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Demarcation of Groundwater Potential Zones by Electrical Resistivity Survey (ERS) Islamabad, Pakistan

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Abstract: A newly developed D-12 housing sector is at the Margalla foot-hills in Islamabad. This housing sector is facing tremendous groundwater problem due to frequent dry boreholes. After conducting the reconnaissance survey, data from the already drilled wells were recorded at different points throughout the study area for measuring average water table and the average total depth. The electrical resistivity survey was conducted in the sector for exploration of groundwater at six different locations with the help of SAS 4000 Terameter using Schlumberger configuration. The acquired data were used to determine the true resistivity on the basis of standard curves. The curves were matched with the borehole data and the surface geological map to prepare lithologic columns based on the true resistivities. Two zones have been categorized for future domestic use, i.e. prospective and non-prospective. The study shows dependence of localization of the aquifers upon the fault-related folding of the area. The aquifers are of two types i.e. shallow unconfined and deeper confined. The unconfined aquifers are found in the alluvium, whereas the confined aquifers are found in the sands of the Murree Formation. The confining beds constitute Murree clays and the shales.

Keywords: Islamabad, aquifer, groundwater, vertical electrical sounding (VES).

Introduction

One of the most important necessities for any area to be urbanized is the availability of fresh water reserves. Among other resources of water, groundwater is one of the most important entities. For the exploration of groundwater, Electrical Resistivity Survey (ERS) technique is used globally which is quite fast and efficient procedure of geophysical investigation. The technique is used to determine the water table depth and determination of potentiometric surfaces (Braga et al., 1999, 2006). Sounding and profiling methods are employed for the vertical and lateral variations of the subsurface resistivity respectively (Bairu, 2013).

The rapid growth of population in Islamabad is making ever increasing demands on natural resources and consequently causing adverse effects on the environment. The D-12 is a newly developed housing sector in Islamabad facing major groundwater problems due to the subsurface geological conditions. The arrangement of strata lying in the subsurface shows geological heterogeneities, which make it difficult to identify the potential zones for the groundwater reserves. The well data collected from the area is comprised mostly of dry wells as compared to water producing wells. The reason for dry wells could possibly be the spatial location of these wells. In accordance with the limitations postulated, for the identification of the potential groundwater reserves in the D-12 housing sector, three major concerns have to be resolved, i.e. establishing the subsurface lateral geological variations with the help of correlation of the ERS interpreted sections, determination of the location of aquifers in the subsurface and measuring water table depth by using Vertical Electrical Sounding (VES) technique.

Physiography of the Area

Islamabad, the capital city of Pakistan, lies in the northern most part of the Potwar plateau ranging between latitudes 33°37' and 33°45' N and longitudes 72°57' and 73°09' E (Fig. 1). Due to uneven topography, the average elevation of the area is around 500 to 600 m above mean sea level. The area lies in the foothills of Margalla having the highest elevation of about 1600 m marking the northern boundary of Islamabad city. The southern part has a gradual slope as it extends up to the Margalla piedmont (Sheikh et al., 2007). Several ridges and valleys occur in the piedmont area, which is mostly filled with the alluvial deposits eroded from the Margala hills.

The climate of Islamabad is typically monsoonal having rainy hot summers and cold winters. Monsoon season starts from the month of June and lasts till September with plenty amount of precipitation (Sheikh et al., 2007). The wettest month is July, with heavy rainfall and evening thunderstorms with the possibility of cloud burst. On 23 July 2001, Islamabad received a record breaking 620 mm of rainfall in just 10 hours. It was the heaviest rainfall in 24 hours in Islamabad and at any locality in Pakistan during the past 100 years. The rainfall lead to the runoff and infiltration through overland flow and seepage through the streams.

