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Contribution of statistical and remote sensing methods to the completion of an accurate piezometric map in sedimentary Kandi basin (North-eastern of Benin Republic, Beninese part of Iullemmeden sahelian basin)

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Abstract

The piezometric map of an aquifer allows to apprehend its hydrodynamic state in a given period, during which this map represents the groundwater dynamic flow, and may for instance allow to know the direction of propagation of a pollutant. The elaboration of piezometric maps is a real issue related to aquifer management. In a contest characterized by a lack of high performance devices to measure elevation essential to have accurate piezometric levels, a new approach based on the use of Digital Elevation Model (DEM) data coupled with statistical methods has been proposed in order to improve the accuracy of piezometric maps. That approach uses essentially the database of IGN-BENIN (coordinates of geodesic marks existing in the survey zone) with an accuracy of 10 cm for the elevations. The use of those methods in sedimentary Kandi basin allowed to obtain a piezometric map, which estimates very well piezometric level values known at measured points, as reflected the values of Nash coefficient (between 0.75 and 1) and RSR (between 0 and 0.5). The groundwater flows globally from the south toward the north, with the River Niger valley and its affluents, in particular River Sota as the main outlet. Piezometric domes are identified in bedrock's border in sectors of Angaradébou westward, of Bensékou and Gando Loukassa southward; another dome less important takes shape at the northeastern end of the basin at Maïlaroukoara. Henceforth, this piezometric map allows to define easily recharge areas located mainly at southern and western borders of the basin. Protection areas could be defined in those sectors for an efficient management of groundwater resources contained in that basin.

Keywords: Kandi, groundwater, piezometry, geodesic mark, DEM

Paper category: Water and Sanitation

INTRODUCTION

Benin uses in majority, groundwater resources for safe water supply to the population. Surface water resources are used in some bedrock area; in that case, water treatment cost is very high (Gbewezoun, 2017). However, poor knowledge of hydrogeological characteristics of fields, heavily compromises exploitation and management at lower cost of groundwater resource for future generations (Boukari, 2007).

The Sedimentary Kandi Basin (BSK) is one among the three sedimentary basins of Benin. BSK is located in the North-East of Benin (Figure 1) and constitutes the Beninese part of the Iullemenden basin. BSK has an area around 8700 km^2 (Achidi et al. 2012). BSK constitutes the main source for safe water supply for the population (around 500 000 inhabitants, INSAE 2016) of North-Eastern Benin (Boukari, 2007). BSK corresponds to the major part of Niger River catchment at Benin scale with its affluents Alibori and Sota (Alidou, 1983).

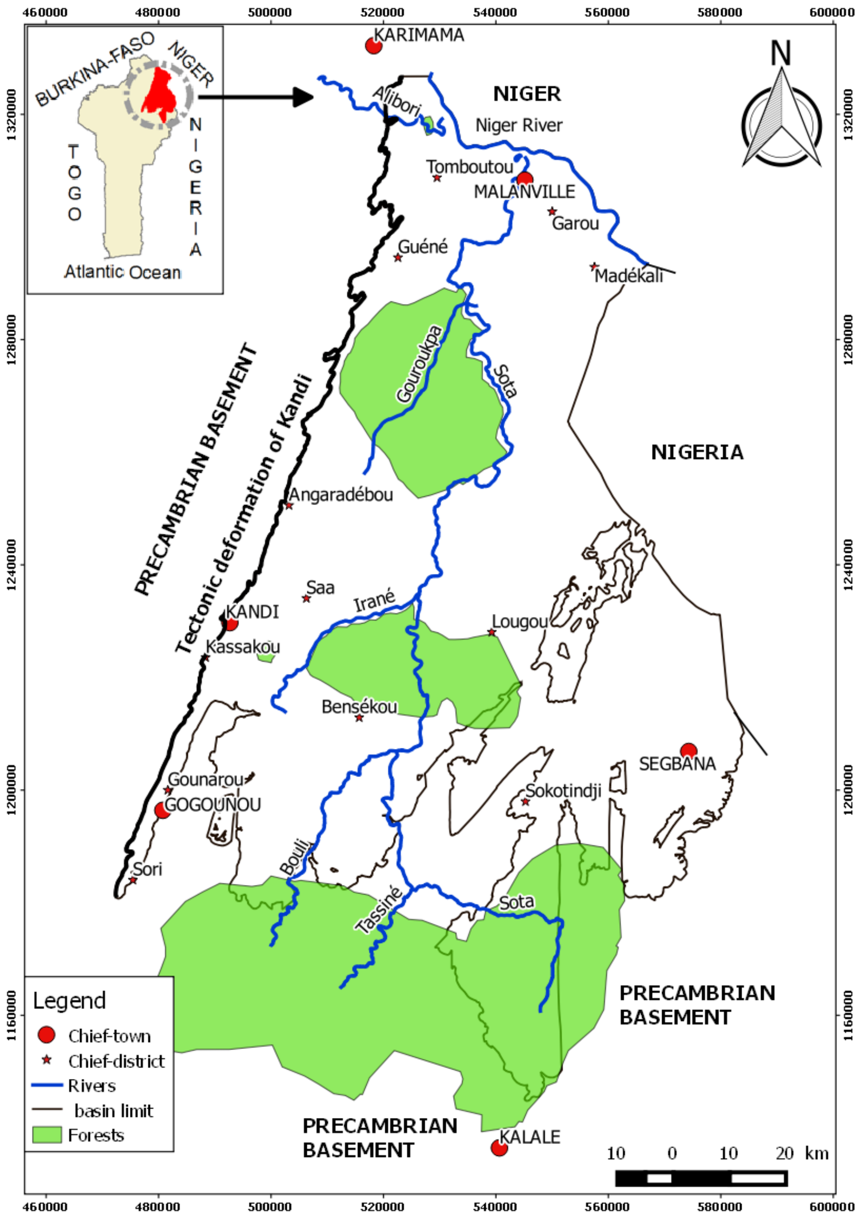

Figure 1: Localization of the sedimentary Kandi basin (BSK)

The climate is predominantly sahelian. Maximum of the mean monthly rainfall is observed in August at Kandi, Malanville and Ségbana (Achidi et al. 2012). On the time scale 1985-2015 at synoptic station of Kandi, the average annual rainfall is 1002.4 mm, the mean annual maximum temperature is 34.70°C and the potential evapotranspiration is 1703.3 mm (Gbewezoun, 2017).

BSK is composed essentially of sandstones and characterized by three superficial layers cut through by hydraulic wells such as: continental Wèrè formation (Cambro-Ordvician), Kandi formation (superior Ordovician to inferior Silurian) and recent formations from Quaternary. These three permeable layers directly superimposed form in this slice of land (around 80 m thick on average), a unique and same superficial aquifer captured by existing exploitation wells and piezometers. This aquifer has thus a simple structure, but made complex by the existence of the Kandi fault and its satellite fractures. Transmissivity varies from very high values (3.08E-02 m²/s) to the ones low (2.99E-05 m²/s), and permeability from high values (1.30E-03 m/s) to the ones moderate (3.37E-06 m/s) (Gbewezoun, 2017).

Why this study?

Dwelling populations use BSK's superficial aquifer for consumption, agricultural and farming needs. Because of that, it is necessary to have deeper knowledge on groundwater resources of BSK, in order to set up a strategy for sustainable and rational management of these water resources to ensure their protection (Gbewezoun, 2017). Hence the aim of this study is to **make a piezometric map in BSK**.

A Piezometric map of an aquifer allows to have an instantaneous view of its status at a specific moment (Gilli et al. 2012). The purpose of piezometric maps is to represent the dynamics of groundwater flow (Michaud et al. 2008) and may for instance allow to know the direction of propagation of a pollutant.

The completion of piezometric maps constitutes therefore a real issue inherent to aquifer management. The actual context marked by: lack of sophisticated equipment for elevation measurements indispensable to have accurate hydraulic head, the great uncertainty of elevation given by navigation GPS, the difficulty to level all points (404) of the measurement of the Static Water Levels (SWL) and the inexistence of differential GPS. Moreover, the primary source of elevation, the topographic maps are very old and the Digital Elevation Model (DEM) available for free or paid download. But it is important to know that presence of error in the elevation of SWL measurement points, can affect significantly the perception of aquifer status, translated for instance by the change of the normal direction of groundwater flow. Hence the proposal of a new approach in order to improve the accuracy of piezometric maps. This approach is based essentially on the statistical correction of elevations extracted from DEM by elevations of geodesic land marks of the National Geographic Institute of Benin (IGN Benin) located in the study area (or near).

METHODOLOGY

The adopted methodology is adapted from Gbewezoun (2017) and can be summarized mainly in 6 steps as it follows:

- **Step 1**: Measurement of Static Water Levels (SWL) with a water level sensor in 404 hand dug wells with large diameter.
- **Step 2:** Measurement of the geographic coordinates (X and Y) of the measurement points with GARMIN GPS. But Z of GPS has not been used because of its low accuracy.
- **Step 3**: Extraction of elevation of geodesic land marks of IGN Benin (with the "Point sampling tool" of QGIS) from six DEM downloaded from ftp://srtm.csi.cgiar.org and http://gdex.cr.usgs.gov.
- **Step 4**: Statistical correction of extracted elevations from DEM by elevations from land marks: we have compared elevation extracted from the six DEM with the ones from IGN based on different criteria: Coefficient of determination R^2, standard deviation of estimation error σ_e (Bois et al. 2007), RMSE-observations standard deviation ratio ***RSR*** (Moriasi et al. 2007), and Nash-Sutcliffe Efficiency ***NSE*** (Nash and Sutcliffe, 1970). These coefficients are in Table 1, with a and b, characteristics of regression equation. Based on the works of Rexer and Hirt (2014), the source CGIAR-CSI v4.1 90m x 90m, is the most suitable in our case. Figure 2 presents correlation graph between elevation

values from IGN and the ones from CGIAR-CSI v4.1 90m x 90m. Equation (1) from regression line (figure 2) allows to correct elevation of the SWL measurement points extracted from DEM in our study area.

$$Z = 1.0003593\ \mathbf{Z\_CGIAR\_CSI\_90} - 1.7109479 \qquad (1)$$

Error! Digit expected.Error! Digit expected.

