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GROUNDWATER QUALITY ASSESSMENT OF A COASTAL AQUIFER USING GEOELECTRICAL TECHNIQUES

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Geoelectrical measurements using the Vertical Electrical Sounding (VES) method are well suited to the investigation of alluvial aquifers with large resistivity contacts. They have also been commonly used to estimate groundwater quality. VES was conducted in a coastal aquifer lying south of Chennai city, Madras, India, using a Schlumberger configuration with 80 locations in a rectangular grid pattern and a maximum AB/2 separation of 33 m. The results of data analysis indicate the occurrence of a fresh water ridge along the central part of the coastal aquifer. The eastern and western margins of the aquifer were found to have groundwater of poor quality. Sea water intrusion has occurred at some locations along the east coast with the interface located 200 - 450 m from the coast. Poor water quality along the western margin is due to the influence of the Buckingham canal.

INTRODUCTION

Electrical resistivity methods have been widely used to study groundwater contamination. The decrease in resistivity caused by salination of groundwater helps to identify the contaminant zones. Coastal aquifers that are prone to saline water intrusion are identified by relatively low resistivity values, indicating salt water intrusion. Monitoring of well data provides information on contaminant concentration at isolated locations within the study area. Also, it is difficult to have an idea about contamination where wells are absent. Thus, they offer a limited constraint on the spatial variability of the locations, the extent of the contaminant, and the depth and degree of contamination. Under these conditions, geoelectrical techniques find useful application in the evaluation of groundwater contamination. In earlier studies, electrical methods have been used in groundwater quality evaluation of coastal aquifers (Arora and Bose, 1981; Balasubramanian et al., 1985, and Melanchton et al., 1988). In this paper, geoelectrical sounding data were analyzed as a part of the ongoing investigation of groundwater contamination in a coastal aquifer located south of Chennai city, Madras, South India.

STUDY AREA

The study area lying just south of Chennai city is enclosed by salt water on all four sides: the Bay of Bengal in the east, Buckingham canal in the west, and the Aadyar river and Muttukkadu estuary in the north and south, respectively (Figure 1). The Buckingham canal, which runs almost parallel to the Bay of Bengal in a north-south direction, contains stagnant saline water. Due to improper pumping along the coast, this aquifer is under a constant threat of saline water intrusion. The study area has a terrain elevation between 3 and 10 m and enjoys a subtropical climate, with the annual temperature ranging between 24.3 and 41°C. It receives most of its rainfall from the northeast monsoon during the months of October, November and December. The average annual rainfall is around 1200 mm.

HYDROGEOLOGY

This aquifer consists of alluvial deposits of interlayered clay, silt, sand, gravel and pebble beds. The thickness of these unconsolidated Quaternary sediments ranges between 10 m and 24 m, and the sequence is underlain by charnockites of Proterozoic age. Eolian dune and beach sands occur along a narrow coastal strip a few hundred meters wide. The groundwater in this coastal aquifer occurs under shallow water table conditions. The water level rises during October to December, with an average water level fluctuation of 2.5 m in a year. Rainfall recharge is the main source of aquifer replenishment. Wells that exist at the landward edge of the beach sand, in white quartz sand below the dunes, are a significant water supply source in the southern part of the city. Field observations indicate that only a few wells penetrate a thin weathered zone in the charnockite, whereas others tap only the Quaternary sediments.

