## Research Article

# Hydrogeological Importance of Bedrock Sediments to the Community and Growth of Sugar Cane in Fadama Rake Area of Madagali, Northeast Nigeria

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**Abstract:** Thirty Vertical Electrical Sounding (VES) points were sited on the alluvial plain of Madagali fadama area. This was aimed at establishing the lithological character of the drainage plain and its contributions to the growth of sugar cane. 1X1D shareware package was used to interpret the curves. Over the floodplain, potential recharge water into the subsurface units probably takes place through migration routes of coarse-grained colluvial deposits which act as effective soak away for surface runoff. The nature of the basin and/or the transporting routes conditioned the thickness of the surface layer. Effects of near surface bedrock or buried granite boulders disengaged from nearby hills are demonstrated by sandwiching of the bedrock in place in the second resistivity layer. Closely spaced iso-ohmic contour values suggest presence of different types of sediments within the medium of deposition. The high thickness associated with this horizon suggests that the basin was large enough to contain the sediments. Clay materials in the third resistivity layer occur as lens bodies within sandy material. Clay free sand and gravel constitute a great proportion of the stratigraphy. Parts of the bedrock's summits that approached the surface at two separate places are resistant to weathering. Thicker sediments were available where sandy and gravelly materials prevailed. Gradual increases in thickness of the sediments suggest a gentle sloping depositional basin. Sharp gradation of the grain size from clay to bedrock within the fourth resistivity layer depicts a basin that did not permit transportation of the material far from its source. Three zones of groundwater potentials were identified from the total longitudinal conductance and the porosity maps of the area. These were based on the weathered products that constitute the aquifer zone where thick saturated sand and gravel are associated to deep aquifer development and thin saturated sand and gravel to bedrock highs. The contributions of the overburden to sourcing groundwater probably attracted Madagali community to the area and promote the growth of sugar cane in the fadama.

**Keywords:** Aquifer, fadama, groundwater, lithology, sediments, sugar cane

## INTRODUCTION

Madagali area constitutes part of the crystalline Basement Complex of Northeastern Nigeria (Fig. 1). The area lies between latitudes 10°53'12.2"-10°55'13.08" N and between longitudes 13°37'36.84"-13°58'32.28" E. Madagali area is characterized by drier climate of semi-arid regions. Annual rainfall lasts for a maximum period of five months and about eighty percent of the rain falls in the months of July and August. During this period of high precipitation, the Fadama Rake (Sugar Cane Wetland) area is recharged directly through infiltration of rain water and surface water runoff from the elevated Mandara hill area by the east. When the rate of precipitation and surface runoff exceed the rate of infiltration, the stream overflows its bank and deposits its load on the low lying plains. Deposits of the fadama area which occurs along the drainage axis coincide with poorly drained areas characterized by braided streams. Along the narrow

river channel which is just a few meters wide and incised less than one meter, there are medium sandy particles. Due to erosional flooding, fine sandy and silty alluvium is deposited over wide areas and it is within these areas fadama farming activities thrive. Drainage pattern over the area consists more or less of braided system of ill-defined streams. The overall drainage pattern is dendritic with extensive areas of braided streams. Principal crops grown in the area consist of sugar cane, guinea corn, groundnuts, beans, tomatoes etc. Sugar cane is the main cash crop grown on the fadama area.

The exercise was undertaken in the month of November, 2012 with the aim of establishing the lithological characteristics of the drainage plain and its importance to the growth of sugar cane. Since the drainage plain is the best exploration target, Vertical Electrical Sounding (VES) points utilizing the Schlumberger configuration were located on the alluvial deposits of the flood plain.

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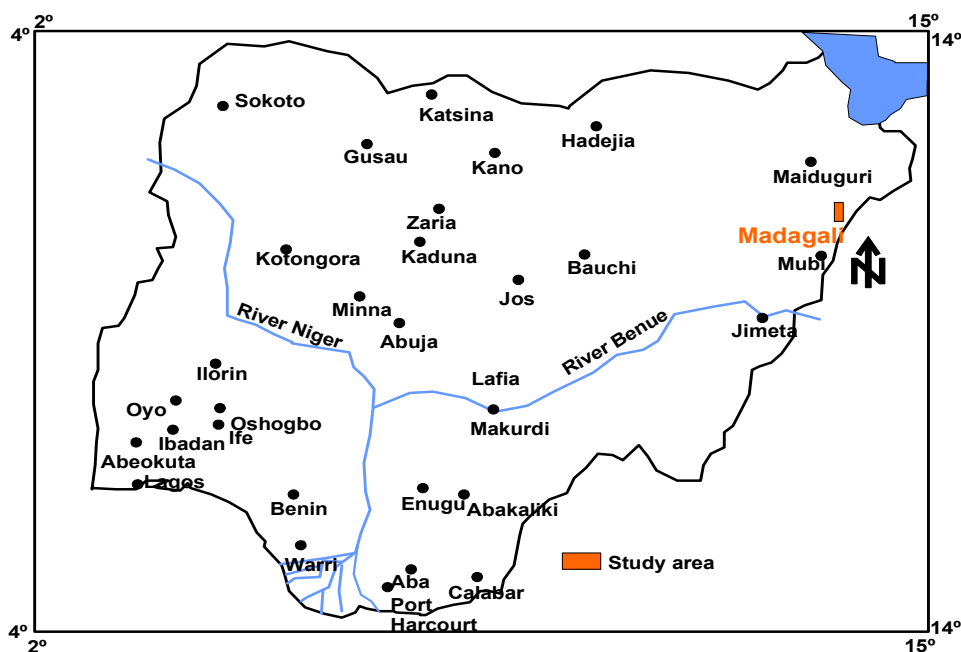
Fig. 1: Map of Nigeria showing the study area

