

## 2D Geo-electrical imaging for shallow depth investigation in Doon Valley Sub-Himalaya, Uttarakhand, India

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**Abstract** A 2D geo-electric profiling was executed close to Rajpur area in Doon Valley Sub-Himalaya, Dehradun, Uttarakhand. Profiling was executed at the site Civil Services Institute (CSI) close to Morvian Institute, Rajpur Road in Dehradun for possible shallow subsurface groundwater aquifer. Two resistivity and IP profiles were carried out to discover the conceivable groundwater zones in this area. It has been discovered that there are two inimitable palaeochannels found in these areas. These two channels act an erosional channel which was before happened to be a little stream. Beneath this, there is thick gravel and coarse sand stores in the close surface which is arranged at a profundity of 0.5–5 m with a thickness of 10 m. This zone goes about as brilliant potential for shallow groundwater pockets. Besides, inside the surroundings of these rock stores, fine to medium sand is likewise present in the vast majority of the zones which also may likewise goes about as potential groundwater resources at a shallow depth. Notwithstanding, this groundwater pockets may not be adequate to address the issues of water in the mid year season and is very much prescribed to search for more profound aquifer in the study area.

**Keywords** Geo-electrical · Sub-Himalaya · Doon valley · Uttarakhand · India

### Introduction

One of the most precious natural resource which has important impact on human life, economic development of mankind (mainly in agriculture, industries etc.) and ecological diversity is the Groundwater. Out of the Earth's whole water systems, only a small fraction is suitable for human consumption (Bachmat 1994; Biswas et al. 2012). The presence of groundwater on the earth is the interaction of the geological, physiographical, hydrological and ecological factors (Biswas et al. 2013). In most of the groundwater studies, it is essentially a hydro-geological, remote sensing and geophysical presumption (Bachmat 1994; Biswas et al. 2012; Biswas et al. 2013; Sharma and Baranwal 2005; Sharma and Biswas 2013). This assumption is dependent on the correct elucidation of the hydrological and other geological indicators and evidences.

Exploration of groundwater has been studied using geo-electric and electromagnetic method which has been found to be very reliable for ground water studies over many years because of good correlation between electrical properties (electrical resistivity, conductivity, etc.), geology and fluid content (Sharma and Baranwal 2005; Sharma and Biswas 2013; Sharma et al. 2014). From a variety of electrical prospecting methods, a vertical electrical sounding (i.e. Schlumberger sounding) is successfully used for groundwater studies due to the simplicity of the technique, easy interpretation and rugged nature of the associated instrumentation. Moreover, electrical profiling, i.e. multi-electrode Wenner profiling, which is used for mapping lateral resistivity variations and is also useful for groundwater exploration (Owen et al. 2005). These techniques have been widely used in different geological conditions for various purposes (Van Overmeeren 1989; Urish

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and Frohlich 1990; Ebraheem et al. 1997; Mondal et al. 2008; Sastry and Mondal 2013; Biswas et al. 2014).

The multi-electrode resistivity strategy is currently genuinely settled as for hypothesis, functional application and understanding procedures (Barker 1981, 1992, 1996; Dahlin 1993, 1996; Loke and Barker 1996a, b; Loke 2000, 2004). Resistivity strategies are exceptionally delicate to varieties in earth resistivity, and are in this manner helpful for distinguishing lithological units and varieties inside lithological units. Such elements and changes are normally exceedingly noteworthy as for groundwater event. Ordinary DC resistivity sounding and profiling has effectively promoted on this part of resistivity reviewing however is feeble in appreciation of spatial scope. By using microcomputer control, the multi-electrode resistivity technique has overcome this shortcoming in resistivity surveying.

In the present study, the multi-electrode resistivity method has been used to assess the groundwater potential in Doon Valley which forms a part of Dehradun District in the North-western part of Uttarakhand state (Fig. 1a). We have reported the first operation of multi-electrode 2D resistivity and IP survey in Doon valley Sub-Himalaya, Dehradun, Uttarakhand to delineate the possible groundwater aquifer in the area.