GEOELECTRICAL SURVEY

The electrical resistivity technique is one of the geophysical methods that enables the determination of subsurface resistivity by sending an electric current into the ground and measuring the potential field generated by the current. Vertical Electrical Sounding (VES) was conducted at eighty locations in the study area using a Schlumberger configuration. The maximum electrode half-spacings (AB/2) ranged from 24 to 33 m; the majority of the soundings used a maximum AB/2 of 27 m. The survey was conducted on a rectangular grid pattern consisting of seventeen

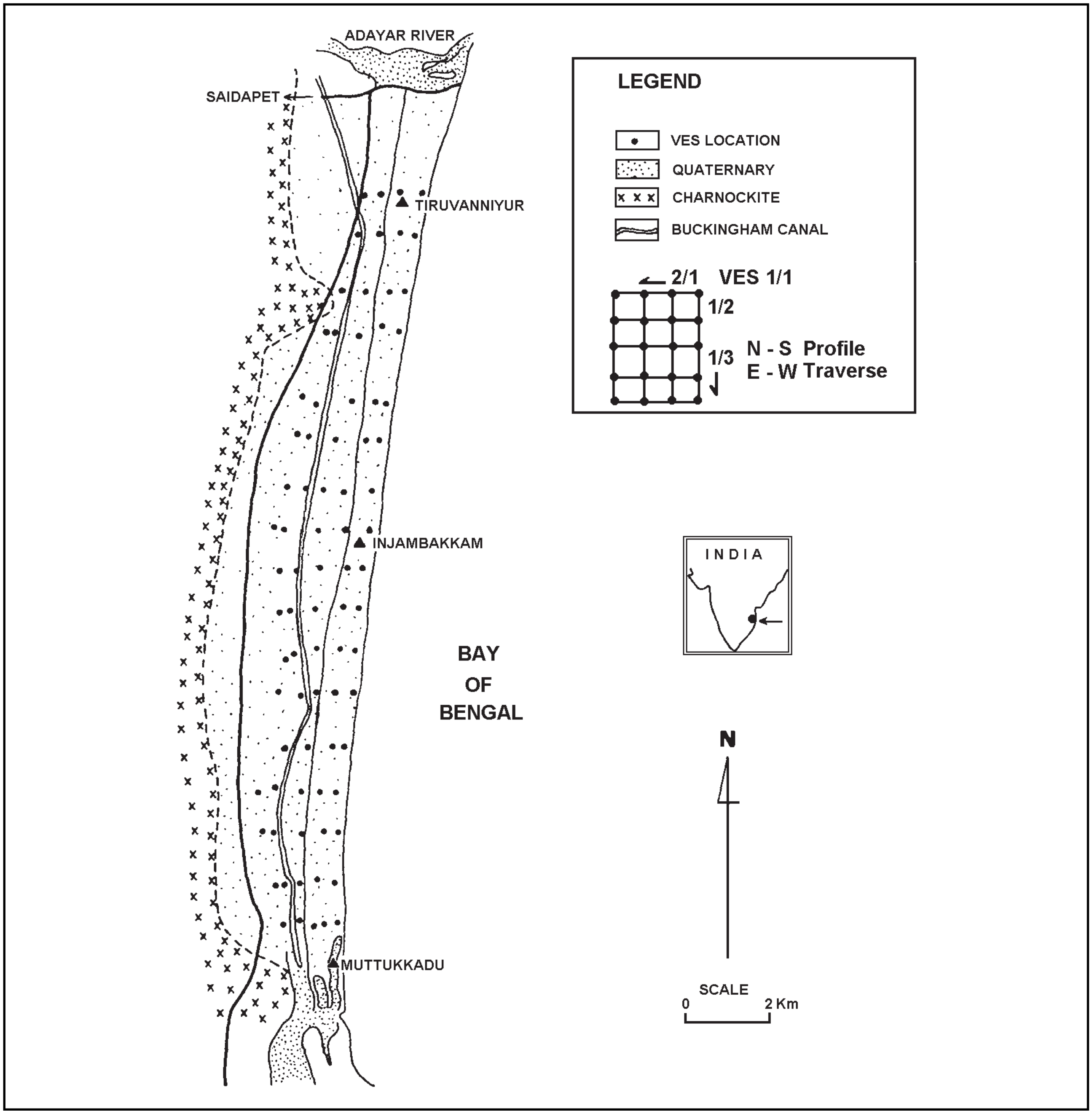

Figure 1. Study area showing VES locations.

traverses (west-east trend) and five profiles (north-south) depending upon the field situation. The distances between the traverses and the profiles were 1000 m and 250 m, respectively (Figure 1). The VES for different locations was taken at points of equal elevation. The soundings were carried out using an Aquameter-CRM 500 model.

