# Subsurface structural characterization of the Chooman Dam site using geoelectric method

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## Abstract

A recent evaluation of Chooman Dam highlighted the potential for dam failure due to either seepage or an earthquake on nearby faults. Unfortunately, this dam suffers from infiltration or leakage problems related mainly to different geological and tectonic factors. In response to these concerns, electrical resistivity surveys employing vertical electric sounding (VES) method were carried out at the dam site, located in Kurdistan Province in the west of Iran in order to delineate potential pathways of leakage occurring thorough the subsurface structure close to the dam body, bed rock depth and lateral discontinuities in the study area. The VES surveys were conducted using the Schlumberger electrode array in 400 points or stations along 28 profiles at a station interval of 20 to 50 m in up- and downstream sides of the dam embankment. For data acquisition, a terrameter SAS 4000 resistivity system, made by Swedish ABEM Company, was used. Maximum separation of current electrodes in the Schlumberger VES surveys was considered 430 m. These geoelectrical studies revealed a thick package of andesite basement in the eastern part and vitriform tuff basement in the western part of the study area. Considering the results and the detection of a strike-slip fault on the downstream side of the dam embankment, it is evident that fractures are the main causative factor responsible for the leakage in the Chooman Dam.

**Keywords:** electrical resistivity, vertical electric sounding (VES) method, Schlumberger array, Chooman Dam, Kurdistan Province, Iran

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## 1 Introduction

Dams are becoming a national concern because they deteriorate as they age and they can become public safety hazards if they are not rehabilitated or regulated. Water seepage, one of the most common problems of earthen dams, usually occurs either through the reservoir bedrock or through the embankment-abutment contact. This phenomenon is often related to geological and tectonic factors, for example, faults, fractures and cavities. Geophysical techniques can assist the construction industry in many ways before, during and after construction to solve construction problems or to facilitate the construction processes for dam site investigations (e.g. Aina et al., 1996; Batayneh et al., 2001) and dam status control (e.g. Van Tuyen et al., 2000; Buselli and Lu, 2001; Panthulu et al., 2001; Voronkov et al., 2004; Cho and Yeom, 2007). The electrical resistivity method is one of the geophysical investigation techniques, which uses the electrical properties of subsurface media to differentiate the subsurface into geoelectric layers. It can give insight to the lithological sections and fractures beneath the surface. For resistivity measurements, various electrode configurations or arrays can be used. However, if the earth is assumed to be horizontally stratified, isotropic and homogeneous media such that the change of resistivity is a function of depth, the Schlumberger configuration is most widely used (Egbai, 1998). Hence, the Schlumberger array has been chosen for this research. Resistivity measurements are attributed to different depths by varying the separation of current and potential electrodes, and can be interpreted in terms of a lithological model of the subsurface (Ezomo, 2011). The primary aim of this research is to investigate subsurface geological structures, determination of potential pathways of leakage, resistive bed rock depth, investigation of lateral discontinuities and detection of local anomalies in the site. To achieve this aim, first, the resistivity sounding or vertical electrical sounding (VES) surveys using the Schlumberger electrode array in 400 points along 28 profiles at a station interval of 20 to 50 m are carried out and qualitative interpretation of the plotted apparent resistivity pseudosections is made. Then, for each sounding point, the apparent resistivity values are plotted against the half current electrodes spacing using log-log graph sheets of the Schlumberger array, and quantitative interpretation of the apparent resistivity data is also made. As a result of this quantitative interpretation, geoelectrical layers are obtained in which the resistivity and depth of each layer are determined.

Chooman Dam is situated in the vicinity of Tajban village, east of Baneh City in Kurdistan Province, west of Iran. The study area enclosing the dam is geographically located in the UTM zone of 38S and UTM coordinates of easting between 561300 and 562200 m and northing between 3978600 and 3979200 m. The purpose of the construction of this dam is to save some parts of rain floods and to meet the area water needs for irrigation and agricultural development. The embankment of Chooman Dam has a clayey core surrounded from both sides by filters composed of sands and various mixtures, covered by coarse rock fill to stabilize the dam and protect its clayey core. The south-north oriented dam body is 340 m long and 110 m high at the floor of the river with maximum dam reservoir storage around 100 million cubic meters.