**Geology:** Madagali is located on ancient crystalline rocks of the Nigerian Basement Complex. Basement Complex rocks constitute the principal and oldest stratigraphic unit in Nigeria and consist mainly of granites, gneisses, migmatites and subordinate schistose rocks. In northeastern Nigeria the granites are 5-600 million years old, while the migmatite are over 2,000 million years old. The basement region, in which the study area lies is exposed over much of the northern part of Adamawa State and is defined tectonically by fault bounded basins containing Cretaceous to Quaternary sediments. The Chad Basin lies to the north and the Benue Trough to the south. The Zambuk Ridge (a shallow basin) links the two basins to the west.

Adamawa State Basement Complex region is affected by faults and fractures which are intensified in the proximity of the two upper Cretaceous graben structures. These structures trend southeast towards the Benue Trough and northeast towards the Chad Basin.

Volcanic activity took place in the area in the late Tertiary; the Biu Plateau is the most pronounced basalt activity in the northeast (Conred Nigeria Limited, 1978). Numerous plugs and dykes occur in the south towards the Benue Trough. Isolated basic plugs outcropped along the line of the Mandara Mountain chain bordering the area by the east, Michika to the south and Mubi to the southeast. Less than fifty kilometres to the north the basement disappears beneath sediments of the Chad Formation.

## METHOD OF ELECTRICAL SOUNDING

Electrical resistivity of earth's materials is measured by introducing electric current into the ground and measuring the potential developed by the current. The resistivity of the materials is controlled by the porosity, water content, water quality and resistivity of the matrix. For Vertical Electrical Sounding (VES) technique, a direct current is introduced into the ground through a pair of electrodes and the potential difference is measured through a second pair of electrodes. The current and the potential measurements are used to calculate the apparent resistivity of the subsurface materials. Increase on the depth of investigation is achieved by progressive increase in the electrodes distance. The Schlumberger array, where four electrodes are placed along a straight line on the surface such that the current electrodes distance AB is equal to or greater than five times the potential electrode distance MN (Ayers, 1989) was adopted using an ABEM Terrameter SAS 300 C. The apparent resistivity given by Gruntorad and Karous (1984) for linear symmetry array of electrodes (AMNB) is determined by the equation:
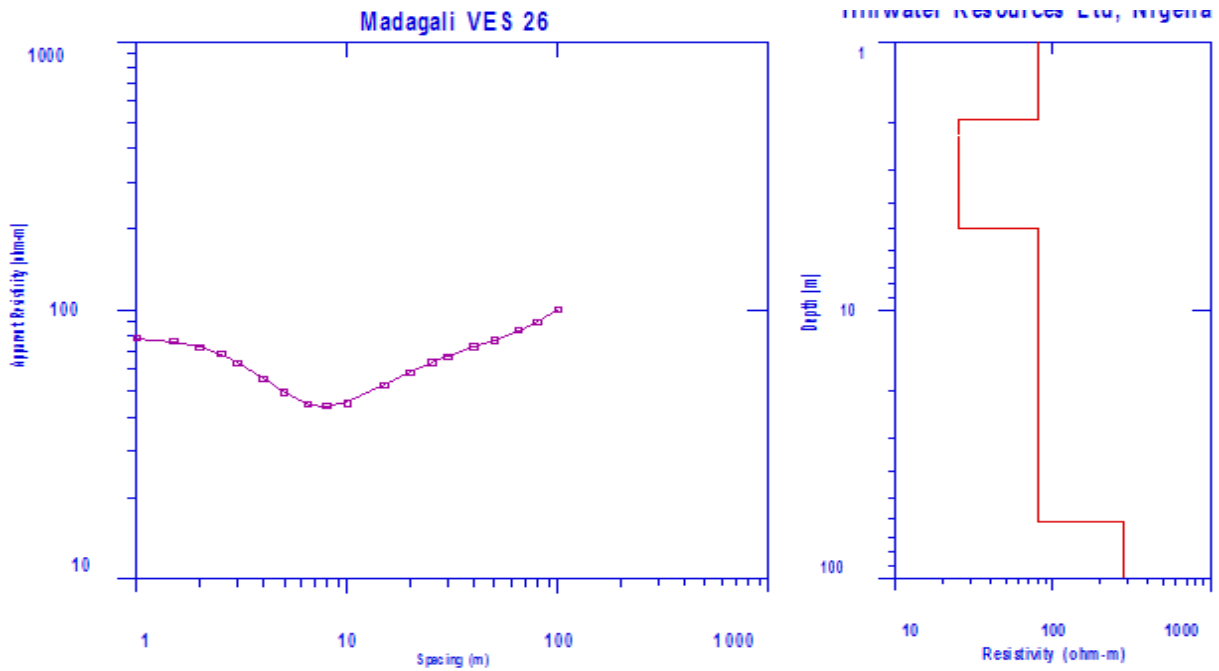
$$\rho_a = \pi \frac{AMAN}{MN} \frac{V}{I} \qquad (1)$$

