



Groundwater resources exploration in a Hillock Valley at Lada refugee camp, Teknaf using electrical resistivity soundings

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Received: 8 June 2018 / Accepted: 7 January 2020 / Published online: 16 January 2020
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Abstract

Teknaf Peninsula, located in a complex tectonic setting, is nearly unsuitable for inhabitants in terms of drinking water availability. Last couple of years, millions of Rohingya refugees migrated from Myanmar to Bangladesh and residing mostly in Hilly regions. Lada refugee camp is such a camp where thousands of people are living. Insufficient drinking water supply is posing a great threat on their health and lives. This camp is built in a hillock valley which is filled with Holocene sediments. Therefore, considering the miserable condition of about 20,000 refugees residing in this camp, groundwater resources are explored for this region deploying the electrical resistivity soundings (ES) survey. Using Schlumberger configuration, this survey is conducted at sixteen locations with different spreading ($AB/2 = 100$ m to 250 m). The result shows that the subsurface sequence of the area is broadly divided into two units, alluvium and sedimentary bedrock, respectively. Maximum thickness of alluvium is found about 81 m at center of the area. Alluvium is composed of mostly clay and silt. Few sandy lenses with variable thickness (2–41 m) are found at southwestern and eastern corners. Thickest lens of sand (41 m) is found at 21 m depth which might be the target for big diameter dug well, while the upper thick clayey layer would prevent vertical contamination. The compacted bedrock might have fractures but not identified. This study thus not found any potential groundwater resources at Lada camp and recommends detail study using electrical resistivity tomography at hilly region in Bangladesh.

Keywords Groundwater resources · Refugees · ES · Alluvium · Bedrock · Aquifer

Introduction

In Bangladesh, the source of water supply is not a problem, as it is mothered by hundreds of rivers. Unfortunately, finding a good quality water source with sufficient quantity is a big challenge in Bangladesh because most of the surface water reservoirs are being limited due to high level of various organic and inorganic pollutants. Contaminants are emerging into water body from both natural and anthropogenic sources and posing a great threat to socio-economy of Bangladesh. Moreover, despite groundwater, the supplies of drinking water

from all the sources wherever possible have been proven inadequate in meeting the growing needs of millions of people in Bangladesh. Therefore, groundwater from either shallow or deep aquifers is being used as a major source of drinking water all over the Bangladesh. Proper assessment of groundwater resources is an effective way for developing the policy in order to reduce the drinking water crisis and thereby to fulfill the growing demand of drinking water.

Groundwater resources at any region are controlled by many factors, mostly the geological and tectonic conditions of the region. It is universal truth that folded mountain belt has always complex geology. Teknaf, located in the southeastern folded belt of Bangladesh, has very complex characteristics both in geologic and tectonic views. Groundwater development in this area is not simple. Even it is very complex, which is considered as the major reason for drinking water crisis in this territory. Because of the unique geographic location and complex nature, Teknaf Peninsula is one of the regions in Bangladesh which has no significant groundwater resources; even some parts of Teknaf are entirely free from groundwater reservoirs. The problem in drinking water supply is more

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severe particularly for refugee's camps because most of the camps are built in hillock's valley. Moreover, this problem has intensified with the inrush of millions of refugees from Myanmar to this region. Now, many refugee camps are built in Teknaf without considering the drinking water supply, which is an extreme overburden for this Peninsula.

Lada is one of the refugee camps at Teknaf. The camp is built on an alluvium-filled valley bounded by hillocks. It is observed that no drinking water sources exist at any particular location in and around the camp. Few dug wells and some springs provide small amount of water during rainy season, although heavy precipitation occurs every year of this region. These limited sources of water supply disappear at dry periods, particularly in winter season. As a result, the demand of drinking water supply increases significantly in winter season in the Lada camp. It is also observed that the average annual rainfall of this area is about 3900 mm (Sultana et al. 2012) which is good enough in quantity to fulfill the demand of drinking water, but this water cannot be used due to lack of good quality surface or subsurface reservoirs. Many government and nongovernment organizations have been supplying the drinking water to the people of the camp free of cost in order to solve the water crisis problem. In addition, a number of attempts have been taken to explore the suitable water sources either surface or subsurface in and around the Lada refugee camp to resolve the drinking water problem. It is unfortunate that these attempts could not resolve the hardship situation at all by providing any sustainable source of drinking water. In this circumstance, groundwater resources may be the solution for sustainable supply of drinking water to the Lada camp. It is therefore very important to assess the groundwater resources for this area. The understanding of the hydrogeological status of this camp area based on existing information is not easy because there is no bore log data except few dug well logs. Moreover, no extensive hydrogeological study has so far been carried out in the area to demarcate the aquifer-aquitard systems.

