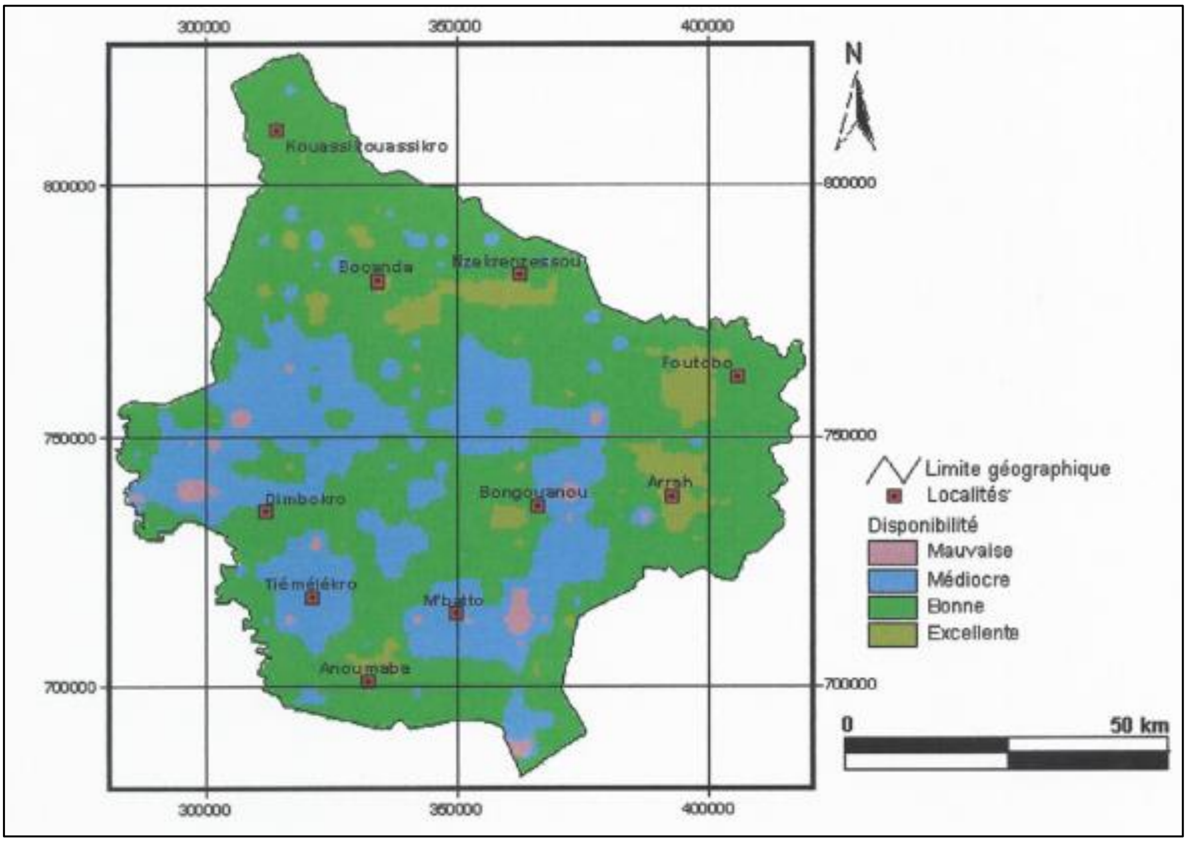


**Figure 3** Groundwater resource availability map

*3.1.2. Accessibility of water resources*

Almost the entire territory offers "good" to "excellent" access to groundwater and this is due to the relatively monotonous relief of the region, with the exception of the area around the locality of Bongouanou which has a somewhat rugged relief (Figure 4).