where V is the measured potential difference and I is the current.

A total of thirty VES points were sited in the area. Each sounding point attained electric current half spacing (AB/2) of 100 m, which is considered adequate to reveal the thickness of the weathered products overlying the bedrock.
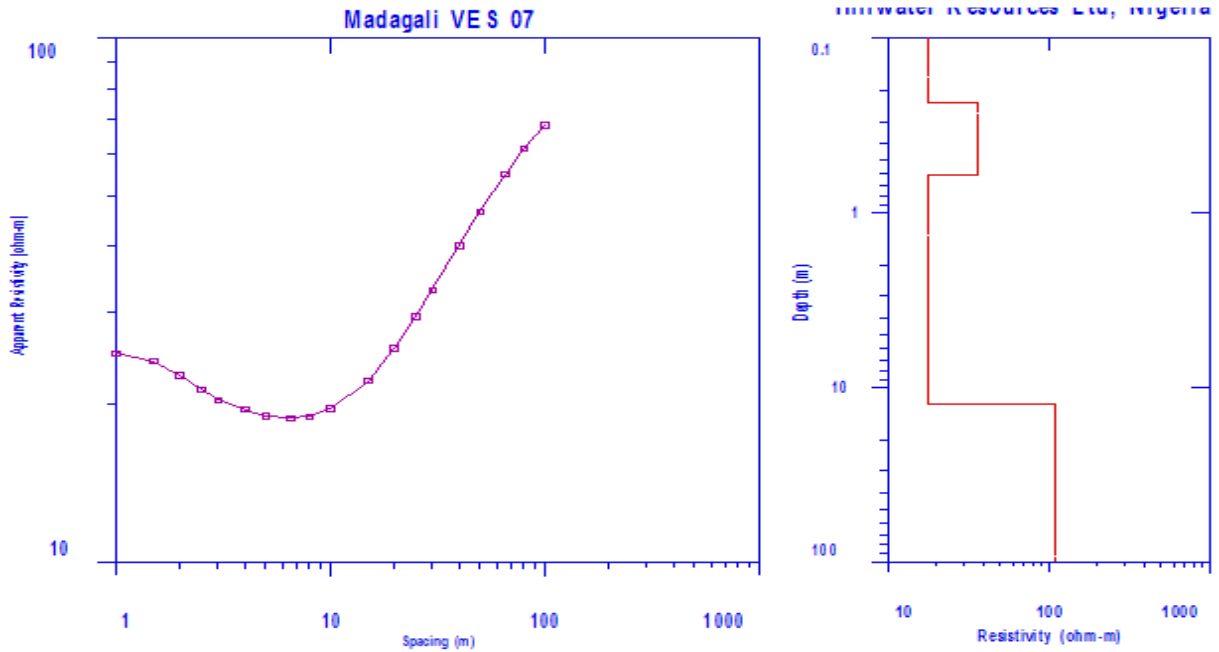
(a) VES point 7



(b) VES point 26

Fig. 2: Interpreted models for VES points 7 and 26

**Data interpretation:** The apparent resistivity data of the field curves were plotted against electrode spacing on bilogaritmic scales. 1X1D (2002) shareware package for Window was used to properly interpret the curves. In entering the field data the AB/2 values were entered first and their corresponding apparent resistivity values were entered later. The AB/2 values were entered in ascending manner; one segment following another. As a consequence of the quantitative analysis, where best fit solutions were sought, the initial model of each curve was modified several times by multiple iteration inversions. When the interpretation was completed a plot of the calculated layer thickness and resistivities, error closure statistics, resistivity parameters and

resistivity sections were given. Samples of interpreted models for VES points 7 and 26 (assumed to consist of four resistivity layers each) are given in Fig. 2.

**Description of the layers' resistivity maps:** Resistivity values of the surface layer shown in Fig. 3a range from those of clay material to fresh bedrock. The clay occupies over 80% of the area. Sand and fresh bedrock occur at the central part. The sand engulfed the bedrock which, in turn is sandwiched by the clay. Sandy material is also observed at the northern part. In Fig. 3b the thickness of the unit ranges from less than 1 m at the central part to 8.5 m at the southern and northern parts. Four major closures are observed around the southern, southeastern, north central and northern parts. Three of such closures have their thicknesses increasing towards their centres.

