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# Preliminary Geophysical Deductions of Lithological and Hydrological Conditions of the North-Eastern Sector of Akwa Ibom State, Southeastern, Nigeria

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**Abstract:** The present study is aimed at evaluating the geophysical parameters of the shallow subsurface for ground water development of the study area. Four profiles of Vertical Electrical Sounding (VES) were obtained in the North - Eastern sector of Akwa Ibom State to examine the subsurface geology and the associated groundwater potential. The combination of VES data and the borehole data provided useful information on subsurface hydrogeologic conditions. Within the western part of the study area covering Obot Akara local government, a sizeable open aquifer was delineated whereas the north eastern part covering Ini local government area has a thick layer of aquitard from the depth of about 10 to 105 m. An isolated resistivity value of the aquitard appear to be extremely high (6130 Ωm) in the deeper layer and this indicates the possibility of intrusive from deep seated layers intruding into low resistivity aquitard. The hydrogeological parameters such as transmissivity, longitudinal conductance and transverse resistance in the Western part of the study area are pointers that the aquifers are prolific.

**Key words:** Aquifer, aquitard, electrical, groundwater, resistivity, transmissivity

## INTRODUCTION

The area of study lies between latitudes 5º15′ - 5º30′ N and longitudes 7º30′ - 8º00′ E (Fig. 1). Geologically, the study area cuts across two Nigerian Sedimentary Basins [the Niger Delta and the Calabar Flank (Short and Stauble, 1967; Murat, 1972)]. The Niger Delta which occupies more than 80 percent of the study area is made up of Akata Formation (Shales intercalated with sands and siltstone), the Agbada Formation (Sands and Sandstones, intercalated with shales) in the middle and the Benin Formation (coarse-grained sands with minor intercalation of clays) at the top. However, Benin Formation, Bende Ameke Group and Imo shale are partly exposed in the study area. According to (Edet, 1993) borehole depth of about 172 m; saturated thickness of about 100 m; static water level of 55 m; draw down of about 42.5 m; yield of 530 $m^3$/day and storage co-efficient of 0.10-0.30 were found in the area from a typical exploratory well.

The geological succession in Akwa Ibom State (Table 1) reflects the progressive growth of the delta into the Gulf of Guinea and consists of mostly shales, sandstones, sands and clays representing the transgression and regression which characterised the development of the southern sedimentary Basin (Petters and Ekweozor, 1982; Ramaanathan and Fayose, 1989). The deltaic and continental Bende-Ameke group represents the regressive phase which is still continuing. Generally, the study area belongs to the low-lying coastal/deltaic plains of Southern Nigeria (Esu and Okereke, 2002; Masasan and Quinn-Young, 1977). The terrain is virtually flat to gently undulating, sloping generally in the direction of the southern part of the state. Elevation is from about 100 to 120 m within the zone. The area is drained mainly by the Kwa Ibo and Cross Rivers and some tributaries like Etim Ekpo River (Esu *et al*., 1999). Vegetation in the study area is tropical rain forest type. It is sustained by the strong climate characterized by high temperature (annual mean 26ºC). The area is also known for high relative humidity (annual mean 83%) and high precipitation (250 mm/annum). The prevalent wet and dry season are marked by fluctuations in the amount of precipitation (230 to 390 mm monthly) rather than by variation of temperature (Edet, 1993).

Table 1: Stratigraphic relations of geologic unit in the area, including type of aquifer

| Age | Formation | Aquifer |
|---|---|---|
| Recent | Alluvium beach ridges | Alluvial deposit |
| Pliocene-Pleistocene | Benin formation | Coastal plain sand |
| Oligocene-Miocene | | Coastal plain sand |
| Late Eocene | Ogwashi-Asaba Or lignite formation | |
| Middle Eocene | Bende-Ameke Group | |
| Early Eocene-Paleocene | Imo shale group | Aquiclude |
| Maastrichtian | Nsuka Formation Ajali Sandstone | Lower sand |

In Akwa Ibom State, groundwater is ubiquitous due to the availability of the subsurface geomaterials that have