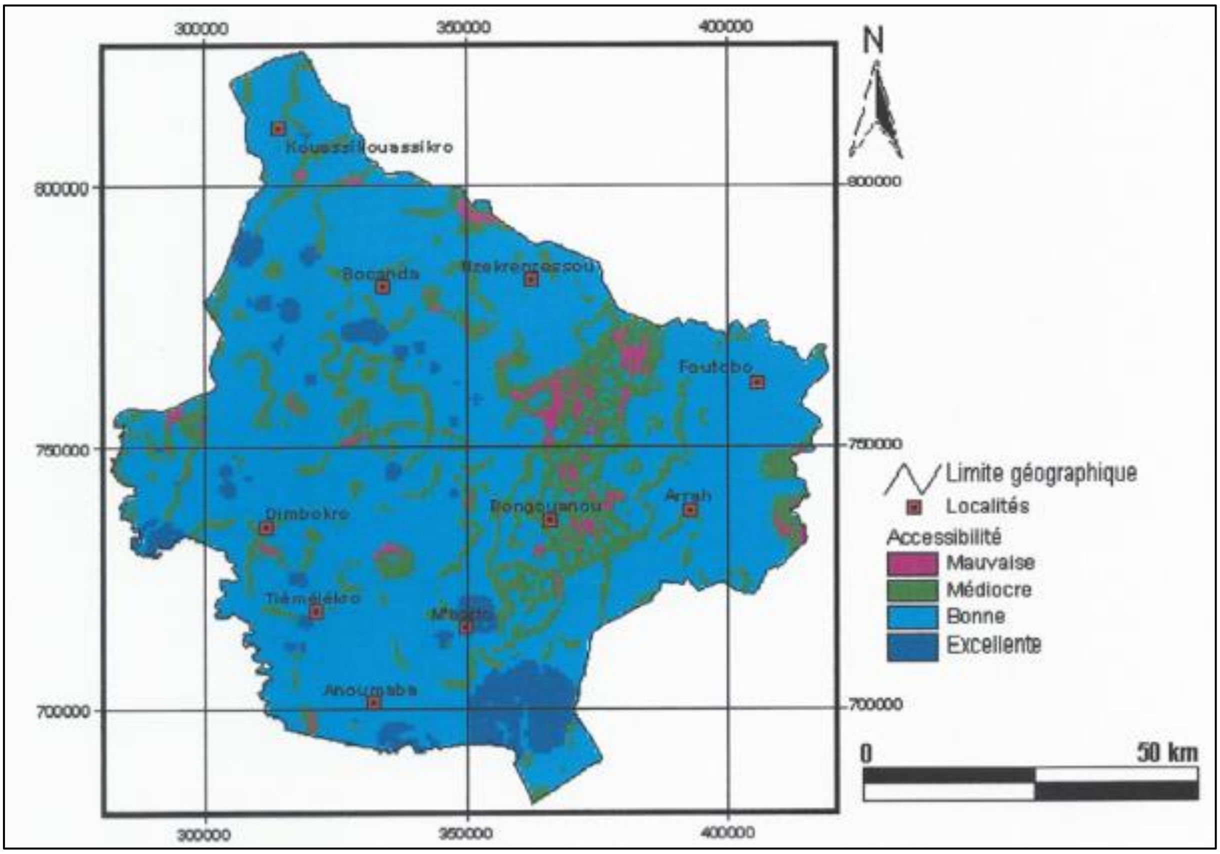


**Figure 4** Groundwater Resources Accessibility Map

### *3.1.3. Exploitability of groundwater resources*

About 80% (65%+15%) of the territory is full of exploitable groundwater. The "good" and "excellent" grades of this indicator cover almost the entire region with some exceptions in some places. The areas concerned are conducive to urban hydraulics and motorized irrigation for modern and large-scale farming. They can guarantee very good flows because of the large reserves present (Figure 5).