Resistivity values of the second layer in Fig. 4a suggest that it consists of clay, sand, gravel and bedrock with varying proportions. Clay occurs in patches at the southwestern, eastern, western, central and northern parts. The clay is sandwiched by sand at the central and northern regions and partly sandwiched by the same

sandy material at the eastern and western edges. Sand also sandwiched gravel in two locations at the central region. The gravel sandwiched the bedrock at the north central and southeastern parts. Lithological compositions of the deposits vary greatly within the three closures. The unit is relatively thick at the northern and eastern sides (Fig. 4b). About nine to ten closures are associated with the unit's isopach map. Thicknesses of the three closures vary greatly.

Clay constituents in the third resistivity layer shown in Fig. 5a occur as a partial closure at the southern edge and in smaller pockets at three other localities. Sand occupies almost half of the southern area. Gravel is enclosed within sandy material at the central part and borders sand by the east to the north. Part of the extreme north contains gravel in the sequence. Fresh bedrock covers a great proportion of the northern part. Gradation of sediments within the two northern closures is sharp. In Fig. 5b the thickness of the deposits ranges from 4-48 m. Apart from the southwest, there is a general gradual increase in thickness of the unit.
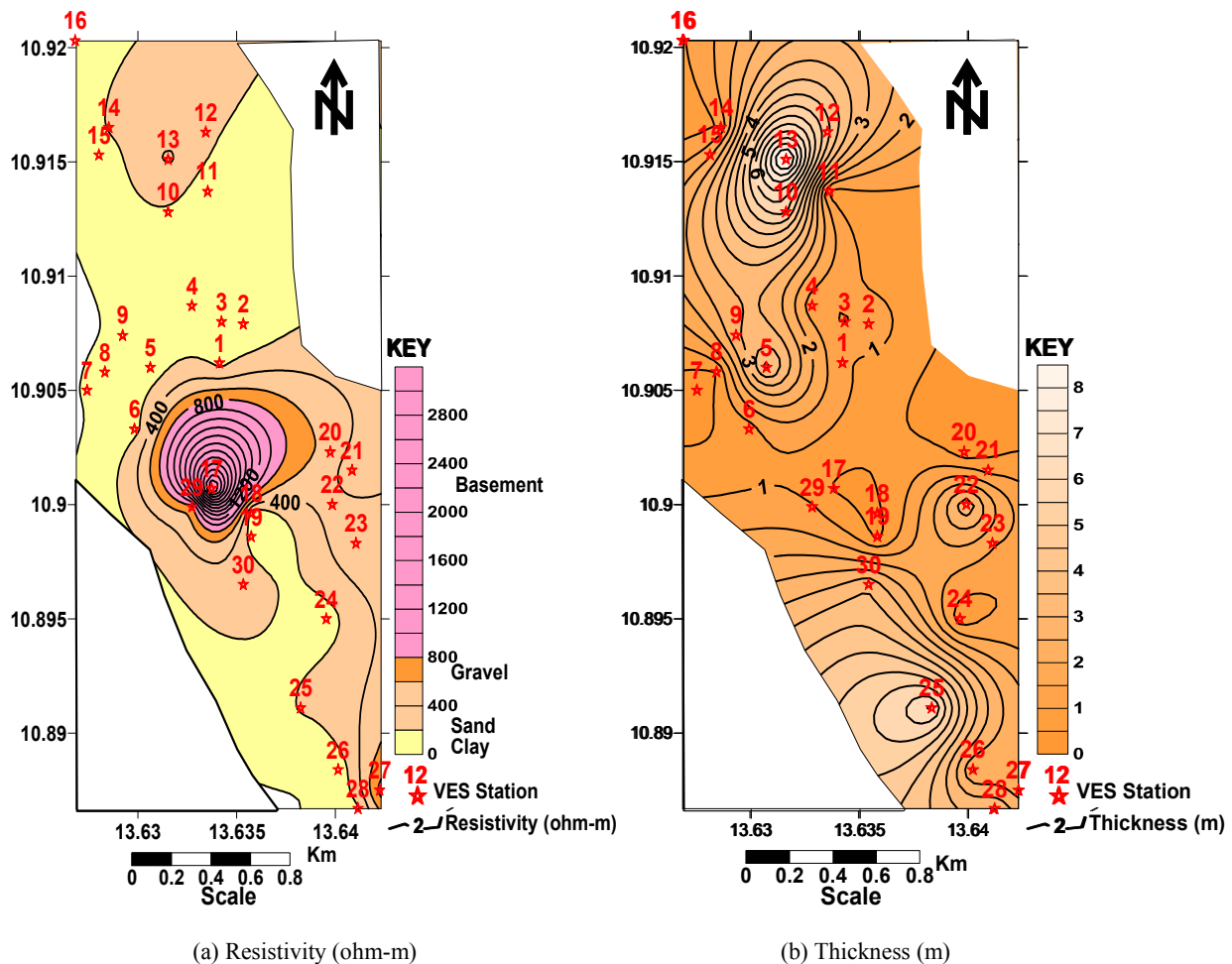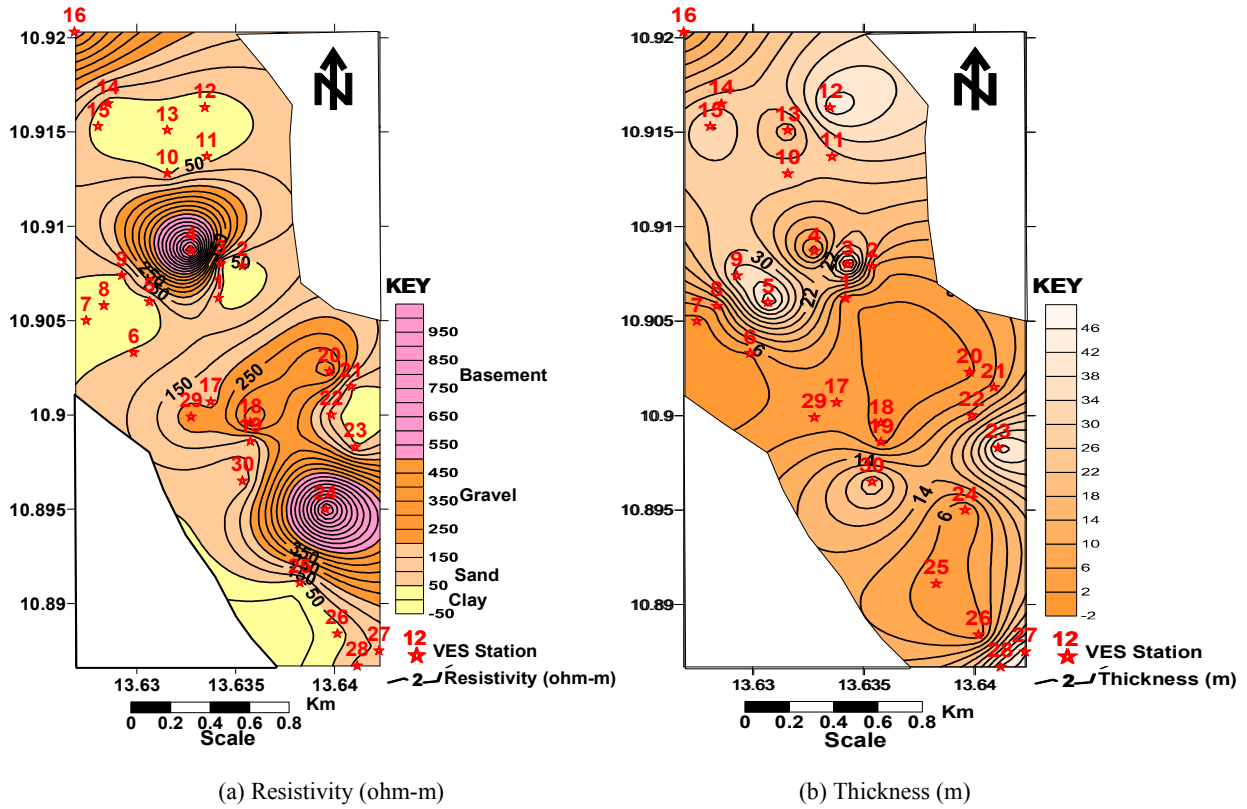


