Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains

Report on Electric Resistivity Survey in Kanakpatti VDC of Saptari District

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1 Background

Groundwater can be explored using different methods. The four major groundwater exploration methods are the aerial method, surface method, subsurface method and esoteric methods. Among these methods, esoteric method is not based on science, mostly based on traditional indicators. Each of the above listed groundwater exploration methods have different sub-methods under them. Geophysical survey is therefore one of the sub-methods under the surface method of groundwater exploration. This method is very important for both groundwater resource mapping and water quality evaluations. Its application for groundwater exploration purposes has increased over the last few years due to the rapid advances in computer packages and associated numerical modeling solutions. Around 244.8 billion cubic meters (Bm3) of ground water are available in the Ganga River basin, with the highest potential in India (168.7 Bm3), Bangladesh (64.6 Bm3), and Nepal (11.5 Bm3), of which an average of 54% has already been developed for irrigation, domestic, industrial and other purposes (Amarasinghe. et. al, 2016; Rajmohan & Prathapar, 2013). Around 61% of available resources in India, 10% in Nepal, and 45 % in Bangladesh are already in use. Hence, the exploration of available resources that have not been fully accessed need to be identified to ensure the supply of drinking water and irrigation water in the Terai region of Nepal

Geophysical survey incorporates the Vertical Electrical Sounding (VES) and Horizontal Profiling activities. The Vertical Electrical Sounding (VES) is currently being very popular with groundwater investigations due to its simplicity. This geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. It provides depth and thickness of various subsurface layers and their relative water yielding capacities.

2 Objective

The main purpose of the study was to assess the groundwater potential at Kanakapati area of Saptari using the Electrical Resistivity Methods to optimize the design of shallow tube well.

3 Study Area

The current study includes the area under the project ***"Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains"*** in Kanakpatti VDC of Saptari district. Saptari district, the focus of this study, lies in eastern Terai region along the southern foothills of Siwalik (Churia) range in Nepal and depends upon groundwater for both drinking and irrigation purposes. Even though several Southern Rivers drain through Siwalik to Terai, people residing in these areas are facing water scarcity for both drinking as well as irrigation (Pathak, 2016). In recent decades, the population in these foothills has been increasing. Most of the agricultural land depends on rained irrigation for agricultural production to fulfill the increased food demand, which motivated to develop the irrigation facilities through groundwater. In this context, the action research on dry season irrigation for marginal and tenant famer (DSI4MTF) in study area (KanakpatiVillage Development Committee (VDC), north from east-west highway) is being implemented. Interventions include the construction of shallow tube wells, introduction of micro irrigation techniques for the efficient use of water, conjunctive use of surface and groundwater, focusing on marginalized and tenant farmers through collective approaches, efficient use of available energy sources, and linking high value products with market.

The study area, Kanakpatti VDC (Siwalik foothill), is bounded between the Siwalik range in the north and Indo-Gangetic plain in the south. The Siwalik range has sedimentary rock, mainly the alternating bed of sandstone and mudstone and conglomerate (Pathak, 2016). The Indo-Gangetic plain has coarse sand, gravel, pebble, cobble and boulders in the southern part (Bhabar zone) and becomes finer (up to gravel size) southwards2 (Pathak, 2016). In Bhabar zone, porous geology exists, which enhances the recharge, but water availability is still restricted at the shallow aquifer due to the deeper water table. Construction of shallow tube wells, as part of the DSI4MTF project, revealed varying characteristics of the shallow aquifer that create different potential for groundwater access. Many of the wells constructed yielded little or no water, further demonstrating that aquifer response and information in Siwalik foothill is not well known A desire to better understand and locate potential groundwater zones, given the water scarcity in the area, motivated this study's exploration of the aquifer using electrical resistivity investigation (ERI).

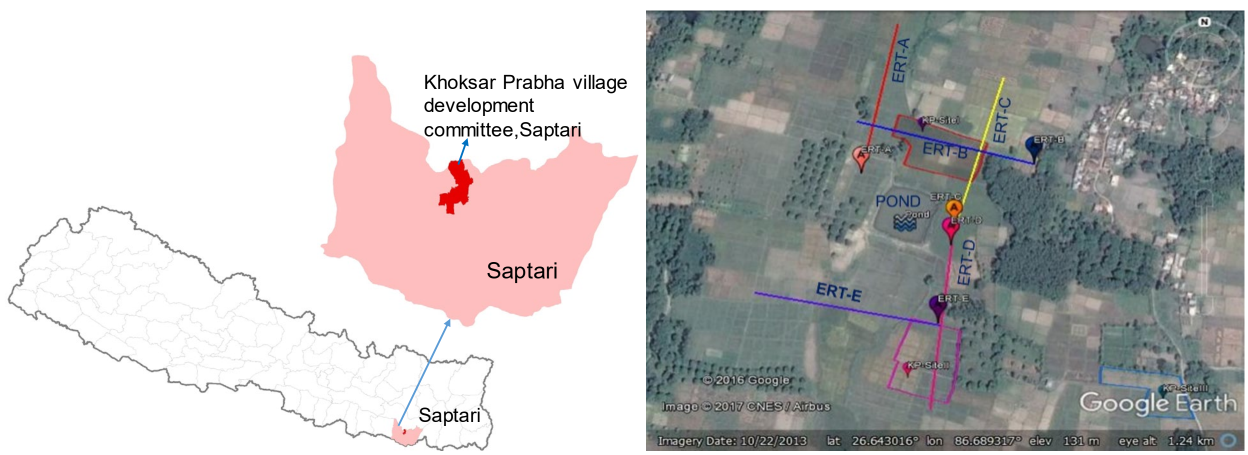

Figure 1 Study area showing the electrical resistivity tomography line in Kanakpatti, Saptari district