However, using the state-of-the-art techniques and tools, it is very convenient to conduct an extensive survey in appraising the hydrogeological conditions (i.e., the existence of good aquifer which can produce a substantial amount of water as much as required for the long-run) in the target area. For characterizing the subsurface geology and hydrogeology, electrical resistivity survey technique is a widely used powerful method. In this method, changing of electrical resistivity values usually correlate with variations in lithology, water saturation, fluid conductivity, porosity, and permeability, which is used in mapping the stratigraphic units, geological structure, and groundwater storage. Electrical resistivity tomography (ERT) and electrical resistivity sounding (ERS) techniques are commonly used for the exploration of groundwater resources. Electrical resistivity tomography (ERT) technique is the latest method in geophysics and also proved to be versatile, fast, and cost-effective in exploring groundwater by

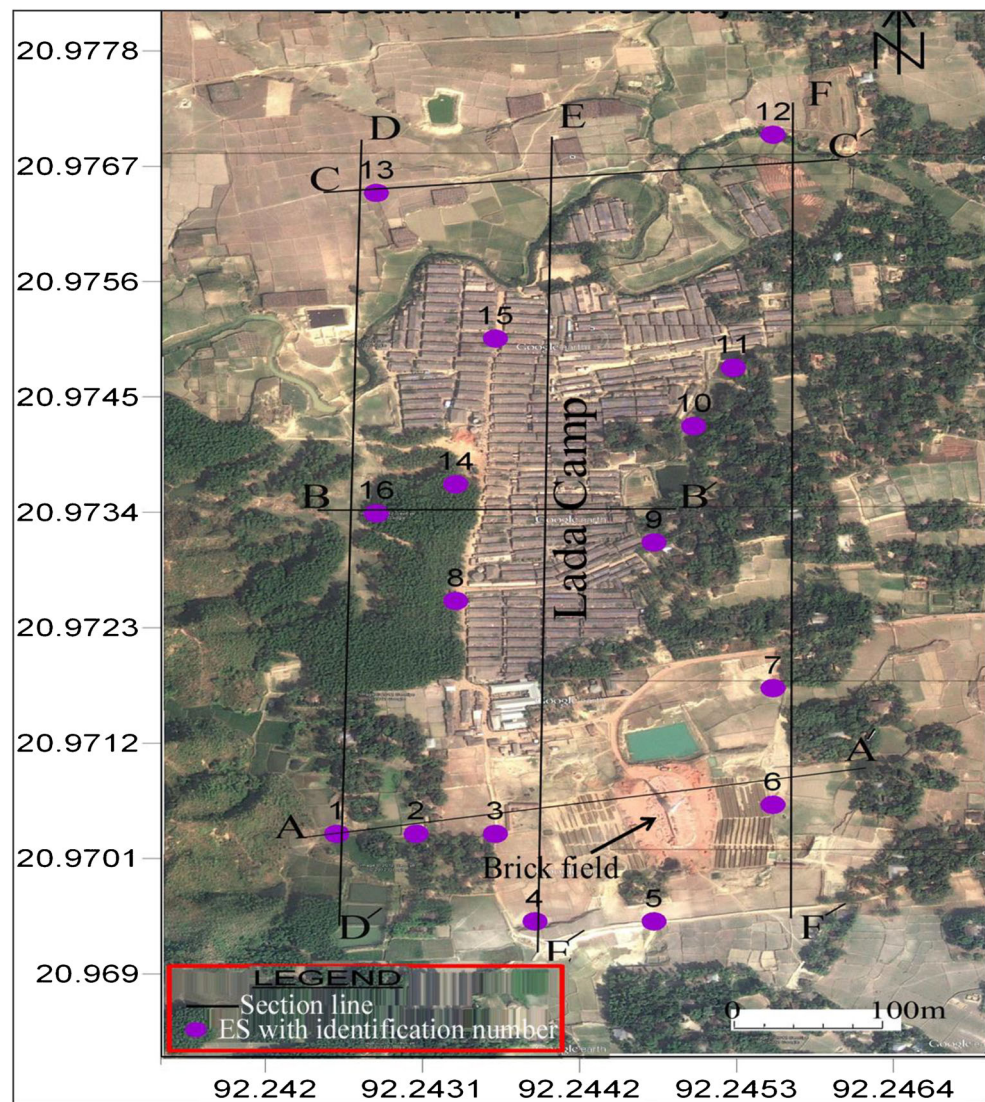
delineating aquifers and mapping shallow subsurface geophysical anomalies like structures and fractures of rock (Kumar 2012). But due to instrumental as well as accessories constraint, we could not deploy this technique for this study. Electrical soundings (ES) on the other hand are comparatively old but found an effective and reliable tool for delineating aquifer geometry as well as assessing groundwater storage (Bugg and Lloyd 1976; Serres 1969; Kumar et al. 2007; Urish and Frohlich 1990; Woobaidullah et al. 1994, 2014). Especially, in sedimentary environment, ES is proved to be reliable in exploring hydrogeology (Emenike 2001). Besides, some studies (e.g., Rahman et al. 2013) found that this classical method is capable to obtain about 90% reality for subsurface geology in the Bengal basin. We therefore, carried out an extensive electrical sounding (ES) survey for this study region. Other available data (e.g., dug well logs, reports) are also utilized along with ES data. This study produces a set of lithological and stratigraphic cross-sections for a better understanding about the lateral and vertical distribution of hydrogeological constraints.

