International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 10 Series. I || October 2019 || PP 30-39

Siting of boreholes using one dimensional electrical resistivity techniques in area of geological transition of basement rocks and sedimentary rocks in Burkina Faso

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Abstract : *The Mouhoun Loop region is one of the 5 regions having the lowest rates of access to drinking water. Further, the failure rate of Borehole is greater than 30%. This area is underlined by both bedrock and sedimentary rocks. In the area, borehole siting is performed using 1D geophysical investigation techniques such as electrical profiling and electrical sounding. In this study, we decided to analyse this approach in order to see if it is adapted to the geological context. To achieve this, the methodology consisted in analysing the geophysical data of the settlements. Then the results were analysed using statistical tools. The results indicate that failure rates are higher on sedimentary rocks than bedrock rocks. In fact, 91% of the boreholes were implanted in sedimentary zone on the consolidated sandstone. These behave like basement rocks that are very heterogeneous. Also, in these geological formations, the boreholes are not deep enough to reach the deep aquifers. So in order to reduce this failure rate, we suggest the use of electrical resistivity tomography. This is a 2D technique that allows you to observe vertical and lateral variations.*

Keywords -*1D electrical resistivity techniques, 2D electrical resistivity tomography, basement rock aquifers, borehole siting, sedimentary aquifers.*

Date of Submission: 01-10-2019 Date of acceptance: 16-10-2019

I. INTRODUCTION

The importance of water for life and as component of the global ecosystem is well known. The history of water and that of men are closely linked. For this reason, the search for water points has long mobilized the energies and the first civilizations were born along the course of the great feeding rivers. Also, this resource that meets the basic needs of man is an important economic potential particularly to generate and maintain prosperity through certain activities such as agriculture, fishing, energy production, industry, transportation and tourism. However, freshwater, which accounts for only 2.5% of the global water volume (97.5% for salt water), is unevenly distributed over the Earth's surface. This resource is becoming scarce in many parts of the world, particularly in sub-Saharan Africa. In addition, the demand for drinking water to meet the water needs of the population is growing due to population grow. Unfortunately, all this is happening in a climate context where precipitation, the main source of fresh water from the atmosphere, exhibits a strong spatial and temporal variability with a declining trend over a large part of Africa [1] [2].

Groundwater is the major water resource in rural areas of Sub-Saharan Africa, because of the poor quality of surface water and its unavailability during in some periods due to high evapotranspiration. As the only source of safe drinking water, groundwater resources condition the food security of these populations. Nearly half of Africa's population relies on groundwater [3]. In order to access these groundwater resources, high quality pieces of work (boreholes in general) that can last for a long time are required. These boreholes must be located in aquifers with significant storage and / or high recharge [6].

Thus, in Burkina Faso over a thousand boreholes are made each year to enable rural people to have access to water. However, some regions have lower access rates than the set targets of about 80% in 2015. This is the case of the Mouhoun loop region which is one of the 5 regions with the lowest access rates in the country with 76% [7]. Also, failure rates in the area are estimated at more than 30% [7]. From geological point of view, this region is underlined by both basement and sedimentary rocks. In the area, borehole siting is done using one-dimensional (1D) electrical resistivity techniques such as electrical profiling and electrical sounding. In this study, we decided to analyse this approach in order to know if it is adapted to the geological context

II. MATERIALS AND METHODS

2.1. Study Area

The region of Mouhoun loop is located between latitudes 13° 42'N and 11° 15' N and longitudes 4° 15' W and 2° 30' W. It is located in north-western Burkina Faso and is limited in the North and North-West by the Republic of Mali and the Northern region, while in the western, southern eastern parts it is limited by the High-Bassins region, the South-West region and the Central-West region, respectively. It covers an area of 34,145 km^2, which represents 12.59% of the total area of the country. It covers 6 provinces divided into 6 urban communities, 41 rural communes and 983 villages. The regional capital is Dédougou(Fig.1).

As part of this study, the provinces of Sourou and Nayala are not taken into account since we could not have data on these communes. The study area, is therefore limited to 4 communes.