Table 1: Comparison parameters of IGN elevation values and the ones extracted from six DEM

	a	b	R²	σ_e	RSR	NSE
Z_IGN versus Z_ASTER_30	0.9887233	7.3013982	0.9925098	5.4954735	0.1063391	0.9883594
Z_IGN versus Z_NASA_30	0.9978592	-1.4143238	0.9934014	5.1580048	0.0864111	0.9923135
Z_IGN versus Z_NGA_30	0.9978592	-1.4143238	0.9934014	5.1580048	0.0864111	0.9923135
Z_IGN versus Z_CGIAR-CSI_90	**1.0003593**	**-1.7109479**	**0.9932679**	**5.2099357**	**0.0847172**	**0.9926119**
Z_IGN versus Z_NASA_90	1.0003593	-1.7109479	0.9932679	5.2099357	0.0847172	0.9926119
Z_IGN versus Z_NGA_90	0.997519	-0.8842161	0.9926931	5.4278158	0.0881146	0.9920075

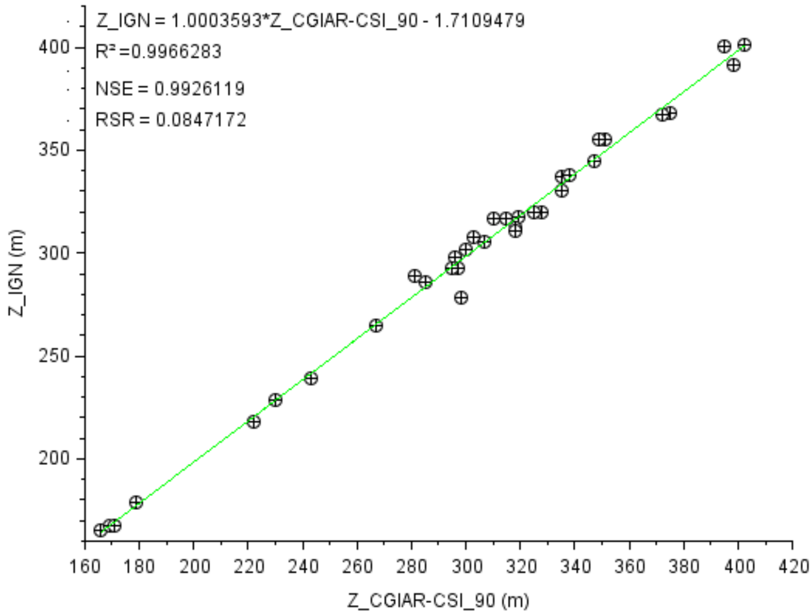

Figure 2: Correlation graph between elevation values from IGN and the ones from the source CGIAR-CSI v4.1 90m x 90m

- **Step 5**: Calculation of the piezometric level H of SWL measurement points with elevation corrected and completion of the piezometric map. The value of piezometric level is obtained by the followed formula (Castany, 1982):

$$\mathbf{H = Z - SWL} \qquad (2)$$

With: H (m) the piezometric level; Z (m) the elevation of the measurement point and SWL (m) the static water level reported to the land surface.

Completion of the piezometric map requires variogram calculation (Figure 3). Journel and

Huijbregts (1978) recommend to estimate the variogram till distances about half of the characteristic length (around 65 km in this study) of the study area. In order to evaluate variogram adjustment pertinence, we have calculated Nash-Sutcliffe Efficiency (**NSE = 0.99**) as Lawin (2007). In the same framework, Gbewezoun (2017) has used RSR (**RSR = 0.06**) criterion developed by Moriasi et al. (2007).
Kriging of piezometric level ***H*** allows to obtain a piezometric map after the choice of power-type variogram model of which the formula is:

$$\boldsymbol{\gamma}(\mathbf{h}) = 110 + 5.15 * 10^{-04} * \boldsymbol{h}^{1.4} \quad (3)$$

Where **h** is distance between two points.

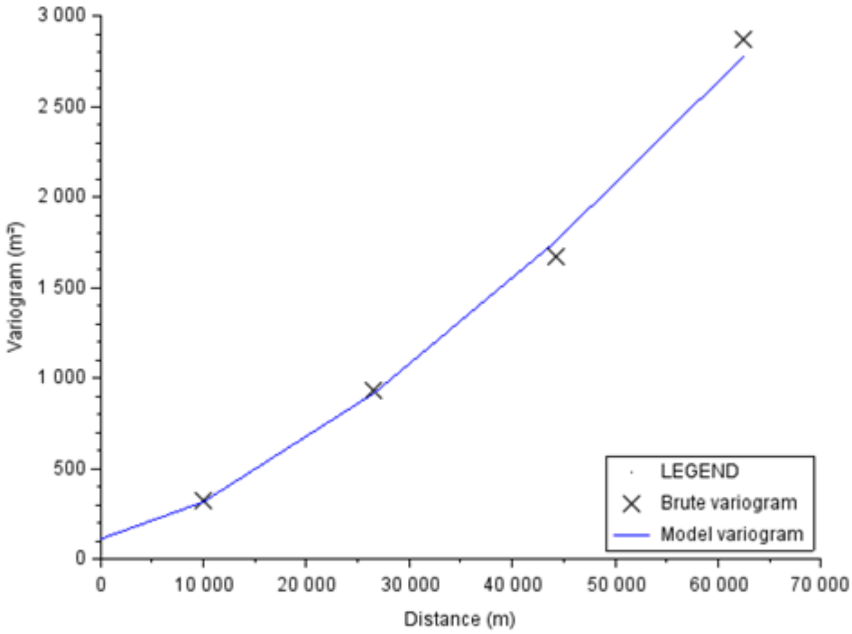

Figure 3: Adjustment of variograms for piezometric levels

- **Step 6:** Comparison of piezometric level values known and the ones estimated by kriging (**NSE = 0.99** and **RSR = 0.10**) and Incertitude analysis: The elevation values Z are accurate within 10 cm (Bah, 2014) and SWL values are accurate within 5 cm (Lawson et al. 2017); we could consider that piezometric level values ***H*** are accurate within 15 cm.

Through these steps the software used are QGIS 2.8.3, SCILAB 5.5.2 and SURFER 11.0.

RESULTS AND DISCUSSION

The adopted methodology allows to obtain relevant results. At one hand, the model variogram chosen, the power-type fits very well ($0.75 \leq$ NSE ≤ 1 and $0 \leq$ RSR ≤ 0.50) to the brute variogram. At the other hand, the estimated values of piezometric level fit also very well ($0.75 \leq$ NSE ≤ 1 and $0 \leq$ RSR ≤ 0.50) to the ones known for the measurement points (Gbewezoun, 2017).

On the piezometric map made for the month of August 2016 (high water period), the piezometric levels vary from 150 m northward to 350 m around southward (Figure 4a). Confidence regions of the map have colored frame from green to yellow for low interpolation error, and the regions with colored frame from orange to red have high interpolation error (Figure 4b). The piezometric map obtained allows to distinguish recharge and discharge areas for the superficial aquifer of BSK. Thus, edge-zones of south (Bensékou and Gando Loukassa), west (Angaradébou) and north-east (Maïlaroukoara and neighborhood) of the basin corresponds to recharge areas, whereas the northern part bordering Niger River, corresponds to the discharge area of the aquifer. The regional groundwater flow is therefore oriented south-north, but Sota River

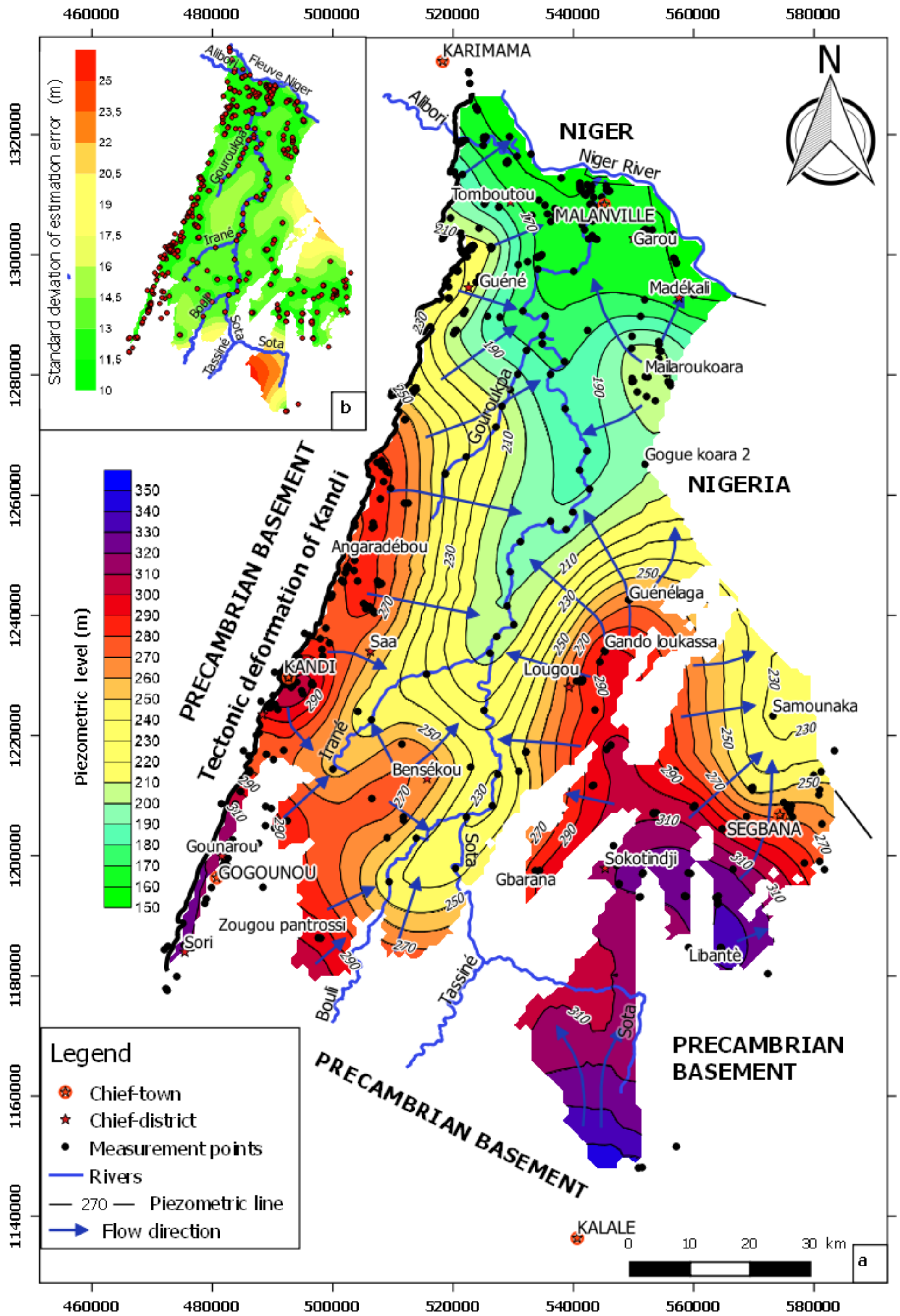

Figure 4: Piezometric map of sedimentary Kandi basin for august 2016 (high water period) (a) standard deviation of estimation error (b)

and its affluents, which drain in general the aquifer, better influence the flow of the regional direction. The same applies locally regarding Gbarana - Gando Loukassa - Guénélaga horst that constitutes then a drainage divide of groundwater resources. The decreasing of the piezometric level from south toward north and the shape of equipotential lines near Sota River indicate that the global groundwater flow is carried out toward Niger valley at the north under the influence of Sota River. On the western contact of the basin with bedrock, groundwater flow is carried out from west toward east reflecting recharge in these areas. These recharge edge-zones were not really highlighted by the piezometric map made by Kpegli et al. (2015). The piezometric domes correspond to the recharge areas, hence must to be put under restriction of activities that can jeopardize the aquifer quality. Whereas the depression zones is more appropriate for intensive pumping of the aquifer (Gbewezoun, 2017).

In the framework of the location of safe water supply system (and related needs) for the dwelling inhabitants, the piezometric map allows to identify three great hydrodynamic for the superficial aquifer of BSK. They are classifying from the highest interest to lowest like it follows (Castany, 1982): favorable type for wells implantation (Niger valley and toward south-western of the basin in the neighborhood of Bensékou) and dubious type for wells implantation (the north-eastern region near Maïlaroukoara and the south-eastern region where are located bedrock outcrops).