INTERPRETATION

Iso-apparent resistivity contours

The iso-apparent resistivity (ρa) maps show that contour patterns are almost parallel to the coast (north-south trend) with decreasing values to the east and west (Figure 2). In the central portion, the apparent resistivity values are very high when compared with the eastern and western margins. This clearly indicates the presence of a fresh water ridge in the central portion of the study area.

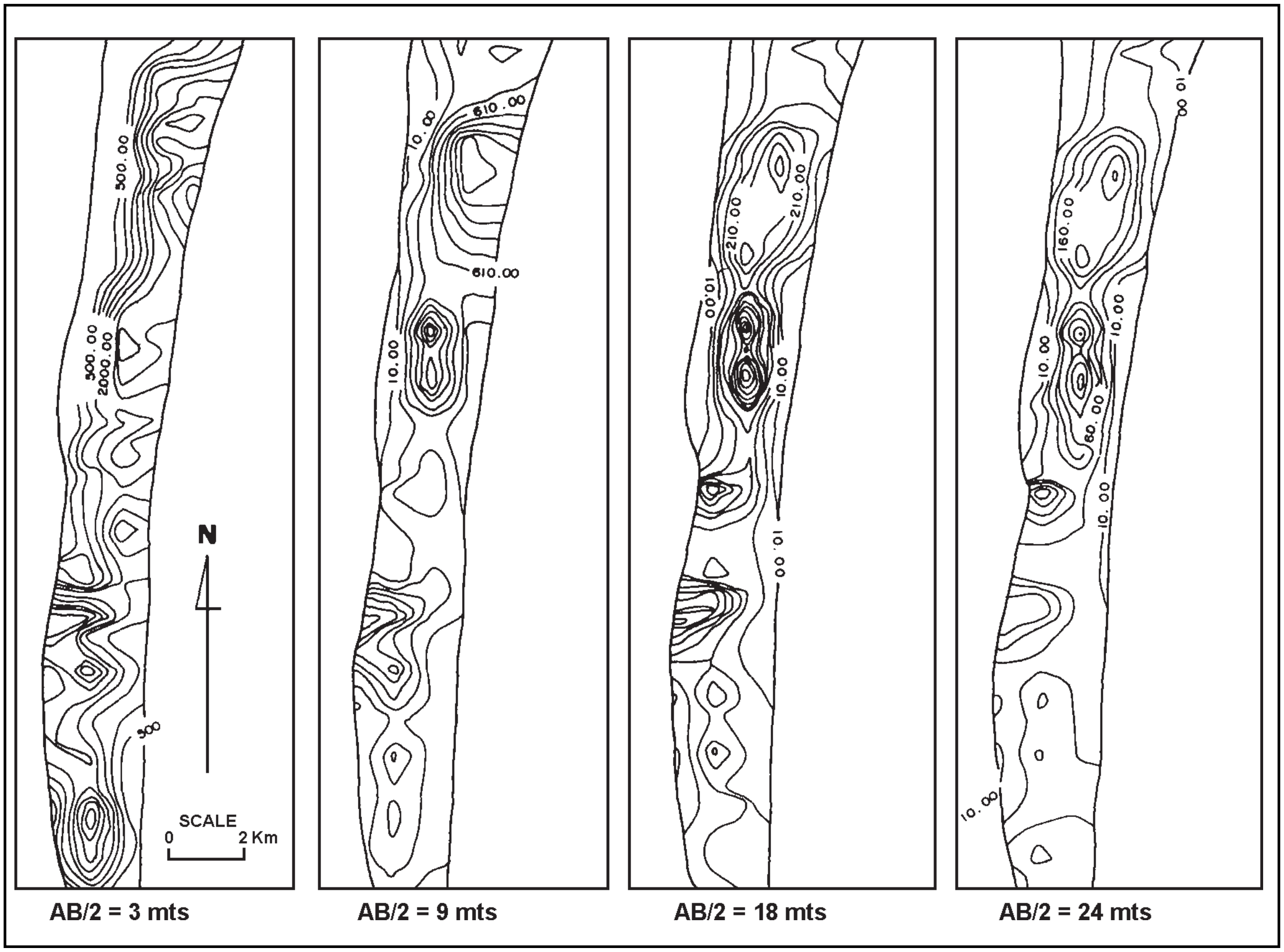

Figure 2. Iso-apparent resistivity contour map of the study area.

The high values of apparent resistivity (500 - 8000 ohm-m) observed at AB/2 of 3 m are attributed to the presence of unconsolidated, dry sand at this depth. The apparent resistivity (ρa) contour with AB/2 at 9 m shows relatively less apparent resistivity. Similarly, the ρa values for AB/2 at 18 and 24 m are observed to be comparatively low. This indicates that the ρa values decrease with increase in the depth of investigation. A sharp decrease in the resistivity values is seen between AB/2 of 3 and 9 m. This clearly shows that unconsolidated, dry sand exists from the surface to a few meters below ground surface, followed by sand containing groundwater. The groundwater along the central portion of the study area is fresh as observed from the apparent resistivity values. Very low resistivity values (less than 12 ohm-m), exist along the eastern and western margins of the study area, and they are an indication of permeable sand formations with saline water. In earlier investigations (Zohdy et al., 1974; Sathyamoorthy and Banerjee, 1985), it has been reported that the zones saturated with salt water show a very low resistivity of less than 10 ohm-m. The saline groundwater along the eastern margin is attributed to sea water intrusion, while the same along the western margin of the coastal aquifer is due to the influence of the Buckingham canal. Clay lenses along the western margin of the study area are also responsible for low apparent resistivity values.

ANALYSIS OF VES CURVES

The study of apparent resistivity curves prepared from the VES data showed three major types of curves. These are: Type I, Type II and Type III as illustrated in Figure 3. Among the three types of curves, Type I and Type II curves were similar in shape resembling a “Q” type of curve with the layer

