Table 6.9. Summary of the profiling results.

Electrode Separetions (m)	Approximate depth probed (m)	Apparent Resistivity resistivity range (ohm-m)	Mean apparent resistivity (ohm-m)
L/2, = 3.98, a/2 = 0.5	5.3	1391-15106	6093
L/2, = 10.0 a/2 = 0.5	13.3	347-3942	1871
L/2, = 39.8 a/2 =5.0	53.3	143-1154	292

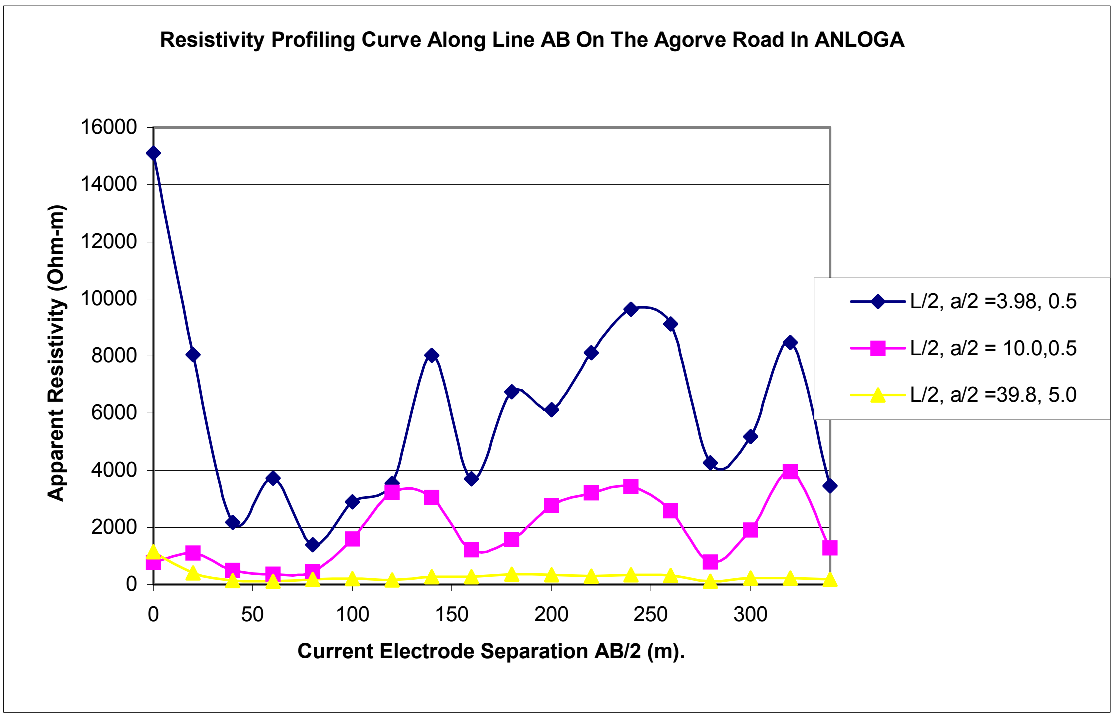

Fig. 6.17 Apparent resistivity response curve along sections of traverse QQ[1]