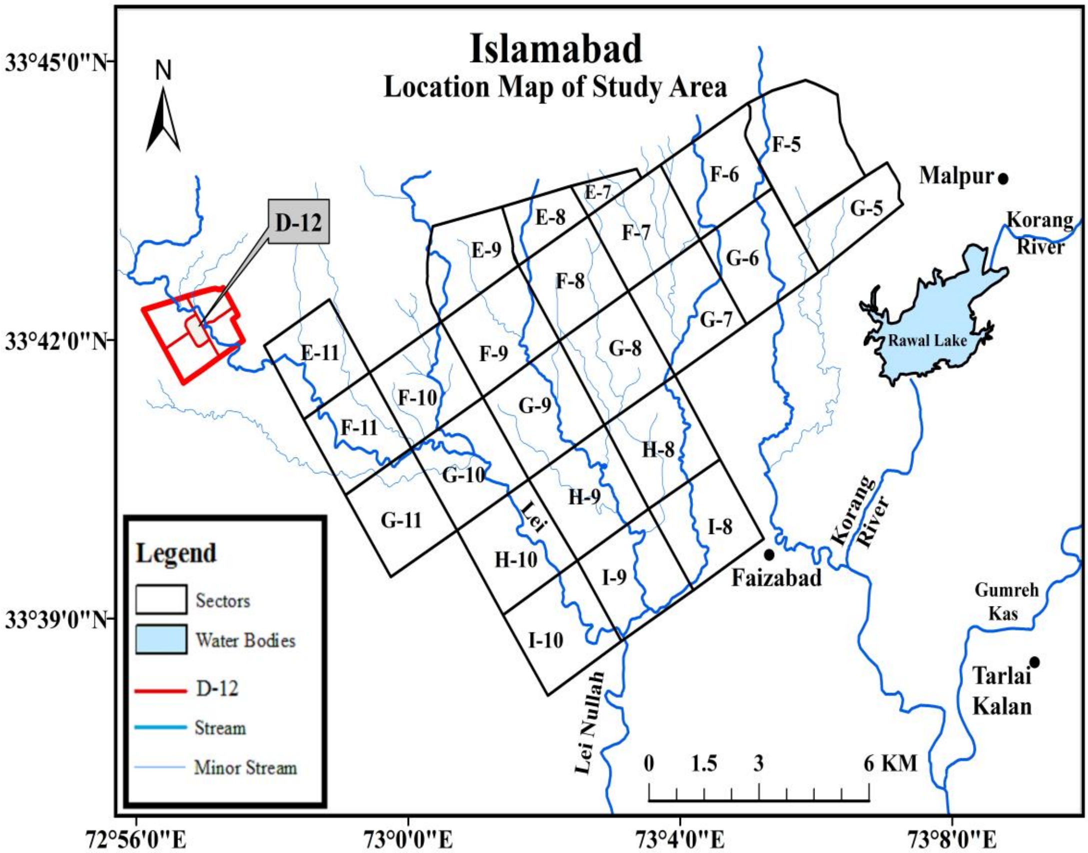

Fig. 1 Location map of the study area D-12 housing sector of Islamabad.

The two main rivers which drain the Islamabad city are the Korang and Soan. Several primary tributaries are also associated with these rivers. Gumreh Khas tributary is draining westward into the Korang river whereas one of the main tributaries which is draining northwestward into the Soan, is the Ling river and another tributary, the Lei nala drains southward into the Soan river (Sheikh et al., 2007). Rawal lake has been constructed on the Korang river, whereas Soan river is the source for the Simly dam in Islamabad. A number of small tributaries and streams are also present in the area originating from the Margalla hills. Generally, the Islamabad city has good groundwater potential having an adequate network of municipal and private wells. The average depth of the wells is around 200 m and most of them are producing groundwater from Quaternary alluvial gravels and sand deposits. The height of the water table decreases from about 600 m at the foot of the Margalla hills to less than 450 m near the Soan river, due to which the saturated zone generally lies 2-20 m below the natural ground surface (Ashraf and Hanif, 1980).

Local Geology

Islamabad lies at the northern edge of the Potwar basin. The Potwar basin represents fold and thrust belt belonging to sub-Himalayan region. The Main Boundary Thrust (MBT) is the major thrust fault running at the foothills (Sheikh et al., 2007). Surface geology of this area comprises the sequence of rocks ranging in age from Cretaceous to Recent alluvial deposits (Khan, 2000). The undifferentiated rock sequence starts from Cretaceous to Jurassic comprising the Kawagarh, Lumshiwal, Chichali and Samanasuk formations. The Makarwal Group comprising of Hangu, Lockhart, and Patala formations overlies the undifferentiated rock sequence. Above the Makarwal Group lies the Chharat Group which is an assembly of Margalla hill, Chorgali and Kuldana formations. The topmost rock unit is the Murree Fromation. The D-12 housing sector lies on the alluvium underlain by the steeply dipping beds of the Murree Formation. The northern part of the area consists of a number of faults probably linked to the MBT (Fig. 2). The southern part of the area is covered with alluvium and scattered exposures of the Murree Formation dipping at a high angle and consisting of sandstone, clay, shale, siltstone and intraformational conglomerates. The alluvium constitutes gravel, sand and clay beds. The cross-section exposes the subsurface geology of this sector. It can be clearly seen that the exposed units are lying at a steeper dip of 50-70 degrees at various places. The cross-section also delineates the same phenomenon in the subsurface. On the northern side lies the Shah Allah Ditta area showing exposures of the carbonate rocks. This area shows many springs that are related to the karst aquifers. Some very beautiful speleothems probably pre-Quaternary to Quaternary related to the karst conditions are also present in this area.