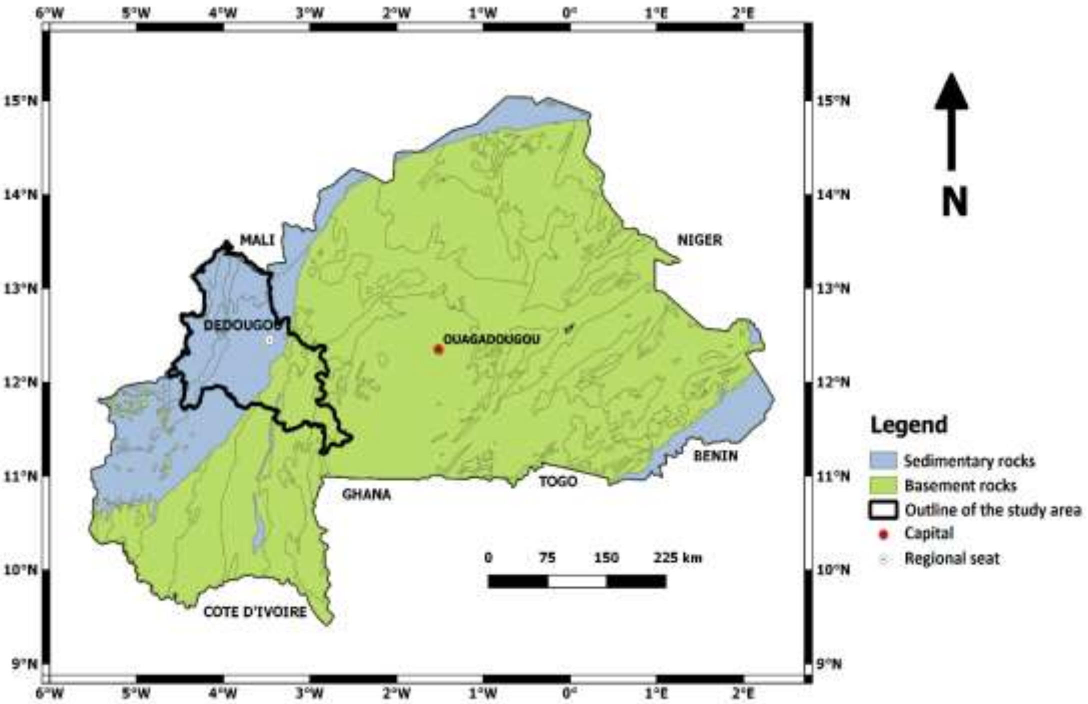

Figure 1: Location of the study area

The climate in this area is of the Sudano-Sahelian type, with a short rainy season (from June to September) and a long dry season (from October to May). The mean annual rainfall varies between 700 and 900 mm and the temperature ranges between 25 and 40°C [8].

The geology of Burkina Faso is characterized by rocks belonging to the West African craton, which has one of the lowest seismicities in the world, characterized by earthquakes with a magnitude less than 4. This craton comprises two distinct entities: the Reguibat Shield in the North, and the Leo Shield, also referred to as the Man Shield, in the South (Fig. 2). These two groups are separated by sedimentary formations called the Taoudeni basin[8].

In the Leo Shield, Paleoproterozoic formations crop out in nine West African countries: Burkina Faso, Ivory Coast, Ghana, Guinea, Liberia, Mali, Niger, Senegal and Togo (Lompo, 2010). The age of the formations is not exactly known, and diverse estimates have been proposed in different studies [9][10][11]. However, this shield can be subdivided into two domains: The Archean or Kenema-Man domain (Fig. 2). This is characterized by two orogenic cycles: the Leonian, dated from 3500 to 2900 Ma, and the Liberian, dated from 2900 to 2600 Ma. The Baoule-Mossi domain (Fig. 2) is dominated by the Paleoproterozoic era. It was recorded in the second domain of the Eburnean orogenic cycle dated from 2400 to 1600 Ma. Regarding the sedimentary formations it is make-up of the Neoproterozoic and Cenozoic (Continental Terminal) sediments of the Taoudeni Basin and the southeastern boundary of the northern rim of the Voltaean Basin [14]. This vast Neo-Proterozoic basin of about 2 million km² which covers in major discordance the heart of the West African craton extends over 6 countries (Mali, Mauritania, Algeria, Burkina Faso, Niger and Guinea). With a thickness estimated at more than 3000 m on average, it is largely make up of limestone and sandstone [15].The southeastern border of the Taoudéni sedimentary basin (260 000 km²) is partially covered by surface formations of Tertiary. In the Burkina Faso part of the Taoudéni basin (45 000 km²), the geological synthesis indicates nine formations in the sedimentary zone subdivided into four groups [14]. From the bottom to the top : (i) the Banfora group, which comprises the formation of the lower sandstones, consists of more or less coarse sandstones containing very fine past, silty with a power of about 300 m; (ii) the Cliff Group composed of Kawara-Sindou Sandstone and Fine Glauconous Sandstone (Gfg) consists of coarse (or even conglomerate) sandstone with a power of about 800 m; (iii) the Bobo Group consists of Quartz Granules, Siltstones , Argilites and Carbonates of Guena-Sourou- Koundinga , Pink Sandstones, Siltstones , Argilites and Carbonates of Samandeni-Kiébani , Siltites and Quartz Sandstones and (iv) Bandiagara group consisting of Fo-Bandiagara Sandstone (GFB), very coarse-grained conglomeratic sandstone, with a thickness of about 50 m, more widespread in Mali.The geology of the region extends over the crystalline basement in the east and the sedimentary basin in the west.

