



# Mapping of laterite zones using 2D electrical resistivity tomography survey in parts of Paschim Medinipur, West Bengal, India: An approach for artificial groundwater recharge

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Earth's most valuable and renewable resource 'groundwater' is depleting rapidly in the last few decades. Due to lack of proper usage and planning of groundwater leads to water scarcity in some problematic areas of Paschim Medinipur, West Bengal, India. The presence of impervious laterite on the surface as well as in the subsurface is the main problem that hinders the natural groundwater recharge in the area. To overcome this issue, artificial recharge of groundwater and rainwater harvesting can be the best solutions. However, this requires precise information about the subsurface structures. Therefore, 2-dimensional Electrical Resistivity Tomography (ERT) surveys are performed at nine locations (separated by 3–4 km distances) covering a distance of about 30 km along a profile in E–W direction centrally located between Kangsavati (in the north) and Subarnarekha (in the south) rivers. The present study area extended between Village Chirakuti in the west to Village Nandakishorpur in the east, in the Paschim Medinipur district of West Bengal. A principle profile line of 30 km with a station interval of 3–4 km is covered along east–west direction. 2D data is collected at nine locations (with 800 m spread) along the principle profile. Every dataset is interpreted using RES2DINV software. The study reveals that the observed resistivity is highest in the western part (1400  $\Omega$ m) and lowest in the eastern part (40  $\Omega$ m) of the principle profile. The 2D interpreted resistivity cross-sections reveal that, the western part of the principle profile has conductive layers overlaid by a resistive layer on the top. The eastern part of the principle profile represents flat younger alluvium deposits. Most of these sediments are clayey sand, coarse sand on top and hard clay, small gravels to 10 mm gravels in deeper parts. The water crisis is mainly in the western part. So puncturing the top laterite layers and allowing the runoff water to penetrate into the subsurface may solve the problem. Building watersheds for agriculture in the western part of the principle profile line could help in increasing of the groundwater level in the study area.

**Keywords.** 2D ERT; Schlumberger and Wenner arrays; principle profile; ground water; laterite.

## 1. Introduction

Freshwater availability is going to be challenging in almost all parts of the world, especially in developing countries. Our mother earth has only 2.5% of fresh water in the form of lakes, ponds and groundwater, and remaining 97.5% is in the form of saline water in oceans which is not suitable for domestic purposes. In India, agriculture is one of the most important economic sectors. Especially in West Bengal, India, most of the farmers depend on the groundwater for agriculture purposes. This situation leads to scarcity of groundwater for drinking purpose in some areas in peak summer. In spite of having high annual rainfall in this region, some areas always have groundwater scarcity. This is due to the fact that in this region impervious laterite layers are present both at the surface as well as in the subsurface. This basically hinders the natural recharge of groundwater. To enhance the groundwater scenario in this region, systematic development of artificial recharge is required. This further requires systematic study of the subsurface structures which can be achieved by appropriate geophysical methods.

Electrical method is the most suitable as well as cost-effective for the solution of various problems related with groundwater studies. The techniques is equally suitable in solving problems associated with groundwater in hard rock, soft rock areas as well as saline water incursion zones in coastal areas (Bevc and Morrison 1991; Nowroozi *et al.* 1999; Choudhury *et al.* 2001; LaBrecque *et al.* 2004; Sharma and Baranwal 2005; Singha and Gorelick 2005, 2006; Bauer *et al.* 2006; Cassiani *et al.* 2006; Chandra *et al.* 2006, 2008; Pidlisecky *et al.* 2006; Koukadaki *et al.* 2007; Swarzenski *et al.* 2007; Kumar *et al.* 2014; Shivaramakrishnan *et al.* 2015; Bharti *et al.* 2019; Singh *et al.* 2019).

While considering the problems in Paschim Medinipur area, in particular, artificial recharge can be a good option, as the monsoon brings heavy rainfall in rainy season. If this rain water is used for artificial recharge, the problem of shortage of water can be dealt effectively. Remote sensing and electrical methods are very useful to locate the surface and subsurface features, which can store water. There are lots of studies on artificial recharge, going on all over the world from the last few decades (Eid *et al.* 2006; Arkoprovo *et al.* 2012, 2013; Gautam and Biswas 2016; Acharya *et al.* 2017). The southern part of Paschim Medinipur district, West Bengal faces water shortage in summer

(Chowdhury *et al.* 2010). As Paschim Medinipur district comes under Rarh region (Ghosh and Guchhait 2015), most of the area is covered by secondary laterites. In this area, Kangsabathi and Subarnarekha rivers are the main water sources. Panda *et al.* (2018) conducted a combination of resistivity sounding and 2-D resistivity imaging in N–S direction between these two rivers and concluded that northern part of the survey area is problematic, while southern part of the survey area is good for groundwater point of view. In the present study, about 30 km long profile is selected in E–W direction (figure 1) and 2-D resistivity imaging is performed (3–4 km interval with 800 m spread). This profile is in a perpendicular direction to the previous study, to know the areal extent of laterite and suitability for artificial recharge.