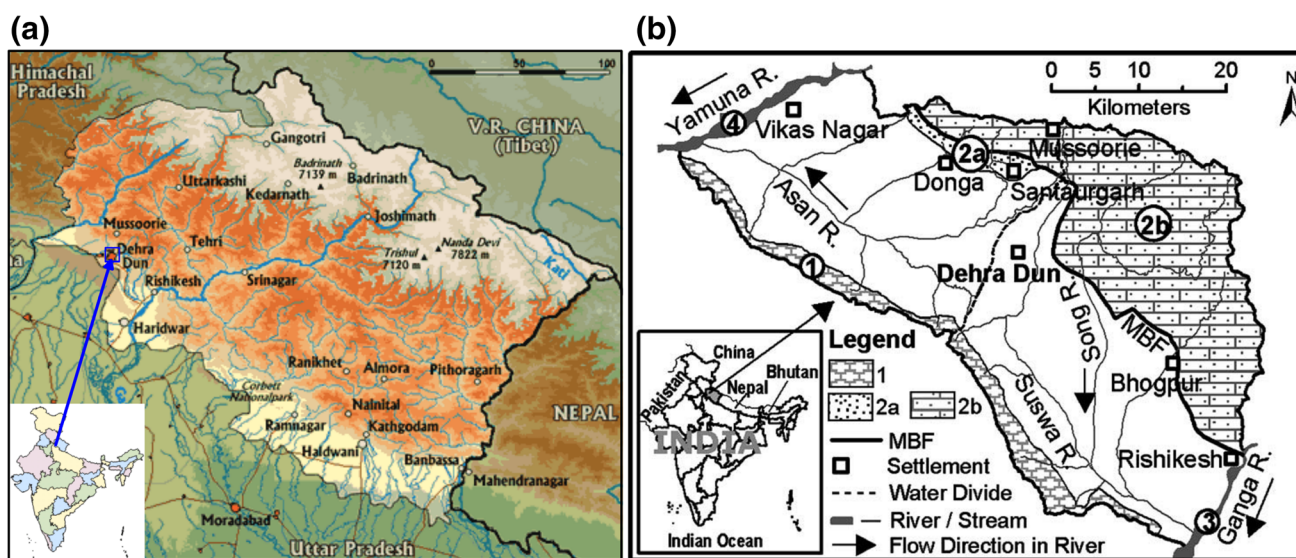
### Regional geology

The Doon valley has particular topographical properties with a wide range of rock sorts extending in age from Achaean to Quaternary (Thakur 1981). Taking into account the assortment of topographical procedures in time and

space, the valley can be subdivided into two noteworthy physiographic-cum-tectonic units, viz. the Gangetic Alluvial Plain and Himalayan Mountain Belt. This valley reaches out from NW to SE and has a length of 80 km and a width of 18 km. The valley catchment lies between latitudes 30°01'N–30°31'N, and longitudes 77°38'E–78°19'E, covering an area of about 1950 km<sup>2</sup>. The geology of Doon valley has been studied by various researchers (Philip 1995, 1996; Sati and Rautela 1998; Chandel and Singh 2000; Patel and Kumar 2003; Singh et al. 2001, 2004; Thakur and Pandey 2004; Thakur et al. 2007).

The valley is limited by Lesser Himalaya and Siwalik slopes in the north and south though the eastern and western part is shaped by Ganga and Yamuna streams, individually. The Gangetic alluvial plain zone comprises of Quaternary fluvial dregs. The subsurface examinations in this zone have uncovered a thick heap of alluvium resting similarly over the Siwalik progression of Neogene to early Pleistocene Period. The thickness of alluvium increments towards north and achieves its most extreme nearby the foot hill fault (FHF), which denote the northern furthest reaches of the most youthful foreland bowl in India i.e. the Ganga Fore profound Basin. The Ganga Fore profound silt stretch out up toward the south of depositional limit of the Siwalik progression and rests over Precambrian cratonic rocks of Peninsular Indian Shield.