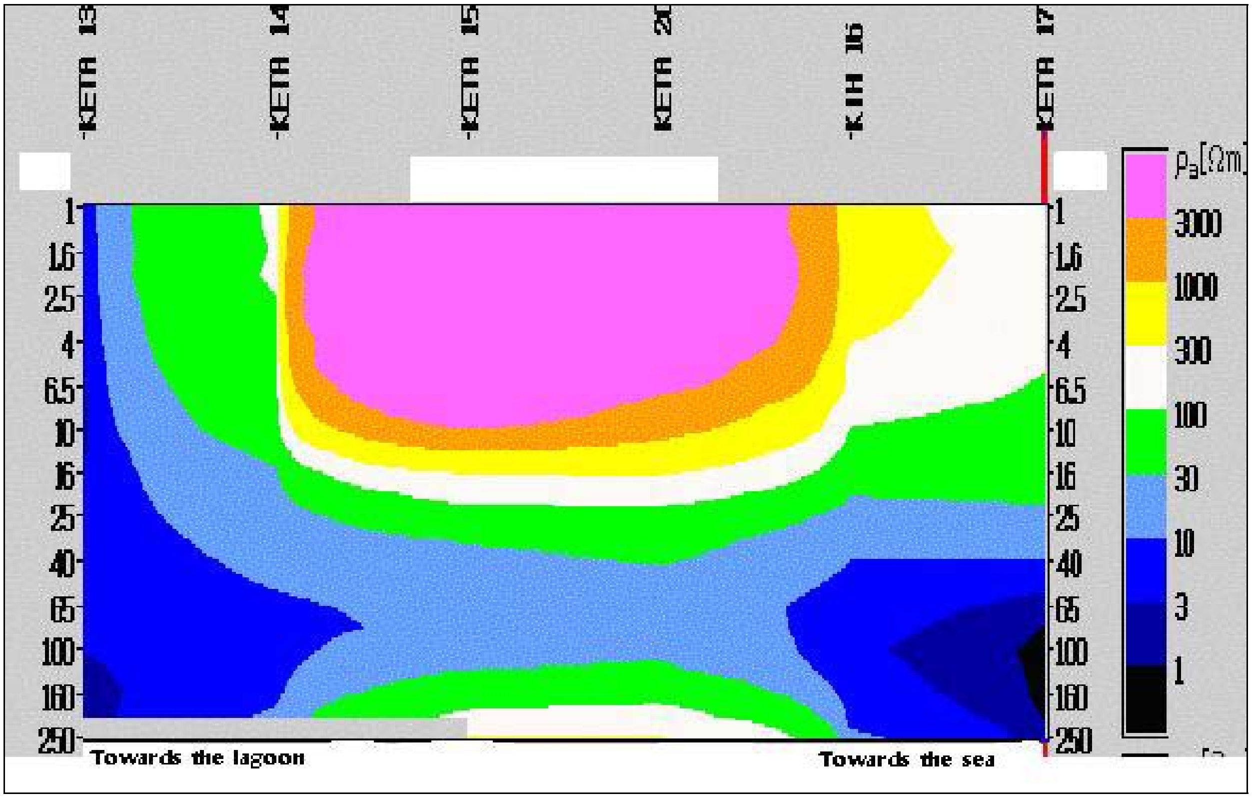

Fig.6.18 Geo-electric section along parts of Agorve road in Anloga (Dry season results)