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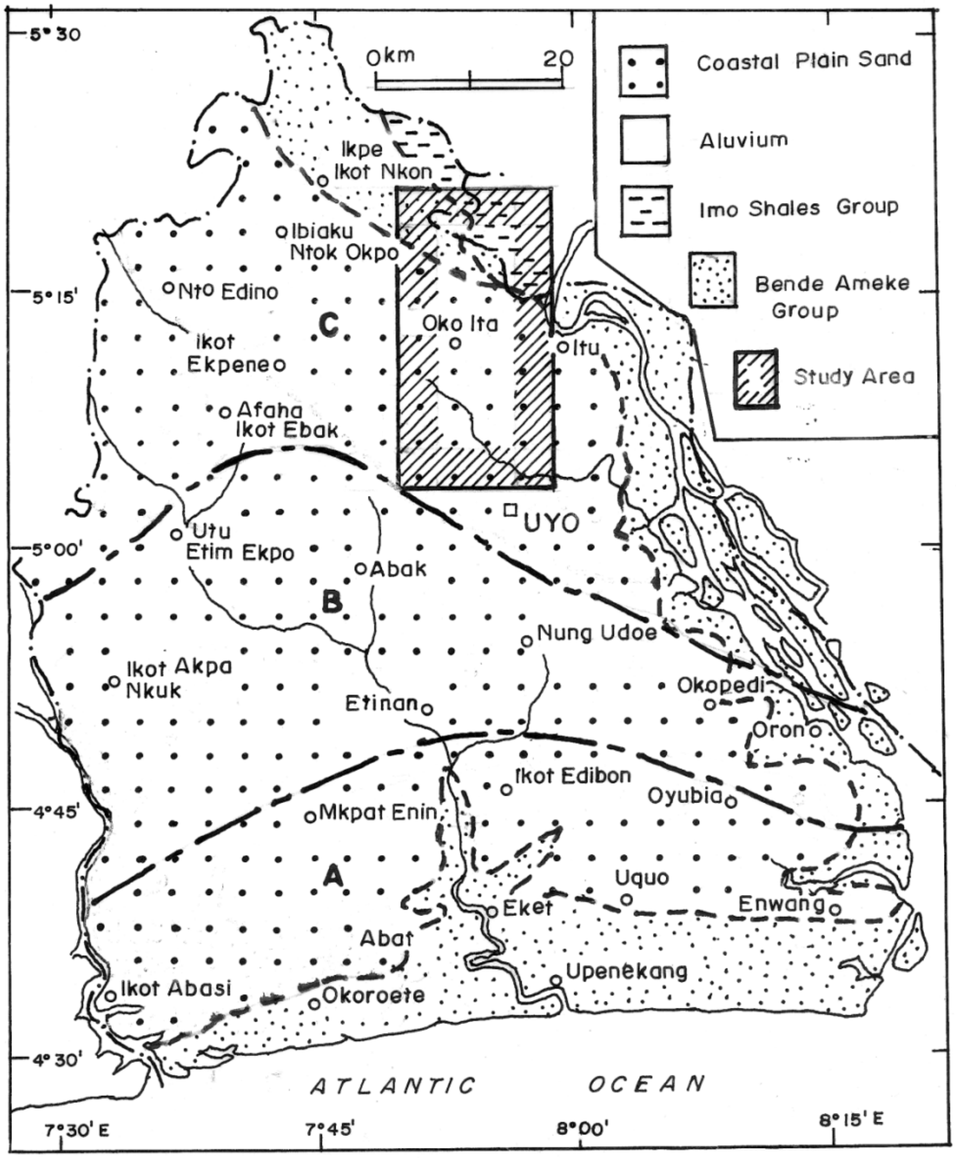


Fig. 1: Map of Akwa Ibom State showing the geology and the location of the study area

the properties which can host water. The availability of these formations at shallow depths enhances the exploitation of groundwater reserve in many areas of the state. However, at the north-eastern part of the state, the story is different due to the subsurface geomaterials which are though porous and capable of absorbing water slowly, cannot discharge water in appreciable quantity into a spring or a well. These geomaterials in Benin Formation include clay and shale Formations. The pores of these formations are not interconnected and as such these formations are only porous but not permeable (Umoren, 1992).