2.2. Methods

2.2.1. Identification of the parameters of the analysis

The parameters of the analysis were divided into two groups according to the sources of information. These are the geophysical parameters and the hydrogeological parameters.

2.2.1.1. Geophysical parameters

Geophysical parameters were identified from data collected by a drilling company. These data were obtained by using electrical resistivity profiling and electrical resistivity techniques. The basis and principles of these two techniques can be found in several documents [16] [17]. The purpose of electrical resistivity is to determine the resistivity distribution of the sounding soil volume. Artificially generated electric currents are provided to the soil and the resulting potential differences are measured [16].

The data acquired from these two techniques were analyzed and interpreted. The IPI2WIN software, used for this purpose, generated curves that were analyzed like in several works [18] [19] [20]. This was to determine the forms of anomalies, the types of anomalies and types of sounding

The data relate to 128 boreholes among which 83 are located in the basement area and 45 in the sedimentary environment (Fig.2).

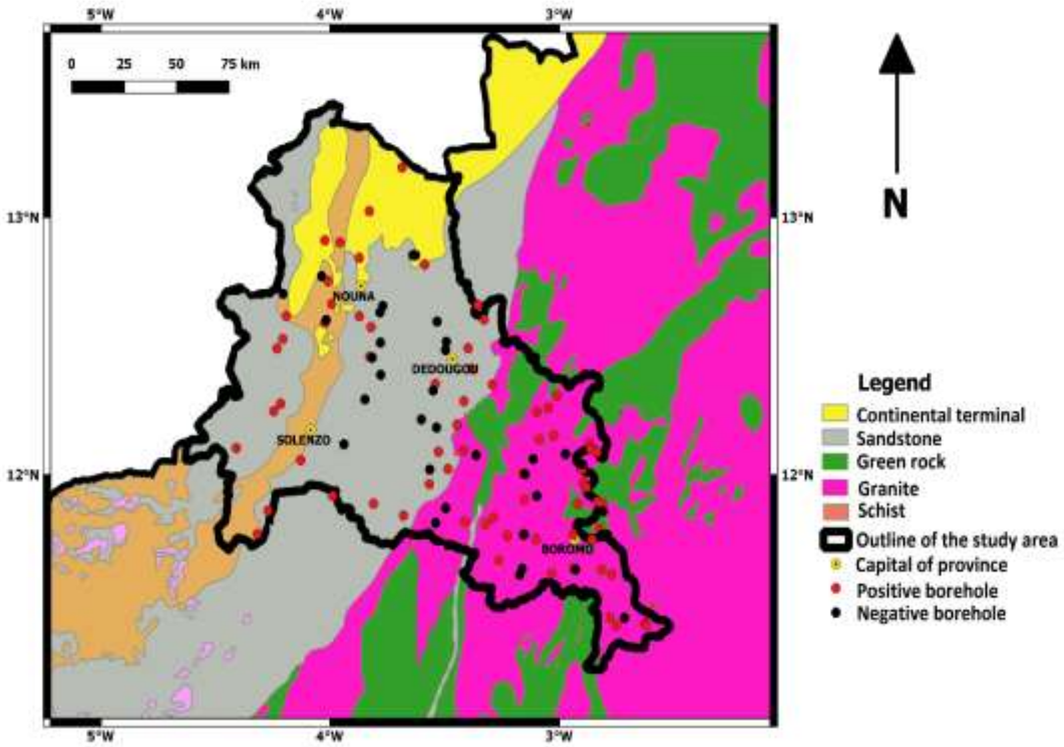

Figure 2: Location of the different boreholes

2.2.1.2. Hydrogeological parameters

The hydrogeological data such as the status, yield, depth and the well logging of the boreholes were obtained from the technical data sheets of the boreholes. The status of the borehole refers to whether the borehole is positive or negative. Thus, all the boreholes whose yield rates obtained after development (blowing) are greater than or equal to 0.4 m3 /h are declared to be positive (successful), otherwise it is negative [7]. The depth is the one that has been drilled. Finally, the well logging allows to know the type of geological formation in which the drilling was carried out. The geological data were collected for borehole used for the identification of geophysical parameters.