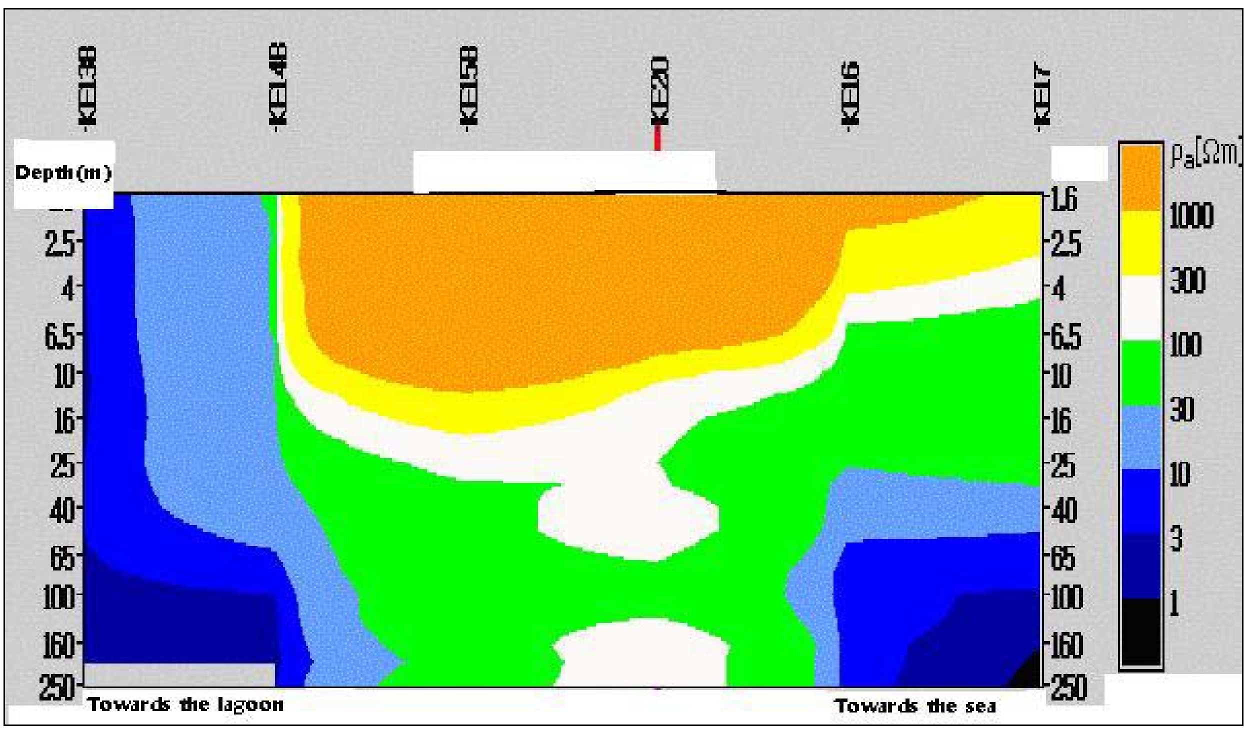

Fig. 6.19 Geo-electric section along parts of Agorve road in Anloga (Rainy season results)

The figures reveal that two highly conductive projections whose apparent resistivities range from 0.1 to 10 Ohm-m were successfully mapped out using the surface resistivity techniques. These conductive layers lie to the northern and southern extremities of the project area and are believed to be due to salinewater inflow from the lagoon and the sea respectively or due to responses from clay. The bodies also terminate in the area underlain by the VES stations Ke15, Ke16 and Ke20. The observation made in the area based on the shape of the conductive bands was interpreted in one of two ways:

1) Should the low (3 to 10 Ώ-m) to very low (< 1 Ώ-m) apparent resistivities recorded be primarily due to poor water quality caused by the encroachment of the lagoon and the sea, then there are indications that the lagoon and the sea are not in hydraulic continuity even at depths <50 m.

2) Similarly, should the low to very low apparent resistivities recorded be due to clay, then the phenomenon of structural thinning or lithologic attenuation could be the most probable factor responsible for the discontinuity in the highly conductive layers (Figs 6.20 and 6.21).

No drilling was carried out to confirm the results on this particular traverse. However, based on the results of the borehole controlled VES and lithologic data from the area the resistivities of the conductive projections identified them more as thick clay layers rather than saline aquifers.

The resistivity of the materials at the zone where the conductive layers terminate range from 30 to 3000 Ohm-m and is characterized as thick accumulation of medium-coarse-gravely sand aquifers with very little or no traces of clay inclusions and extends beyond 50 depth. The two inter-seasonal geo-electric cross-sections therefore confirm the presence of a relatively deeper root of freshwater aquifer in the area that serves as a hydraulic barrier separating the marine clays from the lagoon clays.

A general observation made based on the overall geophysical results is that, there seem to exist, a southward pressure from recharging water on the groundwater flow regimes. This pressure is high enough to push the seawater southwards and thereby preventing seawater encroachment in the area. This observation is supported by the results of the hydrochemical analysis, which helped to prove that there are no indications of seawater intrusion in the area and that, the seawater has not played any significant roles in the salinisation processes in the area.

6.4.2 Salinewater-Freshwater Interface

The analysis of the geophysical data, groundwater conductivity measurements and other hydrochemical parameters shows that the freshwater-salinewater interface in the Anloga area lies beyond an approximate depth of 40 m at the shoreline to a maximum depth of about 100 m at the mid-portion between the lagoon and the sea. The area where the interface appears to be deepest underlies the VES station Ke15, Ke16 and Ke20 (Figs. 6.20 and 6.21). Test drilling close to the lagoon has also indicated that the interface lies beyond 14 m. Generally extremely low apparent resistivity (<1.0 Ω-m) are used to define the saline contaminated zones. Close to the lagoon, and in an area dominated by VES stations Ke1, Ke2 and partly Ke3, the interface seems to occur right at the surface. Further investigations, however, revealed that the very low resisitivity layers at the surface are basically saltwater saturated clays that underlies the flood plains of the Keta lagoon but not saline aquifers. It is also equally important to attribute the persistently low layer resistivities in the northern zones to the fact that, since salt is hygroscopic, these areas which are believed to be highly salinised at the surface retain enough soil moisture to keep the conductivity at measurable levels even when the other areas are relatively dry.

