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Quaternary Paleo-depositional Environments in relation to Ground water occurrence in lesser Himalayan Region, Pakistan

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Abstract

The Haripur basin is located 160 km northwest of Peshawar; the area faces serious freshwater unavailability issues due to diverse depositional patterns in an inter-mountain setting of the tectonically active region. The present study incorporates resistivity, borehole, and geological field data to delineate the paleo-depositional environment for identification and extension of aquifer type. Vertical electrical sounding data was acquired by using Schlumberger configuration at selected locations. The results were later on correlated with available boreholes to generate lithologs indicating different episodes of deposition from the north, east, and west towards center and south of basin. The lithologie were later on correlated to generate seven geo-electrical depositional models A-A′, B-B′, C-C′, D-D′, E-E′, F-F′, and G-G′. These models indicated proximal deposition towards north, east and west while distal sediments were deposited towards the center and south of the basin. Several confined aquifers were identified at a depth ranging from 25-80 m with the lateral extent of approximately 600 m. The Iso-resistivity maps along with geological field data confirmed the results of borehole and VES. The northern, eastern and western sides represent high energy conditions and maximum depositional activity with large particle size suitable for high yielding aquifers while the southern and central parts represent a progressive loss in depositional energy with small particle size associated with low yielding aquifers.

Key words: Haripur basin; Vertical electrical sounding; Geo-electrical cross-sections; Borehole; Depositional models.

1. Introduction

Safe water supply and sanitation are among the essential human rights. Ensuring their accessibility would contribute inconceivably to wellbeing and efficiency of the human race. The situation gets worse in, under developing countries like Pakistan where the budget allocation of water supply and sanitation amounts less than 0.2 % of GDP, as a result, an estimated 250,000 children under the age of five die every year due to water-borne diseases (ASP, 2011). In order to cope with growing population and industry need for quality groundwater is becoming important. The pressure on groundwater resources is increasing with decrease in canal water, which in turn is related to climate change; as a result, groundwater management is becoming a burning issue. In the absence of some regulatory body to monitor tubewell installations the fall in the water table is evident (Qureshi et al., 2003, 2010) unfortunately the management of groundwater resources cannot be carried out in Pakistan which needs instant attention. Proper aquifer identification can rectify management problems and thus serve the local community. Quaternary Paleo-depositional environments have a strong relationship with groundwater occurrence, the interpretation of these environments can help quantify location of suitabl permeable lithologies which can store and transmit adequate quantities of groundwater to local community and industry, several authors have carried out geological investigations of Quaternary deposits and interpreted depositional environments. Kevin (1998) has identified Quaternary break out floods in Peshawar basin.

Sinha et al. (2005) have worked on Quaternary geology in alluvial fan deposits in India. Babar and Jadhav (2014) identified Quaternary fluvial sediments in Sindphana River in India. These authors emphasized on the need for delineation of Paleo-depositional environments for identification of aquifer bearing lithologies. Geophysical tools with the majority of non-destructive tools have been used since the 20th century and proven out to be game changers in modern environments. These tools are easy to operate and interpret in accordance with geology. Seismic reflection, Gravity and Magnetic methods have regional applications in the demarcation of subsurface structures whereas, seismic refraction and geo-electrical surveys have shallow applications, among these two geo-electrical surveying has several applications in water detection and aquifer characterization.

Aning et al. (2014) have emphasized on electrical resistivity survey as an important geophysical tool for groundwater detection. Different subsurface zones containing economic quantities of water were marked by using 596 vertical electrical soundings in Sistan and Balochistan province of Iran by Lashkaripour (2003), by using this research complete hydrogeological conditions were estimated, furthermore based on this study several tube wells were installed. Several other scientists (Jeong et al., 2005; Ozebo et al., 2008; Rao et al., 2008) have used electrical resistivity technique for demarcation of bedrock, estimation of aquifer properties, aquifer extension, and aquifer thickness in relation with hydrogeology of the study area. With further advancements and the introduction of ERT techniques with better inversion results, this method has dominated shallow geophysical methods.