4 Methods used for analysis

4.1 Electrical Resistivity Tomography Survey

In resistivity measurement, current flow tends to occur close to the surface. Current penetration can be increased by increasing separation of current electrodes. An electrode array is a configuration of electrodes used for measuring either an electric current or voltage. There are a number of ways of setting up of current and potential electrodes, in subsurface studies by electrical resistivity methods. The choice of an array and the distance between the electrodes is very important for obtaining the best possible information of the subsurface geology of a given area.

4.2 Electrical Resistivity (2D -Electrical Resistivity Tomography) Survey Design

ERT survey is usually conducted following the various arrangements of four electrodes, two current (C1 and C2) and two potential (P1 and P2) depending upon the specific purposes.

There are many electrode arrangements, which can be used in the ERT field survey. These arrays have advantages and disadvantages. In some geological situations one is particularly better than the other to give better response. To map lateral changes in structures Dipole –Dipole and Schlumberger are better. Wenner seems to have a strong signal/noise ratio but smooths the picture more.

The choice of a particular electrode array for the survey in question depends upon many factors; as summarized below.

Ease in handling:

As mentioned above, gradient and pole-pole arrays are easier to handle. Only two electrodes are moved along the profile during testing. Three electrodes are moved in Pole-Dipole array and all four electrodes are moved in Wenner, Schlumberger and Dipole-Dipole arrays; adding complications in handling more electrodes. However, for multi core cables with take-outs at a fixed distance and automatic equipment's with switchers, there is no need to move any of the electrodes once the cable is laid out. Our equipment,Geomotive GD10 (Geomative, 2016), can automatically switch between electrodes and data acquisition is possible for 1m, 2m, 3m until 95 m of spacing between two electrodes which is almost impossible with manual equipment.

Signal to noise ratio:

In a collinear electrode arrangement, signal to noise ratio (SNR) depends on whether the placement of the potential electrodes (M and N) is within or outside of the current electrodes (A and B). The voltage between M and N and SNR will be higher for the former than for the latter case. In this regard, Wenner array rates higher followed by Schlumberger and Dipole-Dipole arrays. Wenner array has the highest SNR among the conventional arrays. The Pole-Pole, Pole-Dipole and Dipole –Dipole arrays are more sensitive to near surface variations. Hence, even in very noisy areas, the Wenner array measurement is the most reliable.

EM coupling:

Frequencies of source signals used in DC resistivity surveying are usually very low (from DC to 50 cycles per seconds) to avoid electromagnetic effects. Most commercial instruments use square waves or pulsed direct currents as source signals. Such signals yield high harmonics, which may result in coupling between the two dipoles and the wires connecting them to the recording instrument. The coupling increases with the frequency, electrode configuration and conductivity of the medium of the flowing current. In this regard, pole-dipole, gradient, Schlumberger and Wenner arrays are progressively more susceptible to coupling. However, the coupling can be reduced taking special care while laying the current and potential cables in the field.

Lateral resolution:

The resolving powers of these arrays are different. The gradient array has better ability to resolve the steeply dipping inhomogeneity Coggon, (1973) and Dey et al (1975) established that Schlumberger array ranks similar with Wenner array in its lateral resolving power.

Vertical resolution:

A better vertical resolution helps to demarcate the boundary between different lithology/geology more accurately. An experiment (Loke, M. H. 1999) showed better vertical resolution by the Wenner array. The Dipole-Dipole and Wenner-Schlumberger arrays come only after Wenner array.

Anomaly pattern:

Pole-Dipole is an asymmetrical array and gives rise to somewhat more complicated anomalies in the pseudo section. Signal strength or anomaly strength measured with Pole-Dipole array decrease less rapidly compared to Dipole-Dipole array.

Based on the considerations of signal to noise ratio, electromagnetic coupling, lateral resolution, vertical resolution and anomaly pattern it is found that Wenner array has the advantages of i) high signal to noise ratio, ii) symmetrical array and hence symmetrical anomalies, iii) good lateral resolution, and iv) good vertical resolution. Hence, this array method was employed in the present study program. The schematic diagrams of this array configuration are shown in Figure 1 and Figure 2.

However, we also employed Schlumberger and Dipole – Dipole methods for cross-referencing the acquired data for interpretation purposes.