## 2. Geology of the study area

The present study area (figure 1) is in Paschim Medinipur, extends 30 km from village Chirakuti, in the west to village Nandakishorpur, in the east. This principle profile is perpendicular to the previous work's principle profile, done by Panda *et al.* (2018). It comes under Rarh region (Ghosh and Guchhait 2015). Kasai and Subarnarekha (which are overall parallel drainage system) dissects the lateritic Rarh region into the patches of forests and degraded badlands. Most of the area is covered by secondary laterite. The ground water level of this secondary laterite zone varies from 5 to 25 m below the land surface (Goswami 1981). In Bengal, the wet period is considered from June to October and dry season from December to April. Due to dry and wet seasons, the ground water fluctuates. This fluctuation in earth subsurface typically produces a mottled zone. It is characterized by alternating oxidizing and reducing conditions (Tardy 1992). Present study reveals different geological distribution of the subsurface in east–west direction. Most of the area in the western part, the laterite layers are present. While moving in the east and southeast of the district, flat alluvial deposits are found. These deltaic planes and flat alluvial are formed by younger alluvium (Bhunja *et al.* 2012; Pati 2013). These younger alluvial formations are well saturated and have a huge amount of groundwater throughout the year. The alluvial deposits are layered by sandy clay, fine sand, small sized gravels, coarse sand, hard clay, and 10 mm sized gravels.

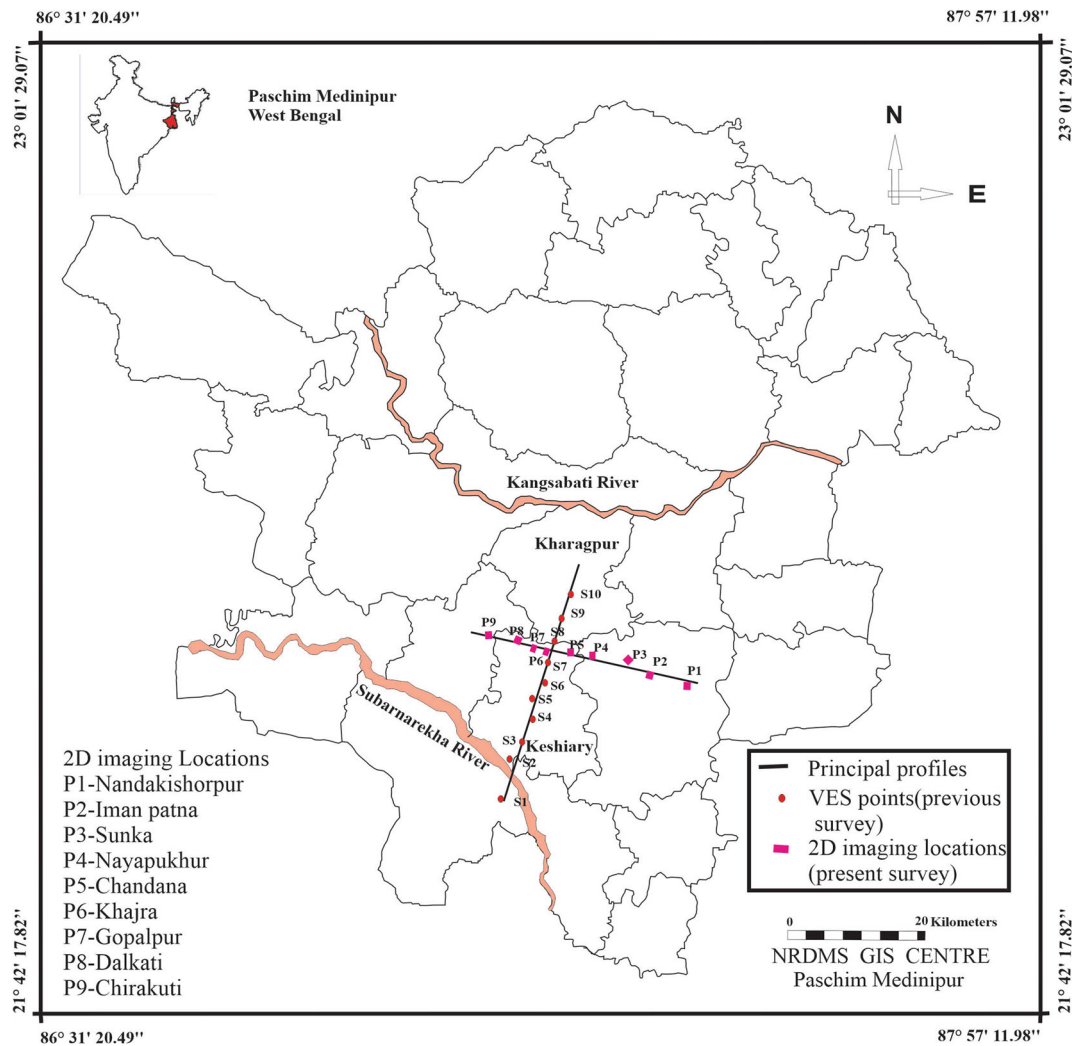


Figure 1. Study area with profiles showing previous (N–S) and present (E–W) profiles.