The obtained piezometric map is an essential tool for groundwater management. This associated to a spatial repartition of hydrodynamic parameters, SWL map and the thickness map of the aquifer could be a very powerful toolkit during decision making by the local and governmental authorities, financial and technical partners. Moreover, this will encourage to the achievement of the Sustainable Development Goals in safe water sector Goals at BSK scale (Gbewezoun, 2017).

CONCLUSIONS

The new approach applied allows establishing a piezometric map of the sedimentary Kandi basin. With this map, the direction of groundwater flow has been defined in the area of interest. Groundwater flows globally from the South toward the North (Niger valley) under the influence of Sota River and its affluents. Furthermore, the map established is an indispensable tool in groundwater resource management, guarantee of access to water for the dwelling inhabitants. Also, the recharge area of the superficial aquifer of BSK has been delineated based on this map established. The knowledge of these recharge areas will be very useful for groundwater resource managers during the definition of aquifer protection areas. Finally, the piezometric map of the sedimentary Kandi basin established, allows the estimation of aquifer capacity in order to optimize its exploitation for safe water supply for local communities.

Works are still in progress in order to refine the methodology used. The recent topographic maps in actualization at the national scale in Benin will also be taken into account during the process of improvement of the piezometric map already established.

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Hydrogeochemical characterization and study of contaminant transfer in groundwater resources of Kandi basin (North-eastern of Benin Republic, Beninese part of Iullemmeden sahelian basin)

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Abstract

Groundwaters major ion hydrochemistry from Kandi sedimentary basin aquifer system was used to identify the natural and anthropogenic processes that control the mineralization. The groundwater resources of this basin have low to high mineralization. These groundwaters relevant distinct dominant chemical water-type namely Ca-Cl and Ca-HCO3, are influenced primarily by water-rock interaction reactions. This is silicate minerals hydrolyse which has a very important role in the basin groundwater mineralization. Water geochemistry has shown the Kandi basin aquifers vulnerability opposite to surface pollution. The anthropogenic process also plays an important role in these waters salinization. These waters are heavily polluted by nitrate ions with a concentration up to 249 mg.L^{-1} *which is widely above the standard (45 mg.L*$^{-1}$*) in Benin. This pollution is underlined by the use of chemical fertilizers and agricultural inputs in crops areas, septic tank of toilets and garbage in urban areas. The soil permeability coefficient at the sampling sites varying from 9.96 .10*$^{-5}$ *to 3.06 .10*$^{-3}$ *m.s*$^{-1}$*, is determined by the sieve analysis method. The contaminants transfer to groundwaters depend of water table depth, the unsaturated zone permeability, the physical properties of the contaminants and the recharge rate.*

Keywords: Benin, Kandi basin, groundwaters, anthropogenic pollution, mineralization, contaminants

Paper category: Water and Sanitation

INTRODUCTION

All over the world, the pressure on water resources and in particular on groundwater resources is increasing, mainly due to increasing demand and the degradation of water quality. Widespread access to drinking water, irrigation, urban expansion, industrial development and tourism all increase these pressures.

In Benin, because of their better quality, groundwater is the most used to supply drinking water to populations, especially in sedimentary environments. In the Kandi Sedimentary Basin (BSK), located in the North-East of Benin, populations are supplied with drinking water from wells and boreholes. The aquifer of the Kandi basin is in fact the source of drinking water in the north-eastern part of the country, encompassing six (06) municipalities with approximately 200,000 inhabitants (Boukari, 2007). These are the municipalities of Kandi, Malanville, Ségbana, Gogounou, Karimama and Kalalé. In this basin, most populations use groundwater whose chemical quality depends on the geochemical nature of the reservoir rocks (Alassane Zakari, 2017).

The degradation of this resource's quality through the proliferation of different sources of pollution (fertilisers and pesticides, untreated waste water discharges, uncontrolled solid waste discharges, mining, urbanisation, etc...) constitutes a threat as important as that linked to the quantitative imbalance. This work aims to analyze the geochemical and anthropogenic processes responsible for the mineralization of groundwater in this basin and the transfer of contaminants through the unsaturated zone.

Study area

The study area (Figure 1) is geographically located between latitudes 10°12' N and 12°8′ N and longitudes 2°45′ E and 3°46′ E and covers approximately 8700 km^2 (Achidi et al., 2012). It is a part of transboundary Iullemeden basin which is a shared sedimentary basin between Benin, Nigeria and Niger basically (West Africa). This basin is known as Sokoto basin in Nigeria, Iullemeden basin in Niger and Kandi basin in Benin. The topography in the study area varies between 160 (around Karimama township) and 410 meters (around Kalalé township) (Kpégli et al., 2015). High altitude values are observed in the southern basin and these values decrease gradually toward the northern basin. The basin of Kandi is bordered in the north by Niger Republic, in the south by the basement rocks, in the west by the regional fault of Kandi and in the east by the federal republic of Nigeria (Achidi et al., 2012).

The area of study belongs to the Sahelian region with a unimodal rainfall distribution. It is characterized by one rainy season (from mid-April to October) and one dry season (from November to mid-April). The mean annual rainfall recorded at Kandi meteorological station (from 1985 to 2015) is 1002.4 mm, with temperature which varies between 25.5 °C to 32.9°C (from 1985 to 2015). The annual mean potential evapotranspiration is 1703.3 mm which exceeds the annual rainfall (Alassane Zakari, 2017).

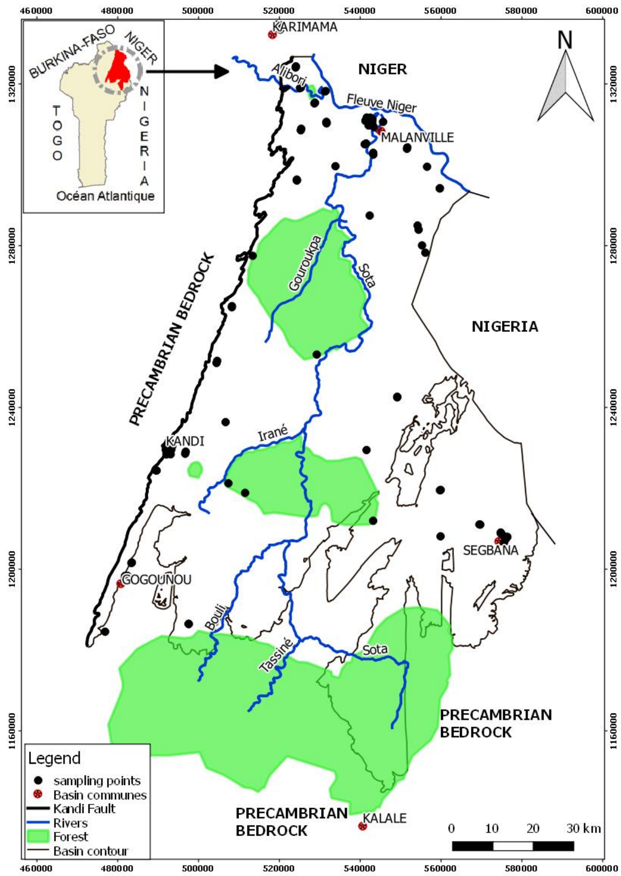

Figure 1: Location map of the study area showing sampling points

In hydrological terms, Niger River is the biggest river that exists in Kandi basin. It has two tributaries in the basin that are from West to East Alibori (seasonal flow) and Sota (permanent flow).

In terms of geology, Kandi basin is a continental basin, of Paleozoic to Secondary age, with Tertiary relics (Boukari, 2007). This basin is characterized by different geological formations. At the base, the conglomeratic formation, called Wèrè formation; the Kandi formation constituted by conglomerates, sandstones and silty clay; Sendé formation, whose deposits are essentially constituted by conglomerates at the base and ferrugineous sandstones at the top; the Continental Terminal formations, constituted by conglomerates, sandstones and clays and the Quaternary formations.

There is also an aquifer system with two-level such as: Cambro-Ordovician aquifer which constitutes the lower aquifer, and the upper aquifer consisting of Ordovician Terminal to Silurian and Quaternary aquifers (Alassane Zakari, 2017).

METHODOLOGY

A total of 109 samples were collected from wells and boreholes throughout the basin, 49 in November and December 2013 and 60 in April 2016. The location of the sampled wells and boreholes is shown in Figure 1. Drilling is purged with a manual or motorised pump until stabilisation of pH, electrical conductivity and temperature is achieved before doing measurements and taking samples. During the water sampling campaigns, measurements such as electrical conductivity, temperature, pH and total dissolved solids are carried out on-site using the WTW 340i conductivity meter and pH meter. The geographic coordinates were taken by a GARMIN GPS. Water samples are then collected and stored in high density polyethylene bottles with caps of 1000 ml for major ion analysis.

During the last campaign, sediment samples were collected from the unsaturated zone at different depths at household garbage dumps. Five sites identified in the cities of Malanville and Kandi, 33 sediment samples, are concerned for the study of nitrate transfer to the water table. The soil sampling was done through an exploration well, every 0.5m.

Chemical analyses concerned major elements (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, Cl^{-}, SO_4^{2-}) and nitrogenous minerals such as NO_3^{-}, NH_4^{+}, NO_2^{-}. The analyses were carried out by the spectrophotometric method at the "Laboratoire d'Hydrologie Appliquée" (LHA) at University of Abomey-Calavi (Benin) and chromatographic method at the Laboratory of Radio-Analysis and Environment (Sfax, Tunisia).

The precision of the device is about 2%. The overall ion detection limit is 0.04 mg/l. The HCO_3^{-}, CO_3^{2-} ions were analyzed by titration with 0.1 N HCl acid.

The ionic balance was calculated to check the quality of chemical analyses especially of major elements using the following formula according to Freeze and Cherry (1979):

$$E(\%) = 100\ x\ ((\sum r_{cations} - \sum r_{anions})/(\sum r_{cations} + \sum r_{anions}) \qquad (1)$$

dwith r the concentrations of ions expressed in milliequivalents per litre.

For all samples analysed, the analytical error is between -5% and 5%, which means that the results of the laboratory analyses are valid for the interpretations.

In the laboratory of the Department of Earth Sciences (DST) at University of Abomey-Calavi (Benin), the soil samples were passed through a sieve column after washing to remove the fine fraction and drying in the oven, in order to determine the different particle size fractions. Leachate extraction for nitrate analysis was carried out using distilled water (Ure, 1996). This type of extraction can be used to simulate natural soil conditions. It must be recognized that, to some extent, the choice of extraction methods is dictated by the equipment available in the laboratory.

The data accumulated during the various works allowed to produce geochemical diagrams of the major elements. According to the nature of the data and depending on the type of result required, a specific processing tool has been adapted.

RESULTS AND DISCUSSION

Groundwater hydrochemical characterization of the Kandi basin

Groundwater temperature varies between 29 and 34.1°C with an average of 31.15 ± 0.16°C. The pH is between 5.02 and 8.31 with an average of 6.93 ± 0.10. These waters are slightly aggressive. The conductivity values recorded during measurements vary from 90 to 3070 $\mu s.cm^{-1}$ with an average of 767.70 ± 84.60 $\mu s.cm^{-1}$. These waters show low to excessive mineralization according to the classification of Potelon and Zysman (1993).