The Himalayan Mountain Belt is a part of the worldwide versatile belt of Mesozoic to Cenozoic age that is accepted to have advanced through the joining of dynamic Indian Plate and uninvolved Eurasian Plate amid the landmass mainland lithospheric impact. Late Proterozoic



**Fig. 1** a Location map of the study area; b generalized geological map of the study area (Doon catchment Valley). 1 Southern Sub-Himalayan belt of Siwalik, 2a northern Sub-Himalayan belt of Siwalik, 2b Lesser Himalayan belt, 3 Ganga River, 4 Yamuna River,

MBF Main Boundary Fault. Un-shaded area is the Doon Valley consisting of a large piedmont alluvial aquifer system (after Srivastav et al. 2007)

(Neoproterozoic) to early Cenozoic crustal arrangements frame a little piece of Himalaya, though the fundamental mountain chain comprising prevalently of Proterozoic rocks speaks to a part of the Indian Shield. The Proterozoic crystalline rocks have been influenced by different orogenic scenes of Mesozoic to Cenozoic Period and hint at numerous periods of distortion and transformative nature. The extra-peninsular locale has a wide range of rocks of sedimentary, metamorphic and igneous origin.

Doon Valley goes under the Outer Himalaya or sub-Himalayan zone. This zone constitutes of a thick Cenozoic sedimentary heap running in age from Paleocene to Upper Pleistocene. Its northern and southern limits are delimited by the main boundary thrust (MBT) and the FHF otherwise called the main frontal thrust (MFT), separately. This zone comprises prevalently of mainland molasses dregs of Siwalik Group running in age from Middle Miocene to Upper Pleistocene. The Siwalik Group has been subdivided into the Lower Siwalik, Middle Siwalik and Upper Siwalik. The Lower Siwalik comprises of fine to medium grained sandstone, the Middle Siwalik is framed of medium grained sandstone with calcareous solidifications and sandy clay and the Upper Siwalik comprises overwhelmingly of combination with lenticular outcrops of sandstone and minor clay.

The focal part of the Doon Valley catchment is chiefly loaded with profoundly porous and permeable unconsolidated to-ineffectively united piedmont alluvial or fan stores of Late Pleistocene to Holocene age, which shape the expansive aquifer framework hidden the study territory (Fig. 1b). These valley-fill stores comprise of thick conglomerates beds with aggregates with pebbles and boulder sized clasts in a fine-grained matrix (Thakur and Pandey 2004), and are privately called the Doon Fan Gravels or Doon Gravels (DG). The Siwaliks of the Sub-Himalayan belt comprise of molassic residue, fundamentally combinations, sandstones, and muds, of Neogene period (Upper Miocene to Early Pleistocene).

## Hydrogeology

The hilly condition of Uttarakhand can comprehensively be characterized into two hydrogeological administrations in particular Gangetic Alluvial Plain and Himalayan Mountain Belt. A wide variety in geography and landforms of the range offered ascend to differed hydrogeological set-up. The range is comprehensively partitioned into three hydrological units to be specific, the Himalayan mountain belt, the Siwaliks and the Doon alluvial fill (Doon rock). The present territory exists in the external Himalayan or sub-Himalayan zone. This zone is made overwhelmingly out of sandstone, ferruginous shale and clay and is more youthful in age when contrasted with alternate units of the belt. The general rise of

the zone is less than 1000 m above mean ocean level. Because of the semi-combined nature of rocks, potential ground water bearing developments are available in zones, which have a decent weathered mantle and exceptionally cracked/jointed rocks. In the Siwaliks, various valleys have additionally been created as an aftereffect of tectonic exercises (e.g. Doon Valley), which are essential from the hydrogeological perspective. The Doon Valley was framed as an Intermontane Valley inside the Siwalik Group of rocks in a foreland proliferating push framework. The Lower, Middle and Upper Siwaliks are uncovered in the region, and the Doon Gravels, a post-Siwalik Formation, were saved with the advancement of the valley. The Doon Gravels are thickly had relations with coarse clastic fan store generally Pleistocene and Holocene age. The thickness of the alluvial fill is ~300 m in the focal part (i.e. close to the valley hub) and ~100 m in the upper/northern part (Thakur and Pandey 2004). The aquifer framework is multilayered in nature, as regularly found in alluvial stores. Groundwater is under unconfined conditions in shallow aquifers and under semi-limited conditions in more profound aquifers (Roy 1991, 1995). The Central Ground Water Board has effectively developed 11 profound tubewells, with release going from 252 to 3197 lpm (liter per minute) in the Doon Valley of Dehradun region. The water levels in these aquifers range from 20 m bgl (below ground level) in the southern part of the valley to around 100 m bgl in the northern part (CGWB 2009, 2010).