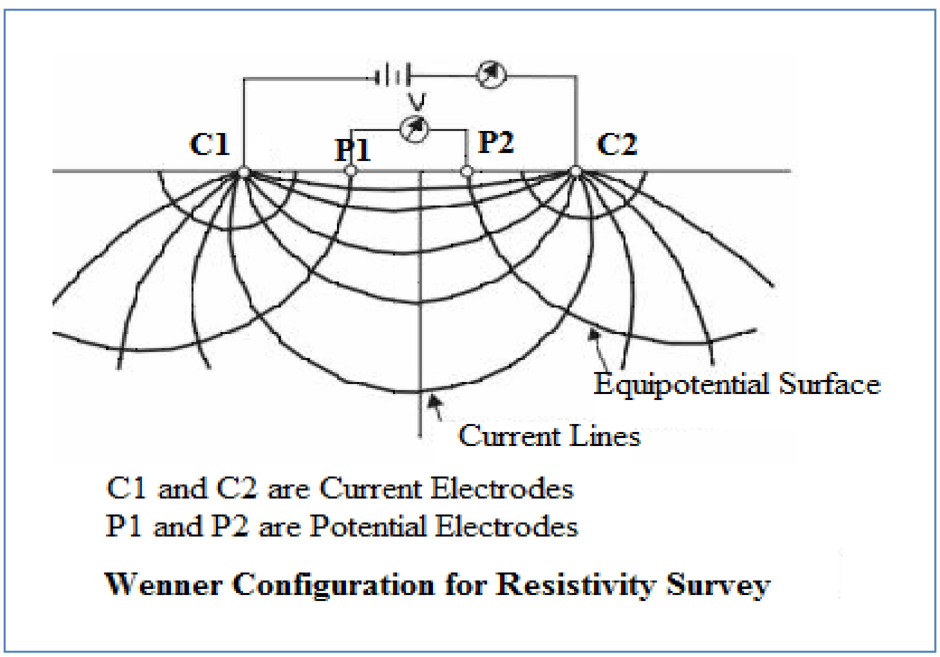

Figure 2: Schematic diagram of Wenner configuration for resistivity survey

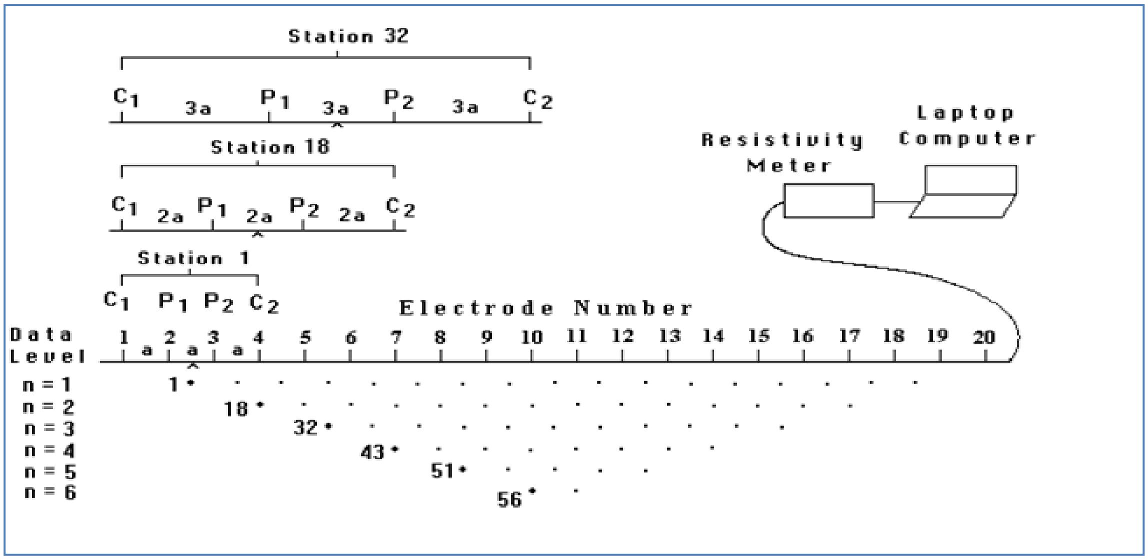

Figure 3: Schematic diagram for sequence of measurements to build up a pseudo section

4.3 2D Electrical Resistivity Tomography Survey

Data Acquisition

The quality of data acquired in the field not only depends on quality of the equipment and accessories but also depends on the topography, geological setup and density of the measurement. Highly heterogeneous conditions are created by surface topography and geological variations. Planning of the fieldwork and layout of profiles is usually based on topographical map. Therefore, site condition consideration is essential for the effective layout of the profiles.

In the present case, five 2D ERT profiles were carried out in the area. To collect information to a depth of around 40 m, employing the full length of profile of more than 240 m in each case. The minimum electrode spacing of 5 m was used in the survey procedure. The survey was carried out using Wenner, Schlumberger and Dipole-Dipole array of electrode configurations. The length of each survey profile was 240m and their location is presented in Table 1 Two-dimensional ERT coverage (all profiles at 240m)

and on Google Earth map in Figure 4.

Resistivity data was collected to obtain a continuous coverage of the subsurface along the line of investigation. As mentioned above Wenner electrode configuration was employed in the present study program. Further, Wenner-Schlumberger and Dipole-Dipole configuration were also employed in the study for cross reference of the acquired data. However, only the Wenner images are presented in this report.