2.2.2. Parameter analysis method

Statistical analyses were done for all the parameters mentioned above. In order to achieve this, geophysical parameters were correlated according to the geological formations, yield, depth of the borehole on the one hand in order to identify the various parameters governing productivity, and other hand, results obtained in the basement aquifer were compared with those obtained in the sedimentary one in order to generate parameters inducing high yield (greater than 6 m^3/h) [7].
The statistical methods used are: the arithmetic mean, the frequency and the standard deviation (1).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{p} n_i (X_i - \overline{X})^2} \qquad (1)$$

where σ is the standard deviation, N is the total number, n_i is the number of value X_i and $\overline{X}$ representing the average value.

III. RESULTS AND DISCUSSION

3.1. Results

3.1. 1. Geological Formations and status of the borehole

In the part of the crystalline basement, 65% and 35% of the boreholes were sate in granite and in shale, respectively. 56 boreholes out of 83, representing 67.5%, were positive while 32.5% were negative.
With regard to the sedimentary part, it consists mainly of sandstone with a recurrence of more than 9 1 %. The so called Continental Terminal is found in some places representing 9 % of the total area covered by the sedimentary basin. The technical data sheets of the boreholes did not allow us to differentiate the different types of sandstone (pink or white). This study was conducted on a total sample of 45 boreholes including 27 positive and 18 negative which represents a failure rate of about 40% in this part.

3.1. 2. Geophysical Parameters and status of boreholes

3.1.2.1. Forms of anomalies

After the analysis of the different electrical profiling curves, it was found that there were 7 forms of anomalies in the two geological formations (basement and sedimentary zones). The most observed form is the V-form anomaly with the frequency of 27% in crystalline basement terrain (granite and shale) and 23% in sedimentary zone (sandstone and continental terminal). This form is followed by the U-form anomalies with 22 % and the K-form with 18% in the basement area and in the sedimentary zone, respectively. The anomaly forms with the lowest recurrences are the W-form and C-form in the basement area with a rate of 9% each and the C-form and the H-form in sedimentary environment with 4% each.

Regarding drilling success rates, K-form and M-form have the highest rates, 78.6% and 87.5%, respectively, in the basement area. The K-form also enable to have a success rate of 75% in sedimentary environment. In this same medium, C-form and W-form deserve special attention because they have the same success rate like the K-form.

Looking at Table 1, which shows the distribution of the shapes of the anomalies according to geological formations and the status of boreholes, we find that the size of the different samples did not allow some analyses. However, several remarks already be made. At the level of the granites the M-, K- and U-forms enable a success rates higher than 75%. On shale, drilling on M-form and C-form have all been successful. Regarding the sandstone, the rates of success oscillate around 60%. The W-form is the one that offers the success rate more than 75%. On the other hand, 62% of the drillings on the U-form failed. All the 4 boreholes drilled in the continental terminal were successful.

Table 1: Distribution of Anomalous Forms According to Geological Formations and the Status of Boreholes

Geological formations		parameters		Form of the anomalies							
				U	V	W	M	K	VS	H	Total
Basement	granite	Status	Positive	10	9	6	5	8	0	2	40
			Negative	3	4	2	1	2	1	1	14
		Total		13	13	8	6	10	1	3	54
		Rate of success (%)		77	69	75	83	80	0	67	74
		Recurrence (%)		24	24	15	11	19	2	6	100
	schist	Status	Positive	2	3	4	2	2	3	0	16
			Negative	3	6	3	0	1	0	0	13
		Total		5	9	7	2	3	3	0	29
		Rate of success (%)		40	33	57	100	67	100	-	55
		Recurrence (%)		17	31	24	7	10	10	0	100
Sedimentary	Sandstone	Status	Positive	3	5	3	2	4	2	4	23
			Negative	5	4	1	2	3	1	2	18
		Total		8	9	4	4	7	3	6	41
		Rate of success (%)		38	56	75	50	57	67	67	56
		Recurrence (%)		20	22	10	10	17	7	15	100
	continental terminal	Status	Positive	0	1	0	0	2	0	1	4
			Negative	0	0	0	0	0	0	0	0
		Total		0	1	0	0	0	0	1	4
		Rate of success (%)		-	100	-	-	100	-	100	100
		Recurrence (%)		0	2 5	0	0	50	0	25	100

3.1.2.2. Types of anomalies

In this study, 3 types of anomalies were identified (CCE, CCL and PC).In the basement terrain, the PC type is the most recurrent with a rate of 71.4%. The CCE and CCL types have substantially equal proportions, 28.92% and 27.71%, respectively. The one with the best borehole success rate (78.3%) is CCL. PC is the anomaly type showing the lowest success rate of 61.1%.