In order to determine the water types, the chemical compositions of the water samples analyzed were positioned on the Piper diagram as shown in Figure 2, nitrate ions are taken into account in this diagram because of their relative abundance in some water points. Two groundwater types are meanly characterized. These are Ca-HCO3 water-type (23 samples) and Ca-Cl water-type (21 samples). Na-HCO3 and Na-Cl water-type are minority. These results confirm those of Kpégli et al. (2015). The chloride ions present in the waters of the Kandi basin seem to come from human activities.

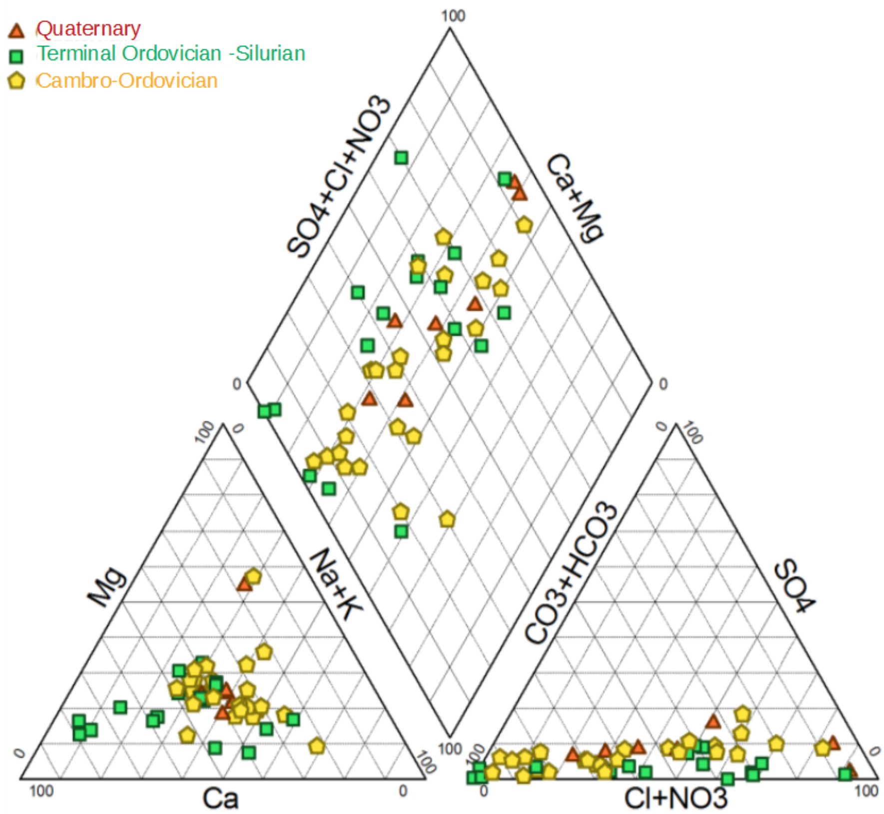

Figure 2: Piper Diagram showing chemical compositions of groundwaters in the Kandi basin

The predominance of calcaferous water-type comes not only from the limestone nodules underlined by Alidou (1983), but also from the alteration of the feldspathic minerals of magmatic and metamorphic rocks (horsts and buried blocks) found in the basin.

The ternary diagram Ca-5*Mg-10*Si (molar) (Figure 3) can be used to identify the lithology of the rocks in which water has circulated (Tossou, 2016). This diagram suggests that groundwater mineralization is mainly derived from hydrolysis of mafic rocks (which contain high concentrations of magnesium and iron), and to some lesser extent silicate minerals from sandstone, crystalline and crystallophyllian rocks.

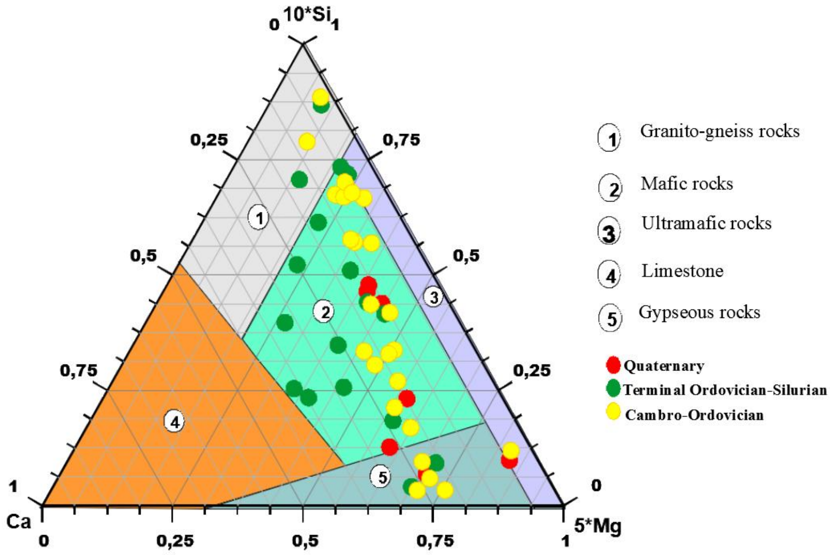

Figure 3: Simplified ternary diagram Ca-5*Mg-10*Si to identify main lithology involved in water mineralization

Statistical study in the Kandi Basin

Principal Component Analysis (PCA) was performed to better discriminate among the hydrogeochemical phenomena contributing to the mineralization of the groundwater.

The first two axes explain 85. 74% of the total variance (Figure 4) which is significant. All the variables were first normalized to minimize weighting effects. The F1 axis which represents 71.78% of the total variance explains the global mineralization of water because it is correlated to the electrical conductivity, calcium, magnesium, bicarbonate, nitrate, sulfate, chloride, sodium and potassium. This means that it is these elements that participate in the mineralization process. In this grouping, the association of nitrate, chloride, potassium, calcium, and sulfate ions corresponds to the anthropogenic pole of water mineralization. Therefore, a significant proportion of the above ions come from human activities: it is the case of nitrate ions. Thus, the F1 component explains both the impact of human activities and the water-rock interaction in the overall mineralization of Kandi's groundwater basin. These results are consistent with those of Ndembo Longo (2009).

The factor 2 explains 13.96% of the total variance (Figure 4). It is determined by SiO2 and the pH, which expresses the influence of silicate minerals in water mineralization. SiO2 is not correlated with the other elements. This is partly explained by the non predominance of silicates in the overall mineralization.

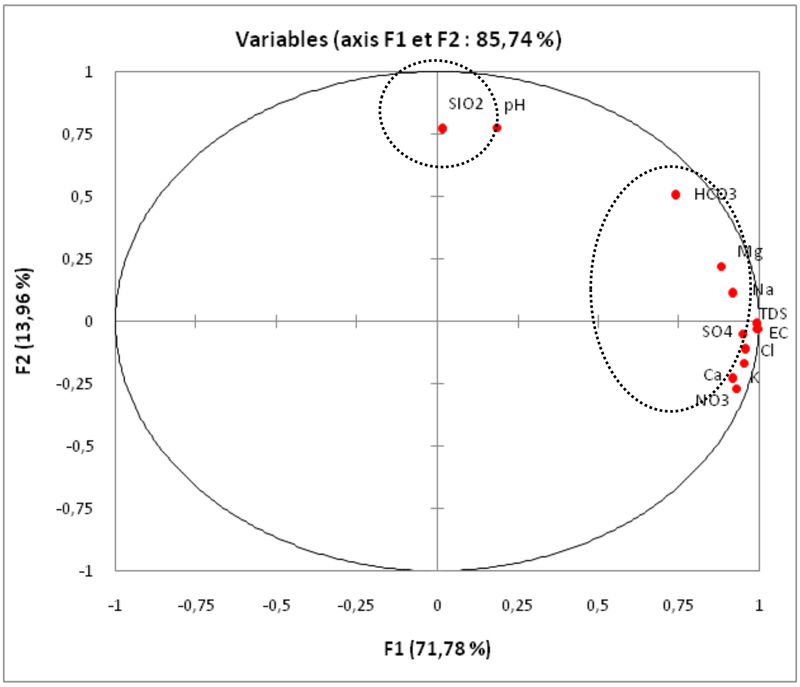

Figure 4: Groundwater PCA of the Kandi Basin

Groundwater chemical pollution assessment in the Kandi basin

Nitrate concentrations range from 1.7 to 249.2 mg/L with an average of 58.82 ± 8.25 mg/L for the water samples analyzed. This variation in concentration shows that 43.33% of the points sampled, have water concentrations that exceed the Beninese standard of 45 mg/L. Knowing that the constituents of the rock matrix do not contain nitrogen elements. Their presence is linked to the impact of human activities. These results confirm those of Kpegli et al. (2015) and Assouma (2011).

Nitrites range from 0 to 30 mg/L with an average of 3.07 ± 0.52 mg/L. In total, 35% of the points sampled, have nitrites concentrations that exceed the Beninese standard of 3.2 mg/L. Consumption of water rich in nitrites may cause oxidation of hemoglobin to methemoglobin in infants (Assouma, 2011).

The ammonium concentration in the basin groundwater ranges from 0 to 141 mg/L with an average of 10.68 ± 2.95 mg/L. A total of 36.67% of samples have their water rich in ammonium, exceeding the Benin standard of 0.5 mg/L, which can also lead to methemoglobinemia in infants. It is a mineral compound that enters the degradation cycle of organic matter. The same observations were made by Assouma in 2011.

Contaminant transfer studies of the unsaturated zone in the Kandi basin

The permeability coefficients determined in the area vary from $9.96.10^{-5}$ to $3.06.10^{-3}$ $m.s^{-1}$. The formations of the Kandi sedimentary basin are therefore generally from permeable to semi-permeable type as a whole, except for a few locations where impermeable formations are found on the surface, as is the case at site 1 in the Wollo district of Malanville.

Overall Kandi's sedimentary basin has a sandy and clayey-sand zone, except in a few places where clays are present (Figure 5).

The graphs below (Figure 6) illustrate the variations in nitrates contents as a function of depth in the Unsaturated Zone (only site 1 is presented in this case). There are strong accumulations of nitrates on the surface with a progressive decreasing as we move towards the saturated zone. This progression of nitrate ion rates in Unsaturated Zone appears to be related to the lithological nature of the same area. However, clay levels seem to be the barriers that slow down the infiltration of water and therefore the transfer of nitrate ions. This is explained by the influence of soil permeability.