The main geological feature of the study area, as shown in Figure 1, is light green, schistosed and metamorphosed volcanic rocks with porphyritic-porphyroclastic to clastic textures (kmv), low level unconsolidated and recent clastic deposits (Qt2), black hornfels with hetragranular and porphyroblastic texture (h) and recent alluvium (Qal). The choice of the electrode array and electrode spacings depends upon the target, its size, depth and resistivity contrast with its surroundings. The subsurface of the study area is investigated by VES method that is conducted in 400 points (Figure 1) using the Schlumberger electrode array because of relatively small separation or distance of the potential electrodes (denoted by MN) compared to the distance of the current electrodes (denoted by AB) that reduces noise, great depth of penetration, ease of operation and relatively low cost.

## 2 Field procedures and data collection

As mentioned earlier, resistivity surveys using VES method were carried out in 400 points in the study area, as shown in Figure 1. The method investigates resistivity variations over depth in a way that at a given surface location as the electrode spacing is increased resistivity information from greater depths is obtained. Resistivity survey lines having lengths of 240 to 440 m were considered nearly parallel to each other at different locations to cover the whole area under study. The resistivity surveys were carried out along the survey lines based on the VES technique outlined by Telford et al. (1990). The station interval of 20 to 30 m was used to establish the sounding points. According to the maximum depth of penetration in the Schlumberger array which may be 1/4 to 1/3 of the maximum distance of current electrodes (AB), the maximum exploration depth was about 80 to 100 m for AB = 430 m. For satisfying the purposes in construction design, this depth was considered enough for site subsurface investigation. The resistivity equipment used for collecting data was Swedish ABEM SAS 4000 terrameter. The apparent resistivity surveys were taken as the current electrodes were spaced dependent on the Schlumberger array condition of AB≥5MN to ensure error reduction in the site data acquisition. The measured contact resistivity between the electrodes and the ground were smaller than 1 kΩ. The measurements were repeated until the standard deviation of the measurements was obtained less than 3%. The result of the site measurements was the computation of apparent resistivity.

