# Groundwater Potential Assessment in the rural Loulouni Municipality (Southern Mali): Decision Tree Approach

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**ABSTRACT**

Groundwater is the main source of drinking water for the rural population in the municipality of Loulouni in southern Mali. The municipality is experiencing water shortages due to population growth and climate variability. The objective of this study is to identify potential groundwater areas to facilitate the construction of boreholes and to help decision-makers improve the rate of access to drinking water in this municipality. The data used consisted of cartographic data, hydroclimatic data, borehole data, and satellite images. The decision tree method was used to map potential groundwater areas with seven decision criteria: slope, effective infiltration, drainage density, fracture density, alteration thickness, geology, and land use. Borehole flows were overlaid on the potentiality maps for validation of the thematic maps. The excellent and good classes dominate with 74%, and the poor and mediocre potentiality classes are poorly represented with 26% of the total area of the municipality. This thematic map, which indicates the potential groundwater-rich area, can be used as an aid for future prospecting and the realization of water wells in the rural municipality of Loulouni.

**Keywords:** Decision tree, GIS, Groundwater, Loulouni rural municipality.

# Introduction

Access to safe drinking water is one of the major objectives of development projects around the world. This drinking water can come from several sources, namely surface water or groundwater. However, surface water resources, which are highly vulnerable to climate change and pollution, have become insufficient to meet water needs [1],[2]. It has, therefore, been observed in developing countries that groundwater is a resource of the first choice for supplying drinking water to populations because it is of relatively good quality and low cost [3]. Thus, the use of groundwater is now systematic, given the context of economic water shortages that African countries are currently experiencing [4].

Indeed, groundwater is a very important resource for many sectors in Mali, such as domestic and agricultural supply, energy, and industry. It is the main source of drinking water for semi-urban and rural populations. The entire Malian population consumes nearly 107 billion m3 per year, most of which comes from groundwater [5]. Therefore, the country has a large amount of water resources. This enormous potential is only 0.2% exploited to date. The rural municipality of Loulouni is mainly made up of crystalline bedrock, where the issue of groundwater causes many concerns, such as water shortages due to population growth and climate variability [5]. However, the municipality has never been subjected to a prior study on groundwater research using remote sensing and GIS. Moreover, the coupling of remote sensing techniques and GIS with multi-criteria decision support analysis is increasingly practiced by many authors [6]–[9], [2]. However, this method lacks predictive capacity and is therefore described as subjective [10]. This is because it assigns weights based on the personal judgments of the expert. Thus, the present study proposes to use decision tree techniques to identify areas of high groundwater potential in the rural municipality of Loulouni to facilitate future water drilling.

# General Information On The Study Area

## Geographic framework

The study area (Fig. 1) is the rural municipality of Loulouni, located in the extreme south of Mali, in the circle of Kadiolo and the region of Sikasso, between latitudes 10° 60’ and 11° 02’ N and longitudes 5° 47’ and 5° 86’ W. It is bordered to the east by Burkina Faso, to the west and south by Côte d’Ivoire, and to the north by the circle of Sikasso. It covers an area of 1,052 km2.

The vegetation is composed of wooded savannah, gallery forests, and open forests. The plant species encountered are: néré, karité, baobab, caïlcédrat, fromager, rônier, etc. [11]. The relief is not very uneven and is interspersed with plains, lowlands, and hills. The climate is Sudanian, with temperatures varying between 21 °C and 32 °C. It is one of the rainiest areas in Mali, with a total rainfall of between 900 and 1200 mm. The main watercours is the Bafing, one of the most important tributaries of the Bagoé, which originates in the sandstone in Côte d’Ivoire. It drains the study area for about 80 km and is a permanent watercourse [12].



Fig. 1. Location of the Loulouni municipality.

## Geological and hydrogeological framework

The geology of the Loulouni municipality fits into the general framework of the geology and the major litho-stratigraphic complexes of Mali (Fig. 2). Most of it is made up of a basement [12]. The basement includes Eburnian intrusive rocks, as well as tectonic structures and formations, volcanic assemblages, detrital to conglomeratic sedimentary assemblages, Sikasso formations (Sikasso FM), Kebeni formations (Kebeni FM), and Massigui formations (Massigui FM). The study area constitutes three (3) types of aquifer formation: Intergranular sedimentary, Igneous, and Precambrian basement.



Fig. 2. Geological map of the municipality of Loulouni.

