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Sustainable Development of Groundwater Resources using Near-surface Geophysical Investigation

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ABSTRACT

Depleting water resources are becoming a significant challenge for India's Economic & social development. An exponential increase in per capita use of groundwater resources with significantly less recharge, creating a negative impact in terms of potential availability. For meeting such demand's new techniques should be adopted to locate fresh groundwater zones. Electrical Resistivity Tomography (ERT) is such a robust geophysical tool used nowadays for groundwater exploration purposes. In ERT, we use a multielectrode setup (act as source/receiver) to send the current inside the earth surface and measure the potential difference to calculate the apparent resistivity. Based on these resistivity values, we interpret different geological layers. If we get a high resistivity value of about 5000 ohm-m, it is due to the presence of hard basalt/granite rock; very low resistivity of 10 to 15 ohm-m infers the clay layer's existence. Using ERT, we can find different aquifer's zones where fresh groundwater is present. Such geophysical technique can be used for finding the recharge site (in terms of flow connectivity path), for estimating the potential groundwater reserve, for helping in the preparation of different water budget plans/policies.

KEYWORDS

Geophysics, ERT, Apparent Resistivity, Aquifer.

INTRODUCTION

Water security is a global issue nowadays in terms of deteriorating quality and quantity. The increasing demand for water for different human purposes is causing the rapid depletion of groundwater resources. Since the late 90's many geophysical methods were used for groundwater exploration purposes, and resistivity sounding was famous. Vertical electrical sounding (VES) techniques were used (Sinha et al. 1990; Urish et al. 1990, Van et al. 1989, Lenkey et al. 2005) for finding aquifer zones, but due to complex geological heterogeneity, Equivalence problem, difficulty in interpretation, these methods are not used often nowadays. Recent Electrical resistivity tomography (ERT) has been extensively used as a near-surface geophysical tool for groundwater exploration purposes. Although ERT is also used for mineral exploration purposes, due to operating physical parameters (resistivity), it is more applied to delineate the geological boundaries where groundwater resides. ERT is used as a tool to map the subsurface lateral resistivity distribution.

Different geological layers are present beneath the earth surface, i.e., clay, silt, sand, hard rock, laterite, etc. The groundwater is present in these geological layers are known as aquifers. The primary two categories of aquifers are present in nature as an unconfined and confined aquifer. Unconfined aquifers are near-surface aquifers in which the water table is directly under atmospheric pressure. In confined aquifers, a non-permeable stratum (ex. clay) prevents the direct exchange of water from the aquifer's surface. In the geophysical method, we demarcate such aquifer boundaries where groundwater is present (clay-sand, hard rock). Groundwater is present in the layers, either porous and permeable or connected by the fractures/lineations. In India, groundwater is found majorly in two types of geological depositional environments, i.e., Northern India layered soft alluvium and south fractured hard rock granite/basalt.

Many geophysical investigations have been carried out in different geological conditions for groundwater exploration (Choudhury et al., 2001; Costall et al. 2018, Acharya et al. 2017, Sathish et al., 2011). Water in aquifer zones is affected by rainfall, recharge rate, pumping rate, no. of borewells in a particular region, quality either saline or fresh etc. The geophysical tool can play a role in the sustainable development of resources by quantifying resources and supporting tools. The need to adopt such advanced techniques is a must to help implement groundwater rules/regulations feasible.

STUDY AREA

As for the case study purpose, the ERT survey was carried out in Kharagpur, West Bengal, India. It was done as a reconnaissance survey for exploring the local aquifers zones. The site is located (Figure 1.) in the Paschim Medinipur district of West Bengal with a latitude of 22.4080°N and longitude 87.3811°E.

Figure 1: Location of the ERT survey area marked in google earth image

Kharagpur city is a famous industrial city in West Bengal state. India's 1st eminence institute IIT Kharagpur is also present here; it also has one of India's most extensive railway workshops. Due to industrial advancement in this region, per capita water use has also increased over the years. Hence, more groundwater resources are needed to be explored in this area.