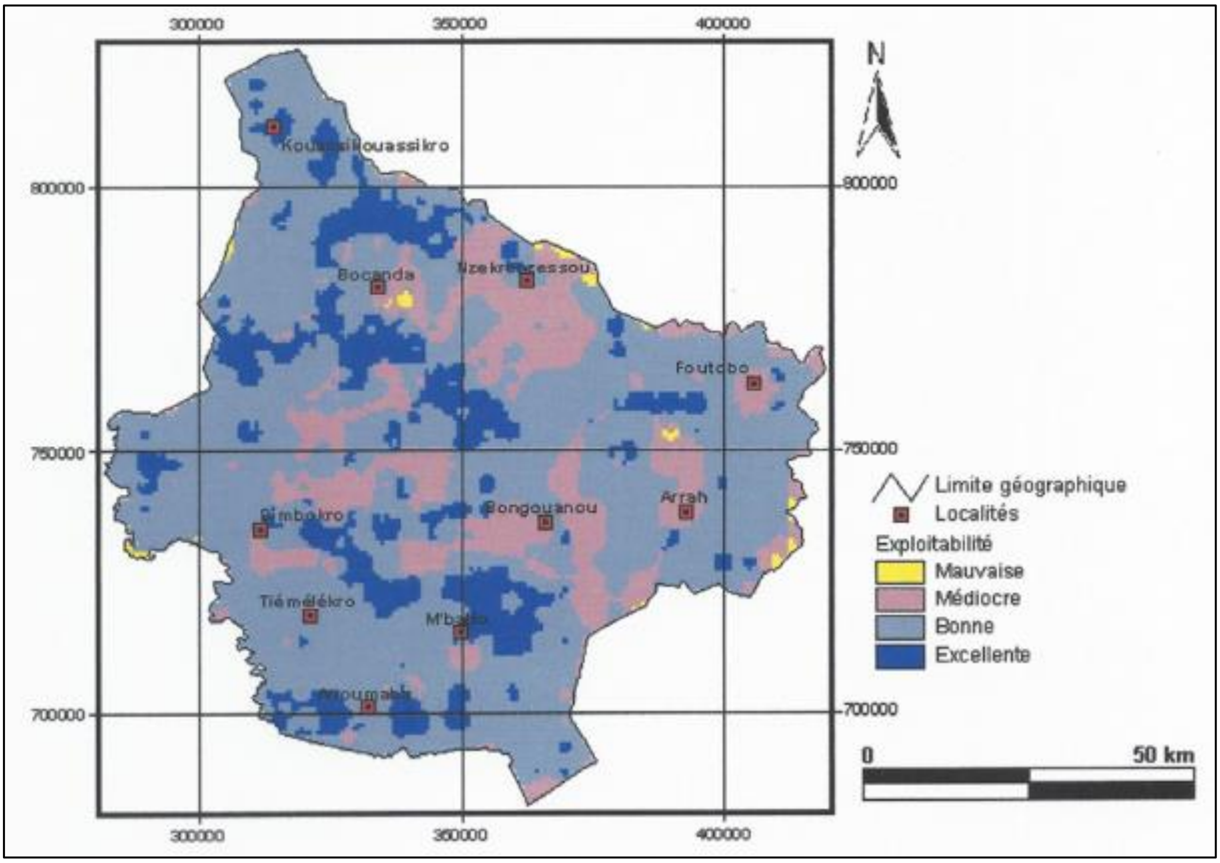


**Figure 5** Groundwater Resource Exploitability Map

In general, we can say that the N'zi-Comoé Region is a region with very significant hydraulic potential that is available, accessible and exploitable.

### *3.1.4. Potential Groundwater Resource Sites*

In total, 63% (50%+13%) of the territory is potentially rich in groundwater. The distribution of this potential is similar to that of the other indicators (Figure 6). The locality of Bongouanou and its surroundings present an opposite situation, as do the localities located north of Dimbokro. This final result is an important tool, useful for the installation of catchment structures likely to guarantee good flows with a high chance of success.