Table 1 Two-dimensional ERT coverage (all profiles at 240m)

Profile No.	ERT GPS coordinates		Profile Direction
	Start	End	
ERT-A	26.644 / 86.691	26.646 / 86.691	South to North
ERT-B	26.644 / 86.693	26.645 / 86.691	East to West
ERT-C	26.643 / 86.622	26.645 / 86.693	South to North
ERT-D	26.643 / 86.692	26.641 / 86.692	North to South
ERT-E	26.642 / 86.692	26.642 / 86.689	East to West

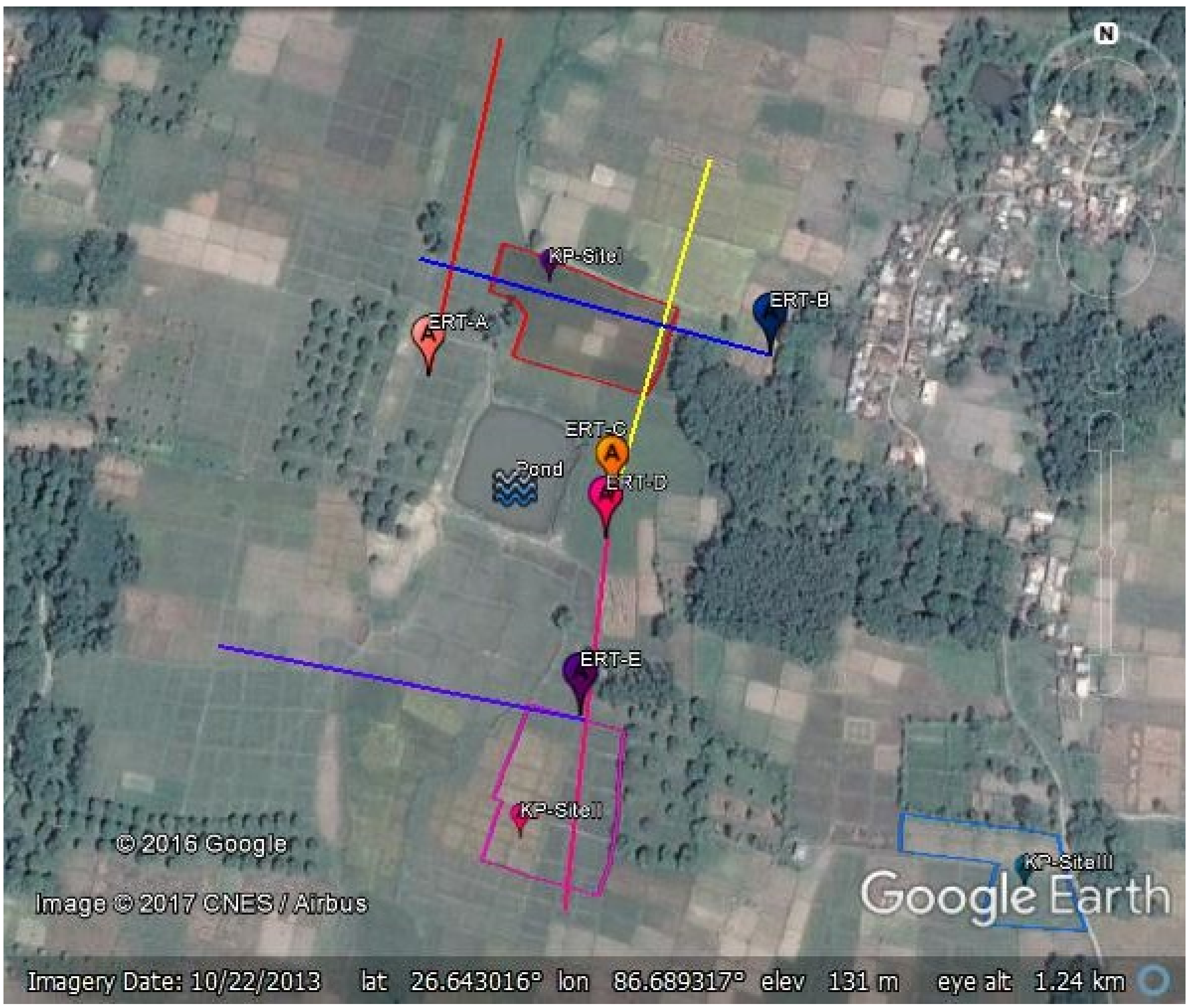

Figure 4: Google Earth map showing ERT profiles in the study area

5 Data Processing, Analysis and Interpretation

Geo-electrical resistivity survey is a widely used geophysical method for subsurface studies; including groundwater exploration, environmental application and other engineering applications. The main benefit of this method is that it allows for performing the survey quite fast and in a cost effective manner. Detection of different types of subsurface geology, water table, variation of resistivity with depths (distinguishing layered earth), contaminants plume detection, detection of bedrocks depth, overburden thickness, etc. are the objectives of ERT survey. The interpretation of electrical resistivity data is the process of deriving the values of true resistivity's (ρ) and thicknesses (t) of various subsurface strata from the values of recorded resistance (R) or apparent resistivity (ρa) at electrode separations (a). There are a number of interpretation techniques for evaluating (ρ) and (t) of each of the stratum as proposed by many investigators. These can be grouped as analytical, numerical, empirical, and graphical; with several procedures within each category.

The computer software, RES2DINV (Geotomo, 2010), was used to analyze the filtered and processed field data. The software inverts the field data, calculates the appropriate model in term of resistivity, and provides output in the form of resistivity contours. This inversion data is used to draw up the lithological and geological information.

The resistivity of any given layer depends upon rock type, grain size, degree of void spaces and amount of water present, degree of weathering, mineral constituents etc. Based on local geological information, correlation of resistivity value of the exposed bedrocks and overburden deposit on the surface and previous studies carried out in different part of Nepal, the general correlation table has been prepared by GWRDB (GWRDB, 2016); which is shown in Table 2.