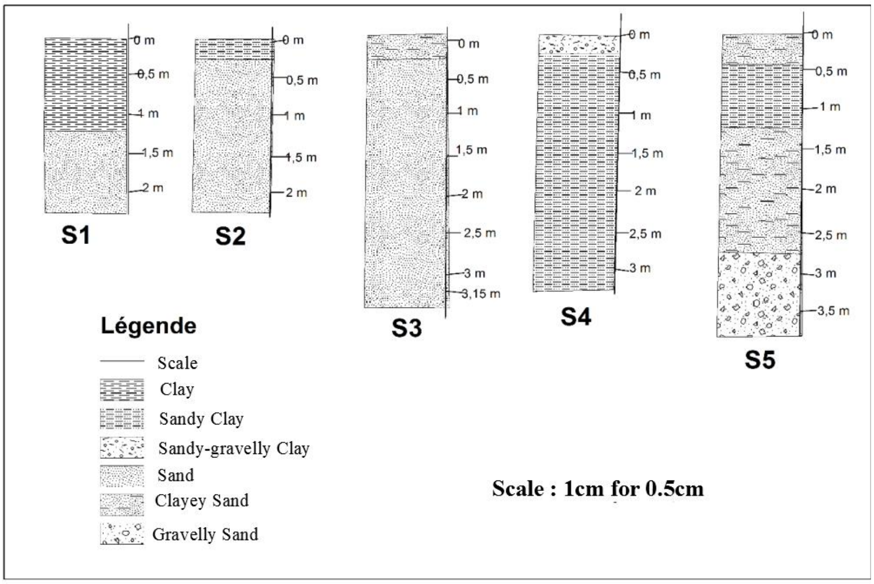

Figure 5: Stratigraphic logs of the different soil sampling sites

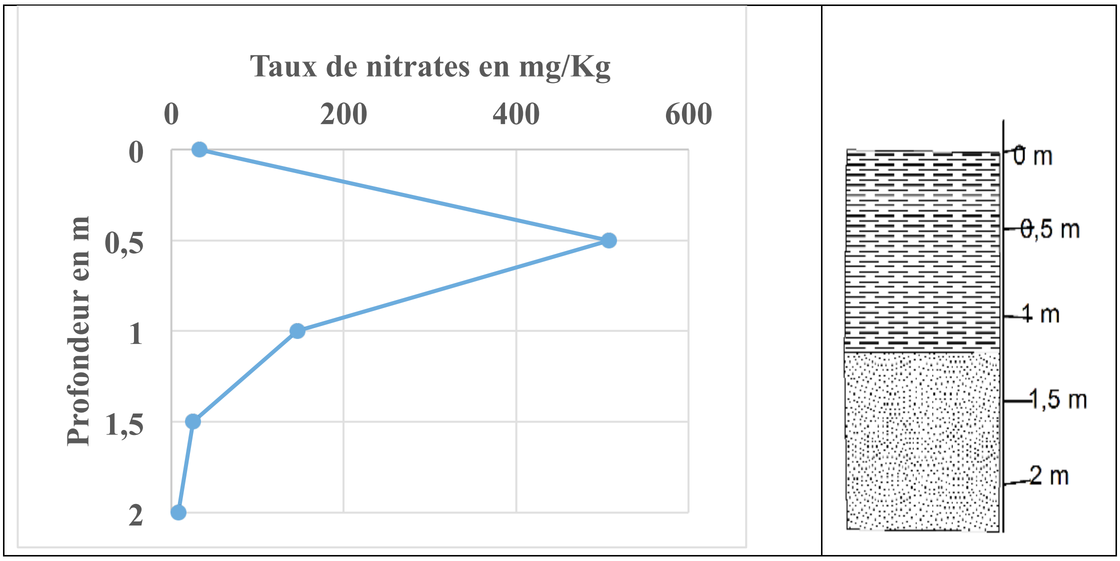

Figure 6: Nitrates transfer monitoring in the Unsaturated Zone at site S1

CONCLUSIONS

This hydrogeochemical study was able to provide new data to qualitatively evaluate the groundwater in the Kandi aquifer system and to highlight the main processes responsible for its mineralization. Groundwaters are low to highly mineralized with electrical conductivity values varying between 90 and 3070 mg/L with an average of 767.7 ± 84.6 mg/L. The groundwaters have mainly two water-types which are Ca-HCO3 and Ca-Cl. The detailed examination of the diagrams showed that the acquisition of the saline load of groundwater results mainly from the interaction of water with the surrounding formations. In addition to these natural mineralization processes, human activities have also played a significant role in the mineralization and contamination of Kandi's groundwater basin. Indeed, the relatively high nitrates concentrations recorded reflect the significant influence of the intensive use of chemical fertilizers and pesticides by farmers to enrich the soil and especially household wastes. The process of transferring pollutants (nitrates) to groundwater in the area depends on the depth of the water table, the permeability of the unsaturated zone, the physical properties of the contaminants and the recharge rate of surface water. However, clay levels are barriers to contaminant transfer.

Acknowledgements

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USING REMOTE SENSING AND GIS TECHNICS FOR FRACTURES AQUIFERS IDENTIFICATION IN ZOU BASIN (CENTRE BENIN)

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Abstract

In Zou catchment, the aquifers serving for drinking water supply are 80% fracture reservoirs. The current survey uses firstly images of the European satellite SENTINEL-1, Japanese PALSAR and American LANDSAT 8 to extract geological lineaments. Secondly, borehole data from Water Resources Direction (DGRE) and geologic maps of OBEMINES have been used to characterize the fracture network aquifers. Filters like Gauss, Frost and Sobel are applied and it turns out that the main directions of the lineamets are N10, N60, N110 and N150. The classification of the borehole flow according to CIEH recommendation, reveals that main direction's lineaments and some neighbour classes such as N70, N90 and N170 are highly productive (more than 1320.86 gal.h-1). Whatever the geologic context, more than 85% of boreholes has very low to low flow (less than 660.43 gal.h-1). The rate of positive borehole is 30% in basalt, granite, and rhyolite fracture aquifers and 40% in terrigenous deposit, quartzite and in Kandi fault's mylonite. In spite of those low productivity values, the groundwater potential remains very useful for drinking water access in Zou basin.

Keywords: Drinking water, basement, lineaments, fractures, productivity, Zou catchment, mapping, digital image analysis.
Paper category: Water and Sanitation

INTRODUCTION

Groundwater is a natural and vital resource for adequate and economical drinking water supply both in urban and rural areas (Magesh & al., 2012). Except low groundwater potential areas, drinking water supply in Benin is essentially drawn from aquifers (Boukari, 1998). An estimation of all water demand in 2025 shows that less than 18% of groundwater available and less than 40% of surface water will be required in the country (Vision Eau 2025, 1999). Therefore, for the coming years, there is generally no concern about water scarcity (Boukari, 2002).

Remote sensing techniques through lineaments extraction play a key role in Hydrogeology because of the possibility to exhibit geological fractures that shelter groundwater (Das, 1990). Furthermore, in basement areas, structural and linear element enhancement from images lead to better geological accident mapping (Youan Ta et al., 2008). In this geologically complex areas, different type of satellite images (Landsat, RSO of ERS, Radarsat, SRTM…) and aerial photos are processed in that perspective for multiple purpose such as groundwater potential evaluation, fractures network identification etc… (Boukari, 1982; Kouamé et *al.*, 2009; Yao et *al.*, 2014; Ndong et al., 2014; Assatse et *al.*, 2016). These Remote sensing data offer an appropriate spectral and spatial resolution for better hydrogeological surveys (Brunner et al., 2007).

In this study, the catchment fracture map is updated in one hand and the hydrodynamic parameter analysed in order to facilitate borehole implantation for drinking water supply. Fractured aquifers recognition on the field during future drinking water supply campaigns can be facilitated and the percentage of positive boreholes increased using the result made available from this study.

METHODOLOGY

Fractures map update require several image processing techniques and interpretations.

Study area

Zou catchment is located between latitudes 7° and 8°33’ North and longitudes 1°35’ and 2°30’ East. At the latitude of Doume-Lakoun till Kitikpli, 2.2 % of the 8491 square kilometer basin covers the Togolese territory. Communes such as Savalou (31.0%), Bante (24.7%), and others are mainly represented. The area is characterized by an intermediate climate between the subequatorial climate of the coast and the Sudano Sahelian one of the North part of Benin (Boko, 1988; Bokonon-Ganta ; 1987 ; Afouda, 1990, Houssou, 1998). It is relatively well watered. The basin represent essentially an area where the influences of the monsoon from South-West and the continental tradewinds also known as harmattan of the North-East are blurred. The rainfall evolves from 18.3 mm at the end of the year to 172.9 mm in July. Many studies such as Alidou et al., (1975), Boukari (1982) and others showed the high geological complexity of the area at the local and regional scale. Hence, the lithology and structure have been modified by several phases of deformation, metamorphism and magmatism. The basin surface is shaped by very old rocks dating from Precambrian (granite-gneissic basement) era.

Data collected

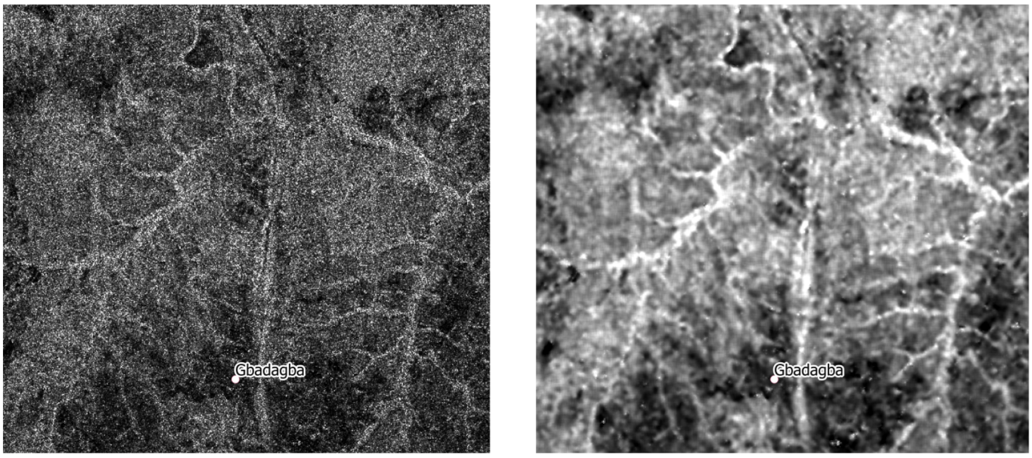
Two scenes of 30 m resolution in multispectral mode and 15 m in panchromatic mode have been downloaded on the website http://glcf.umd.edu/data/. Spectral resolution of the Operational Land Imager-Thermal Infrared Sensor (OLI-TIRS) offers a possibility to evaluate the efficiency of the visible and infrared bands for lineaments identification in basement areas. The paths and rows are respectively 192-54 and 192-55 acquired on 2014-12-28. The band L of PALSAR and band C of Sentinel-1 are downloaded to complete the visible and infrared bands as the goal of the study is to find the right band for lineament extraction. The radar bands have two polarisations (VH and VV) which make the analysis wider. These images are respectively from Advanced Land Observing Satellite-2 (ALOS-2) mission or Daichi-2 which is a next step of the radar (L-SAR) sensor launching program realised by the Japanese Aerospace Exploration Agency and the Copernicus initiative executed by the European commission and European Space Agency (ESA). A database is created from Pira-Savè and Abomey-Zagnanado geological map sheet realised by OBEMINES (1989). Borehole data are obtained from the national database named Integrated Database (BDI) version 2015.

Lineaments identification

A lineament is any kind of linear feature which can be found in a satellite image or aerial photography (Figure 1 and 2). The features are geological limits, slope ruptures, the river path, manmade structures and fracture network areas (Biémi, 1992; Meijerink et al. 2007, Bruning et al., 2009).