### 3. Field survey: Data collection and interpretation

For 2D-resistivity imaging, a large number of equi-spaced electrodes are placed over a profile such that current can be passed from any desired pairs of electrodes and potential difference can be measured between another pairs of electrodes. The position of current and potential electrodes pair changes systematically and a computer-controlled program is used to map the subsurface structures efficiently. Data can be collected for any suitable configuration (Wenner, Schlumberger, etc.) in multi-electrode imaging mode.

In the present study, ABEM LS resistivity imaging equipment is used. The multi-core cable consists of 21 connection points (10 m apart) and four such cables are used (4×21). Since the last and the first electrode take-outs shall overlap at the

cable ends, the equipment allows measuring with 81 electrodes for the system layout (4×21–3) that makes the maximum possible spread of 800 m with the equipment available with us. It is important to highlight that even though with ABEM LS system 84 electrodes are fixed in the ground, equipment has only 64 active connections, thus 20 positions are dummy. However, these dummy electrodes are on the first and last cables, while all 21 electrodes are active on the 2nd and 3rd cables. A typical measurement with 800 m spread with 10 m interval and active electrode positions are shown in figure 2(a and b). We can see that active electrode (data density) is more in the central part (cables 2 and 3), while less in outer part cables 1 and 4.

Data recording is done in such a way that initial measurements correspond to deeper depths and subsequent observations gradually belong to the shallower part. This is because at deeper depths,

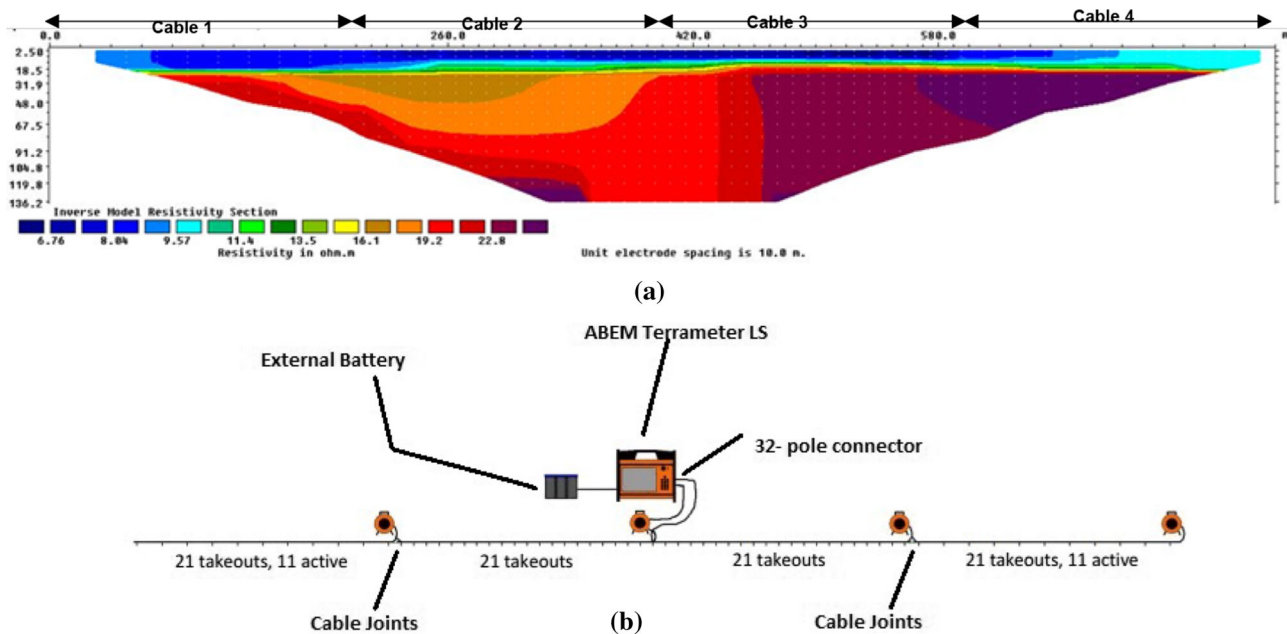


Figure 2. (a) A resistivity section with typical 4 cable arrangement of ABEM LS system and active electrode positions. (b) Instrument setup (modified after Alexey Bobachev).

we need more power supply. If we collect the shallow surface data first, we cannot have much power at the end of the survey, so we cannot cover the deeper portion. This way power supply can be used appropriately to enhance the signal-to-noise ratio. It is important to highlight that negative apparent resistivity is also observed sometimes, which is erroneous. This is due to the self-potential which we cannot cancel precisely in multi-electrode system. Negative apparent resistivity is more common for axial dipole–dipole array, while it is least or none for Wenner array data.

The collected data is first processed to remove negative apparent resistivity values. Subsequently, it is interpreted using RES2DINV inversion software. The processed data are represented as 2D resistivity image together with measured and calculated apparent resistivity pseudo-sections, number of iterations and RMS error.

## 4. Results

For the delineation of the nature of lateritic terrains in the proposed study area, a 30 km long, principle profile is marked in E–W direction (figure 1). Next nine locations are selected at suitable locations to perform resistivity imaging with spread up to 600 or 800 m on the basis of available space in the field. Multi-electrode Wenner array and Wenner–Schlumberger array are

both used to collect the data in the field. However, after processing we observed that Wenner array data is smoother as the structure is mostly soft rock and layered in nature. Therefore for brevity, only results corresponding to Wenner array data are presented.