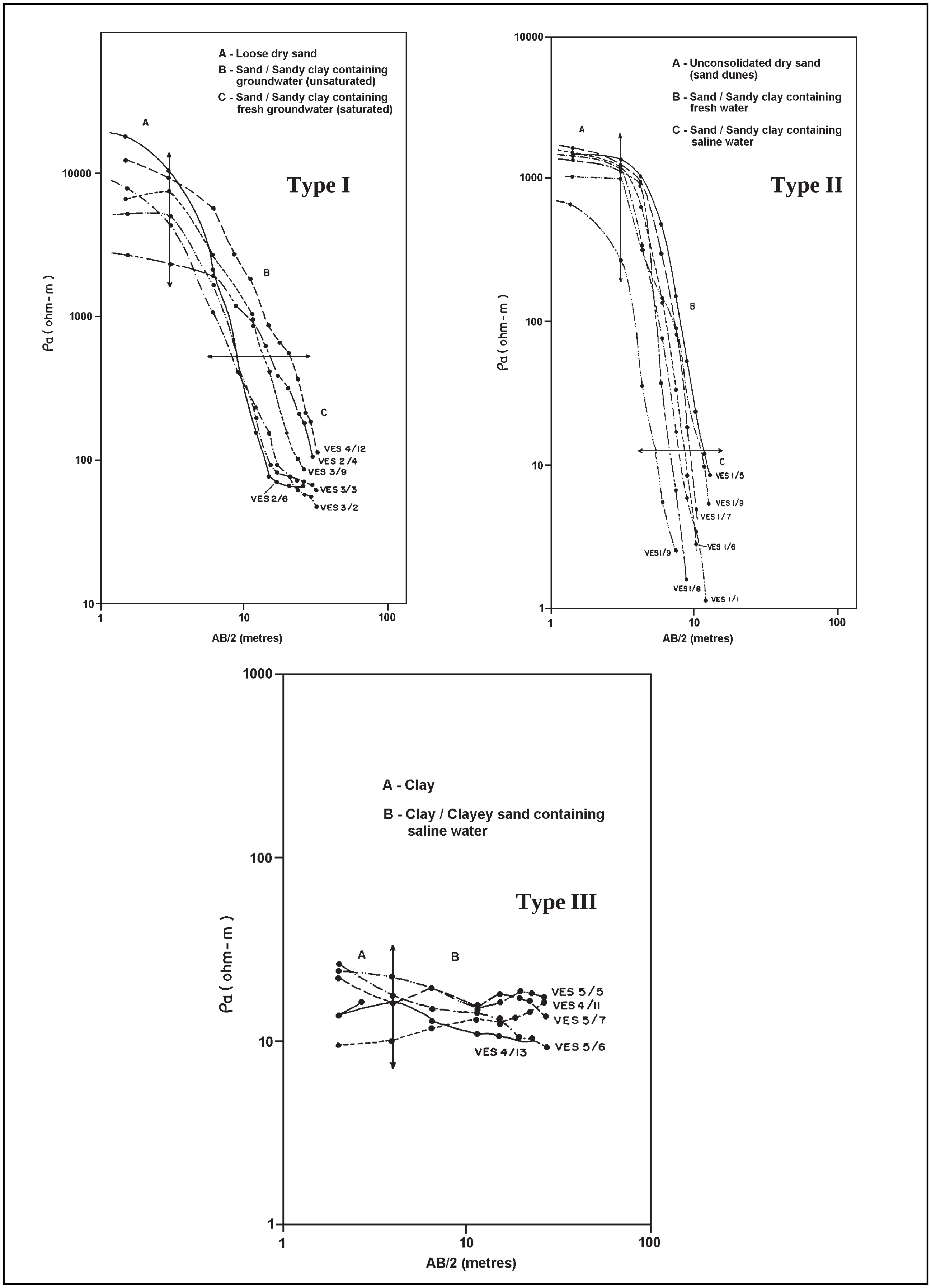

Figure 3. Apparent resistivity curves.

resistivity relationship as ρ1 > ρ2 > ρ3 (Rao, 1983). The Type III sounding curve differs from the other two curves. Though the aquifer consists of alternate bands of sand, sandy clay, and clay, the layers are not evident in the sounding curves. The analysis of each type of curve in relation to groundwater contamination in the study area is discussed in detail in the following sections.

Type I

The Type I curve generally shows (i) a relatively thin surface layer of coarse grained, loose sand/ sand dune existing below the ground surface (ρa between 2000 and 15000 ohm-m), followed by (ii) the presence of unsaturated sand of varying grain size (medium to coarse) with less moisture content (600 - 2000 ohm-m), and (iii) a sandy formation saturated with fresh groundwater (60 - 600 ohm-m). The ρa values decrease with depth from 600 to 60 ohm-m depending on the saturated condition. The field curves of Type I are mostly obtained from the VES conducted along Profiles 2 and 3 in the coastal aquifer. From direct field observation, the surface layer is composed of loose dry sand and sand dunes with a thickness normally less than 2 m. It is to be noted that the apparent resistivity values representing the surface layer in the curves of Type I vary considerably at different VES locations, mainly due to the fact that resistivity depends on the soil moisture content.

Type II

The Type II curve is composed of (i) a thin layer of coarse grained loose dry sand (surface layer) with an apparent resistivity greater than 600 ohm-m; (ii) saturated sand with good groundwater quality (600 to 20 ohm-m), and (iii) a low-resistivity layer with ρa < 12 ohm-m, indicating saline water. The excellent delineation of the saline groundwater present within the porous sandy formation is reflected by the resistivity contrast observed between the second and the third layers. The Type II curves were obtained from soundings taken mostly from Profile 1 located 200 m away from the coast. Well inventories indicate that the water levels in these VHS locations are relatively shallow.