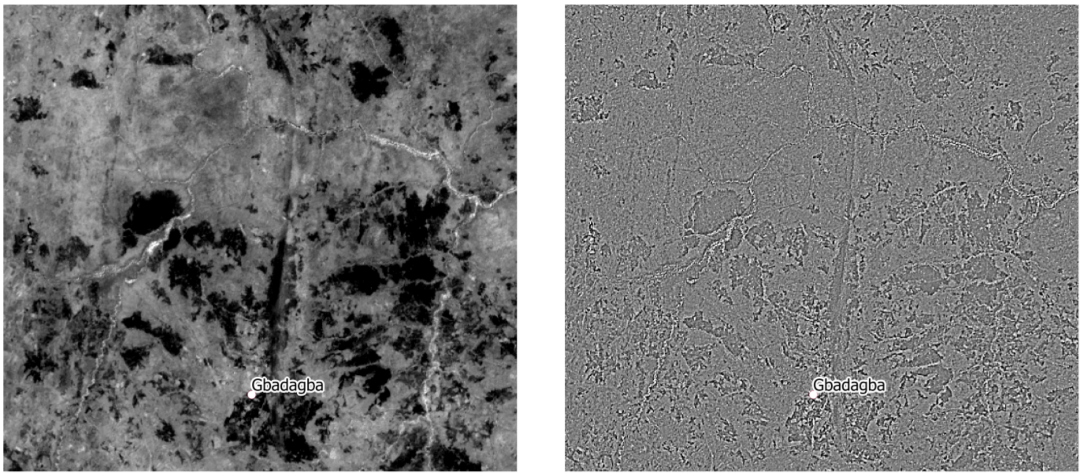
Let’s mention that lineaments detection filters are separated in three categories: gradient filters like Sobel and Prewitt, laplacian filter LOG and optimal filter Canny. Differentiation, smoothing and labelling are the operations necessary to get lineaments (Rahnama & Gloaguen, 2014).

For the electro-optical sensor (LANDSAT-8) images enhancement, the Gaussian filter is used like the Frost filter for radar images referring to the method used by Rahnama & Gloaguen (2014).



PALSAR band L image　　PALSAR filtered band L image (Frost filter)

Figure 1: PALSAR band L image (left) and PALSAR band L filtered image using Frost filter (right)



Landsat 8 bande 5 image　　Landsat 8 band 5 filtered image (gaussian filter)

Figure 2: Landsat 8 band 5 image (left) and Landsat 8 band 5 filtered image using Gauss filter (right)

The directional filters Sobel highlight strong transitions reflectance and high spatial frequencies generally associated with lineaments. The four directions filters are applied to the pre-processed bands (Table 1).

Table 1: Sobel - kernels in four principle directions (El-Sawy K et al., 2016).

N-S			NE-SW			E-W			NW-SE		
Vertical Edge Detect			Right Diagonal Edge			Horizontal Edge Detect			Left Diagonal Edge		
-1	0	1	-2	-1	0	-1	-2	-1	0	1	2
-2	0	2	-1	0	1	0	0	0	-1	0	1
-1	0	1	0	1	2	1	2	1	-2	-1	0

In the lineaments extraction phase, the LINE module of PCI Geomatica software (trial version) is used for automatic extraction. This version was made available after a request addressed to the software builder on http://www.pcigeomatics.com. The algorithm parameters are chosen base on the recommendation of Shankar et al. (2016).

Coincidence analysis

Groundwater prospection in the basement areas requires a clear idea about the fracture network. Based on Bruning et al. (2009) and Alonso-Contes (2011), the coincidence map of lineaments provides a direct and consistent overview of areas that would have undergone tectonic actions where groundwater flow can occur. In this stud, 13 bands are considered to maximize the chance to retrieve the fracture network of the basin. The steps are: (1) to generate a buffer of acceptable size representing on average the zones of fractures, (2) to verify all the interpreted lineaments, (3) to perform a GIS analysis to filter the interpretations and (4) to analyse the performance of the coincidence map (Figure 3). Guiraud and Alidou (1981), Boukari (1982), Adissin (2012) and many other studies made on the basement are considered to have the size of the buffer. However a detailed study on the width of the faults in the basin is missing. At the level of a fracture it is conceivable that the zone of influence is beyond the normal size of the fracture. The size of the buffers around the lineaments is then fixed at 100 m. The buffer layers generated from the 13 layers of lineaments are converted into raster format and reclassified into a binary image (0 or 1). The sum of the binary images gives the number of times the lineaments coincide and therefore the coincidence map of lineament is generated (Figure 3).

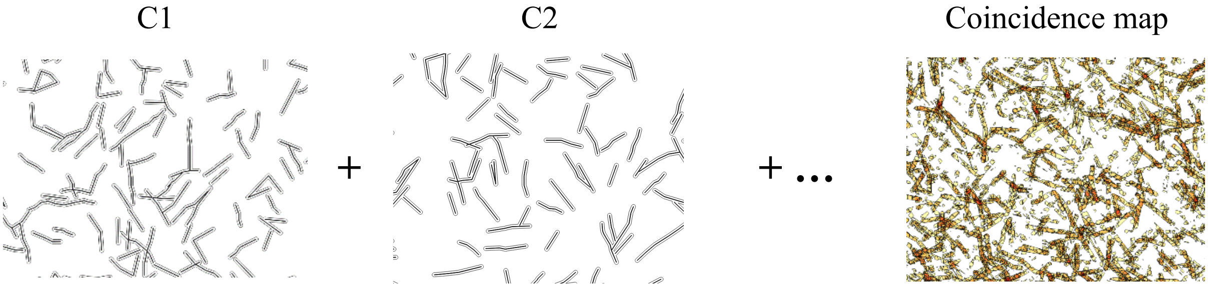


Figure 3: Coincidence layer calculation

The ratio of the total area of the filtered lineament buffer by that of the original lineament is calculated. These values are used to rank the lineament maps.

$$R_{C1} = \frac{Total\ buffer\ surface\ (filtered)}{Total\ buffer\ surface\ (original)} * 100$$

Avec $R_{c1}R_L$: lineament area retained (%)

RESULTS AND DISCUSSION

After all processing, the final results are as followed:

Lineament maps

Visible bands extracted lineaments

The main directions observed are N10, N60, N100 and N150. The Nearest Neighbor Analysis gives an index of 0.72 for an observed distance of 539.7 m. The z score is -40.83 and the p value is zero, so the lineaments extracted from the visible bands are therefore significantly aggregated. Areas with high densities are identified in South of Djaloukou (Savalou) and Kpakpassa. The cumulative length of lineaments interpreted in the N10 direction is 244.3 km and the number of lineaments approximates 351 segments. In the N100 direction, the cumulative length is 205.3 km and the number of lineaments is 274 segments. Directions N60 and N150 have 364 segments for a total length of 247.1 km and 366 for a length of 271.4 km respectively.

Infrared bands extracted lineaments

The nearest neighbor index gives 0.77 and the average distance observed is 491.13 m. The infrared lineaments are also aggregated significantly (Figure 5). The main directions identified are N10, N50, N70, N100 and N140-N150. Note, however, that almost all directions are represented. The areas of high density revealed by the infrared bands are Lèkpa in the north-west of the basin, around Lama, Idaho, Savalou and Yagbo in the East and South in Sowè.

Radar bands extracted lineaments

The average distance observed between the radar lineaments is 535.6 m and the nearest neighbor index is 0.68. The lineaments are therefore significantly aggregated (z-score: -44.41 and p-value less than 0). The bands L and C, respectively, of the PALSAR and SENTINEL-1 images reveal a range of N130 to N170. High density areas are identified around Savalou, Issalè and Idaho. In this range of orientation (N130 to N170), the cumulative length of interpreted lineaments gives 4693 km and the number of lineaments approximates 3549 segments.

Coincidence map analysis

After overlapping the layers, the percentage of area retained varies between 1.29% corresponding to the B6 band of LANDSAT-8 and 68.58% for the C band of SENTINEL-1 (Table 2). It should be noted that only 7% of the identified lineaments meet a level of coincidence greater than or equal to 4. Thus, the rank reveals that the SENTINEL-1 band comes first with the percentage of 68.58%, then the band B2 of the LANDSAT- 8 (44.83%) and LANDSAT-8 band B11 (43.09%). Microwave images are strongly recommended for lineaments identification in basement areas. Nevertheless the LANDSAT-8 bands are however interesting too and can be used when radar bands are not available.

Table 2: Image product rank, based on total area of original lineament buffer compared to total area of filtered lineament buffer

Sensors/Source	**Bands**	**Total area of original lineament buffer (m2))**	**Total area of filtered lineament buffer (m2)**	**% of lineament area retained**	**Image rank**
OLI-TIRS/LANDSAT	B1	1289561157	25781024	19.99%	***11***
	B2	1276828395	572441397	44.83%	***2***
	B3	1388260157	281557849	20.28%	***10***
	B4	2216139658	652497938	29.44%	***6***
	B5	2439235948	689946196	28.29%	***8***
	B6	2311562479	29831945	1.29%	***13***
	B7	2326538180	669990400	28.80%	***7***
	B8	3101794820	674732590	21.75%	***9***
	B9	1554661385	471867763	30.35%	***5***
	B10	1929957485	382213181	19.80%	***12***
	B11	1596496623	688009572	43.09%	***3***
Sentinel	Sent 1A	1387151254	951293654	68.58%	***1***
Alos-2 PALSAR	PALSAR	2403131206	951293653	39.59%	***4***

NB: Buffer surface in m^2.

With coincidence level 4, the fractures of the geological map are identified either partially or completely (Figure 4). The highest coincident level is 7. The areas with high levels are good for groundwater identification. This is the case, for example, in the southern zone of the locality of Bamè in the district of Logozohè (Savalou) and around the district of Gomè (Glazoué).

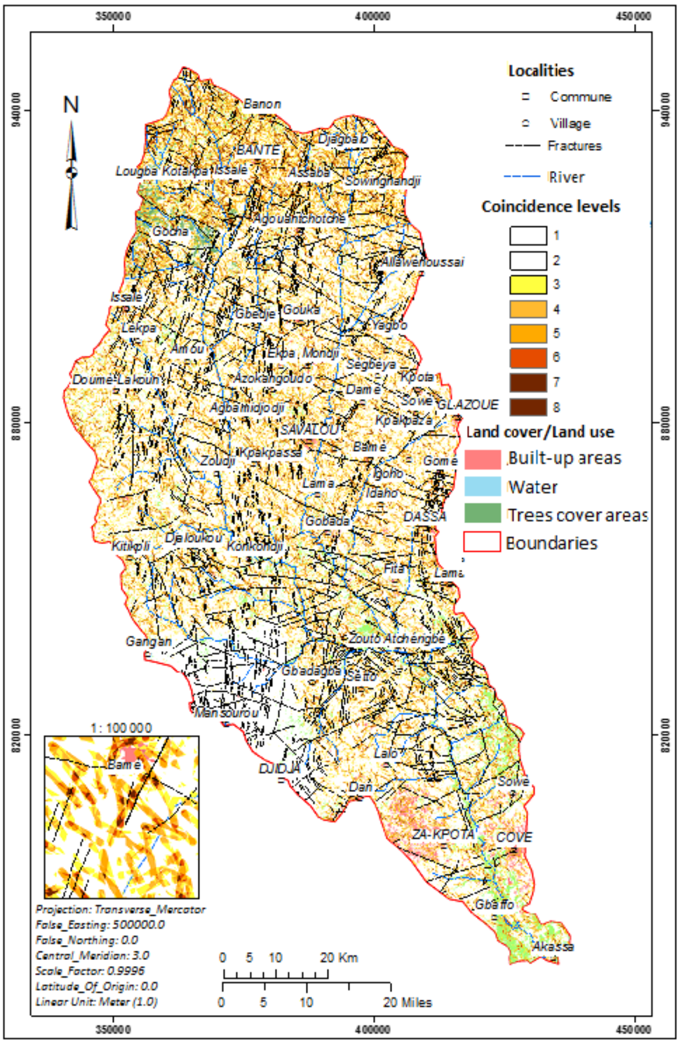


Figure 4: coincidence map

Hydrodynamic characteristic of the fracture aquifers

The classification according to the Inter-African Committee for Hydraulic Studies (CIEH) recommendations indicates globally in the basement a percentage of 76% of boreholes having a very low flow (Table 3). Whatever the lithology (gneiss, granite, mylonites, terrigenous deposits ...), more than 85% of the borehole executed have a low to very low flow rate. The rate of high flow ones oscillates around 7% in granite and gneiss and can exceed 10% in mylonites and terrigenous deposits.