In the sedimentary zone, we notice that the three types of anomalies have roughly the same recurrence rates: 35.56% for CCL, 33.33% for CCE and 31.11% for PC. The recurrence of the other two is 33.33% for the CCE type and 31.11% for the PC type. In this geological terrain, the PC type has the best success rate (71.40%), while the lowest is obtained with the CEC type (60%).

With regard to Table 2, we find in the basement area that the CCL type has the best success rate (83%) in granite terrain. However, the CEC type with success rate of 67% is the most productive on shale. In sedimentary environment, on sandstone, all types of anomalies are below a success rate of 70%. On the continental terminal, all the boreholes were positive (successful).

Table 2: Distribution of Anomaly Types According to Geological Formations and the Status of Boreholes

Geological formations		Settings		Type of anomalies			Total
				CEC	CCL	PC	
Basement	granite	Status	Positive	11	15	14	40
			Negative	5	3	6	14
		Total		16	18	20	54
		Rate of success (%)		69	83	70	74
		Recurrence (%)		30	33	37	100
	schist	Status	Positive	6	3	7	16
			Negative	3	2	8	13
		Total		9	5	15	29
		Rate of success (%)		67	60	47	55
		Recurrence (%)		31	17	52	100
Sedimentary	Sandstone	Status	Positive	8	6	9	23
			Negative	6	7	5	18
		Total		14	13	14	41
		Rate of success (%)		57	46	64	56
		Recurrence (%)		34	32	34	100
	Continental terminal	Status	Positive	1	3	0	4
			Negative	0	0	0	0
		Total		1	3	0	4
		Rate of success (%)		100	100	-	100
		Recurrence (%)		25	75	0	100

3.1.2.3. Types of electrical sounding

There are five types of electrical soundings in basement formations (Q, K, A, H and KH) and four types of sounding in sedimentary formations (Q, K, A and H). In the basement terrain, the H type is the one having the highest recurrence of nearly 45%. It is followed by type A (28 %) and types Q, K and KH with a recurrence of 13 %, 10 % and 10%, respectively. With regard to the sedimentary zone, type H is also the most observed with an occurrence of 45 %. It is followed by types A (24%), K (1 8 %) and Q (13%).

When looking at the distribution according to different geological formations, we notice that in the granite zone of basement terrain of the study area, the type with the most successful rate is H with 20 positive boreholes from the 24 boreholes that were made, representing 83% (Table 3). It is followed by types A (12 positive boreholes out of 16) and KH (3 positive out of 4), representing a success rate of 75% for each type (Table 3). The forms (shapes) having low success rates are Q with 57% (4 positive boreholes out of 7) and K with 75% (1 positive borehole out of 3) (Table3). On the shale, types A and H have the best success rates with 71 % (5 positive boreholes out of 7) and 54% (7 positive boreholes out of 13) (Table 3). They are followed by type Q with a success rate of 50% (2 positive boreholes out of 4) and type K with 40% (2 positive boreholes out 5) (Table 3).

With regard to sedimentary rocks, in sandstone the highest success rate is obtained with type A with a rate of 73% (8 positive boreholes out of 11). The other types indicate the following success rate: 67 % for K (4 positive boreholes out of 6), 47% H (9 positive boreholes out of 19) and 40% for Q (2 positive boreholes out of 5) (Table 3). In the continental terminal, all the types of electrical sounding resulted in positive boreholes, since all the 4 boreholes were positive (successful) (Table 3).

Table 3: Distribution of Survey Types According to Geological Formations and the Status of Boreholes

Geological formations		Parameters		Type of electrical sounding					Total
				Q	K	AT	H	KH	
Basement	granite	Status	Positive	4	1	12	20	3	40
			Negative	3	2	4	4	1	14
		Total		7	3	16	24	4	54
		Rate of success (%)		57	33	75	83	75	74
		Recurrence (%)		13	6	30	44	7	100
	schist	Status	Positive	2	2	5	7	0	16
			Negative	2	3	2	6	0	13
		Total		4	5	7	13	0	29
		Rate of success (%)		50	40	71	54	-	55
		Recurrence (%)		14	17	24	45	0	100
Sedimentary	Sandstone	Status	Positive	2	4	8	9	0	23
			Negative	3	2	3	10	0	18
		Total		5	6	11	19	0	41
		Rate of success (%)		40	67	73	47	-	56
		Recurrence (%)		12	15	27	46	0	100
	Continental terminal	Status	Positive	1	2	0	1	0	3
			Negative	0	0	0	0	0	0
		Total		1	2	0	1	0	4
		Rate of success (%)		100	100	-	100	-	100
		Recurrence (%)		25	50	0	25	0	100

3.1. 3. Hydrogeological parameters and status of boreholes

3.1.3.1. Boreholes depths

The boreholes drilled in the basement terrain and those in the sedimentary zones have almost the same average depth, since the average depth is 71m for the basement terrain and 69 m in the sedimentary zone.