The iso-resistivity crossections drown from the VES results are shown (Figs. 6.20 and 6.21) and from the diagrams, the two zones of possible saline in-flow from the lagoon and sea occurs at depth between 40 and 60 from the sea and the lagoon and persists with the seasons. The resistivity of the conductive projections were compared with the Borehole controlled VES results and the lithologic logs of the deep boreholes in the area and it was discovered the conductive bodies are basically clays and silty materials and not saline aquifers. Interesting about the figures is that the conductive bands terminate (thin out) under VES stations Ke15 and Ke20. This zone of discontinuity was further investigated using resistivity profiling and the results correlate well with those obtained during the sounding at the same stations and indicate that the area is underlain by thick, clay-free sand, gravel and limestone (calcareous materials) that contain freshwater.

6.5 Relationships between Topography and VES Results

Table 6.10 shows the topographic heights of some VES stations and Figure 6.22 shows the local topographic map of the study area.

Table 6.10 The elevations of VES stations above sea level.

VES POINT	ELEVATION (m)	VES POINT	ELEVATION (m)
KE01	000	KE12	3.2
KE02	0.2	KE13	1.8
KE03	0.6	KE14	2.2
KE04	1.6	KE15	3.4
KE05	3.0	KE16	2.6
KE06	3.0	KE17	1.8
KE07	2.4	KE18	2.4
KE08	3.2	KE19	2.2
KE09	1.8	KE20	3.2
KE10	3.0	KE21	2.2
KE11	3.2	KE22	2.8

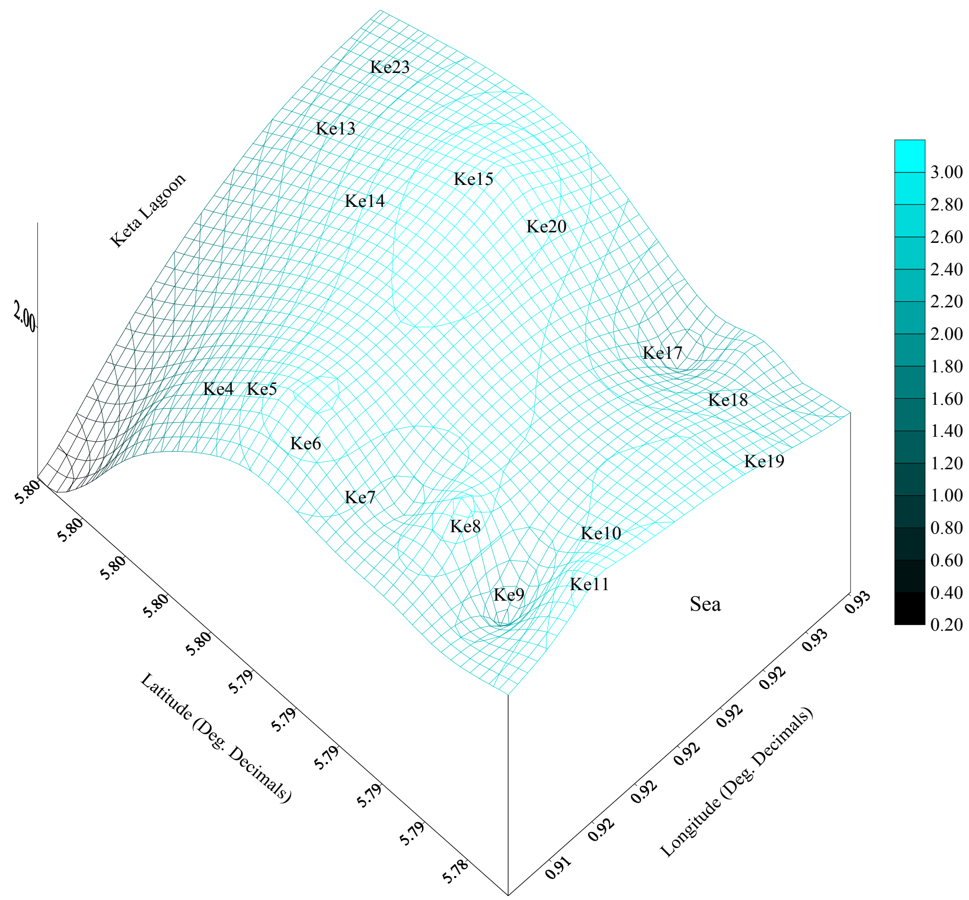

Fig.6.22 Topograhpic map of part of the Anloga area

The diagram reveals that the lowest local topographic area is located at the northern sector between the Accra-Keta road and the Keta lagoon. The VES stations Ke1, Ke2, Ke3, Ke4, Ke13, Ke14 and AN 1-3RST are located in this depression. The land surface here ranges between 0.5 and 1 m above sea level. The low to very low (27 - 0.1 Ohm-m) layer resistivities measured in these sectors were the responses from the silty-fine sands, clay and saline saturated soils.