# MATERIALS AND METHODS

## Data and software used

This study requires a large database composed of image data from two Sentinel-2B MSI scenes (N0208/T29PRN and N0208/T30PTT) acquired, respectively, on 24 December 2019 and PALSAR ALOS-2 (12.5 m × 12.5 m) image from 2007 which is a Digital Elevation Model from the ALOS PALSAR satellite. Geological and topographical maps at a scale of 1:200,000 for the locality of South Mali were obtained from the cartography department of the Institut Géographique du Mali (IGM). Data from 21 boreholes in the rural municipality of Loulouni was obtained from the Direction Régionale de l’Hydraulique de Sikasso (DRH-Sikasso). Climatic data consisted of monthly rainfall (mm) and temperature (°C) measurements over a 1990-2019 period. These climate data were downloaded from the Nasa platform. The reliability of these data was verified using in situ temperature and rainfall data from 1986 to 2013 from the Loulouni station provided by the Direction Nationale de la Meteorologie (Mali-Météo).

In this study, we used QGIS 3.10 software for map rendering and pre-processing of Sentinel-2B images. ENVI 5.3 was used for the land use classification of the municipality and the construction of the decision tree. PCI GEOMATICA 2018 was used to automatically extract lineaments from satellite images using its LINE (Lineament Extraction) algorithm

## Decision tree methods for groundwater mapping

In this study, the application of decision tree techniques for groundwater potential mapping was done in three (3) steps: (i) description of the tree components, (ii) construction of the tree, and (iii) validation of the decision tree.

## Description of the tree components

It takes into account several parameters called decision criteria. In this study, the parameters used are slope, effective infiltration, drainage density, fracture density, weathering thickness, geology, and land use. The result of the classification of the 7 selected criteria is presented in Table I. A score of 10 is assigned to the “very low” or “very high” classes depending on whether they contribute to the excellent achievement of the index considered. In the opposite case, a score of 1 is assigned to these classes. Following the same logic, the scores (8, 6, 3) were assigned to the intermediate classes according to a linear distribution.

TABLE I: Classification and codification of decision criteria

|  |  |  |  |
| --- | --- | --- | --- |
| Decision criteria | Classes | Classes Qualifications | Notes |
| Slope (%) | 0 - 4,7 | Very weak | 10 |
| 4,7 - 9,5 | Week | 8 |
| 9,5 - 18,2 | Medium | 6 |
| 18,2 - 34,4 | High | 3 |
| 34,4 - 109,80 | Very high | 1 |
| Efficient infiltration (mm) | < 25 | Very weak | 1 |
| 25 - 50 | Weak | 3 |
| 50 - 75 | Medium | 6 |
| 75 - 100 | High | 8 |
| > 100 | Very high | 10 |
| Drainage density (km/km2) | 0,05 - 1,12 | Very weak | 10 |
| 1,12 - 1,64 | Weak | 8 |
| 1,64 - 2,17 | Medium | 6 |
| 2,17 - 2,88 | High | 3 |
| 2,88 - 4,60 | Very high | 1 |
| Fracturing density (km/km2) | 0,73 - 1,57 | Very weak | 1 |
| 1,57 - 1,93 | Weak | 3 |
| 1,93 - 2,23 | Medium | 6 |
| 2,23 - 2,55 | High | 8 |
| 2,55 - 3,37 | Very high | 10 |
| Alterite thicknesses (m) | 0,04 - 8,10 | Very weak | 1 |
| 8,10 - 12,21 | Weak | 3 |
| 12,21 - 16,32 | Medium | 6 |
| 16,32 - 23,46 | High | 8 |
| 23,46 - 38,82 | Very high | 10 |
|  |  |  |  |
| Land use | Build-p/barren | Weak | 3 |
| Crops land | Medium | 6 |
| Savanna | Medium | 6 |
| Forest Gallery | High | 8 |
| Water | Very high | 10 |
| Geological Formation | Intrusive Mafiques | Weak | 3 |
| Intrusive Eburnians | Weak | 6 |
| Volanics | Medium | 6 |
| Flysch | High | 8 |
|  | Sedimentary | Very high | 10 |

### Slope (Pt)

The slope is an important factor in water accumulation. It integrates the effect of the slope of the land on the orientation of water transfers and their distribution between runoff and infiltration components. The slope map of the rural municipality of Loulouni was produced using data from the digital elevation model (DEM) of the ALOS PALSAR images.

### Fracturing density (Df)

The fracture density provides an understanding of the spatial distribution of fractures in the area. It was obtained from fractures extracted from sentinel-2B MSI images using the automatic extraction method of the PCI LINE module. The determination of these parameters requires the discretization of the study area into square grids of 5 × 5 km2. Within each grid cell, the fracture density is obtained by calculating the cumulative length of the fractures.