Andre et al. (2016) addressed the application of electrical resistivity tomography and induced potential survey for mapping subsurface alluvial fans. Similar results were discussed by Crook et al. (2008) in the characterization of subchannel architecture. Garg (2007) implied the use of electrical resistivity survey in the delineation of bedrock for construction of multistoried buildings thus shedding light upon its use in geotechnical engineering. Lapenna et al. (2005) and Siddiqui et al. (2012) further deliberated use of electrical resistivity survey in the identification of different anomalies associated with geological structures such as fault, fold, and fractures. Bayode and Akpaoarebe (2011) used integrated geophysical approach to investigate fracture/ fault control springs. Most recent time-lapse ERT studies have been aimed at improving our understanding of subsurface solute transport by using time-varying electrical responses related to known injections of saline traces into aquifers (Slater and Sandberg, 2000; Singha and Gorelick, 2005; Muller et al., 2010; Wilkinson et al., 2010).

The Haripur basin is located about 160km North West of Peshawar. According to latest census total population of this region is 40350,095 and most of the people live in villages (ASP, 2011). The main source of income is agriculture and factories in Hattar industrial estate. Due to increase in population and infrastructure the subsurface aquifer system is under stress. The present paper addresses the groundwater management problem in Haripur basin by using geo-electrical, borehole and geological field data in identification of Paleo-depositional channels that support fresh water, the integration of these datasets will result in the identification of depositional patterns indicating the distribution of aquifer lithologies with different, yielding capacities.

2. Geology of the area

Pakistan has a unique global tectonic framework with three main tectonic plates including an Indian, Eurasian and Arabian plate (Molnar and Tapponnier, 1975). Eurasian and Indian plate's collision occurred about 40-50 million years ago which resulted in the formation of the Himalayan orogenic belt (Kazmi and Jan, 1997). It was a continent-continent collision caused by the compressional forces in which Indian plate was subducted below the Eurasian plate, and as a result, crustal shortening occurred during Cretaceous (Kemal et al., 1991). These tectonic plates contribute to all geologic, the structural and tectonic framework of Pakistan. Haripur basin which lies within the lesser Himalayan region is bounded in the east to the northeast by Nathiagali thrust and Margalla Hills, in the south by Haripur plain and in the west by Gandghar Ranges (Fig. 1).

The areas in Haripur basin are mostly plain containing both alluvial and fluvial deposits (Mirza and Ahmed, 2005). Dor and Harrow rivers are the main deposition agents in this area along with Nathiagali and Punjal thrust that serve as a source of sediments to this area. Hazara slates act as basement rock for overlying fluvial and alluvial deposits (Qasim et al., 2014). The southern part of Haripur basin is irrigated with the water stored in the Khanpur Dam which also supplies water to Islamabad and Rawalpindi (Mirza and Ahmed, 2005). Haripur basin has a semi-arid climate with very hot summer and moderate winter.