Table 1. The geoelectrical layers and data of the six points in D-12 housing sector, Islamabad.

Layer No.	Resistivity Ωm	Thickness (m)	Depth Range (m)	Lithology	Layer No.	Resistivity Ωm	Thickness (m)	Depth Range (m)	Lithology
ERS-01					ERS-04				
1	19.57	12.1	0 to 12.1	Surficial material	1	119.34	1.5	0-1.5	Surficial material
2	70.93	38.9	12.1 to 51	Dry sand	2	14.19	2.8	1.5 to 4.3	Wet sand
3	30.14	49	51 to 100	Wet sand	3	30.42	43.5	4.3 to 47.8	Dry sand
ERS-02					4	117.84	52.2	47.8 to 100	Shales
1	27.44	2.5	0 to 2.5	Surficial material	ERS-05				
2	20.44	46.5	2.5 to 49	Sandy clay	1	22.45	1.8	0 to 1.8	Surficial material
3	15	51	49 to 100	Clay	2	29.3	98.2	1.8 to 100	Wet sandstone
ERS-03					ERS-06				
1	78.49	12.2	0 to 12.2	Surficial material	1	33.67	4.3	0 to 4.3	Surficial material
2	50.96	87.8	12.2 to 100	Dry sandstone	2	25.94	22.5	4.3 to 26.8	Wet sand
					3	9.62	73.2	26.8 to 100	Clay

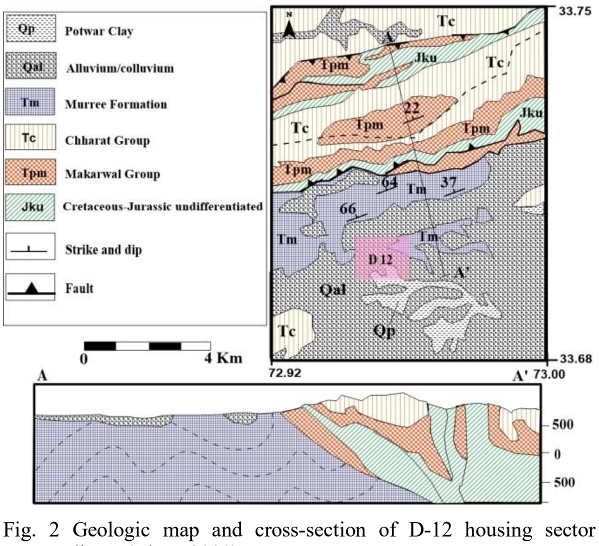

Fig. 2 Geologic map and cross-section of D-12 housing sector surroundings, (Khan, 2000).

Minerals and Methods

ABEM Terameter SAS 4000 has been employed to measure the variations in the resistivity of the subsurface. VES method has also been employed using the Schlumberger array in which a series of field observations are taken. Each successive observation has the electrodes at greater separation, whilst keeping the center of each observation same (Odeyemi, 2014). Depth of investigation depends upon the current electrode spacing. The spacing for the current electrodes is used at a larger range usually lesser than $1/5^{th}$ of the potential electrode's spacing for measuring the apparent resistivities in the field (Alile et al., 2011).

The current electrodes are designated as "A" and "B" whereas the potential electrodes are usually designated as "M" and "N". If the distance between the current and potential electrodes becomes too large i.e. greater than 1/5 of the potential spacing, the potential difference recorded for that specific reading will be too small to be measured accurately (Koefoed, 1979). The values for one side of the array of current electrodes (AB/2) were increased progressively during the measurements, whereas one side of the potential electrode (MN/2) values were kept at smaller values relative to the curre nt electrodes (Milson, 1939). The major benefit of the VES method using the Schlumberger array is that in order to increase the depth of penetration, only the spacing for the current electrodes has been increased for most of the readings, whereas the potential electrodes are shifted after three or five measurements (Reinhard, 1974., Alile et al., 2008). This procedure is less labor intensive as compared to the other procedures.