### 4.1 Profile P1 (Nandakishorpur)

Profile P1 is located at the eastern-most point near Nandakishorpur village, Paschim Medinipur (figure 1). Figure 3 depicts the observed and model data pseudo sections as well as interpreted model. The interpreted 2D resistivity image (figure 3c) reveals that the top layer is well saturated sandy clay. The top layer is extended up to 15–17 m depth and has a resistivity range of 7.6–9.5  $\Omega\text{m}$ . The western part of the traverse line has slightly increasing resistivity, while comparing with the surroundings at a depth of 20 m. Moreover, the resistivity of this patch is around 20  $\Omega\text{m}$ . The western part of the traverse line is showing a high resistivity than the eastern part. These high resistivity values are  $\geq 29 \Omega\text{m}$ . The central part of the traverse line is homogeneously distributed with 22  $\Omega\text{m}$  resistivity. This formation is up to 130 m depth and extending towards west of the traverse line. Since the interpreted resistivity along this profile is  $< 30 \Omega\text{m}$ , only soft rock is present at this point on the principal profile. No high resistive laterite is seen at this profile.

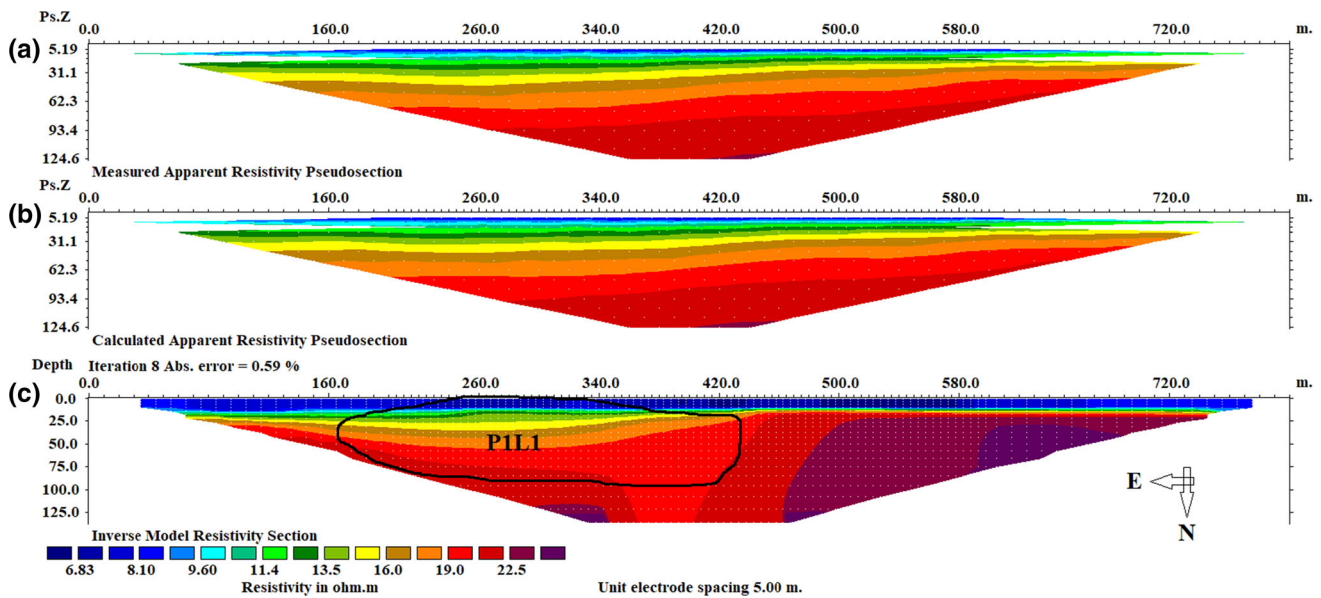


Figure 3. Cross-section showing measured data, model data and interpreted resistivity structure along Profile P1 (Nandakishorpur).



Figure 4. Bore hole samples for every 10 ft depth near Profile P1 (Nandakishorpur).

In this area, we collect information from a 560 feet deep bore well (figure 4). Since driller collected samples at every 10 feet interval, we present borehole information in feet. Borehole data reveal that the first 10 ft is clay and fine sand (in little amount). Next, there is sandy clay layer up to 60 ft. Here the sand size is a little bigger. From 60 ft onwards, the grain size has increased and it continues up to 100 ft. After 100 ft, there is a layer of very fine sand and clay that extends up to 140 ft depth. From 140 ft onwards, the gravel size is increasing gradually up to 180 ft depth. At 180–260

ft depth, we found hard clay. From 260 ft onwards, we found pure sand and it continues up to 310 ft. Again there is a hard clay layer of 20 ft thickness. Beneath this, there is a fine sand layer continues up to 400 ft depth (table 1). So from this borehole data, we can say that the profile P1 has saturated clayey sand as a top layer of a 20 m thickness. Beneath this layer there is a mixture of clay and coarse sand type layer in the eastern side of the traverse line. Below this layer, there is tightly packed clay and very fine sand layer. Due to the compactness, the resistivity increases gradually as

we go deeper into the earth subsurface. In brief, it is observed that the interpreted resistivity structure correlates very well with the samples recovered from borehole (figure 4).