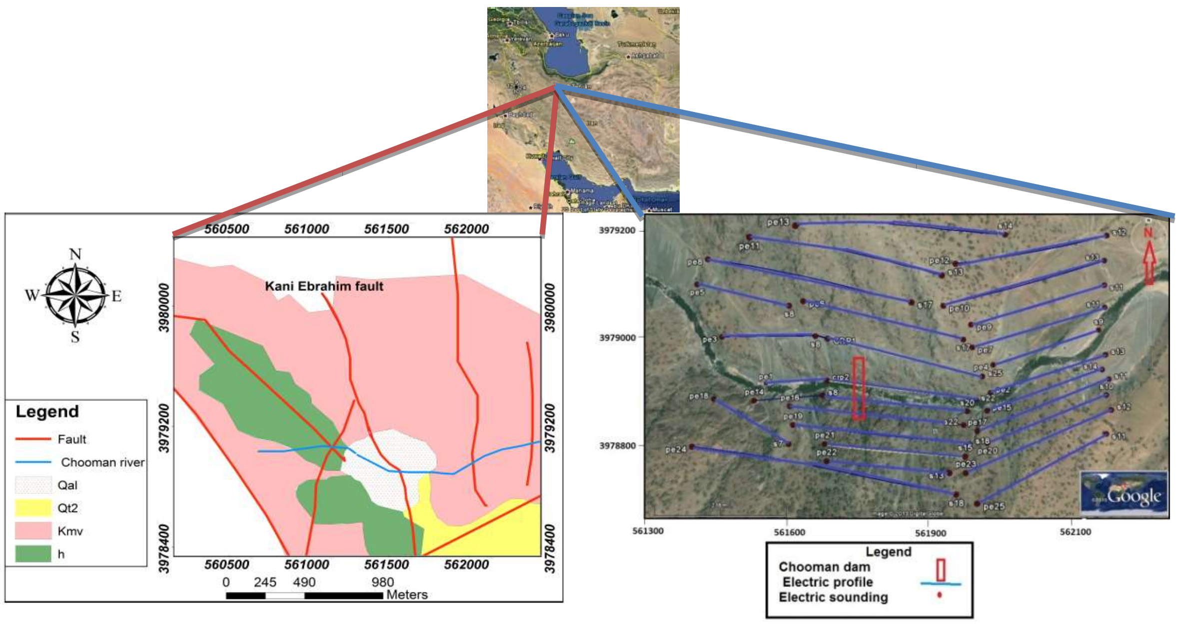


**Figure 1.** Location and geological maps of the study area. The positions of the resistivity survey lines have also been indicated in the location map.

## 3 Results and discussion

The interpretation of the collected resistivity data was carried out in two parts to show both qualitative and quantitative interpretation. First, the resistivity pseudosections composed of the data from the VES points along the survey lines were obtained to get an idea qualitatively about the number of subsurface layers, the subsurface resistivities and possible fractures in the investigated site. Then iso-apparent resistivity maps were constructed to reflect the lateral variations over a horizontal plane at the AB = 43, 92, 294 and 430 m. These maps reflect the lateral discontinuities of electrical resistivity at depths of about 10, 23, 73 and 107 m, respectively. In the quantitative interpretation method, the number of layers and their true resistivities and thicknesses were obtained as a result of preliminary interpretation of the VES data using standard or master curves and then, their final interpretation using the IX1D software. In this way, for each VES point, one-dimensional interpretation of the VES data is made. The results of the 1D interpretation of VES points on each survey line were combined to get the geoelectric section of the survey line. The parameters measured on the site were used to infer the nature of subsurface structure and lithology based on the local geological knowledge and correlation studies.

### *3.1 Qualitative interpretation*

**Iso-apparent resistivity map for AB = 43 m**

The iso-apparent resistivity map for AB = 43 m (Figure 2a) shows the lateral variation of apparent resistivity in a horizontal plane at a shallow depth with resistivity distribution ranging from 20 to 2315 Ωm. In this map, the significant difference between weathered andesite rock with a resistivity of more than 500 Ωm in the western part and vitric tuff in the eastern part of the area, is evident. Because of a high percentage of clay and silt in the surface soil, the apparent resistivity in the eastern part is less than the western part that could be confirmed from the apparent resistivity values of less than 100 Ωm.

**Iso-apparent resistivity map for AB = 92 m**

Figure 2bshows the lateral variation of apparent resistivity in a horizontal plane at a greater depth than the depth of the previous map (i.e. Figure 2a) in which resistivity distribution ranges from 20 to 2470 Ωm. Comparing the iso-apparent resistivity maps shown in Figure 2a and 2b, we can conclude that with increasing the depth of investigation, the variation of apparent resistivity in the subsurface layers are decreased which can be due to the effects of erosion and weathering. The low resistivity zone in the east of the area is due to the alluvial aquifer. Similar to the previous map, the change of intrusive andesitic rocks to vitric tuffs is seen at the construction site. As the depth increases, the subsurface apparent resistivity slightly changes which can be due to the impact of fractures in depth.

**Iso-apparent resistivity map for AB = 294 m**

In Figure 2c, the apparent resistivity distribution in a horizontal plane at a depth of several ten meters in the study area is shown. Significant resistivity differences in andesitic dense bedrock in the western part and vitric tuffs in the eastern part of the study area can be seen. Due to the effective penetration depth of electric current, increasing apparent resistivity values in this map compared to the previous map shown in Figure 2b indicates high electrical resistivity of the intrusive andesite in Chooman River bed.

**Iso-apparent resistivity map for AB = 430 m**

Figure 2d demonstrates the apparent resistivity map for the largest distance of current electrodes in this study which corresponds to a high depth. Compared to the previous map, we can conclude that with increasing depth, the amount of apparent resistivity in the intrusive igneous rock increases indicating high density or compaction of the intrusive igneous body at depth. In addition, the lateral apparent resistivity variation is reduced as the depth increases. This indicates the impact of fractures in depth.