For interpretation of the data, a computer-aided iteration technique is used. The curves are generated by plotting the apparent resistivity values against depth (Odeyemi, 2014). In this case, trial values of the layer parameters are guessed, checked with a computed apparent resistivity curve and adjusted to match the field and computed curves. One dimensional resistivity interpretation software IX1D developed by Interpex USA, is used to process and interpret. Curve matching is done with the help of the software. The data obtained from the field are the apparent resistivity values of the subsurface, which are then plotted in the software. By applying the curve matching technique, the apparent resistivity values are converted into their respective true resistivity (ρ) values. According to the calculated true resistivity values, the subsurface is subdivided into different geoelectric units subsequently transformed to the respective geological units (Table 1).

Results and Discussion

Six locations have been selected to measure the VES in the study area (Fig. 3). The VES when measured, reveals different types of curves based upon matching with the standard curves, i.e. A, Q, Q, H, AH and Q (Fig. 4). On the basis of these curves, the subsurface has been divided into 1 to 4 geoelectric layers (Fig. 4 and Table 1). The trend of the resistivity with the depth is variable and is dependent upon the subsurface geology, encountered in each ERS point. The ERS 1, 4, and 5 show rising values of resistivity with depth, whereas the rest of the ERS show a gradual decrease in the resistivity values with depth. The material designations assigned to these geoelectric layers is table 1, consist of clays, shales, sands, sandstones and dry sandstones (Keller and Frischknecht, 1966; Loke, 1999). Besides, the data from the two recorded wells in the field have also been used to confirm the respective lithologies and their true resistivity (Table 1).

The geoelectric layers interpreted from all the ERS points show both the vertical and the lateral lithologic variations in the area. ERS 1 displayed the A-type curve with three different resistivity layers in the subsurface (Fig. 4a). The apparent resistivity is increasing from 20 to 48 Ωm with depth up to 100 m. The true resistivities determined revealed that the $\rho1 < \rho2 > \rho3$. Lithologic units thus interpreted include the surficial material at the top, followed by the dry and wet sandstone. The wet sandstone may be speculated for the groundwater potential in this area.

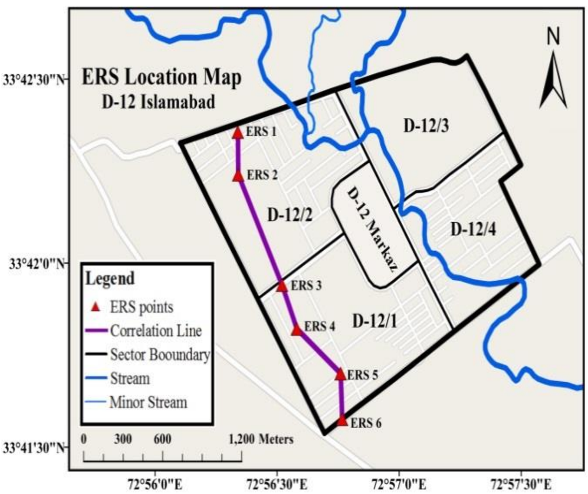

Fig. 3 Location map of D-12 housing sector showing the ERS points and the correlation profile line.

ERS 2 shows the Q-type resistivity curve having the apparent resistivities around 26 to 19 Ωm (Fig. 4b). The curve matching revealed the three-layered geoelectric succession in the subsurface in the order $\rho1 > \rho2 > \rho3$ (Table 1). The lithologies attributed for the true resistivity values include the surficial material and clay. This ERS does not contain any potential aquifer.

ERS 3 shows comparatively higher resistivity values which are interpreted as Q–type resistivity curve (Fig. 4c). Apparent resistivities show the decreasing trend of values with depth from 78 to 60 Ωm. The curve matching reveals a two-layered subsurface with $\rho1 > \rho2$. The interpreted lithology at this location is dry sandstone with no potential of groundwater (Fig. 4, Table 1).