Table 3: Classification according to CIEH recommendations

Q (m^3/h)	Socle		Gneiss		Granite		Basalte		Blastomylonites and mylonites		Terrigenous deposits	
0 – 1	1398	76.1	1239	76.3	62	79.5	3	60.0	49	76.6	32	66.7
1 – 2.5	186	10.1	160	9.9	9	11.5	2	40.0	6	9.4	5	10.4
2.5 - 5	110	6.0	99	6.1	2	2.6	0	0.0	2	3.1	6	12.5
> 5	143	7.8	126	7.8	5	6.4	0	0.0	7	10.9	5	10.4
Totals	1837	100%	1624	100%	78	100%	5	100%	64	100%	48	100%

Discussion

In basement areas, the installation of any drinking water supply borehole is based on fracture network identification. The visible and infrared bands of OLI-TIRS (Landsat 8) and radar bands of SAR (Palsar and Sentinel 1) processed show four main lineament directions in the basin: N10, N60, N110 and N150. First, the N10 direction reveals mainly Kandi faults corridor, which is related to pan-African orogenic cycle in Benin. It characterizes the crystallophyllian orientation of schistose green rocks, gneisses (NS to NNE-SSW, NNW-SSE), migmatites, and the extension of granite and spilite-keratophyre massifs (Boukari, 1982). Then the direction N60 (around N60) indicates the NE-SW steering faults that affected the series of alkaline microgranites (Pougnet 1957, cited by Boukari, 1982). Furthermore, the same lineament orientation can be assimilated to the general orientation of the migmatites (N65) and the emplacement of the large batholiths of the porphyroid granite of Dassa-Zoumé. Finally, the directions of N110 to N150 are comparable to the ESE-NWN aplite injections of 'Lhoto' valley fractures. The coincidence map represents an important tool for fractures identification. Among the 13 bands processed, the Sentinel 1 band C is the more efficient as the percentage of coincidence reached 68%. The result of Bruning et al., (2009) carried out in a basement area in Nicaragua corroborates those obtained in this study. RADARSAT-1 image is given priority over optical images as SENTINEL-1 and PALSAR are better than the LANDSAT-8 bands for fracture identification.

Furthermore, the implementation of high flow drilling is quite delicate in the basin (only 7% to 10%). In this study, regardless of the geological context, over 85% of the works executed have a low to very low flow rate.

Conclusions

In all, access to drinking water in basement environments requires a good analysis of satellite images or aerial photographs. The Zou basin has a complex fracture network controlled by the main directions N10, N60, N110 and N150. The implantation of boreholes is rather tricky and requires the choice of an appropriate image such as SENTINEL-1, PALSAR or LANDSAT if necessary. The hydrodynamic conditions clearly indicate the difficulties related to the exploitation of the fracture aquifers of the basin. However, for at least the drinking water supply of the populations, the lineament directions identified and the analysis provided from the available database can contribute significantly to the achievement of Sustainable Development Goals in the Zou Basin in Benin.

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INAT FINANCED APPROPRIATE TECHNOLOGY PROJECTS EMPOWERING COMMUNITIES: WATER SUPPLY PROJECTS USING HYDRAULIC RAM PUMPS IN KENYA

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Key Words: INAT Projects, Water, Appropriate technology, Empowering Communities.

Abstract

The objective of this paper is to present the process whereby two water projects for rural communities in Kenya received INAT financing. The INAT requirements for funding specified that the technology design must take into consideration the environmental, ethical, cultural, social and economic aspects of the community for which it is designed. The technology must be easy and affordable to maintain, utilize few resources, and most importantly, it should empower the community.

The first project's aim was to supply water to a rural secondary and primary school with 800 students in Kenya to assist in improving the student's health and to reduce time wasted by students fetching water from a neighbouring stream. To achieve this, various water technologies were evaluated to determine the most suitable technology that would not only meet the water supply need but also meet INAT's goals. Among the technologies considered were rain water harvesting, using a solar or wind powered pump, gravitational flow, diesel pump or a hydraulic ram pump. After the evaluation a hydraulic ram pump (hydram) was selected and installed and is now supplying all the needed water for the two institutions.

The second project was for a stalled rural women's group water project in Kenya that included redesign of pumping solution, fabrication and installation of a hydram, construction of a masonry drive tank, drive pipes and delivery pipe connection. The water is now supplying 600 homesteads with water, sold at water vending kiosks.

The evaluation shows that the projects meets INATS goals by using an environmental friendly technology that is cheap and very easy to maintain and requires minimal management. It has realized great social and economic benefits by improving the hygiene, reducing time wasted by women fetching water, child labour, and better animal husbandly increasing wealth and empowering the communities.

Introduction

This paper evaluates two water projects that received funding from the International Network on Appropriate Technology (INAT). The ICAT project was to supply water to a rural secondary school with 250 students and a primary school with 550 students to be used mainly for cleaning the school, cooking, drinking, livestock and for irrigation. This project included the fabrication and installation of a hydraulic ram pump (hydram), purchase and installation of drive and delivery pipes, construction of a masonry pump house and rehabilitation of a drive tank. This project is currently being expanded to include a neighboring technical college which has been struggling with water issues including a strike by the students protesting against being sent to the river to fetch water. The secondary school is currently improving the intake and installing water pipes to replace the open water channel supplying the drive water for the pump. Funding by ICAT was for US Dollars 900 which mainly met the cost for the civil works and the author donated a hydraulic ram pump (Hydram) and supervised the installation. The School offered labour for digging the trenches and connection to their water reservoirs. The project has been supplying the schools with continuous enough water since 2017. In May 2018 floods washed out the intake several times. These were exceptional large floods of a size last experienced in Kenya in 1962. The intake is being improved by the use of a stone gabion weir. The assessment examined whether the use of a hydram was the better option for this project as compared to other options including gravitational flow, rain water harvesting, solar system water pumping or using electric pumps connected to the grid. All of the options met INAT's requirement of using environmentally friendly solutions. However, the hydram option proved to be the optimum solution.

The second project is an INAT funded project to complete a stalled women's group project to supply water in Nyeri County in Kenya. The group had invested heavily on water supply system to reach over 600 homesteads that included about 12 km of delivery and distribution pipes, a 250^3 masonry tank, three water kiosks an intake and a faulty hydram at a cost of about US dollars 50,000. The project had failed due to design flaws that were not suited for a hydram installation and a faulty imported hydram. INAT funded this project with USD 5000 that was used to procure a new CAES 5X hydram, pipes, building of a drive tank, refurbishing the existing hydram and redesigning and reinstallation of the drive system. The system is now supplying about $60M^3$ of water per day which is serving 150 homesteads. However, the system has not yet realized its full capacity due to broken pipes in the delivery system and infighting by the group members. Water problems were also experienced in February 2018 when the water levels were not high enough to supply both pumps. This was due to a very severe draught which had lasted for 2 years followed by record breaking floods that started in March of this year. The choice of using a hydram was made due to considerations of the investment already installed and a very good site for installing a hydram with a head of about 12 meters and a regular flow of water. Other options that the group had considered were using a diesel driven pump, digging a borehole, gravitational water flow from a source about 14km away or using a grid fed electrical pump. These option were judged to be too expensive. The decision to choose hydram water-lifting technology for these projects was based on cost, sustainability, ease of maintenance and environmental friendliness as stated by INAT's project funding goals. To select the project, this review used purposive sampling, a non-probability sampling technique whereby the researcher selects participants on the strength of their experience of the phenomenon under study (Fenny et al., 2001). The beneficiaries and the management committees were interviewed during the review process.

INAT Project Funding Goals

Funding provided for the projects resulted from an invitation by INAT for proposals for funding of practical community based appropriate technology (AT) projects [1]. The invitation stated AT projects as projects designed with special consideration of the environmental, ethical, cultural, social and meeting economic aspects of the community they are intended to serve [1]. The aims for INAT in AT include technology that empowers people focusing on technologies that are human-centered to promote better health, improved access to clean water and energy sources that do not cause ecological imbalance [2]. AT is also shown as a technology that should only require small amounts of capital, emphasize the use of local materials, be relatively labor intensive, be small scale and affordable, comprehensible, controllable and maintainable without the otherwise high levels of education or training that might be required for the maintenance and operation of more capital intensive and complicated and imported technologies [3]. INAT's declaration of Appropriate Technology states that "the resources of our planet Earth must be used to develop appropriate technologies needed to meet the needs of our total population, empower people and at the same time preserve resources for future generations [4]. The declaration further states that "Clean air and water, food security, healthcare, shelter, energy needs and education are basic human rights that can be provided for all of humankind today by devoting the planet's natural, financial and human resources to appropriate technology" [4]. These principles dictated the choice of an appropriate technology for the proposed projects. What follows describes the selection process whereby a locally manufactured hydraulic ram pump for the project was chosen. The process conforms not only to INAT Manifesto principles but the Kenyan Constitution 2010 (COK). Article 43 of the Bill of Rights states that access to safe water and safe sanitation is a guaranteed right for Kenyan citizens.

Technologies Considered for the water projects.
As stated above, various technologies were considered for these projects including diesel driven pumps, boreholes, gravitational water flow, grid connected electricity pumps or hydrams. The decision principles for these projects were based on cost, sustainability, ease of maintenance and environmental friendliness as stated by INAT's project funding goals.

Initial Cost.
Initial cost was estimated by comparing manufactures' costs for pumps and accessories with the capacity of supplying $60M^3$ in 24 hours to a 250 M^3 reservoir. For the women's group project, the comparison shows that installing a diesel driven pump would have been the least expensive followed by installation of a Hydraulic Ram Pump. Installation of a gravitational flow system would be the most expensive mainly due to the cost of pipes to cover a distance of over 10km. A solar electric motor driven pump was third in cost. This puts the diesel driven pump as the cheapest technology to install before other factors are considered as shown on the following chart.