Geological and hydrogeological setting of study area

The camp area, with an extent of about 32,000 sq m and the home of about 20,000 refugees, is located near Lada Bazar, at a distance of 15 km to the north from Teknaf Sadar. The area lies in between the hills of the Dakshin Nila Anticline in the west and tidal plains/salt marshes of the Naf estuary in the east (Fig. 1). Located in a complex tectonic setting, the geology of the area is very complex. It is the part of Chittagong Hill Tracts (CHT), whereas the north-south trending Dakhsin Nihila anticline forms the major structural feature of the area. The geological characteristics and the origin of sedimentary sequences of this area have been studied by many researchers (e.g., Alam et al. 2003; Curray 1991; Umitsu 1993). The valley is filled with unconsolidated Holocene alluvium, composed of mixture of sand, silt, and clay.

The consolidated bedrock exposed in the area is stratified to bedded Bokabil Shale characterized with lenses of fine to very fine sand. In relation with geological setting, hydrogeological condition of the area is also very complex. In a broader view, the whole country has been divided into 15 zones of varying potentiality for development of groundwater resources based on lithology, thickness, and structure of rock formations along with recharge potentiality and aquifer characteristics (UNDP 1982). The Teknaf area belongs to a zone where complex groundwater condition exists and is unsuitable for tube wells. In addition, a recent simplified classification proposed six hydrogeological provinces for the entire country, while Teknaf peninsula falls into a zone which characterized by a complex geology of folded tertiary sediments with very

Fig. 1 Location map of the study area with ES locations and cross-section lines



low potential for large-scale groundwater development (Ahmed 2005).

The hydrostratigraphy of the study area is composed of complex mixture of alluvial sediments. The alluvium is composed of mostly clay and silt with some lenses of sands. Thus the presence of low permeable clay sediments makes the area unsuitable for sustainable groundwater development.

Geographically, the study area is located at the hilly region in Bangladesh where heavy rainfall usually occurs during rainy season. The average annual rainfall is about 3900 mm (Sultana et al. 2012). But most of the precipitated water flows to the Bay of Bengal as runoff due to absence of significant water-bearing formations, i.e., aquifers in the study area. There are some localized occurrences of low-yielding water-bearing formations at a depth around 10 m at certain locations at the study area which can house the low-yielding dug wells (large-diameter wells). These wells can supply water to a small number of families. Besides, some localized aquifers

at a bit deeper level is present in and around the area where shallow hand tube wells with screening depth of about 20 m can be installed (Sultana et al. 2012). These aquifers are mostly lens type and may not be suitable for installation of wells fitted with mechanical pumps.

Materials and methods

The resistivity meter, power source, cables, electrodes, and some accessories are generally used to carry out the electrical resistivity soundings (ES) survey. Covering the whole study area, sixteen (16) soundings points are selected for this study considering the suitability of the array spreading (Fig. 1). In this method, using the Schlumberger array, different spreading length from $AB/2 = 100$ m to $AB/2 = 250$ m is used. Herein, artificially generated electric currents from the power source (12 V Battery) are introduced into the ground through a pair of

current electrodes remain outside in the array (Fig. 2a). Then, the resulting potential differences are measured at the surface through another inner pair of potential electrodes as:

$$\Delta V = V_M - V_N = \rho I / 2\pi \{ (1/AM - 1/BM) - (1/AN - 1/BN) \}, \quad (1)$$

in which V_M is the sum of potential for electrodes A and B at potential electrode M, V_N is the sum of potential for electrodes A and B at potential electrode N, I is the induced current, and ρ is resistivity of the ground and thus can be estimated as:

$$\rho = 2\pi \Delta V / I \{ (1/AM - 1/BM) - (1/AN - 1/BN) \}. \quad (2)$$

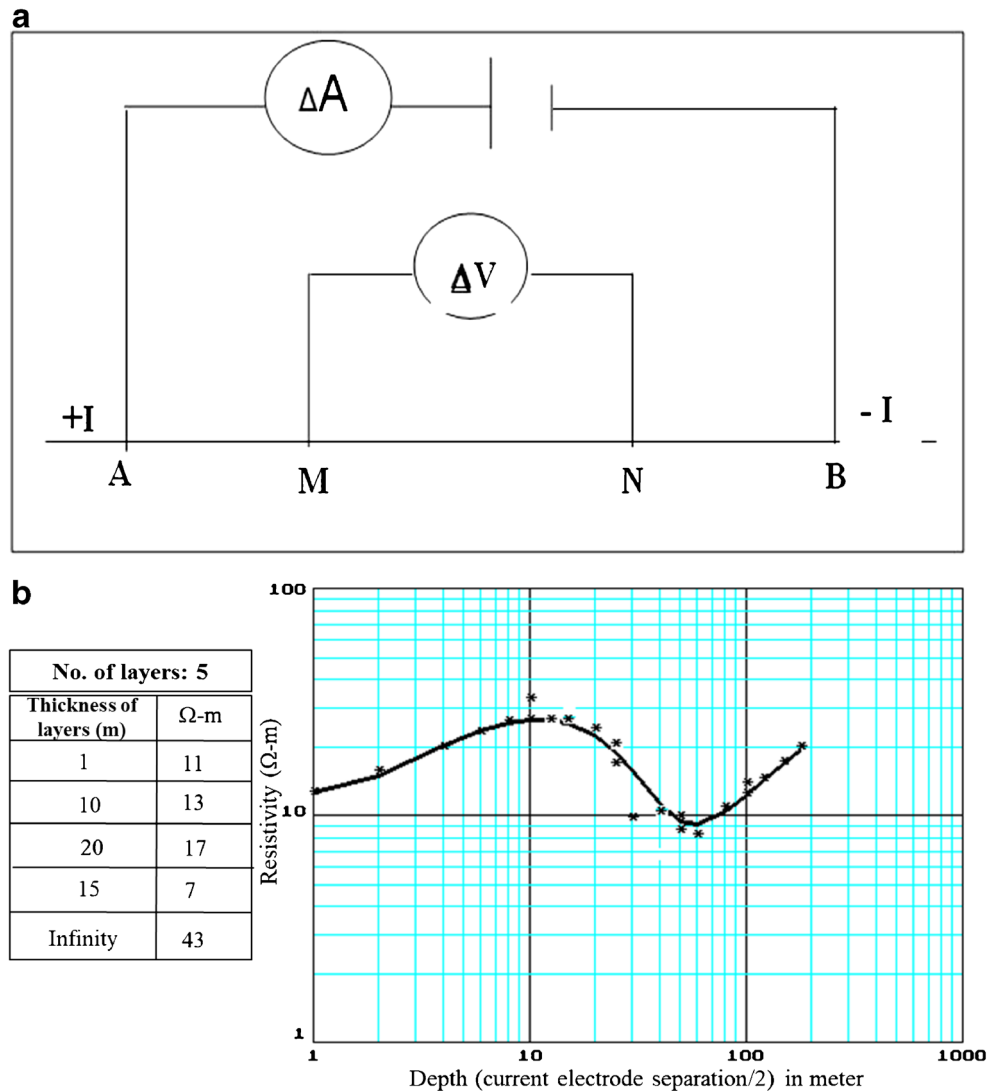
Worthwhile mentioning that for the homogeneous uniform ground, the resistivity calculating in Eq. 2 should be constant and independent of both electrode spacing and surface location. On the contrary, when the subsurface inhomogeneities exist, then the estimated resistivity value will vary with the relative positions of the electrodes. However, any computed value in case of inhomogeneous ground is termed as the

apparent resistivity (ρ_a) and will be a function of the inhomogeneity. Therefore, Eq. 2 is the basic functional form in calculating the apparent resistivity value for any electrode configuration.

In this analysis, the array is configured by four electrodes positioning symmetrically along a straight line and driven them into the ground to make a good contact with the earth (Fig. 2a). The current electrode spacing is progressively increased in order to increase the vertical depths of measurement, while the potential electrode spacing is usually left unchanged. When the ratio of the distance between the current electrodes to the potential electrodes becomes too large, then the potential electrodes spacing is increased by taking into account the accuracy of the potential difference estimates. It is noted that if the ratio of potential electrodes spacing to current electrodes spacing is too small, then the accuracy of the measurement of potential difference might be seriously affected.

To collect the field data, an updated resistivity meter: McOHM (Model-2115), OYO Corporation, Tokyo, Japan,

Fig. 2 (a) Generalized form of the electrode configuration used in resistivity measurements; and (b) example of a well-fitted curve for ES-7



Digital Electrical Prospecting System, is used. In addition, the instrument has the built-in stacking processing function to improve signal/noise ratio as desired. It is a compact device housing the transmitter (current supply unit) and the receiver (potential measuring unit) in a case. During soundings, it performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time, and then digitally displays it. In a similar way, we collect the data from all 16 soundings points in the field.

Two steps for processing the ES data are employed. Initially, the field ES data is plotted manually in a transparent log-log paper to prepare a field curve. The field curve is then fitted with some sets of master curves termed as “theoretical curves” following the partial curve matching technique assuming multilayers of the ground. Based on the apparent resistivity value, different subsurface layers and corresponding lithology are identified. In order to obtain precise result, the second step is followed. In the second step, all the manually delineated layers and corresponding resistivity values are used as input model parameters for software-based interpretation of the ES data. The name of the software used in this analysis is “RESISTIV.” In this program, the trial and error process is continued until the best fitting curve of the data is obtained. When the field curves for the given parameters are well-matched with the theoretical curve (Fig. 2b), then the parameters are considered as final results. Available dug well logs are collected from local stakeholders in order to validate and correct the ES results. Lateral and vertical subsurface lithology distribution maps for this region are prepared by using the Rockware 2004, 2015, Strater 5, and Surfer 8.3 software. In addition, ArcGIS10.1 is used for mapping the location of the study area and the sounding points.