On the basis of stratigraphic relation and lithlogy (Table 1), four main hydrostratigraphic units have been delineated for the entire state. These include three aquiferous units designated as upper, middle and lower sand aquifers, in increasing geologic age and depth of burial. The middle aquifer is the most extensive and is separated from the lower sand aquifer by Imo shale aquitard. These units are thoroughly discussed in chronological order from the youngest using illustrated drilled hole compiled for some existing groundwater wells by (Esu *et al*., 1999; Edet, 1993).

This study represents the first attempt at detailing the geophysical and hydrogeological conditions for the development of a suitable water scheme for the regional exploitation of groundwater resources in the area. During reconnaissance survey, preparatory to this study, over ten failed boreholes were seen in some villages within Ini local Government Area in which the present study was located. These boreholes according to the rural dwellers were drilled by government and other water supply agencies. However, none of the wells were pump tested and documented. There is thus paucity of drilling data for the area and this is the main constraint faced by the present study. Surface geophysical surveys, as a veritable tool in groundwater exploration, have the basic advantage of saving cost in borehole construction by locating target aquifers before drilling is embarked upon (Obiora and Onwuka, 2005). Any rational development of groundwater requires geophysical data input (Omosuyi *et al*., 2008). Geophysical site investigations for ground water exploration are scanty and inadequate in the area and the hydrogeology is not well developed. The present study is therefore, aimed at evaluating the geophysical parameters of the shallow subsurface which will constitute the baseline information about the hydrogeology of the area.

## METHODOLOGY

A total of four (4) VES profiles ($JJ^1_1$, $JJ^1_2$, $JJ^1_3$, $JJ^1_4$) were obtained in October 2010, using the OYO McOHM resistivity meter (model 2115A) with the Schlumberger configuration (M-AB-N) (Fig. 2). For each VES profile, the distance between the potential electrodes (MN) was gradually increased in steps starting from 0.25 m to 14m to obtain a measurable potential difference. The half current electrode separation (AB/2) was usually increased in steps starting from 1.5 to 300 m. In the Schlumberger configuration, all the four electrodes were arranged collinearly and symmetrically placed with respect to the centre.

The potential electrode separation was made very small (AB>>MN) compared to the current electrode separation. The distance between the potential electrodes was increased only when the signal was too small to measure. Apparent resistivity $\rho_a$ was computed at the field using Eq. (1)

$$\rho_a = \pi \left\{ \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right\} \frac{V}{I} \qquad (1)$$

where, (AB/2) is half of the current electrode separation, (MN/2) is half the potential electrode separation and (V/I) is the earth resistance measured by the equipment. The apparent resistivity was plotted against half of the current electrode spacing on a double logarithmic paper and the sounding curves were obtained for each of the profiles. Smoothening was done on the resulting manual curves to eliminate the extraneous signals inherent in the data. The resistivity data and the distance (AB/2) became the input data for the electronic interpretation which was done using Resist Software. The Resist Software employs the

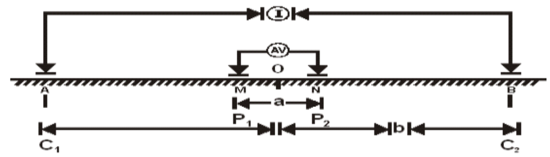


Fig. 2: Schlumberger Electrode configuration

| No | Res | Thick | Drpht |
|---|---|---|---|
| 1 | 237.0 | 0.6 | 0.6 |
| 2 | 1103.0 | 59.4 | 60.0 |
| 3 | 158.2 | -.- | -.- |

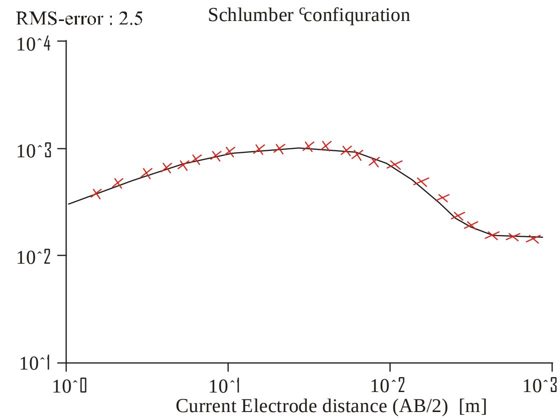


Fig. 3: Modeled curve for VES - $JJ^1_3$ at the aquitard in Ini local government area

| No | Res | Thick | Drpht |
|---|---|---|---|
| 1 | 141.3 | 2.6 | 2.0 |
| 2 | 705.6 | 19.8 | 93.8 |
| 3 | 47.0 | - | - |