Type III

The Type III curve differs from the other two curves to a considerable extent. The Type III curves were obtained from soundings taken mostly from Profiles 4 and 5 situated near the Buckingham canal. Resistivity values of these curves are normally very low, when compared to the other two types. This suggests that the clay occurring at these VES locations is primarily responsible for the low resistivity values (25 - 15 ohm-m). It is clear that the ρa values show significant change with increasing half-electrode spacing. With the increase in AB/2, the ρa values gradually decrease indicating the presence of contaminated groundwater. This is reflected by values of less than 15 ohm-m. The groundwater at these VHS locations is contaminated due to the influence of the polluted Buckingham canal and the presence of clay. It is common that groundwater in clay formations has low resistivity values.

SALINE WATER INTRUSION

Apparent resistivities for the first and second profiles (eastern margin of the study area) were prepared to delineate saline intrusion along the coast (Figure 4). Profile 1 shows apparent resistivity values for half electrode spacings of 24, 18 and 9 meters were considered. Profile 2 shows the ρa values for 24 and 18 meters. The resistivity patterns for the three AB/2 values more or less correspond well with each other in Profile 1. It is clear that the resistivity values decrease with an increase in the depth of penetration. The half electrode spacing of 9 m reveals that, except for VES locations 1/3 and 1/4, the sand formation encountered at this depth contains fresh groundwater. Low resistivity values