Results and discussion

Resistivity property of the ground is very useful and effective parameter in better understanding the hydrogeological conditions at any area. In Bangladesh, it is mostly used in delineating the aquifer and aquitard distribution and distinguishing interface of salt water/fresh water (Rahman et al. 2013; Woobaidullah et al. 1994, 1998). This physical parameter is highly variable and controlled by many parameters, such as porosity, nature of pore fluid, composition of rock materials, compaction and age of the rock, and nature of the overburden sediments. The exposed surface geology in and around the area, the dug wells data as well as the empirical knowledge, is used as a rationale to interpret the ES data. It is observed that the resulting resistivity value is laterally and vertically non-uniform in distribution and covers a wide range. The minimum and maximum resistivity value is obtained as low as 2 Ω.m and as high as 300 Ω.m, respectively, except top soil.

Table 1 Thickness range and corresponding resistivity of the geoelectric layers

Geoelectric layers	Thickness range (m)	Corresponding resistivity value (Ω.m)
Top soil	0.5–1.5	6.0–350.0
Alluvium (sand dominated)	1.0 41.0	14.0–22.0
Alluvium (clay and silt dominated)	1.0 80.0	2.0–12.0
Bedrock	Base not seen	20.0–300.0

The variation of this value suggests complex nature of the subsurface both in lateral and vertical directions.

On the basis of resistivity value, after the top soil, the subsurface sequence up to explored depth is broadly divided into shallow alluvium sediments and deeper sedimentary bedrock. It is found that the thickness of the top soil unit varies from 0.5 m to 1.5 m. The minimum and maximum resistivity value for this layer is of 6 Ω.m and 350 Ω.m, respectively. It is assumed that the dry and wet nature of the surface materials corresponds to this big variation of resistivity value. Usually, high resistivity value represents dry and compacted silty soil, while clayey moistured soil shows lower resistivity value. The maximum resistivity value for alluvium sediment deposits is found as high as 22.0 Ω.m excluding ES-10 and ES-11. In case of bedrock, the higher resistivity value (> 20 Ω.m) is obtained (Table 1). Due to composite mixture of poorly sorted sand, silt, and clay, this result shows a wide range of resistivity values (2 Ω.m–22 Ω.m) for alluvium deposits. Relatively low

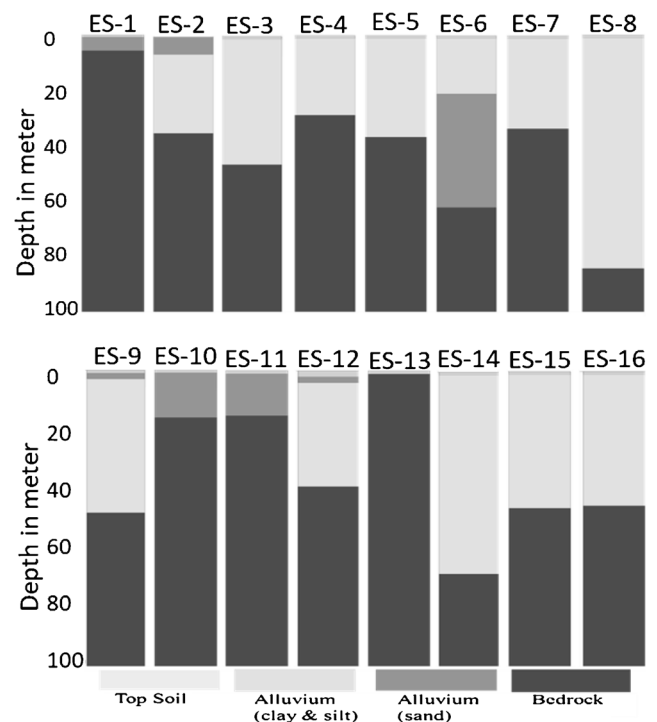


Fig. 3 Graphical presentation of sounding logs for ES-1 to ES-16

resistivity value ($\leq 12.0 \Omega.m$) is characterized by clay and silt, while the sand and silty sand show relatively higher resistivity value and reaches up to $22 \Omega.m$ except locations ES-10 and ES-11. In this study, it is observed from the individual ES result (Fig. 3) that there is no layer of unconsolidated valley filled alluvium deposits thicker than 81 m at any location within the study area.

The maximum thickness of alluvium deposit is obtained in the central part of the study area at ES-8 location. Moreover, the results depict few lenses of sandy layers with variable thickness from 1 m to 5 m at the locations of ES-1, ES-3, ES-9, and ES-12 while 7 m to 41 m at locations of ES-2, ES-6, ES-10, and ES-11 (Fig. 3). By the northern border of the study region, it is found that the alluvium deposit is very

thin and even totally absent at ES-13. Therefore, sedimentary bedrock is covered by a thin layer of weathered top soil in the northern side of the camp. Regardless the result of ES-13, it is observed that the resistivity value of bedrock does not vary spatially and vertically as much as alluvium deposits. The bedrock is composed of mostly compacted Bokabil Shale (confirmed from nearby outcrops).

Six 2-dimensional geoelectric cross-sections along east-west and north-south directions (Figs. 4 and 5) and one fence diagram (Fig. 6) are prepared to visualize the lateral and vertical distribution of various lithological units. Depth to 100 m is selected for each of the above models for better resolution as maximum alluvium thickness is 81 m and bedrock continued till the end of explored depth. Geoelectric cross-section along

Fig. 4 Geoelectric cross-section showing the subsurface lithology distribution (a) along line AA', (b) along line BB', (c) and along line CC'.

