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RESEARCH ARTICLE

MAPPING OF LITHO-STRUCTURAL AND HYDRODYNAMIC PARAMETERS OF THE AQUIFER SYSTEM IN THE DEPARTMENTS OF BOUNDIALI AND KOUTO (NORTHERN COTE D'IVOIRE)

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Abstract

The objective of this study is to map the litho-structural and hydrodynamic parameters of the aquifer system in the Boundiali and Kouto departments. The maps were created based on hydrogeological data from 307 boreholes. The altered thickness map shows that alteredthicknesses between 40 and 60 meters are rare, while the saturated thicknesses of the weathered layers vary from 0 to 54 meters. Water inflows are found exclusively in the bedrock, with the most productive ones located between depths of 25 and 60 meters. According to the piezometric level map, the main watercourse in the study area is fed by groundwater. The transmissivity (1.13 x 10^{-6} to 2.21 x 10^{-4} m^2/s), specific (0.02 to 4.35 m^2/h), and hydraulic conductivity (0 to 2.8 x 10^{-3} m/s) maps indicate that these parameters are generally low across the study area.

Introduction:-

The people of the Boundiali and Kouto departments in the northern region of the Precambrian basement complex of Côte d'Ivoire, a country in West Africa, rely entirely on groundwater resources for their drinking water. Unfortunately, most boreholes drilled in these departments are reported as unproductive (Q < 1 m^3/h) or have low flow (Q < 2.5 m^3/h). When sufficient flow is obtained, many of these boreholes dry up after only two years of use. According to Maréchal et al. (2004) and Leray et al. (2013), mapping the geometry and structure of the aquifer system, along with understanding its hydrodynamic parameters, is essential for comprehending its functioning. This spatial distribution allows insight into the conditions governing the flow and storage of groundwater in this basement terrain, thereby facilitating optimal water resource mobilization. The objective of this study is to map the litho-structural and hydrodynamic parameters of the aquifer system in the Boundiali and Kouto departments.

Study Area

The Boundiali and Kouto departments are located in the Savanes District, within the Bagoué region in northern Côte d'Ivoire (Figure 1). The geological formations of these departments correspond to theBirimian and Pre-Birimian formations (Soro, 2017). Similar to granite formations, amphibolites, gneiss, migmatites, and quartz veins, the boreholes drilled in these departments reveal the presence of two superimposed composite aquifers. Near the surface, there is a weathered aquifer made up of sandy clay and clay layers. In certain areas, the weathered layers can reach a thickness of up to 60 meters. Deeper down, there is a fractured bedrock aquifer.