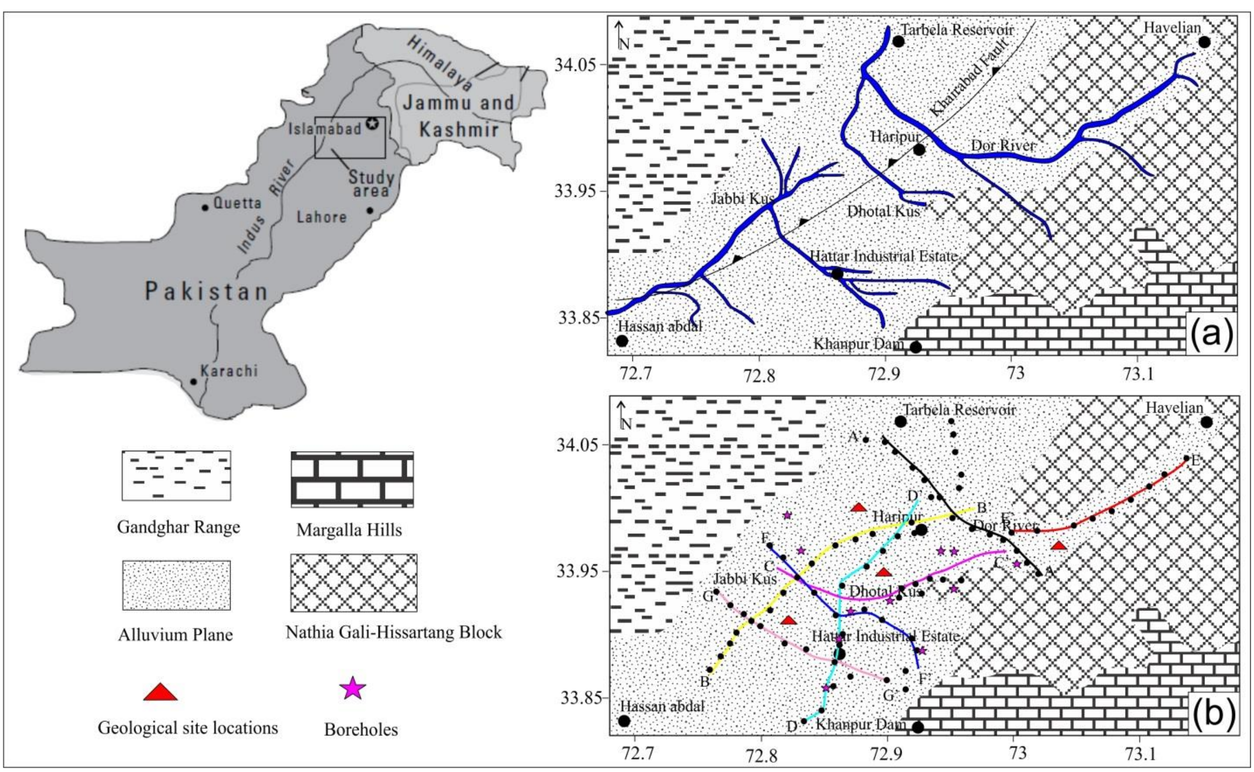

Fig. 1. (a) Showing extension of geological units with Nathiagali and Margalla Hills in the north to northeast, Gandghar ranges in the west and Haripur Alluvium plain in the south. (b) VES points along with borehole and Geological field location points.

2. Methodology

Vertical electrical sounding (VES) data were acquired at various locations throughout the Haripur basin (Fig. 1). Schlumberger configuration was preferred above all other configurations because of its simple operations and greater depth coverage. This configuration made use of four electrodes (two potential and two current electrodes) with potential electrodes remain fixed for first few readings whereas current electrodes are kept moving. After few readings, the spacing between potential electrodes is changed, and current electrodes are moved accordingly. The distance between current electrodes for the whole survey ranged from 1m to 500 m and for potential electrodes from 0.5 m to maximum of 5 m. the distance between current electrodes varied at some locations due to topographical constraints.

3.1 Curve Matching

Curve matching is a process of constructing a curve that has the best fit to a series of data points. It is more accurate and dependent method of interpretation in electrical resistivity sounding where field profiles are compared with characteristic curves. VES curves show the resistivity of different subsurface layers that can be used to investigate subsurface strata information. Thus, on the basis of the shape of the curve, different subsurface layered strata can be categorized into Type H, Type A, Type K and Type Q (Figs. 2 and 3).

3.2 Resistivity Data Calibration with Borehole:

Physical parameters derived from field data (resistivity and thickness) were then correlated with available borehole data, this calibration is necessary as electrical resistivity method being an indirect geophysical method cannot differentiate clearly between similar lithologies in different field conditions. After correlation with borehole data lithology of VES values were generated. These lithologies were later on correlated to check the lateral and vertical extent of lithology (depositional models), to know about the water-bearing horizons and to reconstruct the depositional model. These models were prepared along seven selected profiles (A-A′, B-B′, C-C′, D-D′, E-E′, F-F′, and G-G′) that are based on apparent resistivity values along the vertical depth.