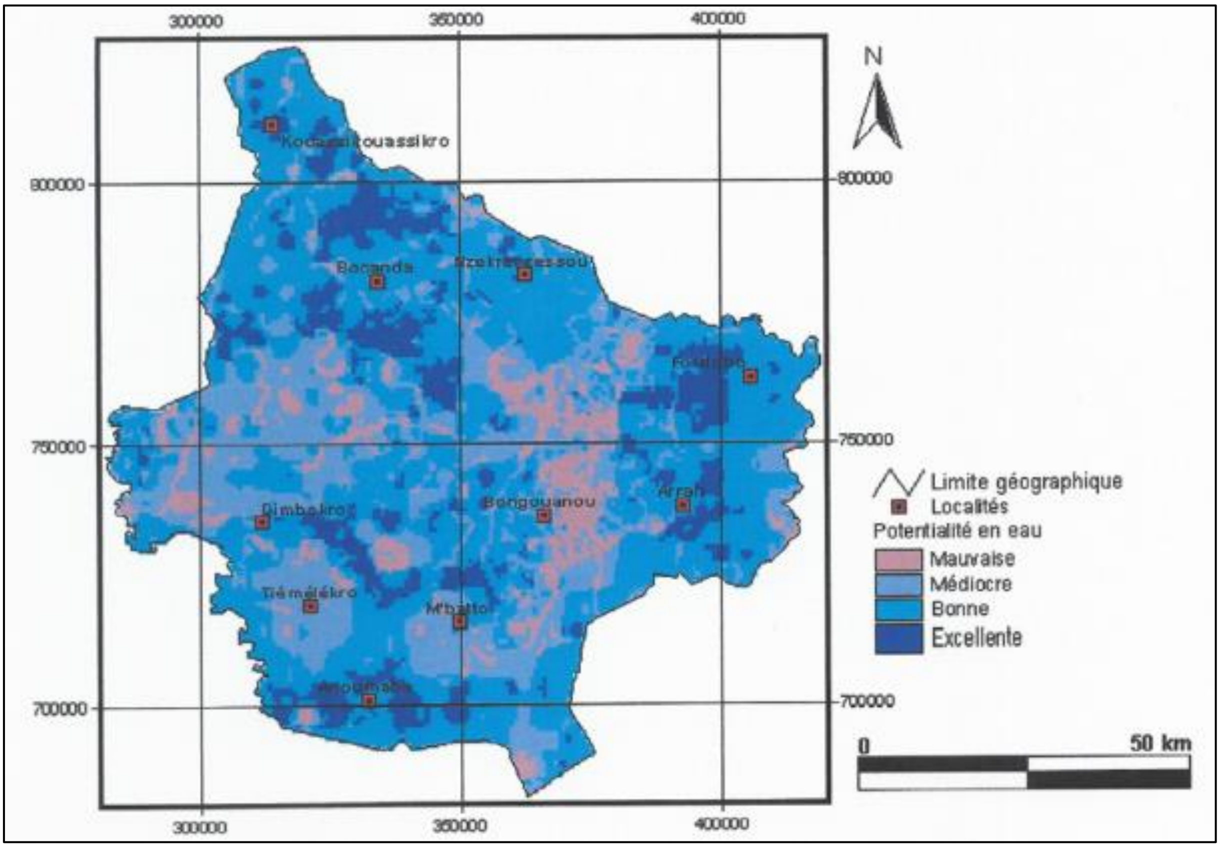


**Figure 6** Map of potential groundwater resource sites

### 3.2. Reliability of the map of potential groundwater sites

The validation of the map of potential sites has given rise to the use of an independent reference system. A summary of these percentages is shown in table 4.

**Table 4** Decadal variation in success rates and average borehole flows

| Sensitivity class<br>Class of flow rates | Excellent (%) | Good (%) | Poor (%) | Poor (%) | Number of boreholes per flow class |
|---|---|---|---|---|---|
| Very Low<br>Q < 0.5 m3/h | 18.6 | 48.1 | 22.2 | 11.1 | 73 |
| Weak<br>0,5 < Q > 1 m3/h | 11.8 | 52.7 | 32.9 | 2.6 | 95 |
| Medium<br>1,5 < Q > 2 m3/h | 10.9 | 32.7 | 47.3 | 9.1 | 110 |
| Fort<br>2 < Q > 2,5 m3/h | 11.6 | 46.3 | 31.6 | 10.5 | 76 |
| Pungent<br>Q > 5 m3/h | 4.1 | 41.1 | 37 | 17.8 | 27 |

Figure 7 shows the evolution of sensitivity trends resulting from the validation of groundwater potential sites based on the percentages of superposition of flow classes.