(a) Resistivity (ohm-m)

(b) Thickness (m)

Fig. 3: Maps of the surface resistivity layer

(a) Resistivity (ohm-m)

(b) Thickness (m)

Fig. 4: Maps of the second resistivity layer
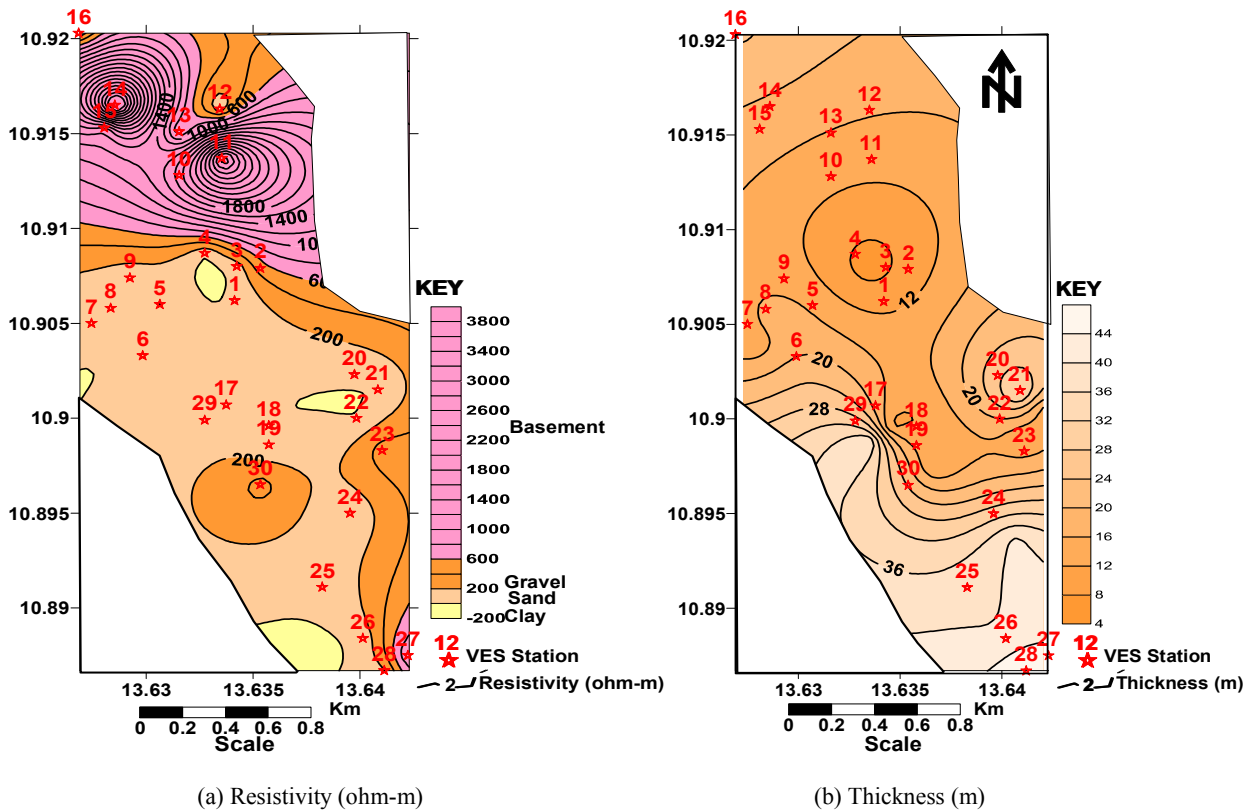


(a) Resistivity (ohm-m)

(b) Thickness (m)

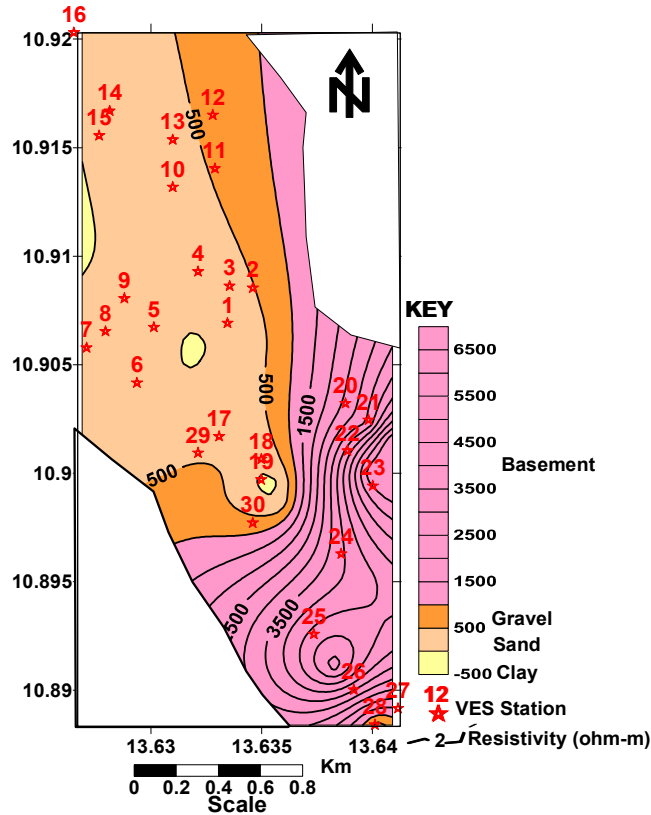Fig. 5: Maps of the third resistivity layer

Fig. 6: Isoresistivity map of the fourth resistivity layer

Isoresistivity map of the fourth layer is given in Fig. 6. The resistivity values of the layer ranges from those of moist clay to fresh bedrock. Gradation in the layer's lithology is sharp. Clay material occurs in small pockets at the central region and trends in the NW-SE direction. Sand lies at the northwestern part and is bordered to the east by gravel. Fresh bedrock was encountered at the northeast and covers almost half of the southern part stratigraphy.

The parameter of the total longitudinal conductance C is important to describe resistivity layer sections. In a basement region the substratum is resistant; the total longitudinal conductance of the layers overlying it is defined by the equation:

$$C = h/\rho \qquad (2)$$

where,
h : The thickness
$\rho$ : The resistivity

Correlation between the total longitudinal conductance and the hydrogeological potentials of the weathered horizon places higher values of total longitudinal conductance to greater thickness of the weathered bedrock. Lower total longitudinal conductance values are linked to near surface resistant substrata.