Table 2: Correlation of resistivity and lithology (Source: GWRDB)

Resistivity Range (ohm-m)	Expected Lithology	Groundwater Prospects
>1000-5000	Boulder, Cobble, Pebble Unsaturated Fractured Bed rock	Poor
250-1,000	Gravel, coarse sand	Good
100-200	Fine to coarse sand	Good
50-100	Silt , fine sand	Poor
20-50	Silt, clay	Poor
< 20	Clay	Poor

The inversion results showing resistivity model with interpretative cross sections of all profiles are presented. Geological/ lithological information extracted from the ERT result (resistivity contour value) are marked in the respective ERT sections in the result figures below. The sections are prepared as per topographic undulations.

5.1 Analysis and Interpretation of Electrical Resistivity Tomography Data

The model sections obtained from data inversion are presented as resistivity tomogram sections. These tomogram sections show the variation of modeled electrical resistivity in depth and along the line of investigation. These variations in modeled physical properties have relation with the subsurface geological and hydrogeological set up. The resistivity tomogram sections are presented from data inversion, which shows the variation of modeled electrical resistivity in depth and along the line of investigation. Those variations in modeled physical properties have relation with the subsurface geological and hydrogeological setup, which are presented for each profile and their hydrogeological and lithological interpretation through representative tomogram section in subsequent figures. Geological/ lithological information extracted from the ERT result (resistivity contour value) are marked in the respective ERT sections and presented as figures below. The 2D ERT with a modeled maximum depth of ~ 40 m, displays a variation of resistivity values both vertically and horizontally, indicating that subsurface geological formations strongly vary in their electrical propertiesRepresentative resistivity tomogram sections for each profile and their hydrogeological interpretations are presented in subsequent figures.

Resistivity Tomogram and Lithological interpretation of ERT -A

This profile runs from South to North direction. The location lies about 20m north of the pond in the project area.

The lithological section can be interpreted as multi layered model. Low resistivity value of less than 70 Ω m dominates in the area, which indicates presence of unsaturated formation consisting of silty clay. Within this dominant silty clay layer, there is a patch of clay at the center portion. The thickness of this clay layer is about 6m.

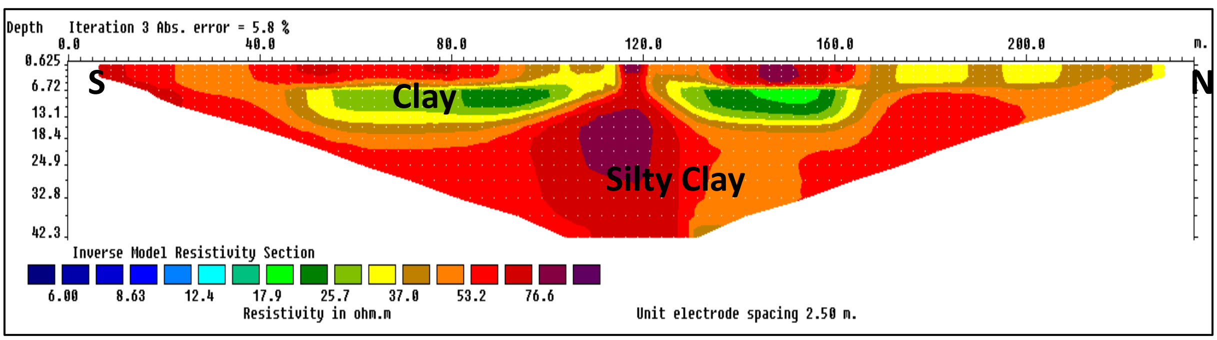

Figure 5: Resistivity tomogram of ERT-A

Resistivity Tomogram and Lithological interpretation of ERT -B

This ERT profile runs from East to west, with east being the starting point. The profile start point lies about 75m north of the pond.

Within this profile, marked variation in lithology is observed from East to West. Towards the East, sand dominates the lithology up to a depth of 18m. While from Center to West, the lithology consists of silty clay. From the groundwater potential point of view, shallow tube well can be constructed in the Eastern part of the profile. Rest of the area in the profile, construction of shallow tube well is not feasible.