Geological setting

Paschim Medinipur district comprises mainly a lateritic environment. The geological strata of this region are of Proterozoic to quaternary age. Mostly consolidated to unconsolidated crystalline rocks, lateritic terrain, and tertiary sand is present over here. The laterite of this region is composed of older alluvium. Due to humidity, high iron content is found in the soil as detrital laterite chunks. A flat and deltaic plain is present in the southeast district (Pati 2013; Bhunia et al. 2012). Subarnarekha and Kangsabati are the two primary river systems of this region. According to preliminary geophysical information, an aquifer is found here at maximum depth up to 50m, with laterite acting as cap layers. The district receives annual rainfall in the range of moderate to high.

ERT survey

Four electrodes are used for any DC resistivity method as current and potential electrodes (Figure 2). Current is injected into the ground, and the potential difference is measured to calculate the apparent resistivity (Loke et al., 2011).

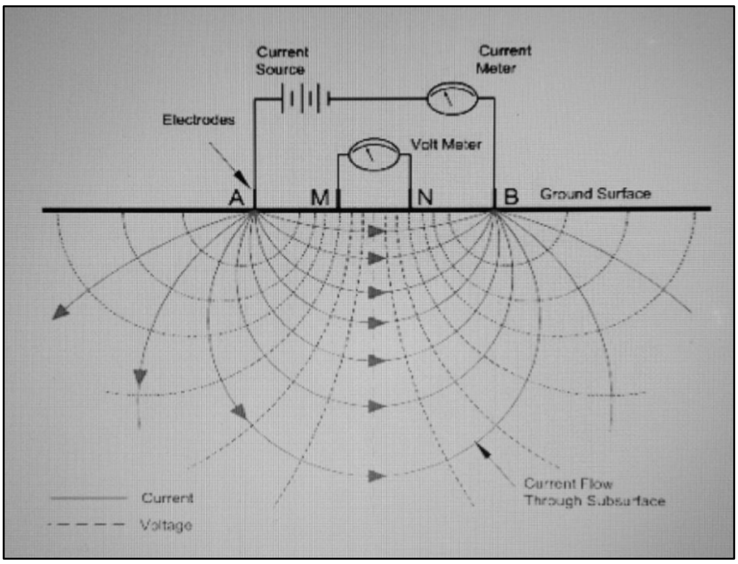

Figure 2. Schematic diagram of the basic four-electrode DC resistivity system

The apparent resistivity is calculated using this expression (Telford et al. 1990)

$$\rho_a = k \frac{\Delta V}{I}$$

Where ρ_a is apparent resistivity in ohm-m, k is the geometrical factor depends on the electrodes' arrangement, ΔV is the potential difference in mV, I is current injected mA.

We have carried out an Electrical resistivity tomography survey using 41 multielectrode ABEM Terrameter (Figure 3). We have acquired seven 2D ERT profiles using the Wenner-Schlumberger array in the area using a 5m electrode spacing interval. Although current electrodes should be kept at a larger separation for a more significant depth of investigation, we have focused more on data resolution in our case. Hence, for better resolution of subsurface, we have kept the electrodes at a lesser separation. 12V DC battery is used as the power source. Profile length was about 200m so that an optimum depth of investigation can be achieved.

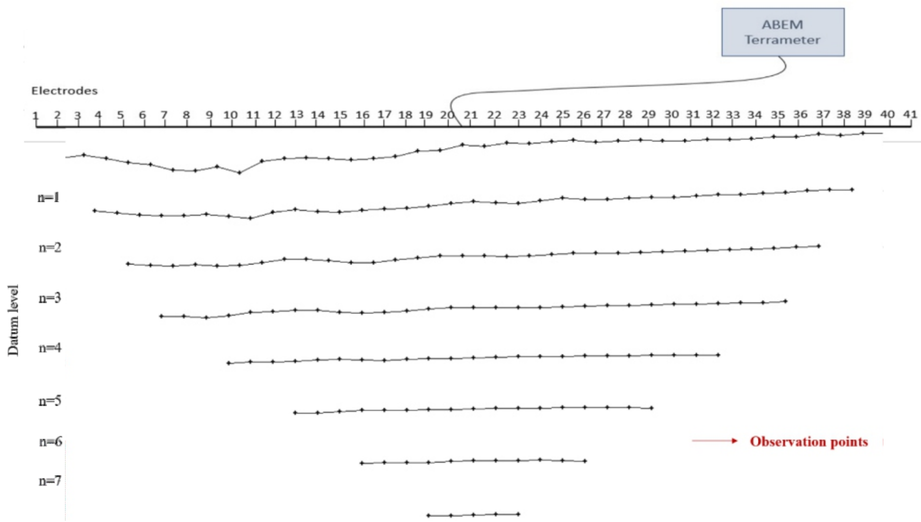

Figure 3. Schematic representation of ERT data acquisition, using 41 electrodes configuration

Profile length was kept at about 200m so that an optimum depth of investigation can be achieved. As we have to target near-surface shallow aquifer zones, so in that case, Wenner-Schlumberger can provide a good signature.