### *3.2 Geoelectrical pseudosection*

The geoelectrical pseudosection shown in Figure 3 reflects the apparent resistivity distribution contour map along survey line 10 that has been obtained as a result of acquiring resistivity data for different electrode spacing values (AB/2) in 13 sounding points with horizontal distance of 30 m from each other along this survey line in the eastern part of the study area having southwest–northeast direction (see Figure 1). This geoelectrical pseudosection generally includes two parts: the first part having high apparent resistivity values which have been obtained from sounding points 1 to 6 along survey line 10 and the second part has low apparent resistivity values obtained from sounding points 7 to 13 along this survey line (see Figure 3). The difference in the resistivity values is due to variation in the two parts in the study area. Areas with high resistivity values indicate the presence of andesite, while those with relatively low resistivity values indicate the presence of vitric tuff. The thickness of top soil layer varies in different parts. However, it often is estimated to be less than 5 m.

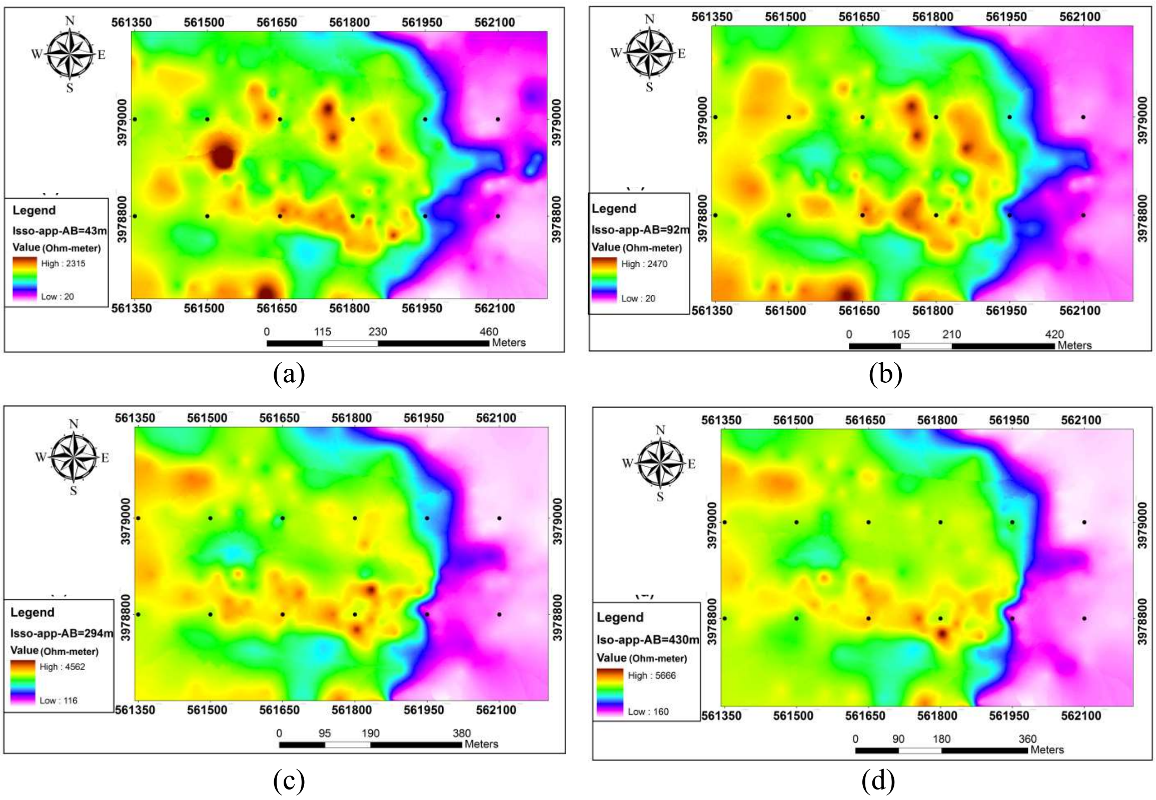


**Figure 2.** Iso-apparent resistivity maps for (a) AB = 43 m, (b) AB = 92 m, (c) AB = 294 m and (d) AB = 430 m.

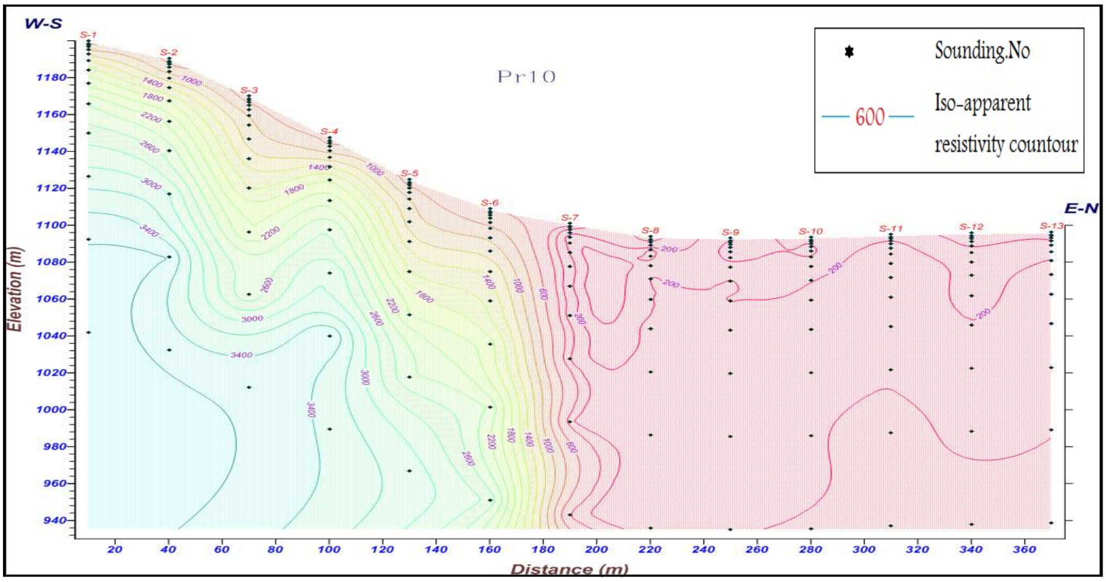


**Figure 3.** Geoelectrical pseudosection along survey line 10.

## *3.3 Quantitative interpretation*

In the quantitative interpretation method, true resistivities and thicknesses of subsurface layers are obtained and the main objective of this interpretation method is to get the geoelectrical parameters and sections. In order to have a good understanding