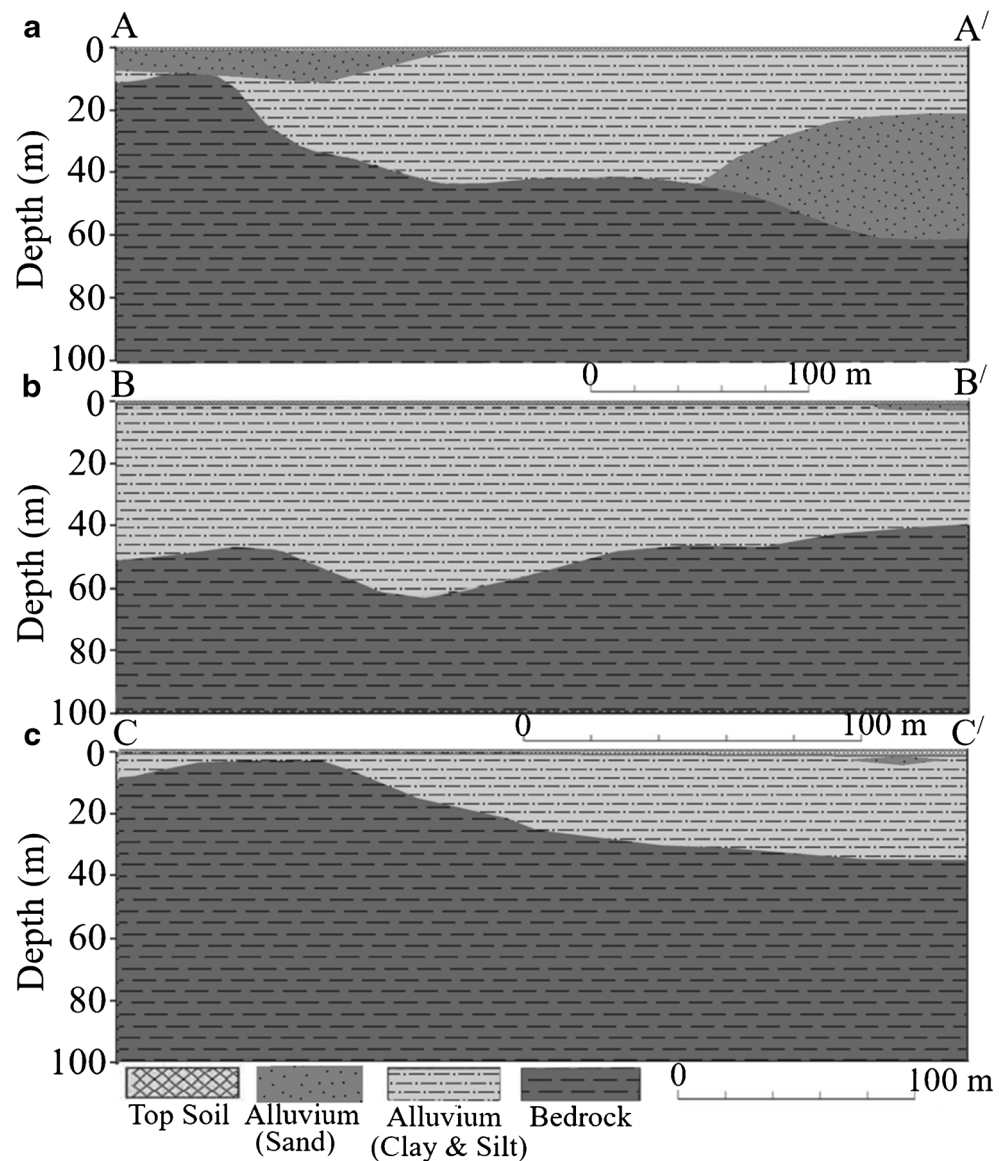
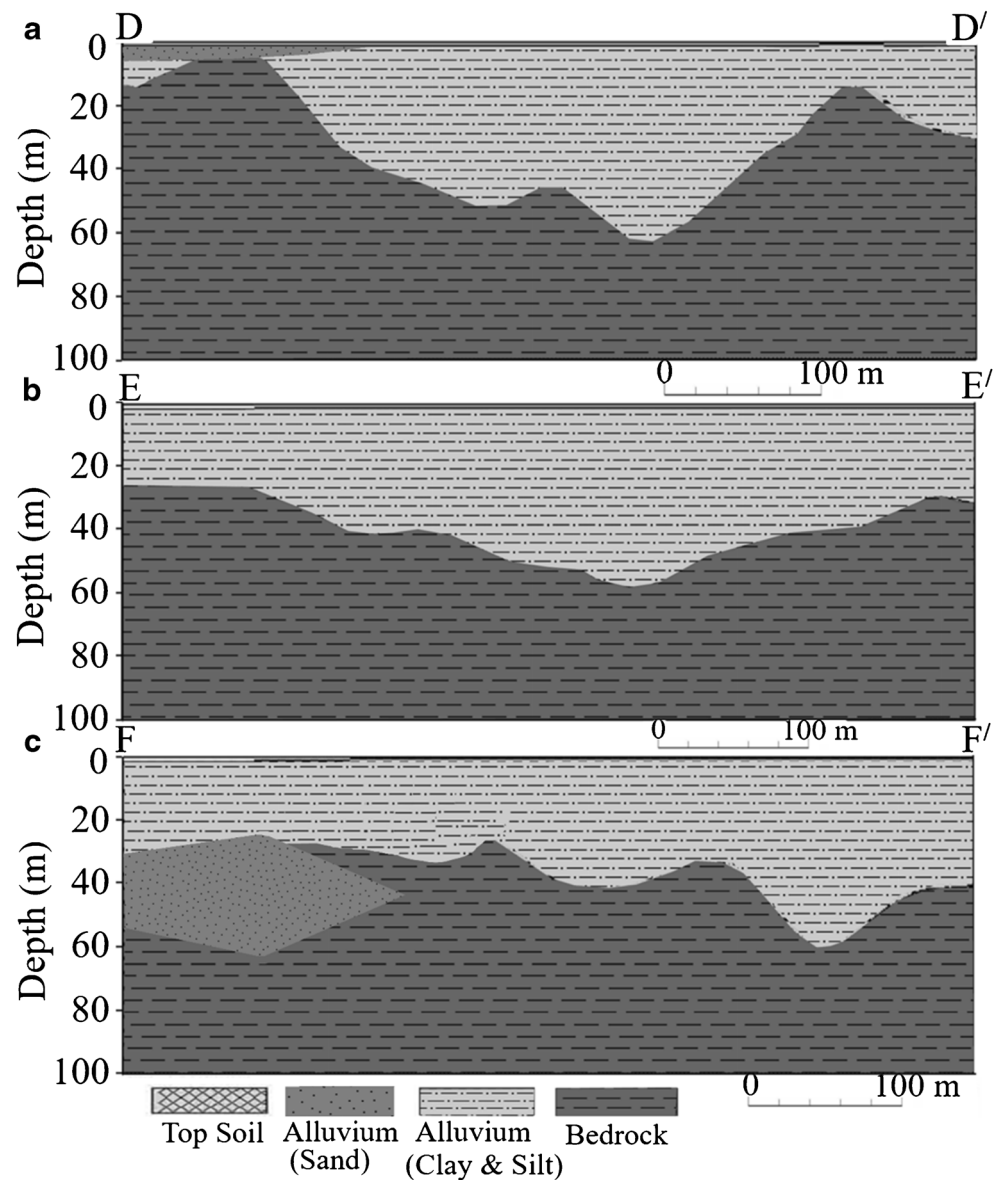