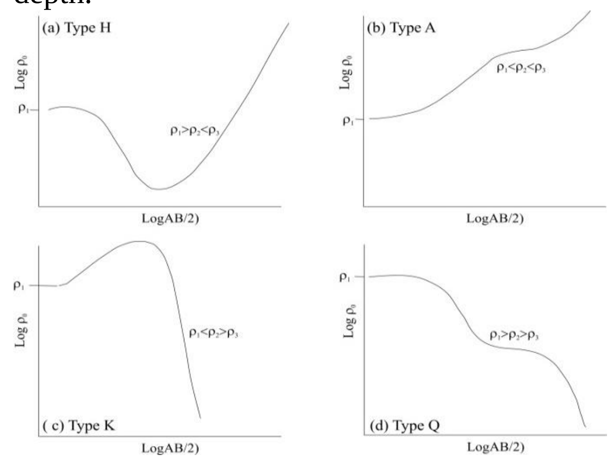

Fig. 2. Representation of different types of master curves which are correlated with field curve to approximate different layers (Raj et al., 2014).

3.3 Geological field data Acquisition:

The geological field trip was carried out at selected (04) locations (Fig. 1) in the study area. The objective of the field was to identify the depositional trend and to correlate surface geological information with VES and Borehole datasets (Fig. 3).

4. Results and discussions

4.1. Cross sections

The cross-section A-A′ lies in the east of Tarbella Lake (Fig. 1) and comprises of one borehole and seven VES points. VES and borehole data indicate three prominent layers .i.e. Layer1, 2 and 3. Layer 1 range from 0-40 m depth and encompasses alternating beds of boulders and clay. Layer 2 comprises dominantly of silty clay with a thickness ranging from 40-90 m. Layer 3 ranges from

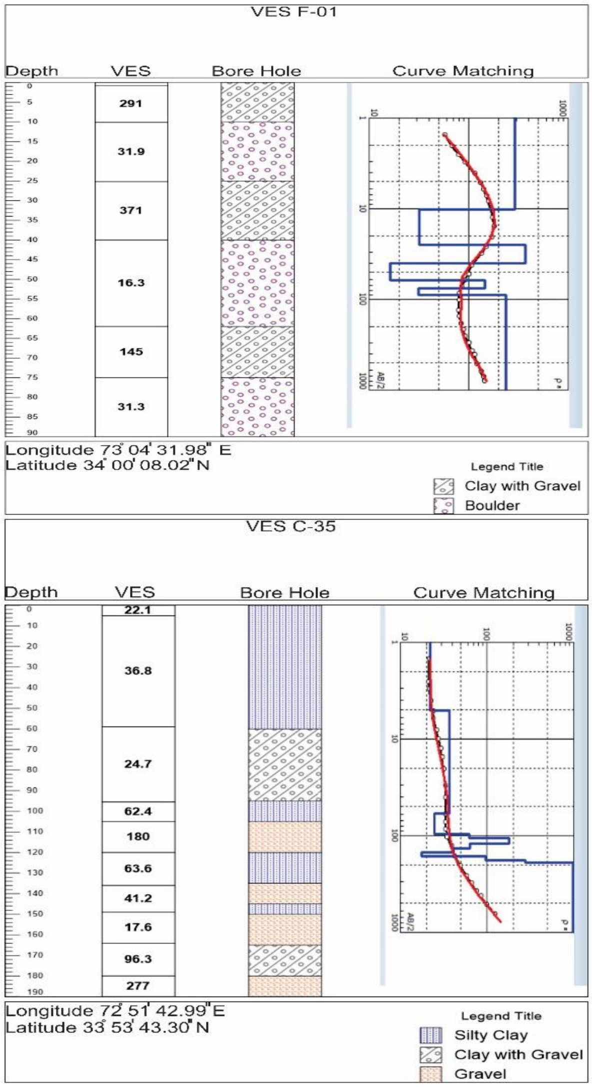

Fig. 3. Representing correlations between borehole and VES points to increase the reliability of the results.

95-140 m and contains alternating beds of boulders and clay (Fig. 4). The resistivity of these layers apprehends to the presence of moisture content and different lithologies. By comparing resistivity values with borehole data, two aquifers have been identified at different depths. First confined aquifer is identified at a depth of 20-30 m, having high resistivity value of 143Ωm with a thickness of 10 m and extending from VES-1 to VES-7 (Fig. 4). The second confined aquifer is identified at a depth of 130-140 m, having medium resistivity value of 91Ωm with a thickness of 10 m and extending from VES-1 to VES-7. As this profile lies at the base of hills and is indicative of different episodes of high low and then high energy conditions, the presence of dominating coarser sediments can be related with high groundwater yield due to permeability.