However, surface resistivities (p_a>10,000 Ohm-m) were recorded at stations located on topographically high areas, notably Ke11, Ke15, and Ke20 due to the fact that these areas are underlain by thick layers of coarse-gravelly sand. The depth to the water table was determined from the static water levels measured from hand dug wells located in the topographically high areas and was found to be greater than 3 m below the surface. This means that the sand layers are relatively dry for most of the time, hence less conductive. The VES stations Ke7, Ke9, Ke16, and Ke17 are located within intervening depressions in the southern sector. The first layer resistivities at these stations range from 100 to 900 Ohm-m and this is due to the fact that the coarse-sandy soil is always relatively wet because of continuous irrigation. Thus, the resistivity boundaries between these distinct zones correlate fairly well with the actual pedologic divisions.

Based on the analyses made so far and in line with the objectives of the study, a generalised model that characterizes the various lithologic units using the geophysical results was generated for the study area (Table 6.11).

Table 6.11 Summary of the litho-geophysical and hydro-geophysical characterization results

LAYERS	APPARENT RESISTIVITY RANGE (Ohm-m)	LITHOLOGIC UNIT	REMARKS
A	ρ_a <1 Ohm-m	clay	Highly saline saturated
B	1<ρ_a <4 Ohm-m	clay	Low-Moderately saline saturated
C	4<ρ_a <10 Ohm-m	Silty-clay/sand	Aquitards/saline saturated sand aquifers
D	10< ρ_a < 50 Ohm-m	Clayey-silty sand	Freshwater saturated
E	50< ρ_a<100 Ohm-m	Fine-Medium-grained sand	Freshwater saturated (prolific aquifers)
F	100<ρ_a<1000 Ohm-m	Medium–coarse grained sand and gravely beds	Freshwater saturated (prolific aquifers)
G	1000<ρ_a < 10000 Ohm-m	Coarse sand and gravely beds	Partially saturated (vadoze zone)
H	ρ_a > 10000 Ohm-m	Coarse sand and gravely beds	Highly dessicated

7.0 CONCLUSION AND RECOMMENDATIONS

The variation in pH show similar trend as reported in earlier reports. The dry season values of February and April 2004 are generally high as can be seen from the plot due to concentration as a result of evaporation. Notwithstanding this general observation, local reactions do occur and in some locations, values of pH in April were low

The main water types are the Ca^{2+} $Na^{+}HCO_3^{-}Cl^{-}$, $Na^{+}Cl^{-}$, Ca^{2+} HCO_3^{-} and $Na^{+}HCO_3^{-}$ Cl^{-} types. The hydrochemistry is dominated by the first two water types and all but one does not have dominant bicarbonate ions and bearing in mind that the aquifer is dominated by sand, the likely source of the bicarbonate is carbon dioxide in the atmosphere and soil vapour. Chloride ions appear to have over-riding dominance and reflect strongly in the Durov diagram

The analysis of the geophysical data, groundwater conductivity measurements and other hydrochemical parameters shows that the freshwater-salinewater interface in the Anloga area lies beyond an approximate depth of 40 m at the shoreline to a maximum depth of about 100 m at the mid-portion between the lagoon and the sea

Drilling results also indicate that the very low resistivity areas are underlain by thick plastic clays, which in part serve as the confining layers to the sand and gravel aquifers. The presence of the clay layers may also impede the downward movement of the contaminant front and also present a confined aquifer system that does not allow the saline water front to develop as a result of high potential gradients towards the sea and lagoon. This may have accounted for the presence of freshwater in the sand and gravel layers located beneath thick clay layers in such a saline environment.

It is recommended that the monitoring of the Keta area aquifers should be discontinued since monitoring activities over the past two years has yielded significant results which depict the extent of vulnerability of the aquifers in this area. Rather the geometry and aquifer characteristics in the Keta aquifers should determined in the ensuing months. Monitoring activities in the Anloga and Woe areas should be intensified in order to study more conclusively the vulnerability of the aquifer systems, the nature and geometry of the aquifer system and the water demand and use in the whole of the basin.