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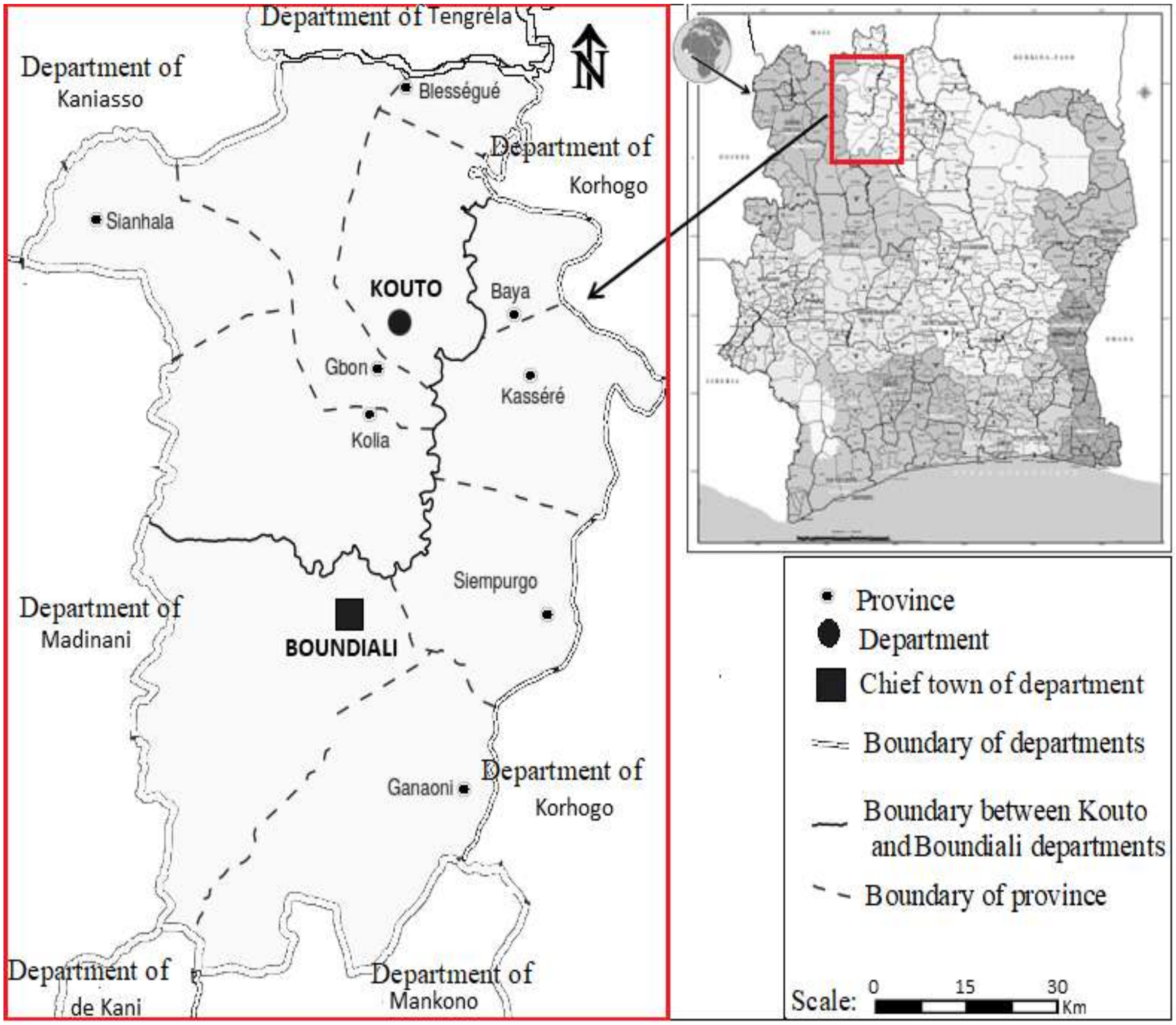

Figure 1:-Location of Boundiali and Kouto Departments.

Materials and Methods:-

The lithostructural maps and hydrodynamic parameters of the subsurface in the Boundiali and Kouto departments were created using hydrogeological data (total drilled depth, thickness of weathered layers, thickness of bedrock, static water level, water inflows, drawdowns from pumping tests, air-lift flow rate, and exploitation flow rates) from 307 boreholes.

Creation of Lithostructural Parameter Maps

The lithostructural parameter maps of the aquifer system in the study area were developed based on the weathering profile, thickness of water-saturated weathered layers, and fractures identified at water inflows points (AE) in the boreholes. For each borehole, the thickness of the weathered layer was determined by calculating the difference between the total borehole depth (Pt) and the drilled bedrock depth (ES). The water-saturated thickness of each borehole's weathered layer was determined by calculating the difference between the thickness of the weathered layer (EA) and the static water level (NS) in the boreholes. The respective maps of weathered and saturated layer thickness were createdusing ArcGIS 10.2 software. A 3D block diagram of the aquifer system in the study area was also produced to visualize the subsurface, using Surfer 13.

Creation of Hydrodynamic Parameter Maps

The maps showing the distribution of hydrodynamic parameters for the aquifer system in the Boundiali and Kouto departments include piezometric level, transmissivity, hydraulic conductivity, and specific discharge maps.