RESULTS AND DISCUSSION

Resistivity data was acquired along with various 2D ERT profiles. After the acquisition of data, it was processed using the RES2DINV software. The least-square inversion scheme was applied to obtain the 2d inversion result. As Wenner-Schlumberger has higher sensitivity for a layered medium (Figure 4), this array provides an excellent sign of an aquifer with laterite deposits.

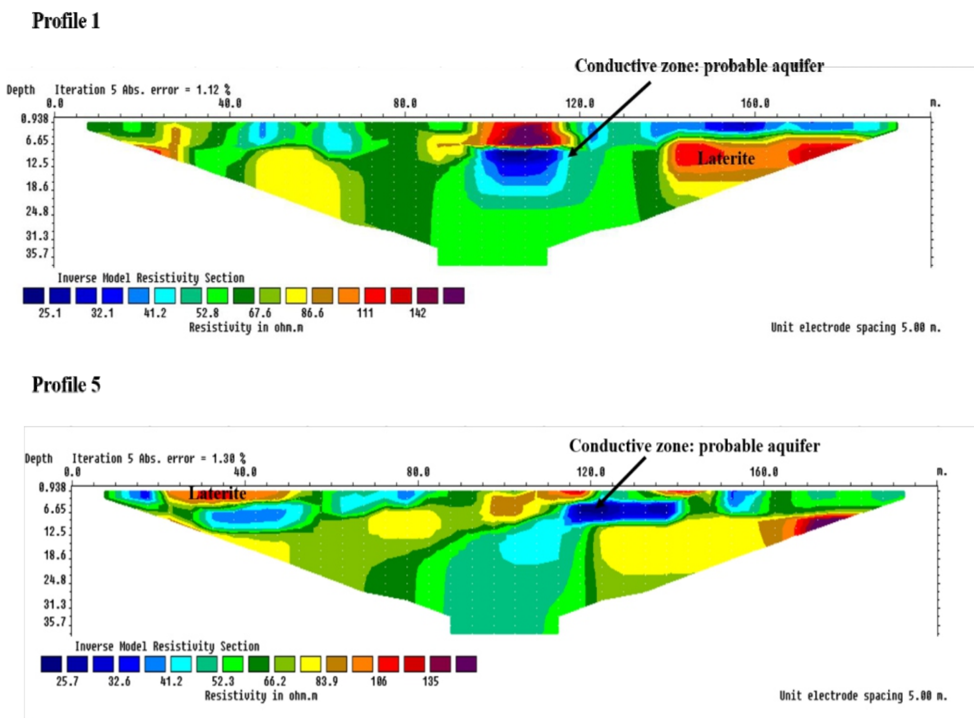

Figure 4. 2D ERT result of wenner-schlumberger array along profile 1 & profile 5

In the 2d ERT section, it is visible that a conductive zone of resistivity 25 to 32 ohm-m is observed. A higher resistivity region 140-150 ohm-m is due to the presence of a laterite deposit. This field result was compared and cross-checked with the existing borehole log data. In the borehole log, laterite was found at a shallow depth of 12m, although laterite can be seen as patches at different locations. In profile 5, it is visible that a conductive flowing path is connected from ground level to subsurface.

CONCLUSION

As different geological layers have different resistivity values, so using ERT, we can delineate such layers. From 2D ERT results, the conductive zones (25 to 32 ohm-m) are inferred as potential aquifer zones. These zones comprise clay to a sand signature, acting as a possible aquifer system. Also, laterite deposits can act as impermeable overburden layers in this region. A clear connectivity path is observed in the ERT results to be used as a groundwater recharge site. Further detailed 3D geophysical investigation (using Electromagnetic and 3D ERT) can be planned in these regions for mapping a complete subsurface picture. These advanced geophysical tools are widely used nowadays, and even they can be jointly used in other environmental assessment domains.

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