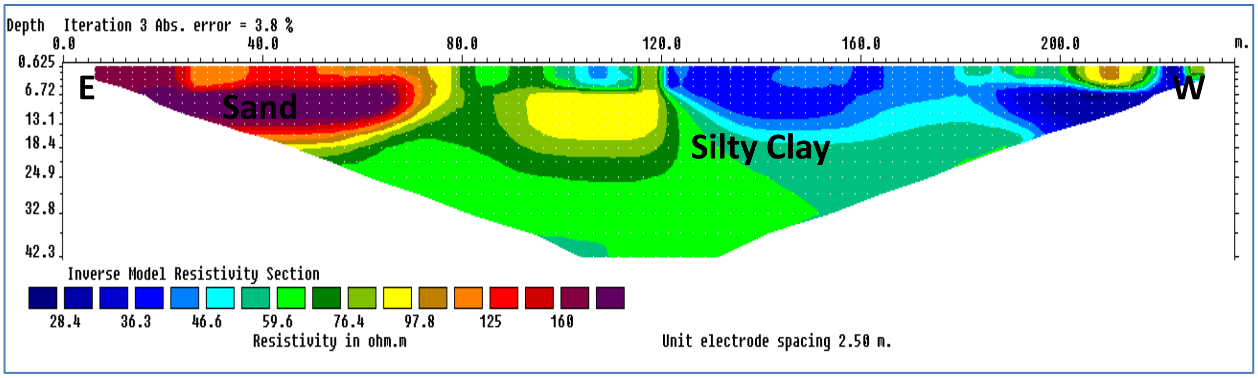

Figure 6: Resistivity tomogram of ERT-B

Resistivity Tomogram and Lithological interpretation of ERT -C

The third ERT profile was carried in South to North direction. The profile lies at the upper-left part of site I of the project area. The starting point of the profile is at the south; located about 30m west of the pond.

In this part of the project area, the lithology shows marked variation in lithology locations and structure. Towards the Central to Northern part of the profile from the depth of about 6m, there exists boulder and coble; the resistivity value of which is very high. This signifies the existence of Bhabar Zone materials in this part. From the Center to South the subsurface lithology consists of sand and gravel which are very good aquifers.

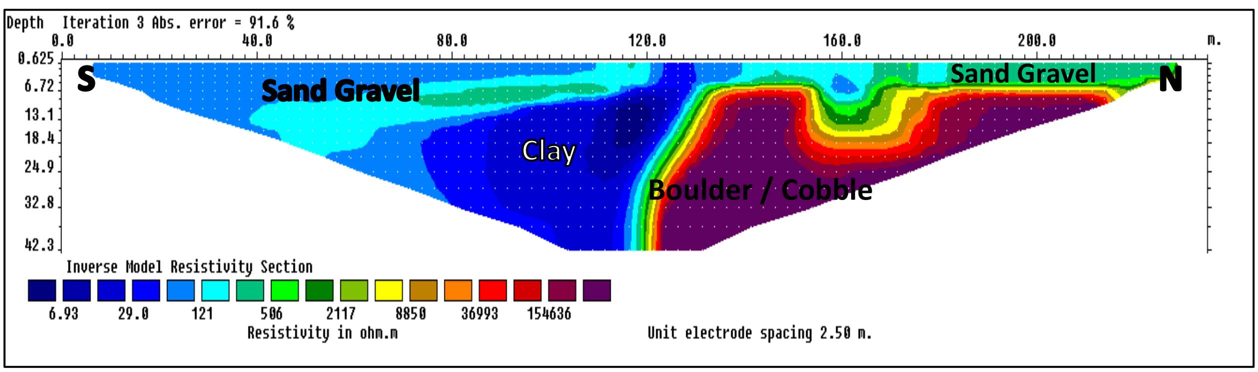

Figure 7: Resistivity tomogram of ERT-C

From the groundwater point of view, the Southern to Central part of the area has potential for shallow tube well construction while at the Northern part the potential for shallow tube well operation is poor due to the presence of very big boulders and cobble. In this part, the water level will be very low so that surface pumps cannot lift the water from the aquifers.

Resistivity Tomogram and Lithological interpretation of ERT -D

This profile also runs from South to North direction; the profile starting point being north. This profile is a continuation of the profile ERT-C. This part of the study area shows that the subsurface lithology consists of two layers; an upper sandy layer underlain by a silty clay layer to the depth of about 42m. This part of the project area exhibit good potential for shallow tube well construction.

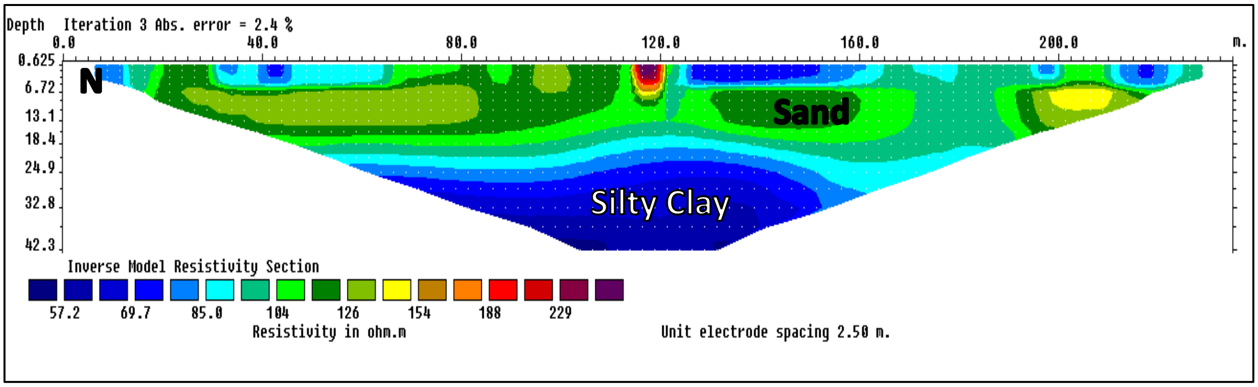

Figure 8: Resistivity tomogram of ERT-D

Resistivity Tomogram and Lithological interpretation of ERT -E

This profile runs along the East West Direction, with the starting point being on the east. The profile is located due south of the pond.