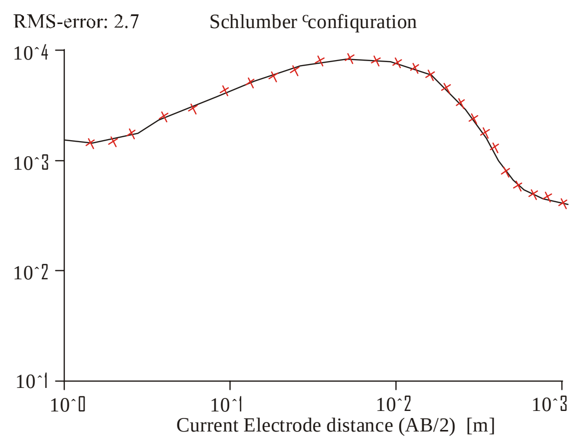


Fig. 4: Modeled curve for VES - $JJ^1_4$ at the aquitard in Ini local government area

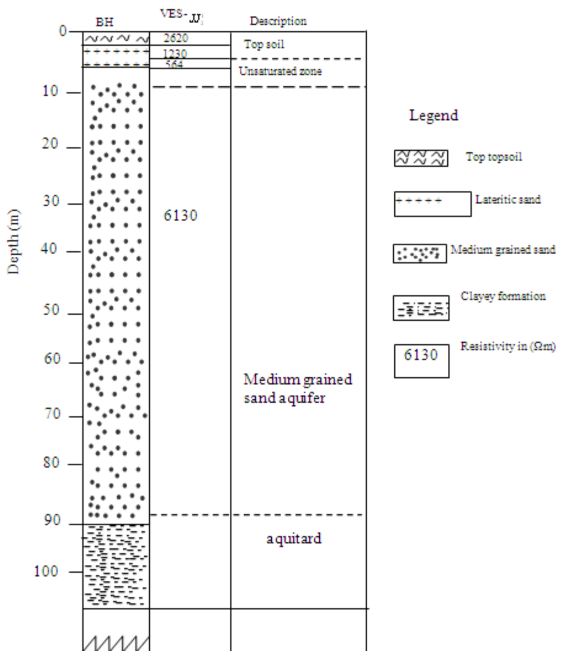


Fig. 5: Representative Example of VES - $JJ^1_2$ data calibration with lithology of the nearby borehole (BH) at Abiakpo, Obot Akara local government area

principle of inversion with the help of the well-known Resistivity Transform. The backward different formula was used for the analysis. The interpretation produced the resistivity models fitting the acquired field data with the least root-mean-square error between the observed and calculated resistivities. The method of iteration was performed until the fitting errors between field data and the theoretical model curves (Bandani, 2011) in Fig. 3 and 4 fell less than 10%. Due to the fact that the electrical resistivity of sediments depends on lithology, water content, clay content and salinity (Mc-Neill, 2003; Choudhury and Saha, 2004) it became imperative to correlate the VES data with the lithological information obtained from adjacent borehole (Hago, 2000). The only nearby borehole log along the traverse was at Obot Akara local government area which abuts on Ini local government area, where groundwater exploitation is difficult. VES - $JJ^1_2$ was constrained with the borehole (BH) as shown in Fig. 5 to ascertain the validity of the resistivity field data.

## RESULTS AND DISCUSSION

Of all the four profiles in the $JJ^1$ traverse, the first layer identified as top sandy soil was found cutting through the traverse. Thin lateritic sand was encountered only in VES - $JJ^1_1$ and VES - $JJ^1_2$ at the villages between Ini and Obot Akara local government areas. The $JJ^1_1$ and $JJ^1_2$ VES profiles at Obot Akara local government area and the nearby borehole showed thick medium grained sand from about 10 m to about 105 m . This layer seems to be infinitely thick towards the western part of the VES location, but sharply abuts on an infinitely thick layer of clay in the eastern part of the VES point near the borehole used for correlation. The clayey layer thickens with depth towards the location of the VES - $JJ^1_1$ and VES - $JJ^1_2$. At the depth of about 110 m, the clayey formation in the eastern part of VES - $JJ^1_1$ and VES - $JJ^1_2$ at Ini local government appears to occupy the bottom most part of the two VES locations at Obot Akara local government area (Fig. 6). Beyond the depth of 105 m, the entire traverse surveyed is covered with clay (aquitard). This is the reason why groundwater exploitation is typically difficult in the shallow depth of the eastern part of VES - $JJ^1_2$. The failed boreholes is due to this formation which is porous and capable of absorbing water slowly from recharge sources but cannot discharge it in appreciable quantity into the drilled water wells.