Fig. 5 Geoelectric cross-section showing the subsurface lithology distribution (a) along line DD', (b) along line EE', (c) and along line FF'



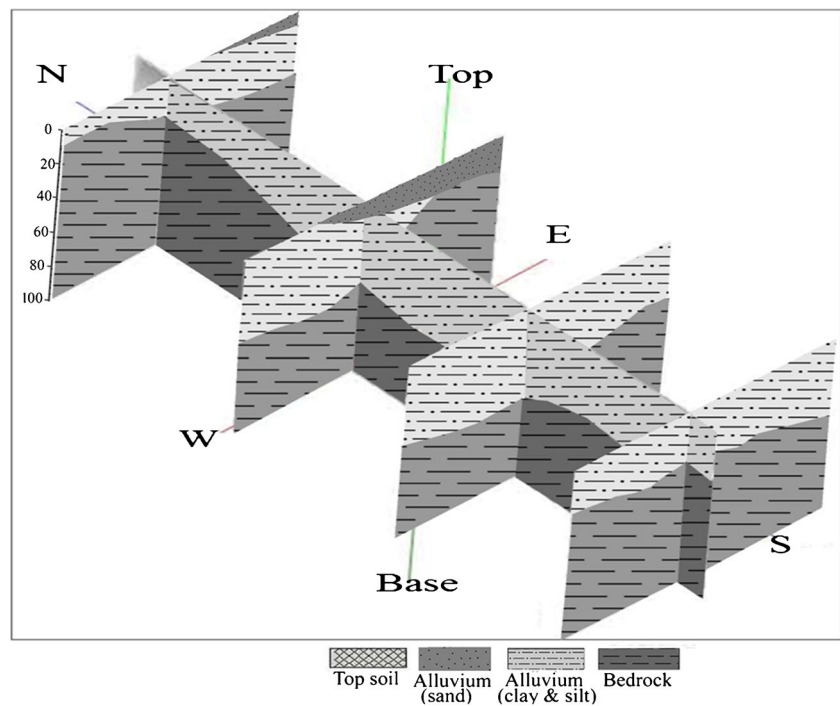
line AA' (Fig. 4a) shows that alluvium deposit thickness is increasing toward east and reaches a maximum of about 62 m. This alluvium deposit thins toward west and even ends up with outcrop rock. The cross-section of BB' (Fig. 4b) shows nearly uniform thickness of alluvium deposit from east to west. Figure 4c depicts the thinning out of alluvium toward west along CC' cross-sectional line.