#### 4.2 Profile P2 (Iman Patna)

The profile P2 is located close to village Iman Patna, West Bengal (figure 1). For brevity, here onwards we do not present the observed and model data pseudo depth sections, but only the interpreted resistivity model. At this location, the 2D processed image section (figure 5) reveals that there are three resistive bodies present in the subsurface. The resistive body which is present at the central region is extending up to large depths. This is a continuous body which extends up to 170 m depth. There are two more resistive bodies; one is on the eastern side and the other is on the western side. The eastern side body is extended up to 30 m depth and its width is around 20 m. The western side body is little shallower. It is extended up to 26 m, and its width is 20 m. Apart from these three bodies, most of the top layer is conductive with a resistivity range of 7–20  $\Omega\text{m}$  and it is extended up to 15 m depth. Below this conductive layer, there is a little high resistive layer having a range of 50–100  $\Omega\text{m}$ . This layer is extended from 15 to 50 m depth.

Table 1. Borehole data.

Borehole data (ft)	Formation type
10	Clay and fine sand (in little amount)
10–60	Clay and sand
60–100	Clay and sand (grain size increased)
100–140	Very fine sand and clay mixture
140–180	Sand gravel size increased
180–260	Hard clay
260–310	Pure sand
310–330	Hard clay
330–560	Fine sand and clay mixture

From 50 m onwards, there is a very high conductive zone with a resistivity range of 1–4  $\Omega\text{m}$  and extended up to deeper depths. This highly conductive zone is separated into two by the central resistive body. This location acts like a confined aquifer and suitable for artificial recharge.

#### 4.3 Profile P3 (Sunka)

Profile P3 is located in the proximity of Sunka village, Paschim Medinipur district (figure 1). The inverted 2D image section is approximately the same as Profile P1. Both P1 and P3 profiles represent horizontal layered structures. In both profiles, the top layers are highly saturated with ground water and the resistivity values are also in the same range. However, at deeper depths the resistivity values are increasing gradually in both profiles. In figure 6, the top layer is conductive with a resistivity range of 10–14  $\Omega\text{m}$ . This conductive layer is extended up to a depth of 10 m in the eastern part of the traverse line. The same layer in the western part continues till 20 m depth. Below this conductive layer, there is the presence of an unsaturated layer extending to the depth of around 136 m. Similarly, the eastern part of the traverse line has low resistivity value of 26  $\Omega\text{m}$  as compared with the western part, where it is >40  $\Omega\text{m}$ . Due to the impermeable nature of clay, the resistivity of the subsequent layers increases with depth.

#### 4.4 Profile P4 (Nayapukhur)

Profile P4, located near Nayapukhur village, West Bengal (figure 1), was 5.5 km away from the profile P3. In this area, we can observe the lateritic outcrops, where at one place there is a pond (at a distance of 10 m from the center of the survey line in south direction), which is 2–3 m deep with lateritic rock material around the margin. The 2D

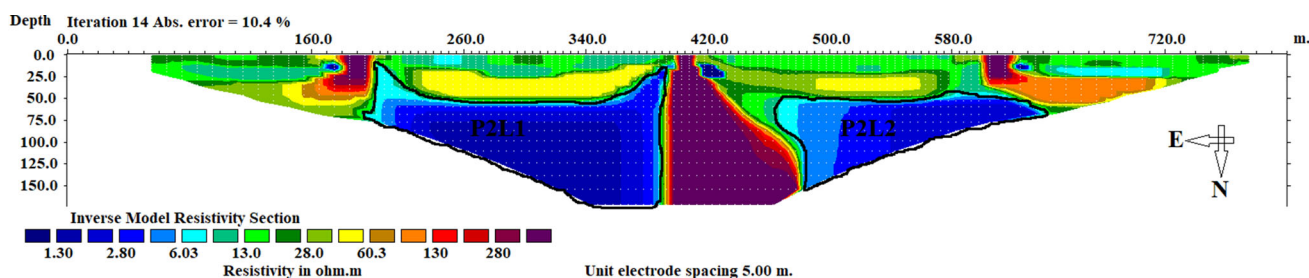


Figure 5. Interpreted resistivity model for profile P2 (Iman Patna).

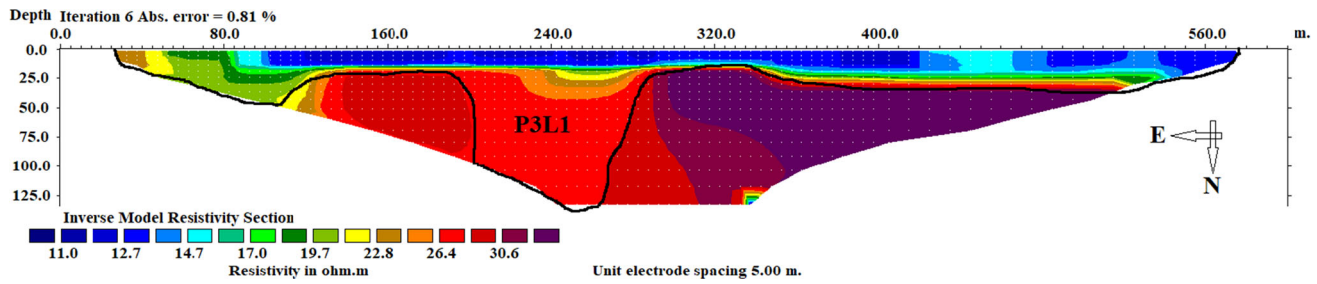


Figure 6. Interpreted resistivity model for profile P3 (Sunka).