The cross-section B-B′ lies in the south of Tarbella (Fig. 1) Lake and is comprised of four boreholes and Eleven VES points. On the basis of VES and borehole data, two prominent layers have been identified. Layer 1 range from 0-115 m and contains alternating beds of boulders and clay having a variable thickness. Layer 2 comprises of coarse sandy clay with a thickness of 115-165 m (Fig. 5). The resistivity of these layers varies due to the presence of moisture content and different lithologies. Layer 1 and 2 represents fluvial deposition conditions which are attributed to the low, high and then low velocity of stream respectively. By comparing resistivity values with borehole data three confined aquifers have been identified. First confined aquifer is identified at a depth of 35-60 m, having high resistivity value of 102Ωm with a thickness of 25 m and extending from VES-1 to VES-5. The second confined aquifer is identified at a depth of 111-160 m, having moderate resistivity value of 81Ωm with a thickness of 49 m and extending from VES-6 to VES-8. The third unconfined aquifer is identified at a depth of 15-65 m, having medium resistivity value of 82Ωm with a thickness of 50 m and extending from VES-9 to VES-11 (Fig. 5).

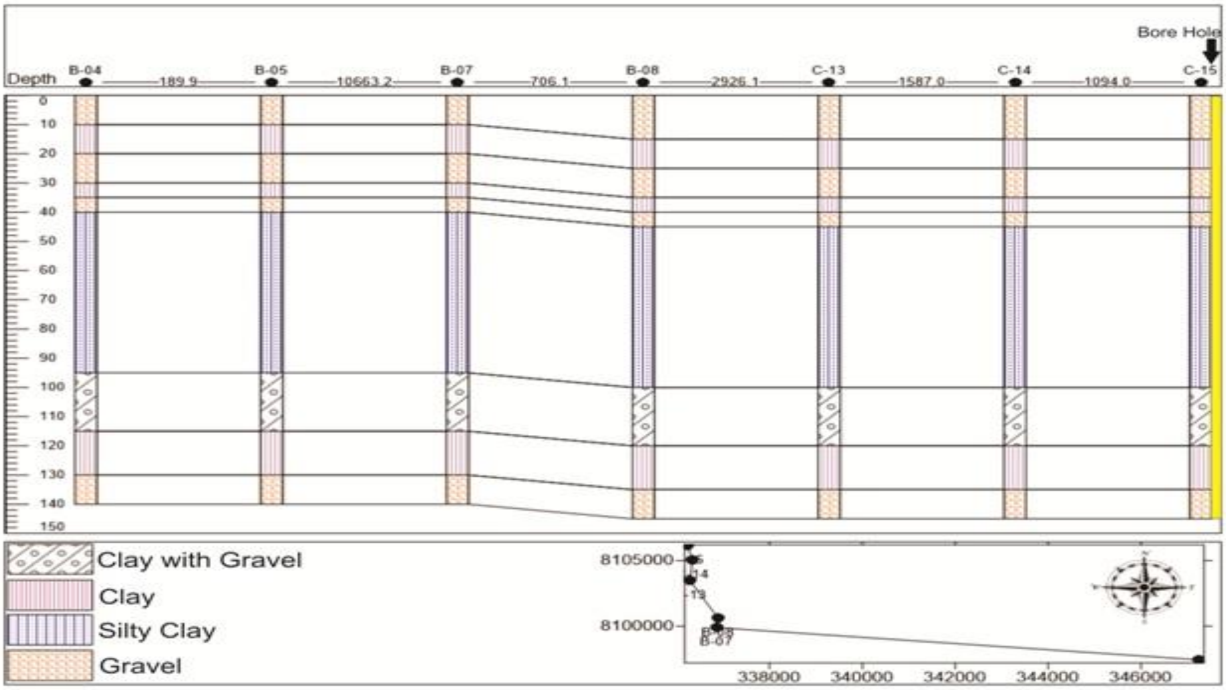

Fig. 4. Cross Section A-A′ is showing a correlation between VES points and boreholes indicating different aquifer lithologies at various depths.