Total longitudinal conductance map of the layers overlying the basic resistant horizon is given in Fig. 7. Conductivity of the sediments ranges from 0.2-3.5 Sm. The map hosts six isolated closures at the northern, central, eastern and western parts. A partial closure is encountered at the southwestern edge. Different higher conductivity zones are recognized around the northern, central and eastern closures.

Estimation of porosity values from the interpreted resistivity data made use of the well known Archie equation and modified for unconsolidated sands; and is given by Doveton (1986), Ayers (1989) and Yusuf and Alkali (2012) as:

$$F = \frac{1.0}{\Phi^{1.3}} = \frac{\partial b}{\partial w} \qquad (3)$$

where,
F : The formation factor
$\Phi$ : The porosity
$\partial b$ : The bulk formation resistivity derived from VES field data
$\partial w$ : The pore water resistivity measured from well samples

Applying the equation to interpreted resistivity points of the second resistivity layer and resistivity measurements of 20.8 ohm-m obtained from one of the
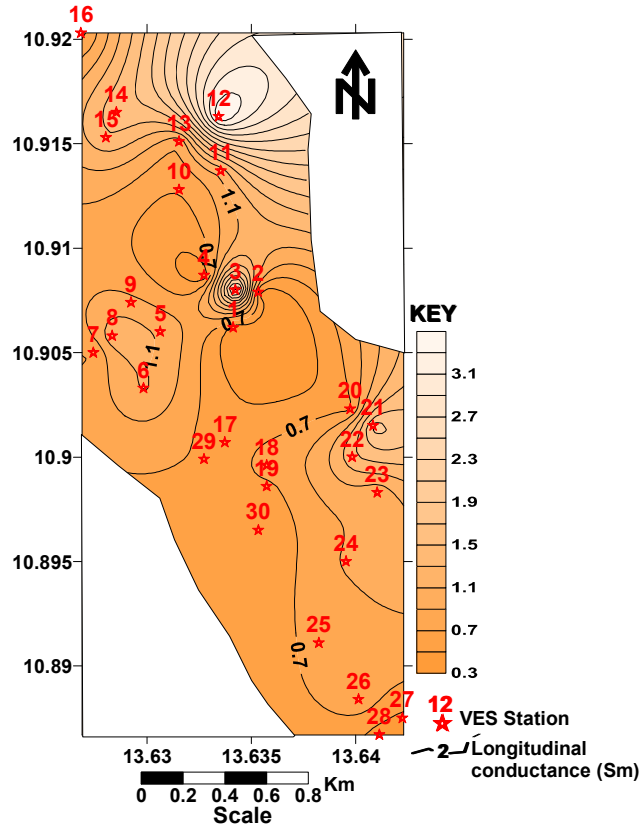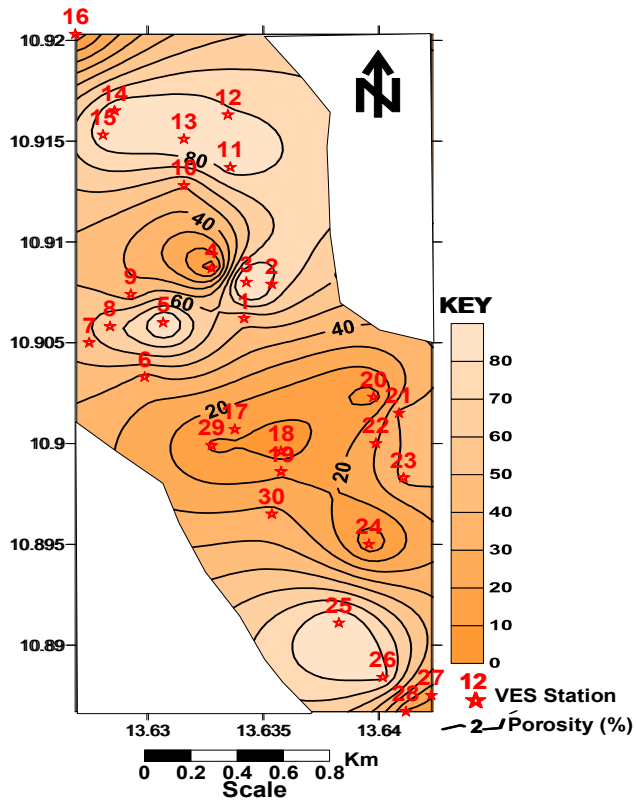
Fig. 7: Longitudinal conductance map



Fig. 8: Porosity map of the second resistivity layer

fadama well, yields porosity values that were used to produce the map in Fig. 8. In the map isolated porous zones are obvious. The southern and northern half of the aquifer is highly porous. Sharp variations in porosity values are observed at the north central and southern closures. The south central part lies within a low porosity domain.