In the granites, the depth of the positive boreholes ranges from 49.5 m to 106 m. The average depth is 69.3 m with a standard deviation of 15.8 m. Negative boreholes were on average deep with an average depth of 83.9 m and a standard deviation of 7.1 m.

With concern to the shale, positive boreholes, with an average depth of 66.0 m and a standard deviation of 14.34 m, are shallower than those in granites. Negative boreholes are on average the deepest of the basement terrain with an average depth of 88.8 m and a standard deviation of 17. 8 m.

Concerning the sedimentary basin, the positive boreholes drilled in the sandstone have an average depth of 61.7 m and a standard deviation of 14.4 m. In this geological formation, the negative boreholes are on average the deepest of the study area with a depth 89.0 m and a standard deviation of 23.5 m. In the continental terminal, the boreholes have an average depth of 71.2 with a standard deviation of 9.4 m.

Table 4: Drill depth statistics for different geological formations

Geological formations		Status of boreholes	Depth (m)			Standard deviation (m)
			Minimum	Average	Maximum	
Basement	granite	Positive	49.5	69.3	106.0	15.8
		Negative	72.9	83.9	90.6	7.1
	schist	Positive	42.5	66.0	101.6	14.3
		Negative	50.4	88.8	100. 5	17. 8
Sedimentary	Sandstone	Positive	46	61. 7	11 1 .5	14.4
		Negative	39.2	89 .0	112.58	23.5
	Continental terminal	Positive	57.5	71.2	78.81	9.4
		Negative	-	-	-	-

3.1.3.2. Borehole yield

The study regarding the yield was conducted on boreholes with a yield greater than 0.4 m^3/ h. The yield ranges from 0.5 to 29.0 m^3/ h.

In the basement terrain, average yield are 5.7 m^3/h and 4.7 m^3/h in granites and shale, respectively. They are more constant than those of the sedimentary basin as their deviations are lower.

The yields in the sedimentary basin are the highest of the study area. Indeed, in sandstone, the average yield is 10.1 m^3/h with a standard deviation of 7.7 m^3/ h. In the continental terminal, the yield is on average 8.4 m^3/ h with a standard deviation of 6.6 m^3/ h.

Table 5: Borehole Yield Statistics for Different Geological Formations

Geological formations		Yield (m^3/ h)			Standard deviation (m)
		Minimum	Average	Maximum	
Basement	granite	0.5	5.7	16. 5	5. 1
	schist	0.6	4.7	14 .0	3.8
Sedimentary	Sandstone	2. 1	10.1	29 .0	7.7
	Continental terminal	2.6	8.4	18. 1	6.6

3.2. Discussion

The forms of anomalies, the types of anomalies and types of surveys identified in the crystalline basement were also observed in other studies in Burkina Faso [18] and in the West African sub-region, especially in Ivory Coast [20] [21] . Also, these anomaly signatures were observed in the sedimentary zone of this study. This findings are the opposites of the model conceptual indicating that the sedimentary formations have a porous porosity allowing the storage and the yield of groundwater in this porous medium [22]. However, this observation can be explained by the nature of the sedimentary formations encountered in the area which are in majority composed of sandstone (more than 90%). In fact, these are indurated and consolidated sedimentary rocks, sometimes metamorphosed, which unconformably overlies the basement rocks [23]. Thus, in these sedimentary formations, several studies have highlighted discontinuities (fractures and lineaments) that are basically found in crystalline rocks [14] [23] [24].

Concerning the failure rates of the boreholes (32.5% in the basement area and 40% in the sedimentary zone), these are slightly better than those observed at the national level of the country (Burkina Faso) in the basement (30-40 %) [8] and in Benin (40 %) [25]. As the sedimentary zone consists of indurated sandstone, the productivity of the aquifers in this formation is low [23]. They owe their aquifer properties from secondary porosity. Water is stored and flows into joints, cracks and fractures [21] [26]. The heterogeneity of the media is the main cause of borehole failure without however omitting the fact that poor borehole drilling and especially the poor borehole siting contribute to this failure. Indeed, borehole siting is very often carried out by geophysical prospecting based on the measurement of resistivity using direct current electrical methods [16]. In Burkina Faso, the common practice is to implement one or more electrical profiles of apparent resistivity of a single line length perpendicular to the major direction of lineaments identified on satellite images. The presence, along the apparent resistivity profile, of more conductive deflections than the rest of the adjacent values is interpreted by practitioners as being the mark of the presence of a wet fracture (the target).In a second step, in order to quantify the thicknesses of the different layers above the target, the practitioner implements one or more electrical soundings to the right of the detected deflections on the profile. According to the results obtained by this electrical sounding, the prospector then sits boreholes in priority order by favouring the sounding points which, once interpreted with a hypothesis of tabularity, present the most important thickness of alteration. Zones of very low resistivity are avoided (but not always) because considered too clayey. Given the high failure rate in the area and even in Burkina Faso, several works, for instance the one by [25], highlighted the limitations of this approach and suggests using two-dimensional (2D)electricalresistivitytomography (ERT). This enable to better appreciate the lateral extension of the structures, contrary to the techniques of electrical profiling and electrical sounding [8] [17] [25]. Moreover, this high rate of borehole failure observed in the sedimentary can also be due to the shallow depths of these boreholes. Indeed, as indicated [23], the aquifers in the zone are often quite deep.