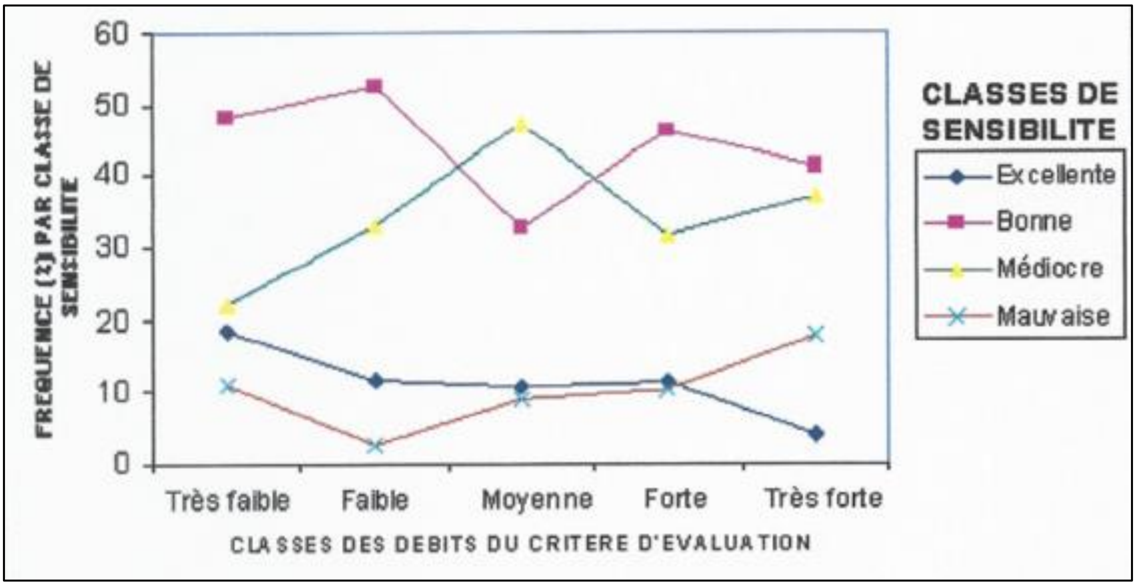


**Figure 7** Trend line of sensitivity classes: test to evaluate the map of potential groundwater sites

The different sensitivity classes are not completely covered by each corresponding flow class. The recovery of sensitivity classes is done inversely to the expected results according to logic. Thus, 4% of the structures with a very high flow rate overlap with the excellent sensitivity class, while about 18% of these same flows are superimposed on the poor sensitivity class. The same is true for low-flow and very low-flow structures, for which respectively 2% and 11% of the structures overlap with the poor sensitivity class, while about 12% (low-flow structures) and 18% (very low-flow structures) of the same structures overlap with the excellent sensitivity class. For these two sensitivity classes, the above observation reveals the non-existence of drilling data in the locations covered by these sensitivity classes. However, the results for good and poor grades are quite close to reality. Thus, 46% of the high-flow structures overlap with the good sensitivity class and 47% of the medium-flow structures overlap with the mediocre sensitivity class. This result reflects the fact that the sensitivity classes express the productivity of aquifers in the field. The validation test shows that the map of potential groundwater sites produced by the weighted aggregation method reflects the productivity of the aquifers in the N'zi-Comoé region.

## 4. Discussion

Although it has led to convincing results, the method used to map potential groundwater sites has limitations for several reasons according to [1]:

- The interpolation of the data leading to the different maps is done on points that are not uniformly distributed over the study area. Since the equidistance between the point differences is not constant, the generation of intermediate points is done randomly;
- Constraints related to the "temporal" scale, in particular the difference in the dates of the data used because some are more recent while others are old;
- The consideration of all criteria as perfectly comparable. Indeed, it is difficult to aggregate quantitative and qualitative data.
- The subjectivity of the weights combined with the risk of oversimplification due to linear aggregation may call into question the results obtained.

However, it should be noted that multi-criteria analysis methods, or more precisely multi-criteria decision support methods, have been used by many authors [4]. These methods have made it possible to map areas favorable to the establishment of high-flow boreholes [10, 11] and the selection of better storage sites [12, 13]. In the case of the present study, the map of potential groundwater sites obtained is a very important database for decision support. It is a pre-prospecting process that avoids cumbersome, slow and costly research phases [14]. This map made it possible to note that the large flows come from the boreholes located or carried out at the nodes of the large fractures, as is the case in many studies.

## 5. Conclusion

The design of the SIHRS targeted by the work carried out made it possible to locate in the region studied the water reservoirs, their accessibility, their operability and above all the suitable places (about 63% of the territory) for the installation of boreholes. This map obtained has the advantage of presenting several hydrogeological elements (weathering thickness, flows, fracturing, drainage density) on a single cartographic support. The multi-criteria analysis that led to the SIHRS has many advantages, as it makes an undeniable contribution to water resources management and rational decision-making.

## Compliance with ethical standards

*Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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