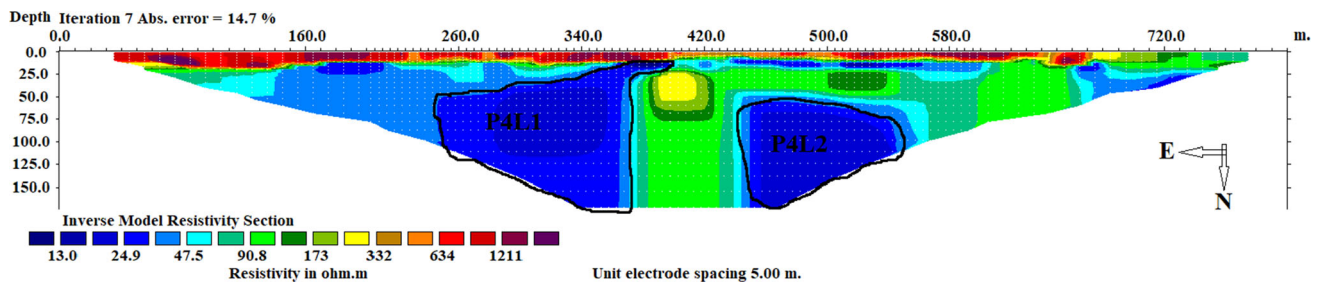


Figure 7. Interpreted resistivity model for profile P4 (Nayapukhur).

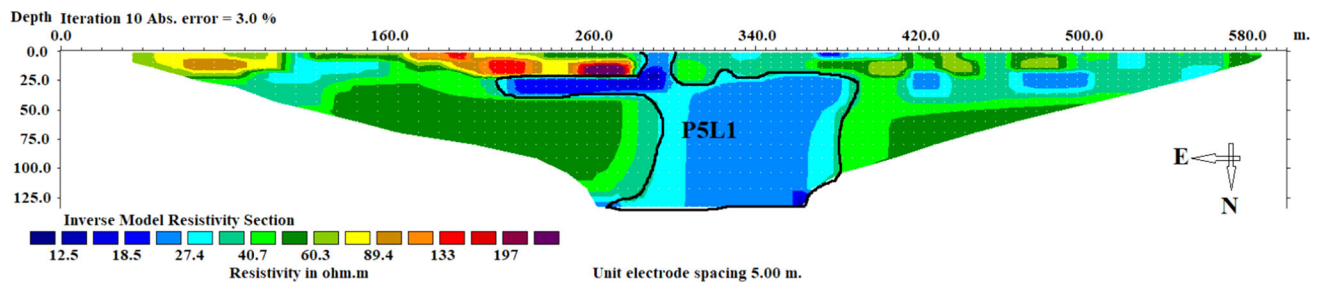


Figure 8. Interpreted resistivity model for profile P5 (Chandana).

image section (figure 7) displays a lateritic layer with resistivity as high as 1400  $\Omega\text{m}$  covering the total area followed by low resistivity layers successively. These high values indicate the presence of laterite clay where low resistivity successive layers may indicate presence of groundwater.

#### 4.5 Profile P5 (Chandana)

For profile P5, we selected a spot near Chandana village in the Paschim Medinipur, West Bengal (figure 1). At this location, the 2D processed image section (figure 8) represents that the eastern part of the traverse line is covered with unsaturated or dry soil. However, at the center part of the profile (i.e., from 285 m to 380 m on surface), the

resistivity values vary from 20 to 35  $\Omega\text{m}$ . This range suggests that there is a good possibility of groundwater in this area.

#### 4.6 Profile P6 (Khajra)

The profile P6 is located in the west of Khajra village, Paschim Medinipur, West Bengal (figure 1). The 2D inverted cross-section (figure 9) reveals that the profile (600 m) is divided into two parts. The eastern part of the profile is well saturated and promising for a good yield of ground water. This conductive zone is extended in the west direction at deeper depths. While the western part has a high resistive layer on top and the resistivity values gradually decrease with depth.

4.7 Profile P7 (Gopalpur)

Profile P7 is located near Gopalpur, Paschim Medinipur, West Bengal. The 2D processed image section (figure 10) suggests that the top layer is formed by secondary laterite. The central part (i.e., 280–365 m on surface) of the profile represents a highly conductive zone which starts from 25 m depth and extends to the deeper part. The eastern part (i.e., 40–160 m on surface) reveals a confined aquifer which extends up to 40 m depth. The western part (i.e., 415–475 m on surface) of the traverse line seems to promise a good aquifer below 40 m depth.

part of the traverse line is more conductive than the western part of the traverse line. Over the profile, at some places, top layer is resistive (like from distance 0–260 m) with resistivity approximately equal to 130  $\Omega\text{m}$ . On the other side (from 600–800 m), resistivity value is  $\sim 150 \Omega\text{m}$  over the profile length. The first patch of resistive layer is extended up to a depth of 35 m, whereas the second patch at the end is 15 m deep. Beneath these two highly resistive bodies, we almost found a conductive zone that extends deeper in the subsurface. We also observed a sharp change in resistivity at the central part of the profile (at 400 m), that may be due to a fault type structure.