In addition, the four boreholes drilled in the continental terminal are all successful, testifying s the continuity of the geological environment. It is a porous porosity that is often observed in this type of geological formation.

IV. Conclusion

At the end of this study, we find thatthe use of 1D electrical resistivity techniques(electric electrical profiling and electrical sounding) in borehole siting results in borehole failure rate of 32.5% in the basement area and 45%in the sedimentary zone. Therefore, this borehole siting approach seems to be inappropriate in the area due to the complexity of the geological formations. Indeed, the sandstones behave like discontinuous environments.

An alternative to both electrical profiling and sounding would be the ERT which takes into account the vertical and lateral variations of the resistivity anomalies.

V. Acknowledgements

The authors acknowledge the Bureau d’étude SAIRA International for providing them with data.

References

[1]. Paturel, J. E., Boubacar, I., L’Aour, A., & Mahé, G. (2010). Analyses of pluviometric grids and main features of the changes occurring in West and Central Africa during the 20th century. Hydrological Sciences Journal, 55(8), 1281–1288. doi:10.1080/02626667.2010.527846

[2]. Karambiri, H., García Galiano, S. G., Giraldo, J. D., Yacouba, H., Ibrahim, B., Barbier, B., & Polcher, J. (2011). Assessing the impact of climate variability and climate change on runoff in West Africa: the case of Senegal and Nakambe River basins. Atmospheric Science Letters, 12(1), 109–115.

[3]. Carter, R. C., & Parker, A. (2009). Climate change, population trends and groundwater in Africa. Hydrological Sciences Journal, 54(4), 676–689. doi:10.1623/hysj.54.4.676

[4]. Lachassagne, P., & Wyns, R. (2005). Aquifères de socle: nouveaux concepts - Application à la prospection et la gestion de la ressource en eau. Géosciences, 2, 32–37.

[5]. Courtois, N., Lachassagne, P., Wyns, R., Blanchin, R., Bougaïré, F. D., Somé, S., & Tapsoba, A. (2010). Large-scale mapping of hard-rock aquifer properties applied to Burkina Faso. Ground Water, 48(2), 269–283. doi:10.1111/j.1745-6584.2009.00620.x

[6]. Vries, J. J. de, & Simmers, I. (2002). Groundwater recharge: an overview of processes and challenges. Hydrogeology Journal, 10(1), 5–17. doi:10.1007/s10040-001-0171-7

[7]. Diabaté, A.-L. (2013). Caractérisation des paramètres géophysiques en relation avec la productivité de la cible hydrogéologique dans la boucle du Mouhoun au Burkina Faso (Mémoire Master). Institut International d’Ingénierie de l’Eau et de l’Environnement, Burkina Faso.

[8]. Soro, D. D., Koïta, M., Biaou, C. A., Outoumbe, E., Vouillamoz, J.-M., Yacouba, H., & Guérin, R. (2017). Geophysical demonstration of the absence of correlation between lineaments and hydrogeologically usefull fractures: Case study of the Sanon hard rock aquifer (central northern Burkina Faso). Journal of African Earth Sciences, 129, 842–852. doi:https://doi.org/10.1016/j.jafrearsci.2017.02.025

[9]. Kouamelan, A. N., Djro, S. C., Allialy, M. E., Paquette, J.-L., & Peucat, J.-J. (2015). The oldest rock of Ivory Coast. Journal of African Earth Sciences, 103, 65–70. doi:10.1016/j.jafrearsci.2014.12.004

[10]. Lompo, M. (2010). Paleoproterozoic structural evolution of the Man-Leo Shield (West Africa). Key structures for vertical to transcurrent tectonics. Journal of African Earth Sciences, 58(1), 19–36. doi:10.1016/j.jafrearsci.2010.01.005

[11]. Feybesse, J.-L., Billa, M., Guerrot, C., Duguey, E., Lescuyer, J.-L., Milesi, J.-P., & Bouchot, V. (2006). The paleoproterozoic ghanaian province: Geodynamic model and ore controls, including regional stress modeling. Precambrian Research, 149(3–4), 149–196. doi:10.1016/j.precamres.2006.06.003

[12]. Sattran, V., & Wenmenga, U. (2002). Géologie du Burkina Faso. Czech Geological Survey.