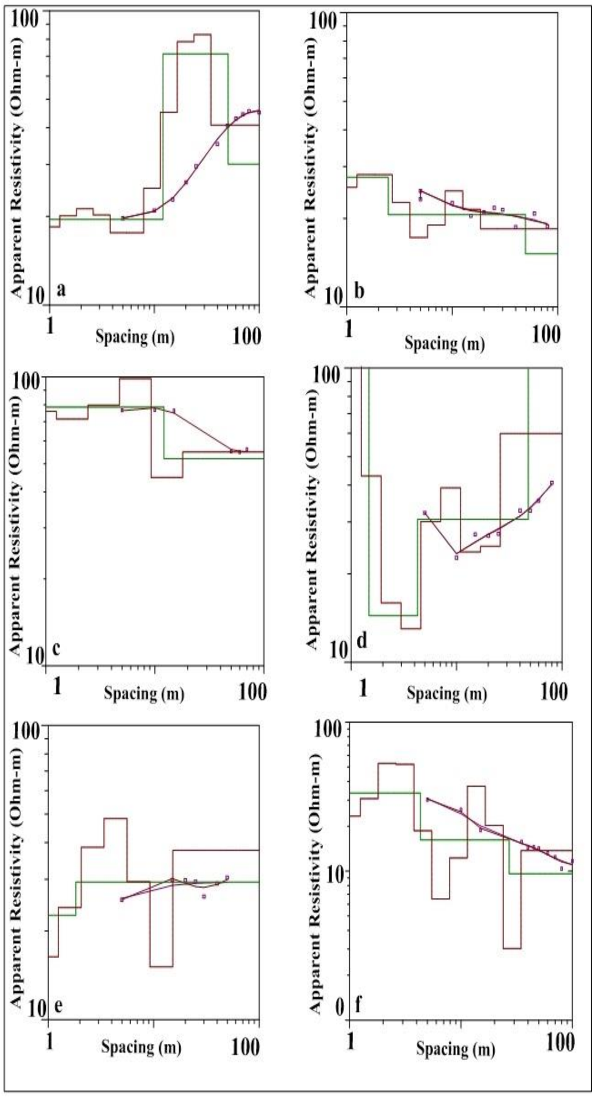

Fig. 4 Interpreted resistivity of ERS 1-6 (a-f). The trend line curve on the data points show the apparent resistivities acquired in the field. Maroon colored line shows the layered model and the green shows smooth model. The A, Q, H andAH-types are determined for these six models.

ERS 4 shows the H-type curve with resistivity values ranging between 23 to 42 Ωm (Fig. 4d). The subsurface on the basis of this curve has been divided into 4 layers with $\rho1 > \rho2 < \rho3 < \rho 4$. The lithologies assigned to these layers include the surficial material, wet sand and dry sand, which can possibly act as the aquifer. However, the last layer true resistivity value shows shales.

ERS 5 shows AH-type curve with the apparent resistivity values ranging from 24 to 31 Ωm (Fig. 4e). There are two geoelectric layers found by the curve matching i.e. $\rho 1 < \rho 2$. The geoelectric layers consist of two types of lithologies i.e. surficial material and the wet sandstone. This ERS shows a high potential aquifer in the area.

ERS 6 shows Q-type curve with the apparent resistivity values ranging from 12 to 30 Ωm (Fig.e 4f). There are three geoelectric subdivisions with $\rho 1 > \rho 2 > \rho 3$. The lithologies designated to each of these layers are the surficial material, wet sand, and clay. The medium potential of aquifer may be designated to this unit of wet sand.

Based on the resistivity survey, the central part of the area shows low potential of groundwater and the corner points such as ERS 1, 5, and 6 show the potential for groundwater development in 49, 98, and 22 m thick sand beds. An attempt has been made to correlate the lithologic interpretations in the form of the geoelectric pseudo section (Fig. 5). The geoelectric pseudo section revealed a continuous top unit of the surficial material, which has very low potential to store the groundwater in certain cases, where it is underlain by impermeable lithologies such as clays and shales. The lithologic units encountered below this included the clay, shales, sands and sandstones. The pseudo section also shows the partial continuity of lithologic units. The lithologies that may act as the aquifers in this area are the sands and sandstones. However, the ERS 1, 5, and 6 show the potential aquifers, whereas ERS 2 to 4 do not show the potential aquifers, which indicates that the aquifers are not in continuation. To address the understanding of this situation the electrical resistivity soundings information was matched with the surface geological map (Fig. 2) and outcrop orientation data were used to understand this geological behavior (Fig. 2). The evolved cross-section interpretation solved the problem of this subsurface aquifer heterogeneity by applying the dipping strata concept in each of the ERS interpreted sections (Fig. 6). This folding is related to one of the important fault running through this region i.e. the Main Boundary Thrust (MBT). This fault juxtaposes the Jurassic Samanasuk Formation with the Miocene Murree Formation. The sector D 12 lies on the hanging wall of this thrust fault (Fig. 2). The Murree Formation consisted of sandstone and clays in alternative arrangement. The deformation happened to this formation, resulted in folding which in response led to the aquifers of very unique character with lateral confinement and inclined nature in the area (Fig. 6). This concept has not been previously applied in the aquifers of Islamabad and it will help out in future localization and exploitation of these types of aquifers.