Piezometric Level
The drawing up of a piezometric level maphelps determine the spatial distribution of thehydraulic head at a given date. In our study, this map was generated using Surfer software. The piezometric level (Np) for each borehole was computed by finding the difference between the ground level altitude Z (m) and the static water level NS (m), according to Equation 1.

$$\mathbf{Np = Z - NS} \qquad \text{(Equation 1)}$$

Transmissivity
The transmissivity distribution map of the study area was created using transmissivity data determined by the Cooper-Jacob method. The transmissivity "T" for each borehole was evaluated solely from the recovery data recorded during pumping tests, following Equation 2.

$$T = \frac{0{,}183Q}{a} \qquad \text{(Equation 2)}$$

This equation is derived from Equation 3 below, which represents the slope "a" of the residual drawdown curve Sr as a function of $(\frac{t+t'}{t'})$:

$$a = \frac{\Delta Sr}{\Delta log(\frac{t+t'}{t'})} = \frac{0{,}183Q}{T} \text{(Equation 3)}$$

"t, t', and Q" represent the pumping duration, recovery duration, and Q the recovery flow rate (average of the pumping flow rates), respectively.

Hydraulic Conductivity
The hydraulic conductivity K used to create the distribution map is calculated as the quotient of transmissivity T and the saturated thickness of the aquifer (Equation 4).

$$T = K.e \text{ d'où} K = \frac{T}{e} \text{(Equation 4)}$$

Specific flow
The specific (Qsp) flow used to create the distribution map were evaluated at the end of the third step after well test pumping. This is a critical parameter for determining the productivity of wells (Neves & Morales, 2007). It varies according to the transmissivity of the aquifer.

The specific flow rate is the quotient between the pumping rate (Q) and the maximum drawdown (Sm) in each structure (Equation 5).

$$Qsp = \frac{Qexploité}{Sm} \text{(Equation 5)}$$

Results:-

Lithostructural Map of the Aquifer System
The subsoil of the study area exhibits a highly variable weathering thickness, ranging from 5.3 to 60 m, with an average thickness of 20.14 m. On the granitic basement, the average thickness is 16.8 m, while on schist, it is 23.5 m. The weathering thickness distribution mapin Figure 2a shown that weathering thicknesses between 40 and 60 m are rare, occurring only in the localities of Tindara (Kouto Department) and Kaniélé (Boundiali Department). Thicknesses between 20 to 40 m are observed from north to south and in the west of the study area, while thicknesses between 5 and 20 m are mainly found in the extreme north, northeast, northwest, and east.

The saturated thicknesses of the weathered layer vary from 0 to 54 m. Saturated weathering thicknesses between 0 and 17 m are encountered throughout most of the Boundiali and Kouto departments (Figure 2b). Saturated weathered layers with thicknesses from 17 to 35 m are sparse and located in the north, center, and south. Saturated weathering thicknesses beyond 35 m are observed only in Tindara (Kouto Department) and Kaniélé (Boundiali Department).