Cost of scheme Installation in US Dollars	**Diesel**	**Solar**	**Hydram**	**Grid Electricity**	**Gravity Flow**
Cost of pumping equipment	750.00	3,500.00	1,500.00	1,500.00	
Civil Works Intake,	1,000.00	1,000.00	1,000.00	1,000.00	2,500.00
Civil Works Delivery Pipes,	120.00	120.00	120.00	120.00	8,000.00
Civil Works Drive Pipes,	0	0	60.00	0	0
Civil Works Pump House	500.00	500.00	500.00	500.00	0
Electrical Supply Installation	0	200.00	0	6,500.00	0
Scheme Total Cost	**2,370.00**	**5,320.00**	**3,180.00**	**9,620.00**	**10,500.00**

A second chart examines running and maintenance costs. The annual cost of running the diesel pump was the highest, outstripping all the benefits gained in installation cost. Pumping via grid electricity was the second highest cost. Cost for Solar and hydram would be the lowest with gravitational flow being a little more expensive due to the added maintenance cost of intake due to distance from the consumer and the long supply pipe. Considering cost of installation and running cost alone, the only cost effective technologies were the Solar and Hydram pumping solutions.

Chart 2.

Running Cost in US Dollars	**Diesel**	**Solar**	**Hydram**	**Grid Electricity**	**Gravity Flow**
Annual Scheme maintenance cost	600.00	120.00	120.00	120.00	250.00
Fuel Cost	3,500.00	0	0	3,000.00	0
Annual Scheme Cost	**4,100.00**	**120.00**	**120.00**	**3,120.00**	**250.00**

INAT's environmental impact principles were also considered in selection of the pumping solution. Among the technologies evaluated diesel engines were found to have the greatest negative impact to the environment mostly due to their use of non-renewable energy source and air pollution that impacts on human health and cause global warming [5]. Gravitational flow though a clean energy source was found to have adverse environmental impact as it required large amount of excavation running about 15KM to lay delivery pipes. While grid electricity in Kenya is mostly produced from renewable resources, a small percentage is derived from fossil fuel driven generators. Solar driven pump and hydram's were found to be the most suited technology in consideration of environment.

Other INAT Requirements for Projects.

Other criteria specified by INAT's principles require technology manufactured locally with locally available materials and able to be service and repaired by the local community. Diesel engines, solar and grid electricity equipment are largely dependent on imported materials. Gravitational flow and hydram's are the only technologies made from locally manufactured parts making them the most suited. When interviewed, the community was found to be receptive to all technologies with little preference for one over the others with the exception of gravitational flow. The pipes would traverse land owned by non-beneficiaries of the project which would cause increased conflict and possible interference by non-members. Obtaining right of way for the pipes from non-beneficiaries could result in high demands for compensation that would increase the cost. End user repair and maintenance was also reviewed to determine how difficult it would be to train the users and the cost of equipment required to carry out the work.

Locally Manufactured Hydraulic Ram Pump (LM Hydram) Technology.

Hydram's are a mature technology that has been in use since the 18th century. The technology had mostly been replaced by the internal combustion engine and motorized electrical pumps since that time. However, it has regained its importance with the increased cost of fossil fuels and the increased need for environmentally friendly technologies. Hydram use is limited because of limited knowledge about them even for sites where they would be the best suited solution. Initial cost of imported hydram's is also very high and a barrier to their use. However, with research now available for fabrication of simple but good quality and efficient hydram's, their use should increase.

The installed hydram's were fabricated using designs from the engineering department of University of Nottingham that the author has modified over the years for adaptations to specific sites. All materials used in fabricating the hydram are from recycled steel plates, pipes and rubber products from used conveyor belts and tires. Some of the materials and a welder are available within the project area. Other resources are available at a neighboring town 5km from the site. A highly competent retired mechanic is in charge of servicing the hydram and competent plumbers are available in the project area. All the tools used to fabricate the hydram are available at the neighboring town and all repairs can be undertaken there.

Figure 1. Locally Manufactured Hydram by Author

Figure 2. Students Drinking Water Supplied by Hydram.

Project Benefits

The two projects have benefited the communities they are serving in many ways. The School project main beneficiaries are 800 students, with the aim of also serving a neighbouring

technical school with about 200 students. The schools have also benefited from the increased amount of water for their Livestock including cows, goats and pigs at the secondary school and cows at the technical institute. The institutions are now able to increase their food production by using the water to irrigate their farms reducing the cost of food. Agricultural student gardens are now provided with adequate water supply close to the school, replacing riverine plots far away from the school improving their performance in the subject.
The students were required to collect water from the river, a process that required much time, damaged river banks, and would often result to injuries and conflicts among the students. The increased quantity of water provided by the hydram pumps promotes better cleanliness of classes and improves student hygiene. Dosing of the water with chlorine makes the water potable, thereby reducing incidences of diarrhea and other infections that afflict many children and cause high mortality among children in rural areas [6]. Increased water has also reduced labor requirements, thereby saving the schools the money used to buy water, a significant previous overhead for the schools. Water is also available for the schools' livestock and for the vegetable gardens which increases their production and reduces the need to drive the livestock to the river where they come into contact with other livestock increasing cross-infection of disease and damage to the river banks.

Women group project benefits.

Beneficiaries of this project are mainly women and the youth who bore much of the burden of water collection. Water collection for most of the members in the project consumed many hours and caused health problems by reason of carrying heavy loads, sometimes in wet and slippery paths that results in injuries. The two hydram's installed for this project have been supplying the community with 60,000 Liters of water each day. This amount of water is equivalent to the community making about 3000 trips to the river with an individual carrying 20 liters on each trip. If each trip on average takes about 30 minutes, the amount of time required to collect 60,000 liters would be 1,500 hours.

Nearly all the water used by the community was fetched from the river except for a few homes that have dug productive shallow wells that are very expensive to dig and normally yield very low volumes of water and it has to be lifted manually. Rain water harvesting is also common during the wet seasons but normally only yields small quantities of water that is mainly only used for cooking and drinking.

Water supplied by the hydram increases the amount of water each family receives for domestic use, livestock and vegetable gardens, young trees and fruit seedlings increasing the vegetation cover for the area. Increased water improves hygiene and reduces pollution of the rivers and cross- infections of deceases. Cattle also receive more water without the need of driving them to the river, thereby improving their health and furthering the community's wealth. Vegetable gardens and increased fruit trees improve the community's diet, thereby improving health and reducing healthcare costs.

Conclusion.

The INAT projects have empowered the communities they serve by supplying water a key need to human life recognized as a human right in Kenya's constitution. These contributions include: -

- Reduced burden of water collection mainly by women and children allowing the community to dedicate more time to other economic activities like farming and taking care of their livestock.
- Increased water availability has improved the health of the community as bathing and cleaning is enhanced due to availability of water reducing health problems.
- The projects serve as pilot projects that can be replicated by other communities
- The communities are also empowered by increased wealth created by providing water for healthier and more productive livestock, better gardening that has increased irrigation for vegetables and herbs that also improves the health of the community.
- The project supply has reduced damage to the water resources by livestock and human beings damaging the water banks and polluting the river.
- The quality of livestock has also been improved by reducing cross-infection of animals by reducing contact with other cattle while drinking at the river
- Availability of water to for plants during the dry seasons has improved survival rate of trees improving the environment.
- The use of hydram's that do not require fossil fuels or electricity has made the project cheaper to maintain and more sustainable

Based on the extensive project review, the projects have addressed INAT project requirements and achieved extraordinary results. Prospects for the communities being able to sustain the projects made possible by INAT funding are exceptional as the technology is simple and easy to maintain with all materials sourced locally and inexpensive.

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Water and Sanitation Poster Presentation Papers and Abstracts

Comparative analysis of Optimization Models and Computer Simulation Application in Household Waste Management Systems

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Abstract

Optimization also known as mathematical programming has been introduced and used since the beginning of the 20th century. Since then, many techniques and algorithms have been developed and applied in various fields. The past overviews of optimization modelling applications have been grouped in nine sections based on the solution to the theme-based real world problems, including Solid Waste Management (SWM). Simulation on the other hand has been introduced and used since World War II; since its development, it has been a very important tool to many industries and organisations. The objective of this paper is to analyse the various applications of optimization modelling and computer simulation and to determine their advantages and pitfalls, if any, in household Solid Waste Management systems (SWMS). The method used is extensive literature survey and comparative analysis. Although other parameters such as environmental and social concerns cannot easily be modelled in the optimization process, it has been found that mathematical programming, along with simulation techniques, has been extensively used and has provided substantial benefits for the optimization of solid waste management systems around the world. The paper concludes by determining the optimization approaches and computer simulation techniques that have been mostly used to optimize the SWMS by minimizing the total design and operations cost of different waste management infrastructures and resources; it describes the pros and cons of these methods, and it also identifies the gaps that exist in the application of optimization techniques and simulation in waste management.

Keywords: Solid waste, Mathematical programming, Modelling, Optimization, Simulation.

Water recycling as an alternative source of water supply

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Abstract

In today´s changing environment, two major trends are emerging and impacting the reliability of the existing water supply: climate change and increasing population.
Year over year the drought periods are increasing while the water demand is increasing.
Many alternatives are under development to enforce the existing infrastructure, major development can be observed for example using sea water and desalination.

Salt water being accounting for more than 97% of all water available water reserves on earth, with more than the required desalination is an energy and cost intensive process, which also produces a significant share of wastewater, a highly salt concentrated brine. If this alternative can help supplying important volumes in areas with strong population density, ideally closely located to the sea shore, for many other regions it is not an affordable solution. Beside further options such as groundwater and wells, efficient water cycles need to be developed. Starting with the recycling of used water, that is often less costly than using new resources. Today only a few wastewater treatment plants are installed more than half of them not properly working. Today the available technologies allow a complete recycling and purification of used water with the implementation of more and more natural technologies to support regional hubs with a strategic additional water supply.

In this paper, an overview of both current water recycling status quo and available reuse technologies will demonstrate the strategic character of this approach that offers in combination. A concept proposal with development of a data intelligence and water management for the future of water management will be explained with focus on strategic low efficiency water smart grids.

Keywords: Water resources, Climate Change, Sea Water Desalination, Wastewater recycling, Water economics, Costs of Ownership.

The Contribution Of Traditional Water Treatment To Development Rural Area In Sudan

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Abstract

The current study focused on the contributions of some indigenous knowledge (IK) methods to water quality during collecting, harvesting, storage and management of water. The study reviewed, investigated and examined various technologies such as filtration, coagulation and other appropriate techniques to contribute to treatment of contaminated water that is harvested by traditional technique during rainy seasons. The review showed the role of different tribal and ethnic institutions for the control and proper use of common property. The government, which is committed to improve public health can do so by improving the infrastructure for quality of life; however, it should also remember that access to sufficient, safe and potable water is the most important thing.

In this context, this paper gives more attention to IK and culture; IK is a result of heritage and beliefs from centuries of practice, which has produced and transferred knowledge, both in years when population faced difficult season's and drought and in years of abundance. Some plant roots have bee used to clear turbid water through coagulation with special reference to moringa seed. The quality of water is also improved by filtration and adsorption processes to reduce biological contamination, as well as removing cations and anions. A suitable technology can be examined such as sand filter, pottery clays and other types of plants. IK can be adopted as an appropriate technology for water management especially for rural areas in Sudan that are far away from the central government. Finally, indigenous knowledge can inform the implementation of appropriate technology to sustain public health.

Keywords*:* *Traditional water treatment, indigenous knowledge, coagulation, appropriate technology*