of the subsurface geology of the study area, geoelectric sections have been drawn for each of the survey lines. In this case study, the results of the quantitative interpretation of VES curves are presented as geoelectric sections and true isoresistivity map of the bed rock.

### Geoelectrical section

The geoelectrical section of survey line 10 as shown in Figure 4 suggests that the area is underlain by two parts. The first part is formed of the superficial cover having a resistivity values ranging from 500 to 700 Ωm, which have been obtained from quantitative interpretation of sounding points 1 to 5 along survey line 10. This part, which consists of surface soil and different dimensions of andesitic igneous rock fragments, has a nearly stable thickness of 5 to 8 m. The second part is thicker and more resistive than the surface layer as its resistivity ranges between 1300 and 1700 Ωm. This part includes weathered andesite rock, which is above the fresh bed rock having resistivity ranging from 3400 to 4600 Ωm and is extended beyond sounding point 5. As a result of quantitative interpretation of sounding points along survey line 10, the depth of bedrock layer is estimated to be 17 m and increases to 36 m toward the center of the survey line at sounding point 5. From sounding point 6 to the end of the survey line, the type of subsurface layers varies. In this part of the survey line, the resistivity values of surface fine-grained soils and vitric tuffs vary in the ranges of 120 to 250 and 330 to 380 Ωm, respectively. Moreover, as indicated in Figure 4, a subsurface lens is seen in the location of sounding points 8 to 11 that has a resistivity ranging from 320 to 340 Ωm and thickness of 20 m.