## RESULTS AND DISCUSSION

A closed drainage system that weakens the velocity of the transporting agent enhanced accumulation of debris in the resistivity map of the surface layer. The closely spaced contour values around the central closure are linked to diverse composition of the colluvial materials because they were not transported far from the depositional environment. Owing to its coarse-grained character, colluvial deposit at the central part may act as effective collectors or "soak away" for surface water runoff from nearby hills. Thicker sediments in the unit were probably deposited within depressed parts of the underlying layer created by past erosional activities on the underlying layer. Alternatively the nature of the transporting route might have conditioned the thickness of the surface layer, where thicker sediments are associated with gentle slopes and thinner ones with steep slopes. Compactness of the isopach map contour values at the northern and southern closures clearly suggests that the gradients were steep as to hinder accumulation of thicker sediments along such paths.

Sandwiching of the bedrock by gravel in the second resistivity layer is a clear demonstration of the presence of fresh bedrock which approaches the surface or a buried bedrock boulder that was disengaged from a nearby parent hill. Diverse composition of the sediments indicated by the sharpness of the contour values show that the material were not opportune to undergo long transportation distance and the depositional medium did not permit sorting of the materials. The high thickness associated with the second horizon suggests that the basin was large enough to contain the sediments. It may also suggest that weathered materials were readily available and the effect of erosion on them was mild.

Low clay content in the third resistivity layer is explained by the fact that some of it disappeared with time. The clay recorded in the unit probably survived because they were trapped as lens bodies by the sandy material. Since sand and gravel occupy more than half of the area, it may be deduced that these materials are clay free and can readily give out their water in storage. The two isolated summits that constitute the bedrock probably approached the surface at two separate places because of their resistance to weathering. Isopach map of the unit shows that thicker sediments are encountered where sandy and gravelly materials prevailed. Lower thicknesses lie within the domain occupy by the

bedrock. Gradual increase in thickness of the sediments in the layer suggests that the slope of the basin's surface was gentle.

Sharp gradation of the deposits from clay to bedrock in the fourth resistivity layer depicts a closed basin that did not permit transportation of the material far from its source. A quite water body played a significant role to the presence of clay lenses within the sandy material. The bedrock at the northeast region stands high because of its resistant to weathering; however, parts of it might have contributed to the weathered products of the unit.

Map of the total longitudinal conductance indicates a high groundwater potential zone around the northern, central and eastern parts. These areas may contain thicker arenaceous materials in the stratigraphic sequence (Goni *et al.*, 2003; Alkali, 2007). The intermediate conductivity zone at the western side may constitute decreasing arenaceous contents, possibly containing fine grained matrix in coarse grained fractions. Lower groundwater potential zones that are kept apart by the central groundwater zone are associated to presence of fractured bedrock with minimum degree of decomposed rock fragments.

By making reference to porosity values of Davis (1969) and Schwartz and Zang (2004), it is observed that most of the area lies within porosity values of weathered bedrock aquifer. Slightly lower porosity values are associated with areas that are composed primarily of wet clay or at least saturated fine grained material or even fractured bedrock. Intermediate porosity values probably indicate a mix of coarser grained clastics and very fine grained sediments.

**Significance of the sediments to the growth of sugar cane:** Over the floodplain the subsurface units receive recharge directly through infiltration from the surface layer. Where the clay unit is present, potential recharge water probably cannot infiltrate the low permeable layer and therefore must take an alternative migration route through the colluvial deposits. Where the land is irrigated for other economic crops, water is extracted from the aquifer and transported by surface drainage. The second and third layers associate thick saturated sand and gravel to deep channel development and thin saturated sand and gravel to bedrock highs.

From the map of saturated thickness it is certain that the permeable sand and gravel units extend beneath the uplands. Based on the total longitudinal conductance and porosity values, it appears that Madagali alluvial aquifer is in hydraulic continuity with permeable units underlying the uplands at some locations. The contribution of the overburden to groundwater accumulation probably prompted settlers of Madagali community to the area because groundwater is easily obtained even during adverse conditions. The constitution of the aquifer horizons

offers adequate water supply for sugar cane to thrive in the fadama area.

## CONCLUSION

Interpretation of thirty resistivity points of the alluvial plain of Madagali fadama revealed that potential recharge water into the subsurface units from surface runoff take place through the coarse-grained colluvial deposit. The nature of the basin and/or the transporting routes conditioned the thickness of the layers. Tightly closed iso-ohmic contour values suggest presence of diverse sediments within the same depositional medium. Thicker layers are associated with basins that were large enough to contain the sediments. Where the basin slopes gently, the thickness of the sediments increases gradually. Three groundwater potentials zones constitute the aquifer in the area. Thick saturated sand and gravel are associated to deep aquifer horizon and thin saturated sand and gravel to bedrock highs. Easily obtainable groundwater resource attracted Madagali community to the area and enhances growth of sugar cane in the fadama.

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