## Methodology

### Basic principle

Both Electrical sounding and profiling are routinely utilized for groundwater exploration, and are all around portrayed in standard geophysical texts (Parasins 1962). To get a detailed picture of the subsurface, a point by point photo of the subsurface can be acquired by joining the 1D sounding and profiling information to give 2D cross sections, which can in turn be joined to give a 3D model of the subsurface. In such type of work, it is very much of time consuming and highly cumbersome. This has led to the improvement of multi-electrode resistivity system (Dahlin 1996). Such instrument involves the utilization of numerous electrodes, associated by means of multi-core links to an exchanging box, which thusly is associated with a DC resistivity meter. A PC convention document teaches the exchanging box to consequently choose blends of four electrodes at a period as indicated by the study outline, and the resistivity meter takes readings for every arrangement of chose terminals, in this way delivering a 2D information set.

## Electrical resistivity

This survey provides the subsurface resistivity distribution through the measurements on the ground surface. The ground resistivity depends on the various geological parameters such as mineral and fluid content, salinity of the contained water, porosity and degree of water saturation the subsurface materials (Sharma and Baranwal 2005; Sharma and Biswas 2013; Biswas et al. 2014; Biswas and Sharma 2016). The fundamental law of resistivity survey is Ohm's Law that governs the flow of current in the ground. The Ohm's Law in vector form can be defined as

$$J = \sigma E \quad (1)$$

where  $\sigma$  is the conductivity of the medium,  $J$  is the current density and  $E$  is the electric field intensity. The resistivity  $\rho$  is equal to the reciprocal of the conductivity ( $\rho = 1/\sigma$ ) and measure in ohm-meter. As the subsurface condition is inhomogeneous in actual, the measurements provides the apparent resistivity ( $\rho_a$ ) of the medium which is calculated by

$$\rho_a = k \frac{\Delta\phi}{I} \quad (2)$$

$$k = \frac{2\pi}{\left(\frac{1}{r_{C1P1}} - \frac{1}{r_{C2P1}} - \frac{1}{r_{C1P2}} + \frac{1}{r_{C2P2}}\right)} \quad (3)$$

where  $k$  is the geometric factor that depends on the arrangement of the four electrodes,  $I$  is the current and  $\Delta\phi$  is the potential difference,  $r$  is the distance between the current electrode ( $C$ ) and the potential electrode ( $P$ ).

The subsurface resistivity is sensitive to type of material, water saturation and salinity of the contained water in the subsurface material. In this relation given a law and defend the resistivity as

$$\rho = a\rho_w\phi^{-m} \quad (4)$$

where  $\rho$  is the rock resistivity,  $\rho_w$  is fluid resistivity,  $\phi$  is the fraction of the rock filled with the fluid, while  $a$  and  $m$  are two empirical parameters (Keller and Frischknecht 1966). For most rocks,  $a$  is about 1 while  $m$  is about 2.