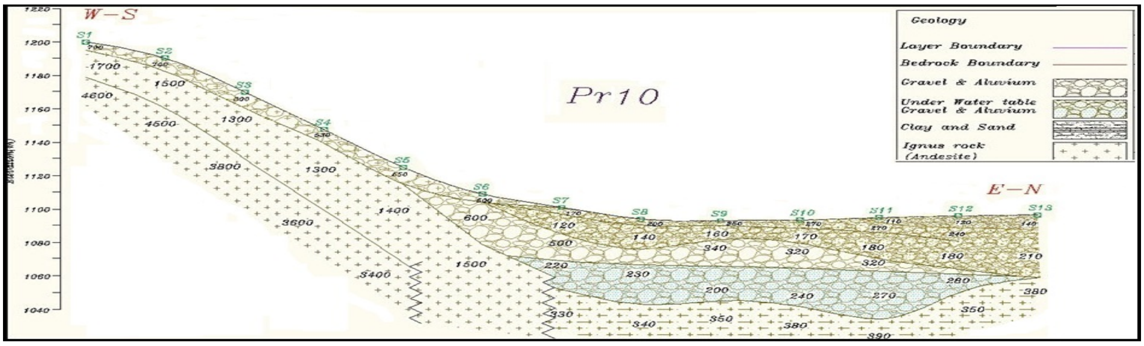


**Figure 4.** Geoelectrical section of survey line 10.

In order to look at some subsurface structural trends in the study area and to reveal the lithololgical sequence of the subsurface formations, specialized maps including iso-true resistivity, depth to the basement and structural map of the investigated area have been produced from the interpreted resistivity data of all the VES points or stations. These maps essentially indicate the lateral resistivity variation over a horizontal plane at certain depths. Furthermore, because the foundation of the dam should be distant from faults, the regional faults in the study area have been recognized and considered as another information layer to develop required maps in the area.

The resistivity values of the fresh basement obtained in the course of the interpretation have been used to plot the iso resistivity map of basement underlying the study area (Figure 5-a). This map has been produced by contouring the resistivity values of the fresh basement to view the distribution of fractured and unfractured rocks underlying the weathered basement.The map shows that resistivity distribution of the investigated site ranging from 188 to 6579 Ωm and in terms of real electrical resistivity is divided to vitric tuffs having resistivity values ranging from 188 to 1600 Ωm in one-fourth of the eastern part and andesitic masses having resistivity values ranging from 1600 to 6579 Ωm in three-quarters of the western part. As can be seen from Figure 5, the dam has been constructed in the central area of Chooman River and has a fresh basement.

The interpreted depth to the basement, longitude and latitude of each sounding point, and the overburden thickness map have been used to view the geometry of the variation in the overburden thickness or topography of the basement in the study area (Figure 5b). The map shown in Figure 5b suggests that the depth to the fresh basement in the investigated site ranges from about 10 to 64 m and follows the topography of the investigated area. The least depth to the fresh basement is seen below the Chooman River.

On the other hand, considering the geological information and a large number of sounding points on the resistivity survey lines having a specific direction and almost parallel to the river, the structural map of the study area was prepared to view the distribution of fractures in the investigated site (Figure 5c). As seen from this figure, the direction of the faults in the area is N-S and perpendicular to the direction of the Chooman River flow. As a result of the geological studies in the area, it is understood that the central part of the study area is underlain by Kani Ebrahim Formation and a strike-slip fault, which could be the main cause of some problems such as infiltration or leakage related remarkably to these geological and tectonic factors.