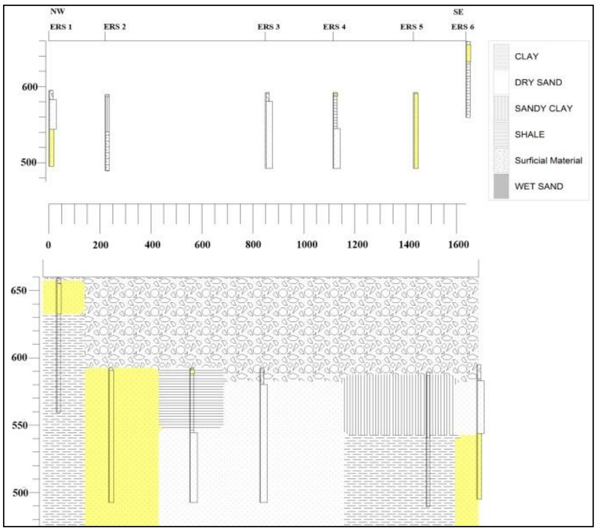

Fig. 5 The lithologic variations in six ERS points and the geoelectric interpreted section for the conceptualization of the shallow subsurface geology. Horizontal and vertical units are given in meters.

The correlation revealed that the aquifers localization is mainly dependent upon the geological structure of the study area. In terms of the groundwater potential of the D-12 housing sector, on the basis of the resistivity interpretation and the results depicted by the correlation of the area, it has been observed that the presence of wet sand packages in the southern part of the correlation profile makes it better prospect for the groundwater.

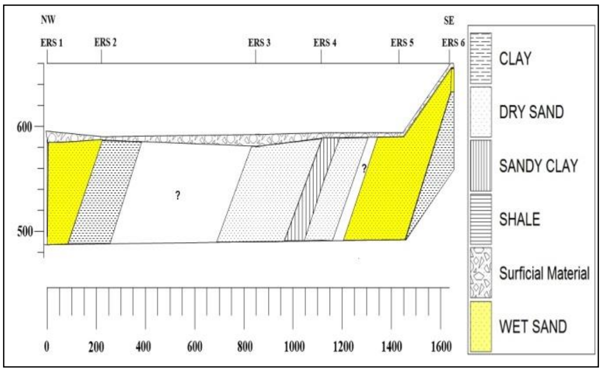

Fig. 6 The geological conceptualization coupled with the resistivity survey in the D-12 housing sector, Islamabad. The horizontal and vertical units are given in meters.

On the basis of cross-section it can be interpreted that there are two aquifer levels in the subsurface. The first one lies in the top most alluvium above the angular unconformity, whereas the second most important aquifers occur in the sands of the Murree Formation of Miocene age. The formation comprises of shale and sandstone, which provides very good aquifers at most of the locations. In the very near future, it is expected that the aquifers of the Murree Formation will be under stress due to over exploitation as a result of extensive development in this area. The aquifers lying in the alluvium are the perched type. The aquifers in the Murree Formation are completely different from the aquifers of the alluvial fills and may be categorized as the confined type. There is a complete lateral confinement of the aquifers in response to the clay confining beds. The folded geological structure localizes the depth and the nature of the aquifers in the area.

Conclusion

The study area is located adjacent to a major fault zone i.e. MBT that resulted steeply dipping attitude in the Murree Formation. Five types of resistivity curves have been found after thorough interpretation, i.e. “A”, “Q”, “H” and “AH”. The aquifer unit found in the interpreted lithologic columns is composed of sand and clay. The important aquifers are in the sands of Murree Formation. The average depth of the aquifer is related to the depth of water table and stays somewhere between 14 to 100 m in the subsurface. The confined and unconfined aquifers are found with the help of the correlation of the resistivity interpreted lithologic columns. On the basis of overall correlation, it is inferred that the central part of the D-12 housing sector contains clayey part of the Murree Formation below the alluvium and has a lower potential for groundwater development. The interpretation of the lithologic columns is evident of the fact that the D-12 housing sector (1, 2) is situated above the recharge area which has profound impact on the hydrogeology of the surrounding areas. The folding of lithologies of the Murree Formation has also a great impact on the hydrogeologic localization of aquifer system in this area.

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