[13]. Savadogo, N. A., Nakolendousse, S., & Diallo, S. (1997). Étude comparée de l’apport des méthodes électromagnetiques Max Min et électriques dans l’implantation des forages à gros débits dans les régions de socle cristallin du Burkina Faso. Journal of African Earth Sciences, 24(1–2), 169–181. doi:10.1016/S0899-5362(97)00034-1

[14]. Tirogo, J. Y. (2016). Etude du fonctionnement hydrodynamique de l’aquifère sédimentaire du bassin du Kou au sud-ouest du Burkina Faso (PhD Thesis). Université Pierre et Marie Curie-Paris VI, France.

[15]. Tirogo, J., Jost, A., Biaou, A., Valdes-Lao, D., Koussoubé, Y., & Ribstein, P. (2016). Climate Variability and Groundwater Response: A Case Study in Burkina Faso (West Africa). Water, 8(5), 171. doi:10.3390/w8050171

[16]. Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., & Richard, G. (2005). Electrical resistivity survey in soil science: a review. Soil and Tillage Research, 83(2), 173–193. doi:10.1016/j.still.2004.10.004

[17]. Dahlin, T., & Zhou, B. (2004). A numerical comparison of 2D resistivity imaging with 10 electrode arrays. Geophysical Prospecting, 52(5), 379–398. doi:10.1111/j.1365-2478.2004.00423.x

[18]. Dieng, B., DE HEUSCH KOUASSI, A., & Bakyono, B. A. (2004). Optimisation de l’implantation géophysique des forages en zone de socle au Nord du Burkina Faso.

[19]. Kouassi, A. M., Ahoussi, K. E., Yao, K. A., Ourega, W., Yao, K. S. B., & Biemi, J. (2012). Analyse de la productivité des aquifères fissurés de la région du N’zi-Comoé (Centre-Est de la Côte d’Ivoire). LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2602-7828, (10).

[20]. Coulibaly, A., Lasme, O. Z. de, Youan, T. M., Soro, G., Lasm, T., & Soro, N. (2019). Multidisciplinary approach for a basement aquifer location in Tanda Region, Côte d’Ivoire. Journal of Water Resource and Protection, 11(9), 1111–1128. doi:10.4236/jwarp.2019.119065

[21]. Maréchal, J. C., Dewandel, B., & Subrahmanyam, K. (2004). Use of hydraulic tests at different scales to characterize fracture network properties in the weathered-fractured layer of a hard rock aquifer. Water Resources Research, 40(11), W11508. doi:10.1029/2004WR003137

[22]. Soro, D. D. (2017). Caractérisation et modélisation hydrogéologique d’un aquifère en milieu de socle fracturé: cas du site expérimental de Sanon (région du plateau central au Burkina Faso) (PhD Thesis).Université Pierre et Marie Curie-Paris VI, France.

[23]. Ouédraogo, I. (1994). Géologie et hydrogéologie des formations sédimentaires de la boucle du Mouhoun (Burkina Faso). Doctorat, Université Cheikh Anta Diop, Sénégal.

[24]. Koussoube, Y. (2010). Hydrogéologie des séries sédimentaires de la dépression piézométrique du Gondo (bassin du Sourou): Burkina Faso/Mali (PhD Thesis).Université Pierre et Marie Curie-Paris VI, France.

[25]. Alle, I. C., Descloitres, M., Vouillamoz, J.-M., Yalo, N., Lawson, F. M. A., & Adihou, A. C. (2018). Why 1D electrical resistivity techniques can result in inaccurate siting of boreholes in hard rock aquifers and why electrical resistivity tomography must be preferred: the example of Benin, West Africa. Journal of African Earth Sciences, 139, 341–353. doi:10.1016/j.jafrearsci.2017.12.007

[26] Lachassagne, P., Wyns, R., & Dewandel, B. (2011). The fracture permeability of Hard Rock Aquifers is due neither to tectonics, nor to unloading, but to weathering processes. Terra Nova, 23(3), 145–161. doi:10.1111/j.1365-3121.2011.00998.x

Donissongou Dimitri Soro" Siting of boreholes using one dimensional electrical resistivity techniques in area of geological transition of basement rocks and sedimentary rocks in Burkina Faso" International Journal of Engineering Science Invention (IJESI), Vol. 08, No.10, 2019, PP 30-39