### The thickness of weathering (Ea)

The alteration thickness indicates the fringe of the bedrock alteration. The weathering thickness map was produced using the inverse distance weighted interpolation (IDW) method from the borehole data sheet.

### Land use (Os)

The land use map is an important indicator for the selection of sites for artificial groundwater recharge. Land use and land cover play an essential role in water recharge. They affect recharge rates, runoff, and evapotranspiration. The land use map is based on remote sensing data (satellite images: Sentinel-2B) using supervised pixel-oriented classification.

### Efficient Infiltration

The effective infiltration represents the fringe of water that will effectively feed the aquifers. The infiltration value of the study area is determined by the water balance. With the formula of Thornttwaite Equation (1):

(1)

where:

**Ie:** Efficient Infiltration in (mm)

**P:** Annual mean rainfall (mm)

**ETR:** Actual evapotranspiration (m)

**R:** Trickling water (m)

### Drainage density (Dd)

Drainage density is an important parameter in the assessment of potential groundwater areas. It is generated by processing the Digital Terrain Model in regular grids of 5 × 5 km2, well adapted in the municipality. In each grid cell, the total number and cumulative length of drains are determined. The interpolation of the cumulative length of the drains per grid cell allows the generation of the drainage density map of the study area. The calculation consisted of the ratio between the cumulative length of drains for each grid cell and the area of the grid cell Equation (2):

(2)

where **Dd:** drainage density (km), ∑**L:** cumulative length of drains (en km), and **A:** the area of the surface unit (km2).

## Decision tree methods for groundwater mapping

The decision trees were constructed using the CART (Classification and Regression Tree) algorithm. The spatial prediction was done by hierarchically combining parameters so that the most important parameter is at the root of the tree. It allows the construction of branches to divide and distribute the observations into the more and more homogeneous group that will constitute the leaves of the tree or nodes. The divisions will stop when the terminal nodes are created, and the criteria for each class of potentialities are defined [2]. This approach we used for the evaluation of potential zones is shown in Fig.3. In this study, the most important parameter is the fracture density (Df) which is at the root of the tree. The prediction of the different productivity zones was done by combining parameters according to the rules of the groundwater potential tree (Table II). For example, for the identification of the excellent class, we proceeded as follows: for the fracture density between 6 and 10 by asking a succession of binary questions (of the Yes/No type), “Yes” the slope is between 8 and 10 until the effective infiltration parameter (Ie) which is equal to 10 to end up with the excellent potentiality class.

TABLE II: Rules of the tree for groundwater potential

|  |  |
| --- | --- |
| CLASS | RULE |
| Excellente | 6≤ Df ≤10 ; 8 ≤ Pte ≤ 10 ; |
| 8 ≤ Geo ≤ 10 ; 8 ≤ Ea ≤ 10 ; |
| 8 ≤ Dd ≤ 10 ; 8 ≤ OCS ≤ 10 ; |
| Ie =10 |
| Good | 3 ≤ Df ≤ 6 ; 6 ≤ Pte < 8 ; |
| 6 ≤ Geo < 8 ; 6 ≤ Ea < 8 ; |
| 6 ≤ Dd < 8 ; 6 ≤ OCS < 8 ; Ie = 10 |
| Mediocre | 1< Df ≤ 3 ; 3 ≤ Pte < 6 ; 3 ≤ Geo < 6 ; |
| 3 ≤ Ea < 6 ; 3 ≤ Dd < 6 ; |
| 3 ≤ OCS < 6 |
| Poor | Df = 1 ; 1 ≤ Pte < 3 ; 1 ≤ Geo < 3 ; 1 ≤ Ea < 3 ; 1 ≤ Dd < 3 ; 1 ≤ OCS < 3 |

**Note: Df**: Fracture density; **Pt**: Slope; **Geo**: Geology; **Ea**: Alteration thickness; **Dd**: Drainage density; **OCS**: Land use; **Ie**: Effective infiltration.



Fig. 3. Building the Decision Tree in ENVI 5.3.

### Validation of the decision tree

The potentiality map by decision tree classification was validated with borehole flow data using the sensitivity trend curves proposed by Jourda [6], and Jourda *et al.* [13] (Fig. 4). The validation of the potential zones is done by comparing the shape of the sensitivity class trend curves with the theoretical curves.



Fig. 4. Sensitivity trend curves in the basement environment [6].

Fig. 5 summarises the methodological approach to the production of the groundwater potential map in the rural municipality of Loulouni.



Fig. 5. Flow chart of groundwater potential mapping steps.

# RESULTS AND ANALYSIS

## Validation of the thematic map according to the decision tree

Fig. 6 shows the different zones of potential productivity. The potentiality has been classified into four (4) zones: Excellent, Good, Poor, and Bad.