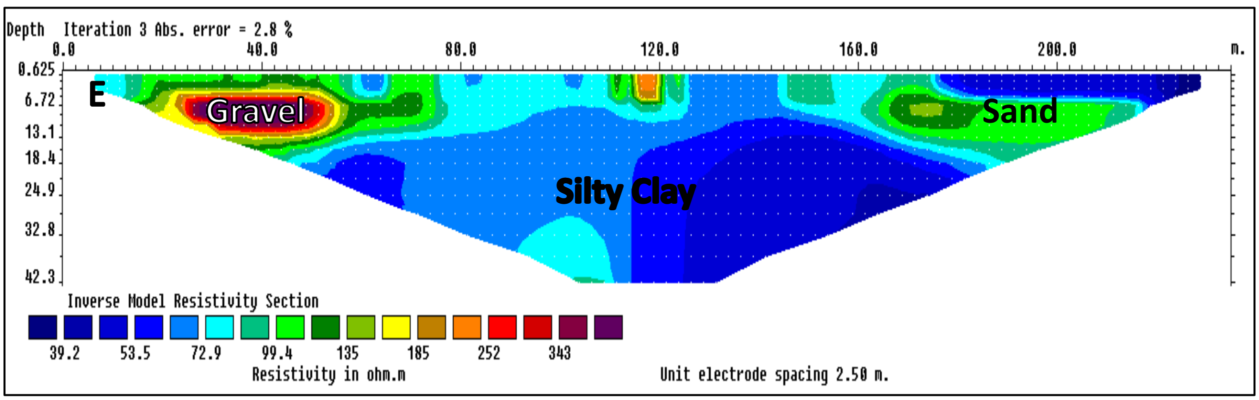

Figure 9: Resistivity tomogram of ERT-E

Comparing the west and central parts to the eastern part, the eastern parts have greater potential for shallow tube well construction. The central portion of the profile has poor aquifer due to the dominant silty clay aquifer materials. In the eastern and western parts, the depth of the well should not be more than 13m to tap into the gravel and sand layers, respectively.

5.2 Discussion

The objective of this research is to evaluate the water potential of the study area by investigating the shallow subsurface aquifer material properties and moisture distribution using 2D ERT techniques. During the shallow tube well design and development in the study area, some patches of land does have good potential and some does not, which motivated to understand the aquifer properties, aquifer material, and response. Hence the 2D ERT was carried out, oriented around the pond in the center (as shown in Figure 1) and five ERT profiles , each with a section of 240 m. From the transect profiles of resistivity, an assessment of the aquifer material was made to provide insight of the groundwater potential around pond.