## Induced polarization (IP)

In IP survey we measure the chargeability in milliseconds (mV/V), it is the ratio of amplitude of the residual voltage to the DC potential just after the current cut-off. In the time domain chargeability can be defined as

$$m_t = 1870 \frac{\int_{0.15}^{1.1} V_s dt}{V_{DC}} \quad (5)$$

Apparent IP is calculated by two models using original and perturbed conductivities as

$$m_a = [\phi(\sigma_{IP}) - \phi(\sigma_{DC})]/\phi(\sigma_{DC}) \quad (6)$$

$$\sigma_{IP} = (1 - m)\sigma_{DC} \quad (7)$$

where  $\sigma_{DC}$  is the conductivity measured through the normal resistivity survey and effect of the chargeability is decrease the effectively conductivity to  $\sigma_{IP}$  and  $\phi$  is the calculated potential.

## Data acquisition

2D geoelectrical resistivity imaging can be achieved by integrating the techniques of vertical electrical sounding with electrical profiling. It involves apparent resistivity measurements from electrodes placed along a line using a range of different electrode separations and midpoints. The procedure is repeated for as many combinations of current and potential electrode positions as defined by the survey configuration. 2D resistivity imaging can be seen as continuous vertical electrical sounding (CVES) in which a number of VES conducted in a grid are merged together or as a combination of successive profiles with increasing electrode spacing. Now a day's 2D resistivity surveys are usually carried out using large numbers of electrodes connected to multi-core cables and the area covered by the survey can be extended along the survey line using the roll-along technique (Dahlin and Bernstone 1997). A number of arrays have been used in recording 2D geoelectrical resistivity field data, each suitable for a particular geological situation.

In the present work, we collected resistivity-IP data along to two parallel profiles of 96 m A–B and C–D through Multi-electrode resistivity imaging system "Syscal Pro-72" system of M/s IRIS Instrument France. As we were interested to obtain the horizontal as well as vertical lithological and ground water information on the basis of resistivity distribution, with this goal we chose Wenner-Schlumberger array (Griffiths and Turnbull 1985; Griffiths et al. 1990; Oldenburg and Li 1999; Olayinka and Yaramanci 2000) with 2 m electrode spacing at Rajpur site in Doon Valley Sub-Himalaya (Fig. 2). Total of 48 electrodes were used and electrodes were arranged along a line with a constant spacing of 2 m between the adjacent electrodes.

## Forward modelling and inversion

RES2DMOD algorithm was used to forward modeling to calculate the apparent resistivity-IP pseudo-section for a user defined 2D subsurface model. The algorithm is based on least-square method involving finite-element and finite-difference methods (deGroot-Hedlin and Constable 1990; Sasaki 1992) and can support the user in choosing the appropriate array for different geological situations. This



**Fig. 2** Field Location Map of the study area with ERT profiles on Google map

program perform for almost all type arrays, however we have used Wenner-Schlumberger array for data acquiring in our study (Edwards 1977). In other hand to invert the data to produce continuous and seamless model, we used RES2DINV software. This utilized an iterative technique where starting from initial model and program tries to obtain improved model, whose calculated apparent resistivity values are closer to measured values (Loke 2000, 2004). The smoothness-constrained least-squares method is based on the following equation.

$$(\mathbf{J}^T \mathbf{J} + u \mathbf{F}) \mathbf{d} = \mathbf{J}^T \mathbf{g} \tag{8}$$

where

$$\mathbf{F} = \mathbf{f}_x \mathbf{f}_x^T + \mathbf{f}_z \mathbf{f}_z^T \tag{9}$$

$f_x$  = horizontal flatness filter,  $f_z$  = vertical flatness filter,  $\mathbf{J}$  = matrix of partial derivatives,  $u$  = damping factor,  $\mathbf{d}$  = model perturbation vector,  $\mathbf{g}$  = discrepancy vector.

### 2D high-resolution imaging

The electrical resistivity is sensitive to lithology, intrinsic properties, porosity, fractures, degree and nature of fluids filling the pores, etc. The geo-electrical 2D model is assumed to vary both vertically and laterally along the survey line. The observed apparent resistivity values are

commonly presented in pictorial form using pseudo-section contouring which gives an approximate picture of the subsurface resistivity distribution. The shape of the contours depends on the type of array used in the investigation as well as the distribution of the true subsurface resistivity. The pseudo-section plot serves as a useful guide for detail quantitative interpretation. Poor apparent resistivity measurements can easily be identified from the pseudo-section plot. The pseudo-depth values are based on the sensitivity values or the Frechet derivatives for a homogenous half-space. All geological structures and spatial distribution of subsurface petrophysical properties are inherently three dimensional in nature. The three-dimensional effects of subsurface structures are more pronounced in environmental and engineering investigations where the geology is highly heterogeneous and subtle.