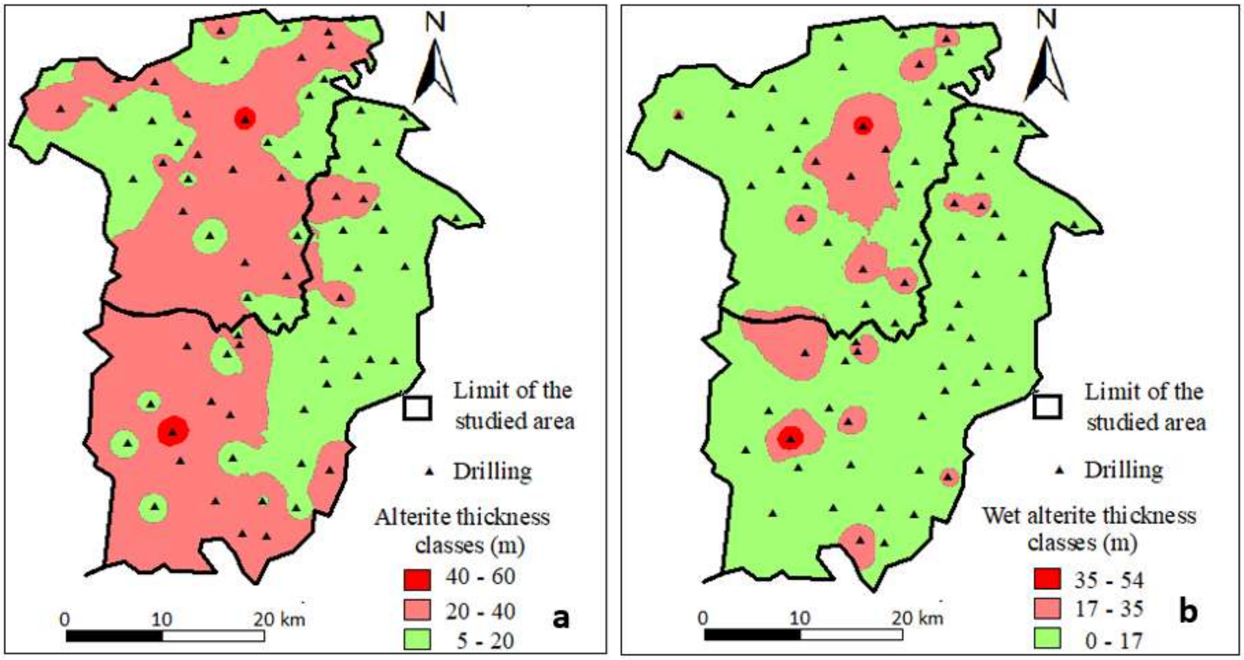

Figure 2:-Distribution maps of weathering thickness (a) and saturated weathering thickness (b).

The lithostructural characteristics of the aquifer system across the entire study area are also illustrated by a block diagram (Figure 3). The weathering profile shows a vertical structuring of formations, with variations in the piezometric level, groundwater inflow points, and the top of the bedrock. The piezometric level is located either within the weathered layer, the fractured bedrock, or at the transition zone between the bedrock and the weathered layer. Groundwater inflows occur exclusively within the bedrock. The most productive groundwater inflows in the Boundiali and Kouto departments are found between 25 and 60 m deep.