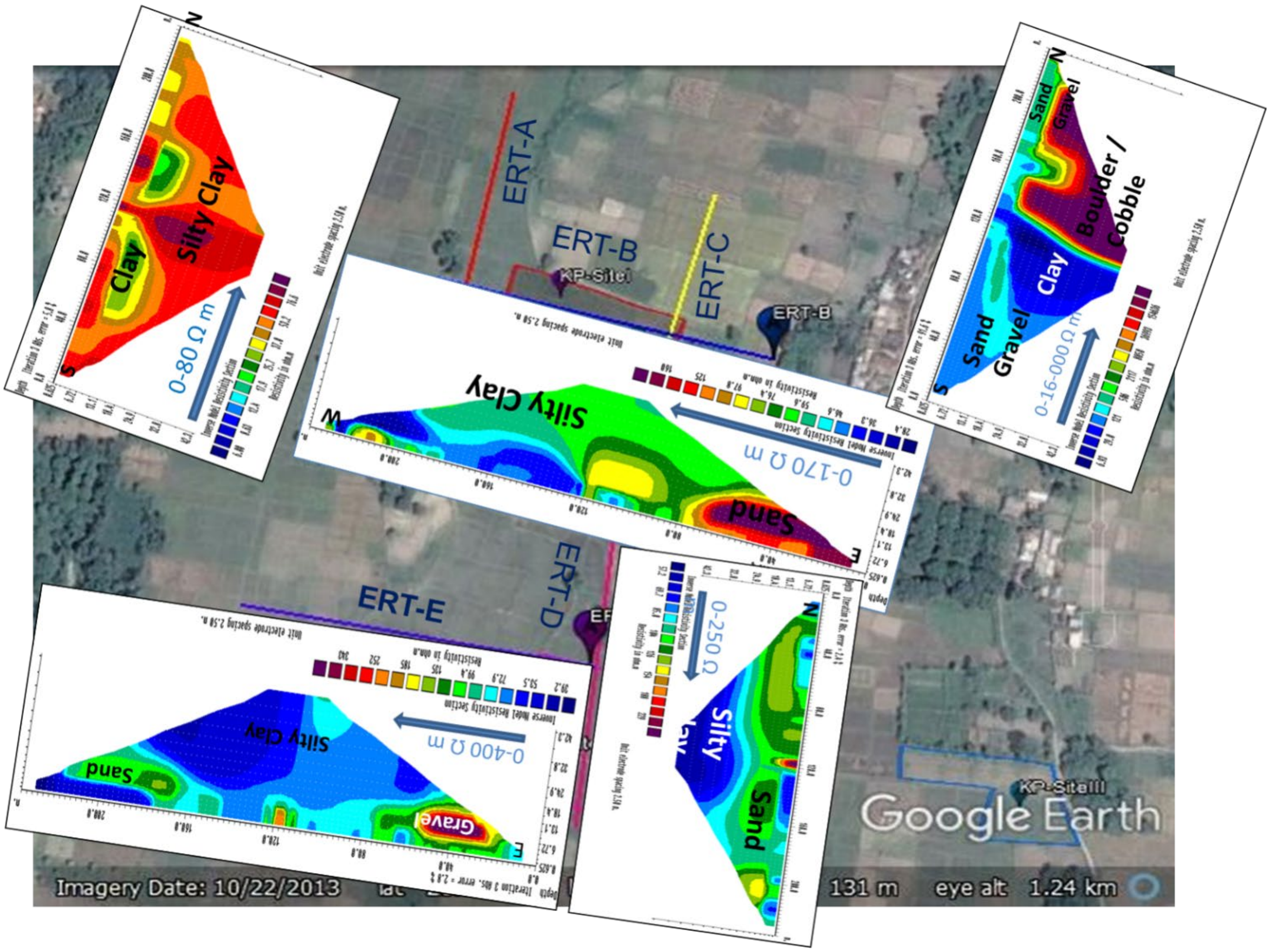

Figure 10: Resistivity section along five ERT profiles

Analysis of five 2D ERT sections reveals that most of the study area is underlain by silty clay from a depth of 10 to 18m, except for the northeast corner of the study area, which is underlain by boulders and cobble (Figure 10). The section of ERT Profile A and lateral distance of 80-240 m along the section of ERT B are dominated by silty clay and clay particles, which can be zoned as poor aquifer Zone A (Figure 11) not favorable for the shallow tube well development. Similarly, lateral distance of 0-80 m of ERT profile B and 0-120 m of ERT profile C up to 5-10 m depth shows sand and gravel. As a continuation of ERT Profile C, there is also aquifer material of sand and gravel in shallow depth up to 6 m and beneath this depth boulder and cobble dominates in aquifer material. This section can be zoned as limited groundwater potential aquifer (Zone B in Figure 11) with low storage capacity of aquifer material. ERT Profile C lateral distance up to 40 m, shows an upper layer consisting of clay and good aquifer material sand and gravel on limited depth up to 13 m in the eastern part, underlain by silty clay along the ERT Profile E. This can be zoned as good groundwater potential aquifer (Zone C in Figure 11) within the sandy aquifer. 80-240 m lateral distance along the ERT Profile E, where dominant sand aquifer material exists in a limited depth up to 5-10 m, can be zoned as limited groundwater potential (Zone D in Figure 11). Table 3 summarizes the aquifer structure of the different zones as identified and mapped from five electrical resistivity sections.

Figure 11: Spatial presentation of aquifer material as a factor of groundwater potential

Table 3: Descriptive spatial interpolation of aquifer structure around study sites in Kanakpatti

Zone	Characteristics	Groundwater prospects
A	Clay lenses underlain by silty clay. Area has very poor aquifer for the depth of assessment.	Poor aquifer
B	Limited depth of sand aquifer (between 5 and 10m) underlain by gravel, boulder and cobble	Less to moderate aquifer having low storage capacity
C	Sand and few lenses of gravel material to depths of 13 to 15m, underlain by silty clay.	Good potential aquifer
D	Shallow sand aquifer (5-10m) underlain by silty clays.	Less to moderate aquifer

The study confirms observations and experiences of the farmers as practiced in their farming and groundwater access infrastructure. The study reconfirms the limited water availability and/or failure of shallow tube wells bored in the areas within Zone A and Zone B. This study also highlights the successful water retention capability of the pond between Site I and Site II as it points to the likelihood that the pond is located at the area underlain by silty clay hence the very low water loss from deep percolation.

The historical farming activities, or lack thereof, in the area around the southwest corner of the study area is also indicative of the community's experience of limited water availability in this area. The area is one of the places with the least shallow tube well borings in the area.

6 Conclusions

The assigned project "Geophysical Survey at the Kanakpati VDC of Saptari District " was carried at different locations around Site I and II of Kanakpati project area of the study "Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains". The survey was carried to find out why certain patches of land in the intervention site in the Kanakpati do not yield groundwater from shallow tube well.

The findings from the 2D ERT sections align with the observations, perceptions and experiences of the farmers while developing the groundwater infrastructure. The historical lack of farming activities in the area around the southwest corner of the study area also indicates the community's experience of limited water availability in this area. The study confirms the limited water availability and unsuitability of shallow tube wells bored in the areas within Zone A and Zone B during the shallow tube well development. This study also highlights the successful water retention capability of the pond between Site I and Site II 13as it points to the likelihood that the pond is located at the area underlain by silty clay hence the very low water loss from deep percolation.

The results of the survey indicate that the good potential area lies mostly along the southeast to central east parts of the study area (primarily Zone C). The study shows a patchwork of clay, silty-clay, sand, gravel and boulder materials, which provide for varied aquifer potentials. Installation of productive shallow tube wells has thus been a chance at locating the tube wells within productive patches/lenses of aquifer material. The reliability of any such well also depends on the extent of the aquifer, and hence the storage potential as well as the hydraulic conductivity of groundwater flow within the tapped aquifer material as well as the neighboring materials. When developing the shallow tube well in the study area, spatial variation of the productive aquifer, hydraulic conductivity of groundwater flow within and nearby the tapped aquifer, and geological and lithological material need to be considered.

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