### Results and discussions

The resistivity and IP images of the earth subsurface obtained at the study site Rapur, Doon Valley Sub-Himalaya is shown as the inverse resistivity and IP models in Figs. 3 and 4. The inverted geo-electrical sections were obtained through the optimization technique of RES2DINV by minimizing the difference between the calculated and measured the apparent resistivity values. The range of root

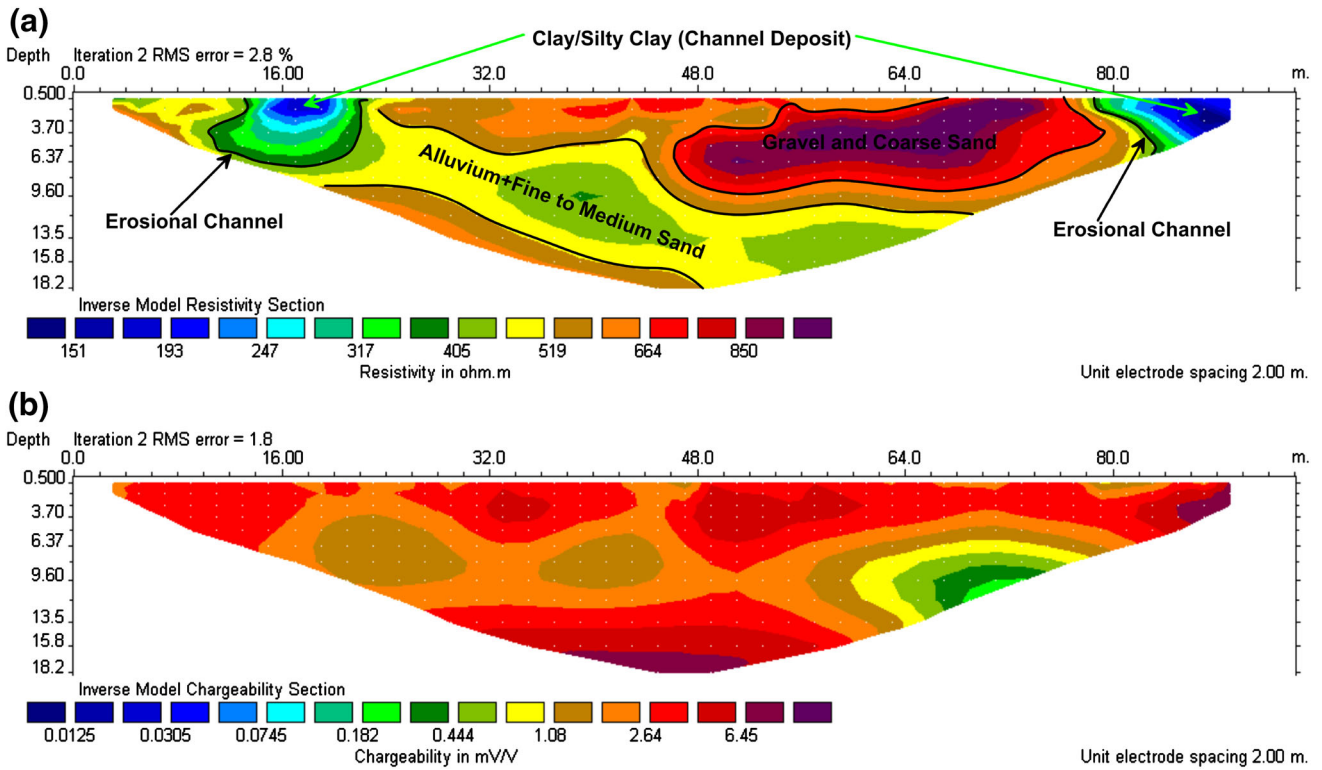