It is found from the geoelectric cross-sections along north-south direction (Fig. 5a–c) that the northern part of the area is covered by very thin alluvium sediments, the middle part is developed with comparatively thicker alluvium cover (~65 m), and the southern part is filled up with moderately thick alluvium deposits. The overall distribution of these geologic units is clearly inferred from the fence diagram (Fig. 6). It represents that central part of the study area is covered by greater thickness of alluvium which reduces gradually toward

both in north and south directions (Fig. 6). Moreover, this diagram shows that few lenses of sandy alluvium are present in the east central part of the camp area.

However, the result of this analysis shows that there is no substantial water bearing formation up to the explored depth of 250 m within the study refugee camp. The valley filled alluvium deposits are a mixture of dominant clay and silt which are not suitable for groundwater development except some isolated sandy lenses (ES-6, ES-10 and ES-11). The sandy lenses may serve as groundwater sources to develop large-diameter dug well for small-scale water abstraction and may not support to tube wells for long-time drinking water supply to the community resides in the camp. The thick clayey deposits above the sandy lenses might be a good protector to save the water in the dug wells from the contamination.

Fig. 6 Fence diagram showing the subsurface lithology distribution in 2-dimensional view



The bedrock, composed of dominantly compacted shale with occasional calcareous bands of sands and interbeddings of very fine-grained silt and sandstone, is not suitable to sink tube wells with the local drilling techniques. Sometimes, this bedrock can be a good reservoir if it is well-fractured. But due to technical limitation, we could not analyze the bedrock properties. 2-dimensional and 3-dimensional subsurface imaging using ERT can be carried out for further detail investigation of hydrogeological properties of the subsurface materials in the study area.

Conclusions

Drinking water supply scarcity is a big threat for the people living in the refugee camps in Bangladesh. This problem is very acute especially for the camps built inside the valley bounded by the hillocks. Lada is such a hillock-bounded refugee camp where tens of thousands of people are living. It is one of the biggest and oldest refugee camps in Bangladesh. Unfortunately, yet there is no sufficient drinking water supply sources for these unprivileged community in and around the camp. Therefore to resolve the drinking water scarcity of this Lada camp, it is very important to assess the potential groundwater sources in and around the camp area. Geophysical electrical resistivity survey is an effective method to explore the underground drinking water sources. To evaluate the groundwater resources for Lada community, we conduct the electrical resistivity soundings (ES) survey. Although electrical resistivity tomography (ERT) is a more effective tool to explore

groundwater resources for the complex geological settings, we could not use it because of instrument unavailability. However, in ES survey, the Schlumberger configuration is used, and closely spaced 16 locations were selected in such a way that the maximum subsurface information can be obtained. The different spreading length ($AB/2 = 100$ m to 250 m) is used at various locations. The obtained field data is analyzed manually and digitally (computer-based program). The sounding models are also verified with the available dug well logs data. For better understanding of the subsurface in the camp area, we developed some 2-dimensional and 3-dimensional cross-sectional models along east-west, north-south directions based on the final soundings models. These sections show the lateral and vertical distribution of different lithologic layers at various depths. The result shows that the lithology beneath the Lada camp up to 250 m is broadly divided into two units, unconsolidated mixed alluvium and compacted high resistive bedrock, respectively.

The thickness of alluvium deposit is variable, and maximum is about 81 m at the central part of the camp. This deposit is admixture of sand, silt, and clay. It is usual that the alluvium deposit works as a good aquifer, but in the study area, most of deposits are dominated by fine-grain silt and clay which prohibits the deposits to be a good aquifer. In contrast, some lenses of sand deposits are found at few locations in the camp area. For example, in the south-east corner at location ES-6, about 41 m thick sandy alluvium is present, whereas at south-west corner of the camp, thin sandy alluvium is observed. Only these sandy layers can be probable sources of drinking water supply for the Lada refugee camp. Therefore large-

diameter dug wells can be constructed at these specific locations, and the thick clayey deposits might work as safeguard to prevent the contamination of dug well water. Bedrock, composed of mostly high compacted shale with occasional calcareous bands and inter-beddings of very fine-grained siltstone and sandstone, is characterized with a high resistivity value ($> 20 \Omega.m$). This bedrock might have fractures which would serve as aquifer but needs detail study. The result of this study thus concludes that within the alluvium deposits there is no suitable aquifer which may supply substantial water to minimize the drinking water crisis of refugee camp. It is therefore recommended that further detail study such as electrical resistivity tomography (ERT) and deep boring can be carried out, or alternative surface water sources can be explored to mitigate the drinking water supply problem.

Funding information This research is financially supported by the NGO Forum for Public Health, Bangladesh to M.M Rahman and A.S.M Woobaidullah. We thank to Mohammed Hossain for his invaluable supports in arranging this grant to carry out the research work. We used the survey instruments from the Geology Department, University of Dhaka, Bangladesh. We are grateful to the Chairman of PME Department, Jessore University of Science and Technology, Bangladesh, for allowing us to carry out this research. We thank to S K Gosh and Rajib, Dhaka University for their valuable supports during survey. We are grateful to all local stakeholders for providing us supports.

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