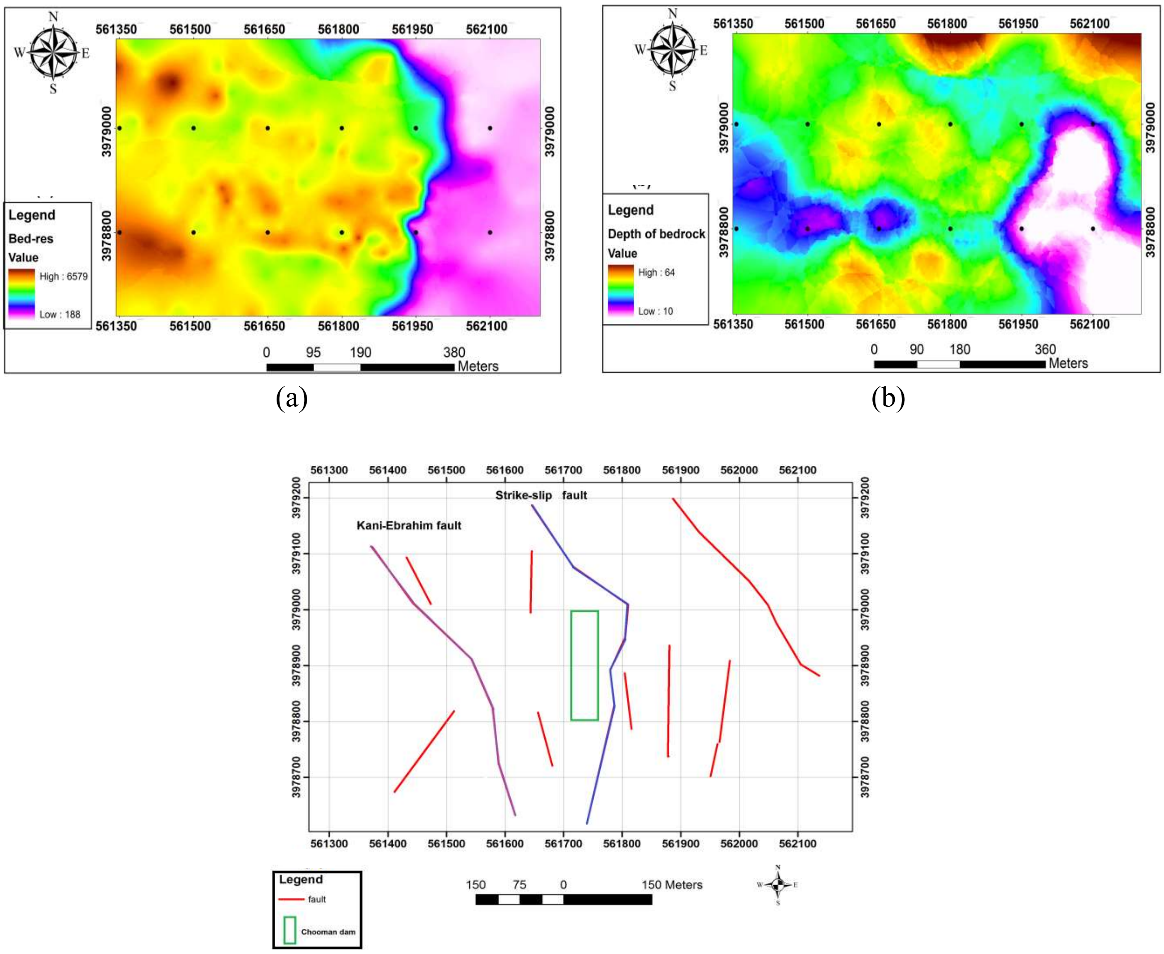


**Figure 5.** (a) Bedrock resistivity map, (b) depth to the basement map and (c) the structural map of the study area.

## 4 Conclusions

This work was proposed with the objective of outlining the subsurface structure of Chooman Dam reservoir, delineating weak zones responsible for water seepage and understanding deeply the origin of leakage problem through applying a geophysical technique known as electrical resistivity method close to the embankment of the dam. The resistivity field operation was performed along 28 survey lines having the lengths of 240 to 440 m in up- and downstream sides of the dam embankment. The results indicated that the resistivity method has been well capable of recognizing subsurface structures. In most places of the study area, the resistivity of andesitic igneous intrusion increases from surface to depth. This increase is because of decreasing weathering and erosion in the formation effect from the surface to depth. The maximum impact of weathering and erosion to a depth of about 10 to 15 m has been the cause of the occurrence of the permeable surface layer within the site. Furthermore, several subsurface structural anomalies were identified within the fractured bedrock. Accordingly, it is believed that the permeable surface layer and detected features close to the main dam axis are the main potential causes of water leakage from the dam reservoir.

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