Fig. 3 Inverted 2D section for resistivity and IP-chargeability for Profile 1

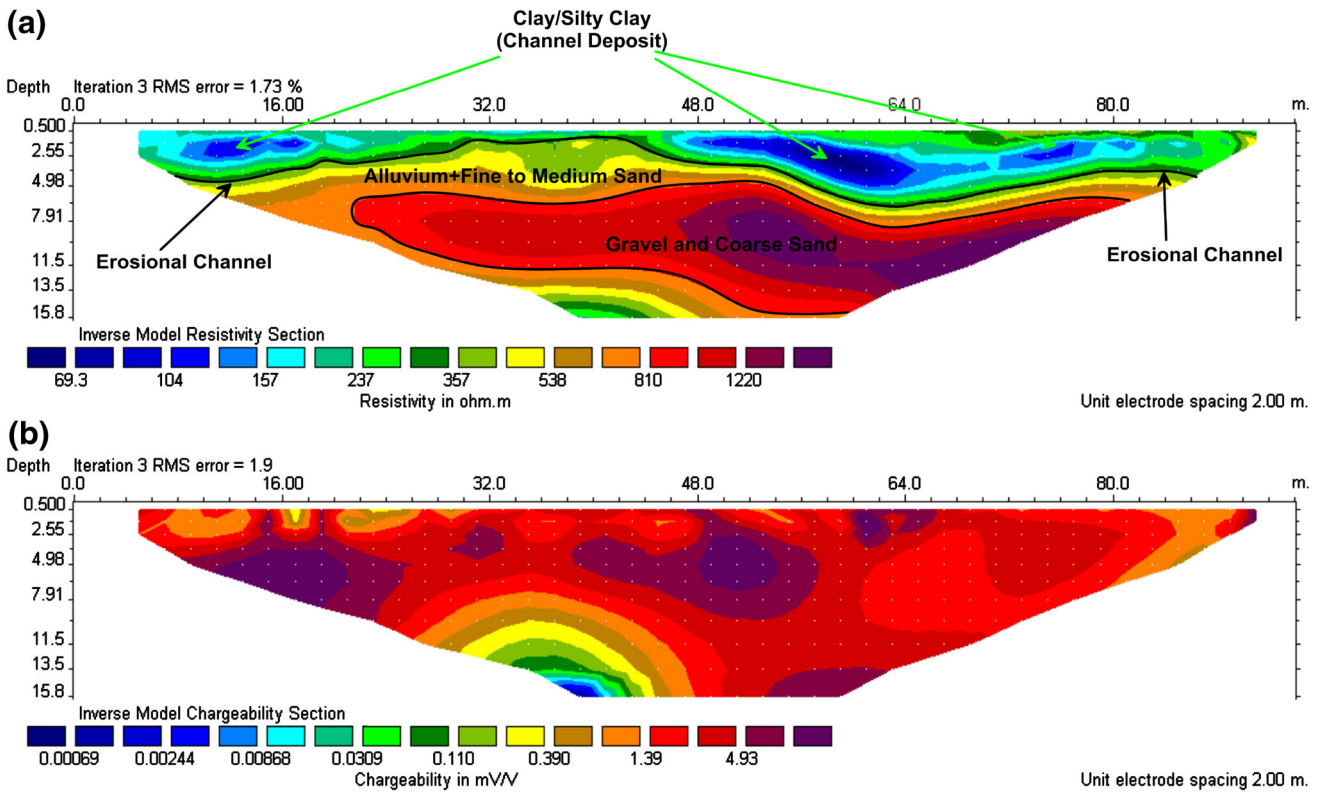


Fig. 4 Inverted 2D section for resistivity and IP-chargeability for Profile 2

mean square error (RMS) of obtained inverse models is from 1.8–1.9 % on iteration 2–3. The small range of RMS indicates a good correlation between the subsurface images depicted by the models. The models indicate the resistivity as well as IP variation upto the depth of approximately 20 m from the surface and covering an extent of 96 m.