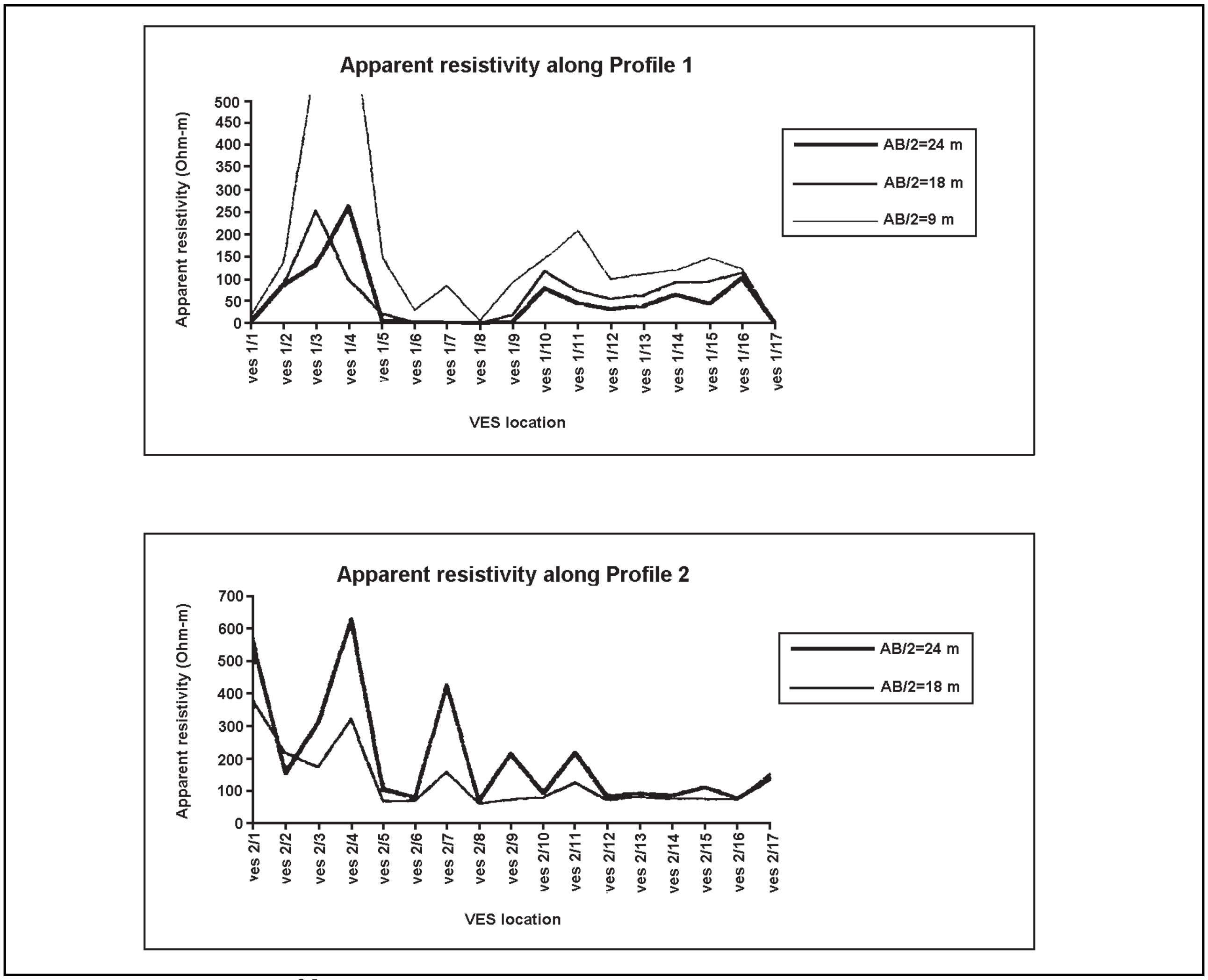

Figure 4. Resistivity profiles.

are observed at locations 1/1, 1/8 and 1/17. The groundwater in these locations is of poor quality due to sea water intrusion. At half electrode separations of 18 and 24 m, the groundwater quality is very poor at locations 1/1, 1/5, 1/6, 1/7, 1/8, 1/9 and 1/17 as seen from resistivity values less than 10 ohm-m. The poor quality of groundwater in these locations (except 1/17) is attributed to the salinity caused by sea water intrusion. Field investigations reveal that over exploitation of groundwater by heavy pumping has resulted in sea water intrusion in these locations. The poor groundwater quality at location 1/17 is due to the influence of the backwaters (lagoonal condition) near Muttukkadu.

The apparent resistivities along Profiles 1 and 2 were correlated to study the saline water interface. It is clear that the groundwater along Profile 1 is affected by saline intrusion. Profile 2 shows no indication of salinity since the minimum ρa value was normally above 50 ohm-m. This reveals that the formation encountered at AB/2 of 18 and 24 meters in Profile 2 contains groundwater of good quality. Thus, it could be concluded that the sea water interface exists between Profiles 1 and 2 at a distance of 200 to 450 m from the coast in the study area.

CONCLUSIONS

The use of surface geoelectric measurement provides an inexpensive method to study groundwater quality. A fresh water ridge has been delineated in the central portion of this coastal aquifer, and the quality of groundwater is good. The eastern and western margins of the aquifer, however, contain groundwater of poor quality. Three types of curves have been inferred from the analysis of the sounding curves. The Type I curve indicates the presence of loose, unsaturated sand with high apparent resistivity values followed by saturated sand containing water with good quality. The Type II curve, on the other hand, shows the presence of unsaturated sand followed by permeable saturated sand containing saline water. The Type III curve has low ρa values indicating the presence of clay as the surface layer, and groundwater being contaminated by the Buckingham canal. Thus, the sounding curves are useful for easy recognition of different geological formations and the quality of the groundwater within the formations. Sea water intrusion has occurred at some VES locations of Profile 1, with the interface existing between Profile 1 and Profile 2, 200 to 450 meters from the coast in the study area. It is concluded that the surface geoelectric survey was useful in assessing the groundwater quality of this coastal aquifer.

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