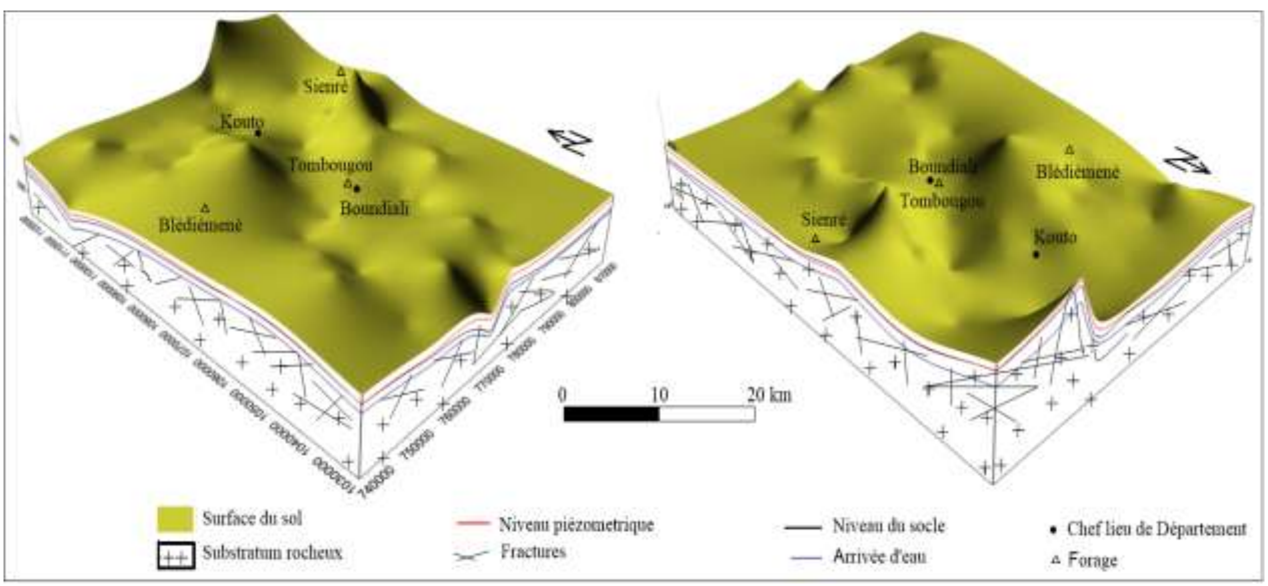

Figure 3:-Lithostructural block diagram of the aquifer system in the study area.

Maps of Hydrodynamic Parameters of the Aquifer System
Piezometric Level

The piezometric level map shows more closely spaced piezometric contours reaching up to an altitude of 490 meters at the extreme north of the study area (Figure 4). In other parts of the study area, piezometric levels do not exceed

430 meters in altitude. Notably, there are piezometric domes marked by diverging flow lines, found in the northern, northeastern, and southern parts of the study area. Naturally, between these domes, there are piezometric depressions. The most significant depressions are located along the boundary between the Boundiali and Kouto departments. This boundary actually corresponds to a watercourse, which is thus fed by groundwater.

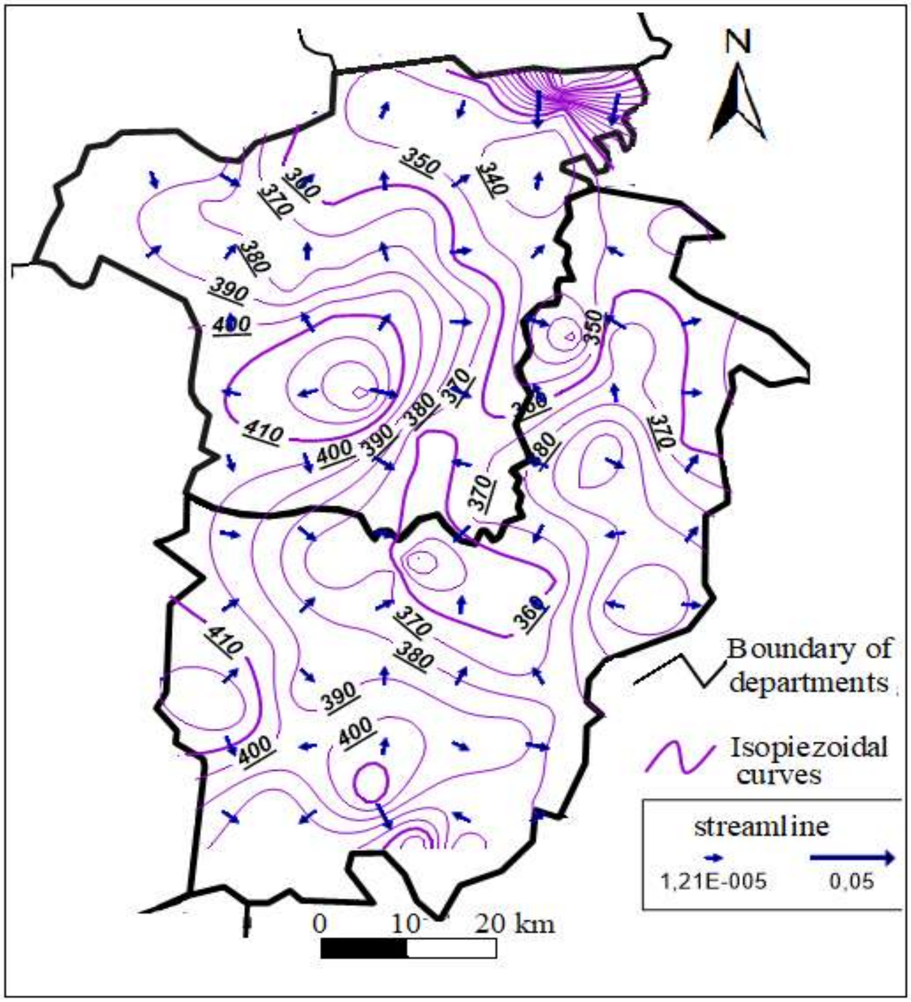

Figure 4:-Piezometric Level Map of the Kouto and Boundiali Departments.