### Profile 1

Inverted resistivity section (Fig. 3a) can be characterized lithologically on the basis of different resistivity values distribution. We observed wet silty-clay material upto the depth of approximately 7 m on either side of the profile under the electrodes from 12 to 24 and 74 to 88 m respectively and the resistivity range of this material is 151 to 250  $\Omega\text{m}$ . Likewise, these two zones also show high chargeability (Fig. 3b). This layer was probably deposited in an earlier stream channels. Moreover, there is a clear demarcation of the Erosional channels in these two zones as marked in the figure. These were formed earlier and due to sediment deposition in those stream channels, it is now buried under the sediments or as palaeochannels. The near surface materials under the electrode distance from 24 to 48 m up to a depth of about 6 m, have resistivity range of 500–650  $\Omega\text{m}$  is observed alluvium and medium sand deposits while the distance ahead from 48 to 72 m up to the depth of 10 m shows moderately high resistivity range from 650 to 900  $\Omega\text{m}$ , which occupied with a thick deposit of gravel and coarse sand. This deposit is a probable zone of shallow groundwater pockets. Under this material it has been observed a  $\sim 6$  m thick fine sand layer with resistivity range  $\sim 450$ –500  $\Omega\text{m}$  which is inclined at  $\sim 30^\circ$  from horizontal. This layer starts from surface first electrode 2–68 m and extent up to the depth of 18 m; it is also found some pockets of clay-sand materials having resistivity range of 400–450  $\Omega\text{m}$ . This zone also acts as a potential groundwater source. The interpretations are validated with variation of chargeability at corresponding distance and depth in IP section shown just below of resistivity section.

### Profile 2

Interpreted resistivity section (Fig. 4a) shows mostly clay to silty-clay deposit intermixed with sand at the near surface with prominent clay layers at 10–18 and 48–82 m respectively and the resistivity range of this material is 50–350  $\Omega\text{m}$ . This profile also shows a long erosional channel at a variable depth of 1–8 m. This clearly indicates the presence of a buried stream channel or palaeochannels. Below this layer a very thick gravel and coarse sand deposit can be seen almost the whole of the profiles shows very high resistivity range from 800–1250  $\Omega\text{m}$ . This zone will act as an excellent potential

for groundwater reservoir in this area. Moreover, this zone also shows high chargeability (Fig. 4b) because of presence of groundwater in the aquifers. This layer is surrounded by Alluvium with fine to medium sand deposit with its resistivity value ranges from 500–800  $\Omega\text{m}$  which may also act as a good groundwater reservoir. However, it is clearly evident that below a palaeochannels, it is expected to get a good groundwater aquifer within the subsurface. This is also evident from the first profile as shown above. Hence, it is highly recommended to trace the palaeochannels in this region to get a good groundwater aquifer in this region.

## Conclusions

A 2D geo-electric profiling was carried out near Morvian Institute at CSI, Rajpur road in Doon Valley Sub-Himalaya, Dehradun, Uttarakhand. Two resistivity-IP profiles were obtained to delineate the possible groundwater body as well shallow sub-surface lithological variation in this region. The near surface is mostly covered with clay to wet silty clay deposits. Below this layer, a prominent clay layer is seen at a variable depth. It is also observed that the possibility of two prominent palaeochannels in the study area. These two channels act an erosional channel which was earlier happened to be a small river. Below this, there is thick gravel and coarse sand deposits in the near surface which is situated at a depth of 0.5–5 m with a thickness of 10 m. These zone acts as an excellent potential for very shallow groundwater pockets. Moreover, within the surroundings of these gravel deposits, fine to medium sand is also present in most of the areas which may also acts as potential groundwater reserves. However, this groundwater pockets may not be sufficient to meet the needs of water in the summer season. Nevertheless, it is well recommended to look for deeper aquifer within the area to get a good amount of groundwater in the study area. It is also advisable to map the entire area for possible fracture/lineaments which could be a possible source of holding good amount of groundwater.

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