Hydrogeologically, the subsurface materials at Obot Akara are potent for groundwater resource at shallow depth, mostly towards the western part of Ini local government area. However, at deeper depth beyond 110 m, the extension of the aquitard from part of Ini local government area seems to preclude Obot Akara local government area from having subsurface geomaterials that are aquiferous. Groundwater resource according to the calibrated borehole with VES data and the equivalent geoelectric section shown in Fig. 6, cannot be exploited at the shallow depth at Ini local government area, precisely up to the depth of about 120 m. However, deep seated confined aquifer can be exploited from the area by using sophisticated rig to drill beyond the 120m depth.

Geophysically, the aquitard has resistivity range of 47.0-6310 Ωm and the average value is 1012.5 Ωm. The high range of resistivity and the consequent high average value observed at deeper depth might be attributed to the intrusives which are common in the Calabar Flank end of the study area. The model curve types in the aquitard are AKQ, QHK, K and H. The drop in VES curve is due to H and K layer combinations which are not significant to translate into saturated sand beds of significant water wells within the dept of maximum current penetration.

The minimum and maximum Dar zarouk parameters for the two VES points, VES - $JJ^1_3$ and VES - $JJ^1_4$ that cut across the assessed depth of aquitard were estimated. For the VES - $JJ^1_4$, the minimum transverse resistance estimated is 282.6 $m^2Ω$ and the maximum transverse resistance for this profile is 64774.08 $m^2Ω$. For the VES - $JJ^1_4$, the minimum transverse resistance is 142.2 $m^2$ while the maximum transverse resistance for the assessed depth at maximum current electrode separation is 6534.00 $m^2$. In like manner, the minimum longitudinal conductance is 0.0014 $Ω^{-1}$ and the maximum longitudinal conductance