Transmissivity, Specific Flow, and Hydraulic Conductivity

The transmissivity and specific flow of the study area are closely related, as shown in Figures 5a and 5b. Figure 5 illustrate the spatial variation of transmissivity *T* and specific flow

Qsp, respectively. The transmissivity ranges from $1{,}13.10^{-6}$ and $2{,}21.10^{-4}$ m^2/s, and the specific flow varies from 0,02 à 4,35 m^2/h. Throughout the study area, transmissivity is low, with values below $4{,}5.10^{-5}$ m^2/s. The specific flow follows a similar trend, with values between 0.02 and 4.35 m^2/h. With the exception of the locality of Poundiou, situated in the eastern part of the study area, where transmissivity (2.21×10^{-4} m^2/s) and specific flow (4.35 m^2/h) are higher, the aquifers in the Boundiali and Kouto departments exhibit a low capacity for mobilizing water. A similar pattern is observed with hydraulic conductivity, except that the area with significant permeability is located in N'Déou, in the northern part of the study area (Figure 5c).

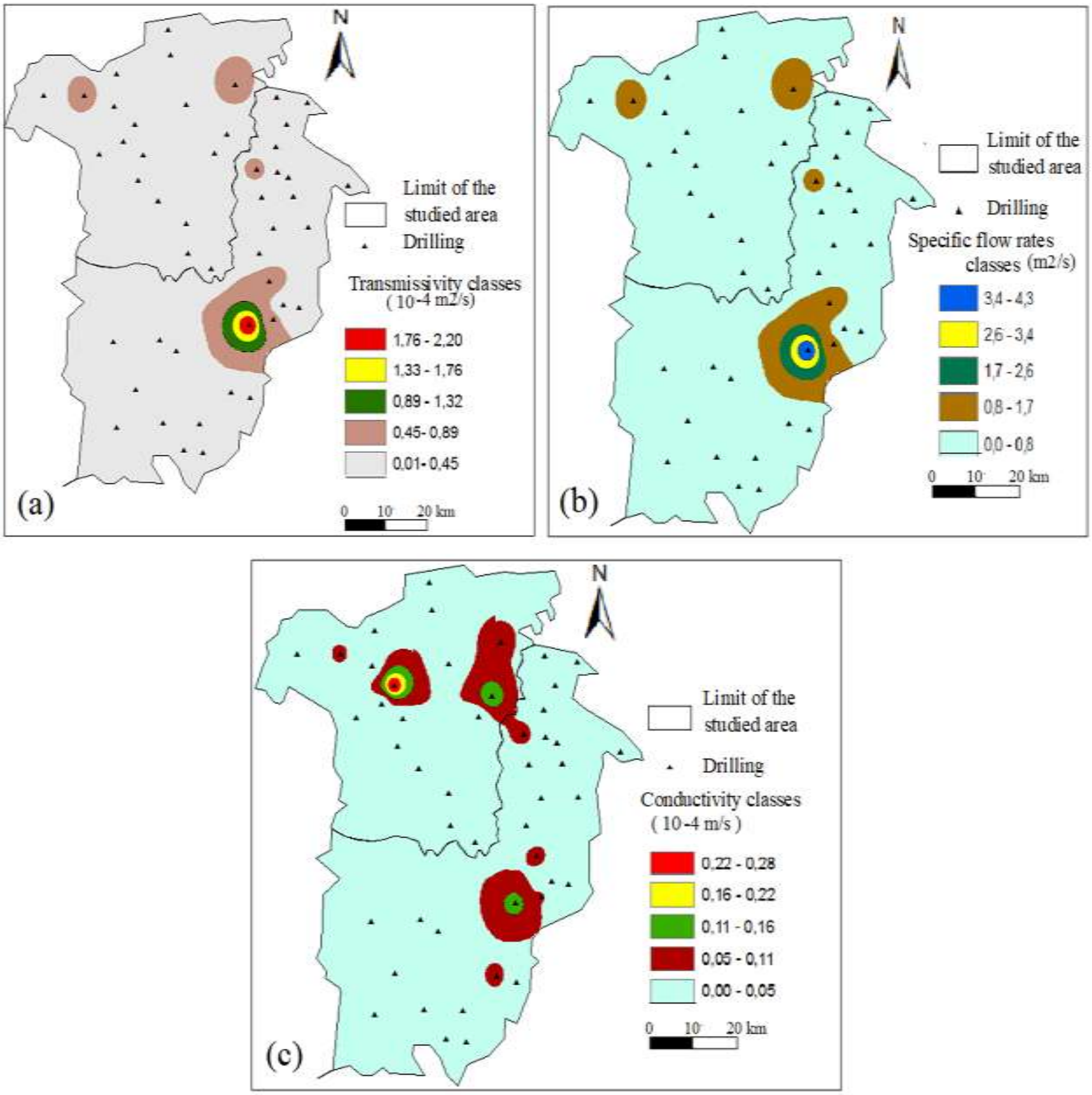

Figure 5:-Distribution map of transmissivity (a), specific flow (b), and hydraulic conductivity (c) in the study area.

Discussion:-

The average thickness of the altered horizons, at 20.14 m, aligns closely with Engelanc's (1978) proposal of 15 to 20 m. These average alteration depths over granitic and schistose substrates are consistent with observations from CEFIGRE (1990) in West Africa, which estimated alteration layers to extend 10 to 20 m in granito-gneissic domains and 15 to 40 m in schistose regions. Researchers like Wyns et al., 2004; Dewandel et al., 2006; and Lachassagne et al., 2011, have emphasized the importance of alteration horizons in recharging fractured aquifer systems.