Fig. 6. Groundwater potential map using the decision tree model of the Loulouni municipality.

The analysis of this map shows that the classes of poor and mediocre potentiality are weakly represented throughout the study area, corresponding to 18% and 8% of the territory, respectively. They are mainly located in the southeast and around the town. These classes are not favorable for the installation of water wells and are essentially characterized by areas with low permeability and steep slopes. As for the good and excellent potential classes, they are mostly represented and cover 74% of the total area of the Loulouni municipality. They are favorable and highly sought-after for the installation of high-flow boreholes. Indeed, these areas are characterized by significant water infiltration, low and very low slopes, and medium to very high fracture thickness and density.

## Validation of the thematic map according to the decision tree

The map in Fig. 7 shows that the different flow classes overlap to a greater extent with the corresponding areas. Table III shows the percentage of boreholes of a flow class that overlap with a given thematic class.

The analysis of this table shows that 65% of the boreholes with very high flow rates overlap with the excellent sensitivity class, and 50% of the boreholes with high flow rates overlap with the good sensitivity class. Furthermore, the analysis shows that 15% of boreholes with a medium flow rate overlap with the good sensitivity class and that the poor sensitivity class covers 50% of boreholes with low flow rates. In addition, 65% of the very low flow boreholes overlap with the poor sensitivity class.

TABLE III: Percentage of the number of boreholes according to flow rate classes (Decision tree)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SENSITIVITY CATEGORIES (%) | | | | | | |
|  |  | Excellente | Good | Mediocre | bad | Number of boreholes |
| FLOW RATE CLASSES (m3/h) | Very weak | 0 | 0 | 50 | 65 | 1 |
| Q<1 | 0 | 0 | 50 | 33 | 6 |
| Weak | 10 | 15 | 0 | 0 | 4 |
| 1<Q<2,5 | 25 | 50 | 0 | 0 | 4 |
| Medium | 65 | 35 | 0 | 0 | 6 |
| 2,5<Q<5 | 0 | 0 | 50 | 65 | 1 |

The graph of the percentage of boreholes according to the flow rate classes shown in Fig. 8, shows that the water potential map reflects the sensitivity of the terrain. Thus, the sensitivity curves provide evidence of the validity of the groundwater potential map based on the decision tree method in the rural municipality of Loulouni.



Fig. 7. Relationship between decision tree productivity index and throughput.



Fig. 8. Percentage plot of the number of boreholes according to the flow rate classes using the decision tree method.

# DISCUSSION

This approach is not widely used here in West Africa, particularly for mapping groundwater potential. It shows that the contribution of remote sensing and GIS coupled with the decision tree has enormous advantages in the search for potential groundwater areas in the rural municipality of Loulouni. However, this method presents difficulties in its implementation. These include the choice of criteria used to map the potential areas, which differ according to the work and the availability of data. There are also difficulties in choosing the class limits of the criteria chosen for the method. The choice of class limits depends on the operator’s ability to discern and his sense of judgment, on the one hand, and the values displayed by the histograms of the criteria, on the other [13]. Despite these difficulties, we note a good consistency between the flow classes, although the trend curves of the sensitivity classes are more or less distant from those of the theoretical curves established by Jourda *et* *al.* [13].

The results obtained are in line with the work of Lee *et al.* [10] and Duan *et al.* [14], who applied the decision tree model for groundwater potential mapping in Korea and China, respectively. They obtained satisfactory results. It is then found that decision tree classification is an accurate, fast, and more reliable method for groundwater potential assessment. This method is, therefore, well suited to help solve multi-criteria support problems. The thematic map of aquifer potential zones is, therefore, a decision support tool that avoids the sometimes difficult and costly strategic prospecting phase.

# CONCLUSION

At the end of this work, the results obtained show the importance of remote sensing and GIS in the mapping of groundwater potential in the rural municipality of Loulouni. Indeed, the methodological approach implemented allowed the objectives set to be achieved. The results obtained by the decision tree method reveal 74% of the potentiality in the good and excellent classes and 26% in the poor and mediocre classes over the whole territory. More than half of the surface area of the Loulouni municipality is favorable for the installation of large flow boreholes. Thus, this study provides a geographical overview of the spatial distribution in the municipality of Loulouni of the zones that are favorable for the installation of large flow facilities. Overall, this groundwater potential map would be an essential tool for future prospecting campaigns, which are important for agricultural activities, but also the supply of drinking water in residential areas.

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# Conflict of Interest

Authors declare that they do not have any conflict of interest.

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