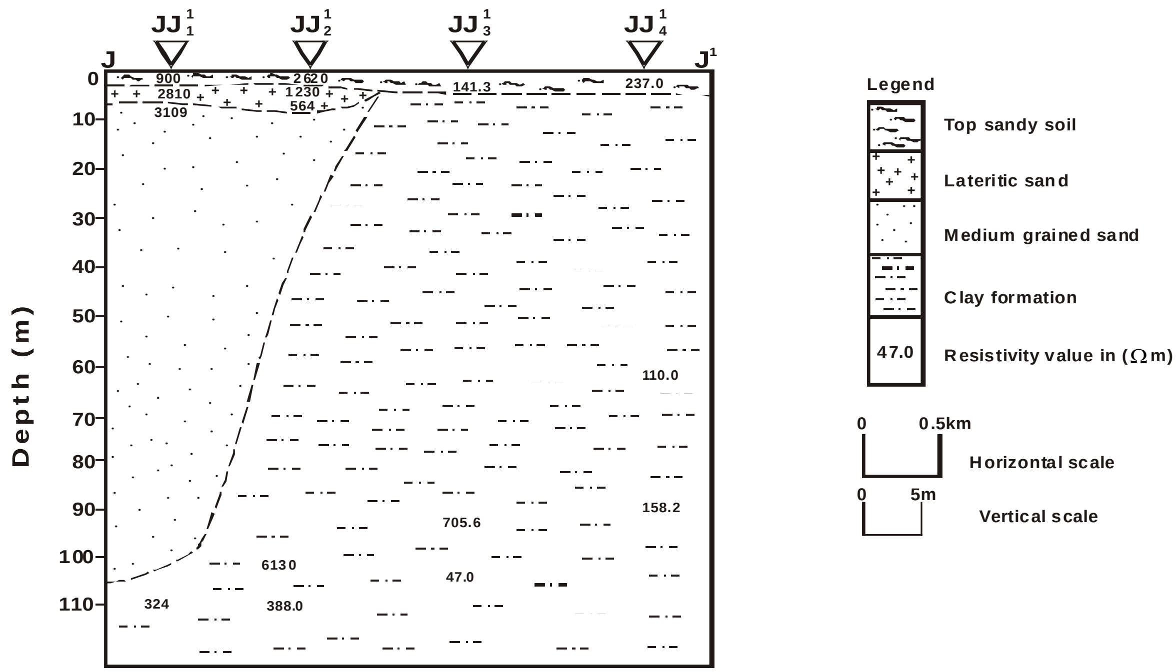


Fig. 6: Equivalent geoelectric section along ll[1] traverse in the coastal region of Akwa Ibom State

for the electrode separation is 0.13 $\Omega^{-1}$ for VES - $JJ^1{}_3$ profile. For the VES - $JJ^1{}_4$, the minimum and maximum longitudinal conductance are 0.0025 and 0.54 $\Omega^{-1}$, respectively.

The transmissivity values for the aquifers at Ikwen and Abiakpo in Obot Akara local government area were estimated using a general hydraulic conductivity value of 8.64 m/day given by Fetters (1980), Mbonu *et al*. (1991) and Pantelis *et al*. (2007) for sand/well-sorted gravelly sand aquifer in the absence of pumping test data for the existing borehole within an area. The transmissivity values for aquifer at Ikwuen and Abiakpo were estimated to be 889.92 and 874.37 $m^2$/day for VES - $JJ^1{}_1$ and VES - $JJ^1{}_2$, respectively. The product of permeability $K$ and electrical conductivity $\sigma$ were also estimated for the aquifers at VES - $JJ^1{}_1$ and VES - $JJ^1{}_2$ to be 00.55 and 0.0014 per Ω/day, respectively. The geophysically estimated quantities for the subsurface of the zone are very useful for characterizing the aquifers at Obot Akara local government area and also for use as input parameters in modelling the aquitard at Ini local government area. The transmissivity and the Dar zarouk parameters are functions of the formation thickness and resistivity and can give information about the thickness of the aquifer within the surrounding. The Dar zarouk parameters give information about the transverse and longitudinal orientations of the subsurface formation. The $K\sigma$-values of aquifers at Obot Akara are low and this indicates that the boreholes within the medium grained sand in the area have fresh water and are devoid of brackish water.

## CONCLUSION

The geometerials of the north - western part of the study location have been found to be prolific based on the litho and hydro-resistivity cross section constrained by lithological log near the point where vertical electrical soundings were carried out. However, the north-eastern part of the zone has been found to have aquitard starting from the depth of about 10 m to the maximum depth of about 120 m. The penetration was enhanced due to subsurface conducting material which was not resistive. The zone at Obot Akara local government area found to be prolific appears to have the bottom most layer covered with aquitard found in eastern part of the zone. Shallow exploitation of ground water at the north eastern area is precluded because the subsurface geomaterials can only absorb water slowly but can not discharge it in appreciable quantity to the drilled water wells in the area. The clay formation thickens with depth and spread laterally within the subsurface. At the deeper layer of the aquitard where extremely low resistivity was found, some uncorrelated high resistivity values were found and this may be an indication of intrusives penetrating into the aquitard from the deep seated layers.

Lithologically, the zone has medium grained sand in the western region while the eastern part is characterized by clayey Formation at the shallow subsurface. This very lithological condition affects the hydrogeological condition adversely. Shallow aquifer of medium grained sand is noticed at Obot Akara local government area being the western part while aquitard occupies the shallow subsurface of the eastern part of the zone. The estimated quantitative parameters for the aquitard at the penetrated depth can be used as input parameter for modelling. Although the shallow layer of the zone is not potent for ground water exploitation; the clay formation noticed can be exploited as raw materials for pottery for ceramic industries that abound in the country. It is recommended that sophisticated rig should be used to exploit the confined aquifer that is below the shallow aquitard. Exploratory well should be drilled at different locations to actually discern the complex geology of the zone while wild cat borehole drilling should as a matter of fact be discouraged in the zone for efficient exploitation of ground water resources.

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