4.8 Profile P8 (Dalkati)

Profile P8 location is near to Dalkati village, Paschim Medinipur, West Bengal (figure 1). The inverted 2D image section (figure 11) represents that the eastern

4.9 Profile P9 (Chirakuti)

Profile P9 location is in the vicinity of Chirakuti village of Paschim Medinipur district. The

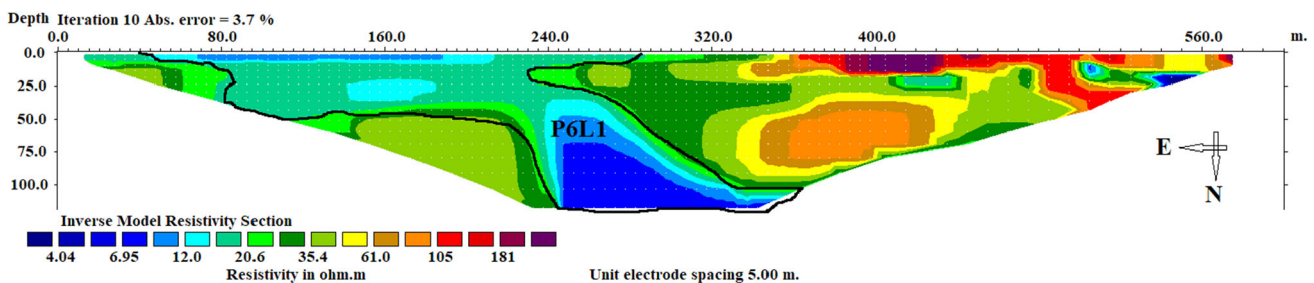


Figure 9. Interpreted resistivity model for profile P6 (Khajra).

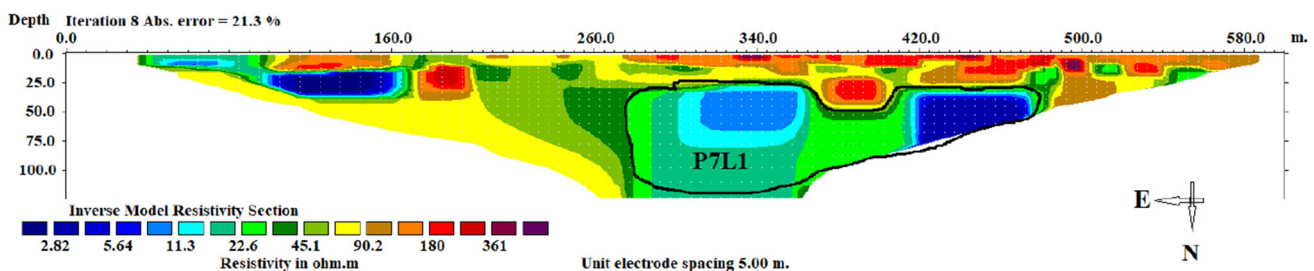


Figure 10. Interpreted resistivity model for profile P7 (Gopalpur).

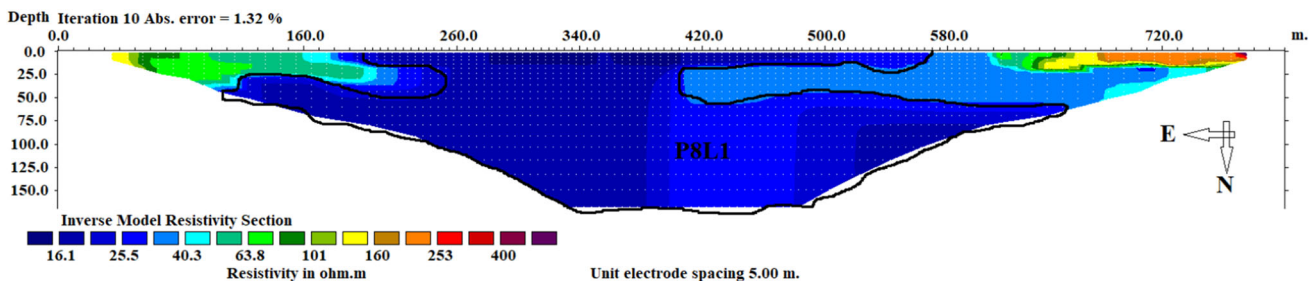


Figure 11. Interpreted resistivity model for profile P8 (Dalkati).