The most productive water inflows (AEs) in the Boundiali and Kouto departments are found between 25 and 60 m. This is in line with previous studies conducted in Côte d'Ivoire by Camerlo& Fahy (1981), Faillat (1986), Soro (1987), CEFIGRE (1990), Biémi (1992), and Lasm (2000), which found AEs between 20 and 40 m. The flow of these inflows is determined by counting the number of productive fractures encountered while drilling (Kouadio et al., 2010). In this study, AEs are specifically located in the fractured bedrock zone, starting from the bedrock's upper boundary.

Transmissivity values in Boundiali and Kouto range between $1,13.10^{-6}$ and $2,21.10^{-4}$ m^2/s. These values fall within the range typically found in West African fractured basement areas and are consistent with values recorded on the Ivorian basement (Faillat, 1986; Biémi, 1992; Dibi et al., 2004 in the Aboisso region; Ahoussi, 2008 in the Agboville region; Soro, 2010 in the Grand Lahou region).

Specific flow is a critical factor in determining the productivity of water capture structures (Neves & Morales, 2007). The specific flow range in Boundiali and Kouto (0.02 to 4.35 m^2/h) is comparable to values observed in Kourwéogo province, Burkina Faso (Ouédraogo, 2016), and in Côte d'Ivoire (Soro, 2010). Most specific flow values (Qsp) observed in the region are low, rarely exceeding 1 m^2/h.

Conclusion:-

The Boundiali and Kouto departments in northern Côte d'Ivoire exhibit a wide range of alteration thicknesses (5.3 to 60 m) and wet alteration zones (0 to 54 m). Similar to highly altered zones, saturated zones are sparse in the study area. Water inflows are observed exclusively in the crystalline basement, with the most productive inflows occurring between 25 and 60 m deep. Transmissivity, specific flow, and hydraulic conductivity in the study area are predominantly low and are closely interconnected.

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