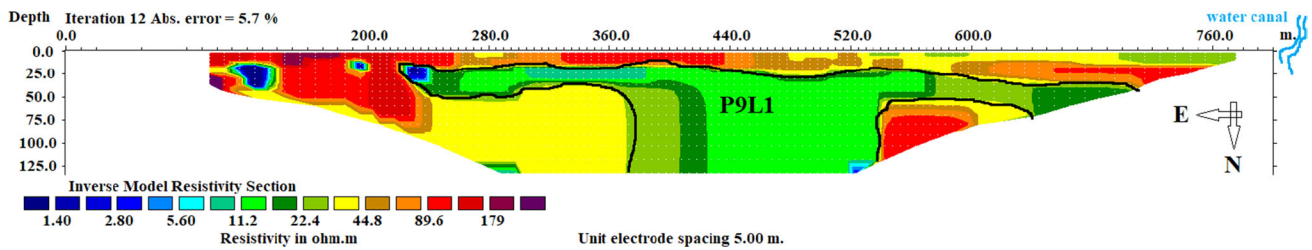


Figure 12. Interpreted resistivity model for profile P9 (Chirakuti).

Table 2. Profile-wise suitable zones.

Profiles	Suitable zone for pumping or artificial recharge (L: low resistive zone)
P1	P1L1
P2	P2L1 and P2L2
P3	P3L1
P4	P4L1 and P4L2
P5	P5L1
P6	P6L1
P7	P7L1
P8	P8L1
P9	P9L1

processed 2D image (figure 12) reveals that the top layer is highly resistive (along profile P9, 0–110 m, as a hard lateritic layer is present on the surface; the data is not represented due to the skipping of the poor contact electrodes). In the eastern part of the profile from 0 to 440 m extended up to 20 m in depth. Beneath this high resistive layer, there is the presence of less resistive layer with 20 Ωm resistivity. The situation is reverse in the western side of the traverse line, where top layer has low resistivity equal to 50 Ωm. At the end of the traverse line, there is a water irrigation canal that flows from north to south direction.

### 5. Discussion

Electrical resistivity imaging survey is performed to map the lateritic layers in the study area. Data are collected using Schlumberger and Wenner arrays at nine different locations; however, only interpreted results for Wenner array are shown in the present study. All the 2D datasets are inverted individually by RES2DINV software. The eastern part of the principle profile, that involves profiles P1–P3, shows alluvial deposition strata. The 2D cross-sections of Profile P1, P2 and P3 reveal that the earth subsurface has a layered

structure. The borehole data acquired closer to Profile P1 correlates well with the Werner 2D cross-section obtained for Profile P1 (figure 3). Topmost layers are water saturated, hence have low resistivity values (10–20 Ωm). However, resistivity increases with depth as the compactness of clay increases. The borehole data also reveals hard clay layers at deeper depths as shown in 2D resistivity section (figure 3). On the other hand, the western part of the principle profile almost has a highly resistive layer on the top with resistivity value ranging from 150 to 1500 Ωm (figure 3). 2D cross-sections of Profile P4 and P5 reveal that the top layers are highly resistive in nature and conductive zones are found beneath. Profile P6 contains resistive layers at deeper depths, but the eastern part of the profile is capable of sustaining groundwater. The 2D cross-sections of Profile P7 (figure 10) and P8 (figure 11), reveal that the top layer contains patches of lateritic material. These lateritic patches are impermeable, so most of the rain water does not infiltrate into the subsurface. Puncturing the lateritic layers or building check dams may help in improving the ground water level. The 2D cross-section of profile P9 (figure 12) represents that a 10–15 m thick layer of laterite is on the top, beneath this resistive top layer, there is a presence of conductive zone and it extends into the deeper depths. In summer, to overcome the water scarcity in this area, we have to perforate the top layer so that the rain water can infiltrate into the subsurface. From all the 2D cross-sections, we conclude that the western part of the principle profile is problematic due the highly resistive lateritic layers on the top. This will cause rain water to draw-off from the surface and will not allow infiltration into the subsurface. Good planning for check dams, and perforating the top layers may increase the ground water level in this area. The eastern part represents younger alluvial deposits and yields a good amount of ground

water. Transporting water from this area may help to serve water in the western part in peak of summer season.

## 6. Conclusions

Electrical resistivity imaging survey is performed in Paschim Medinipur district, West Bengal, India, to map the lateritic terrains for the selection of a suitable area or areas for the implications for artificial groundwater recharge schemes. Since resistivity survey over N–S profile in the study area has already been performed in the past, in the present study, resistivity survey is performed in E–W direction covering a distance of about 30 km from Nandakishorpur to Chirakuti. Resistivity study along Profiles P4, P7 and P9 reveal that these areas will be problematic for artificial recharge due to presence of thick impervious lateritic layer on the top. Zones covering Profile P1, P2 and P3 are suitable for artificial recharge, like building check dams and infiltration of rainwater to greater depth. Locations around Profiles P5, P6, and P8 show that top layer is partly lateritic, therefore, rainwater may percolate only from suitable locations (table 2). It can be concluded that the western part of the area is more lateritic and problematic for infiltration of rain water, while eastern part of the area is suitable to yield good amount of groundwater through hand pumps, bore wells, etc. The zone in the western side, i.e., from Profile P4 to P9, needs proper rainwater harvesting and artificial recharge scheme to solve the groundwater problem in the area. Combining the results of the previous study, it can be concluded that NW part of the study area is problematic for infiltration of rainwater due to presence of laterite layer, while SE part is suitable for groundwater. There is a need to develop an artificial recharge scheme (like building check dams, by puncturing the top lateritic layers and allow the rain water to infiltrate, etc.) in the NW part of the study area.

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