The cross-section G-G′ lies in the south of Tarbella Lake (Fig. 1) and comprises of two boreholes and six VES points. On the basis of VES and borehole data, from VES-1 to VES-4 alternating beds of boulder and gravels are present having the depth of 70 m. From VES-5 to VES-6 alternating beds of silty clay, boulder and gravel are present at a depth of 76 m (Fig. 6). These fluvial deposition conditions are attributed to the high velocity of the stream. By comparing resistivity values with borehole two aquifers are identified at different depths. The first aquifer is present at a depth of 40-70 m, having average resistivity value of 42Ωm with a thickness of 30 m and extends from VES-1 to VES-4. Another aquifer is present at a depth of 50-75 m, having high average resistivity value of 291Ωm with a thickness of 25 m and extends from VES-5 to VES-6. The eastern part of profile comprises of finer lithologies while the western part is dominated by coarser lithologies, i.e., that are deposited by Gandghar ranges, furthermore, these coarser sediments thin out towards the east, i.e., towards the center of the basin as the distance from depositional agent increases. In terms of aquifer yield, the aquifers towards the west of basin will have high yield capacity due to the presence of permeable lithologies while in the central part of the basin the aquifer will have less yield due to the domination of finer lithologies (less or no permeability).

4.2. Iso-resistivity map

Iso-resistivity/Spatial distribution maps represent the connection between equal electrical apparent resistivities which in turn confirms two-dimensional lateral variations in subsurface lithologies. These maps are drawn between AB/2 and an apparent resistivity at specified depths of 30, 50, and 80 m using Golden Graphic Software Surfer.

Iso-resistivity map generated at 30 m depth (Fig. 7a) shows high resistivity contours of 200-320Ωm representing coarser sediments (gravel and boulder) in the north-western part of the area while low resistivity contours 20-60Ωm indicating finer sediments (silt and clay) in the southern part of the area. Furthermore, the results represent high yield aquifer lithologies distribution towards the north-eastern part and low water yielding lithologies towards east and center of the basin.

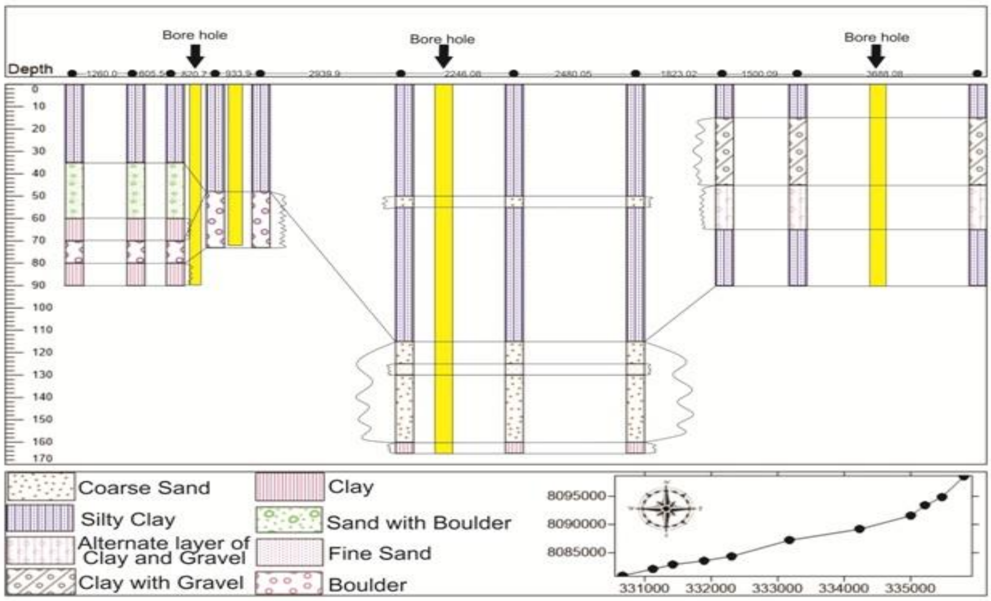

Fig. 5. Cross Section B-B′ showing correlation VES points and boreholes indicating aquifer lithologies at various depths.

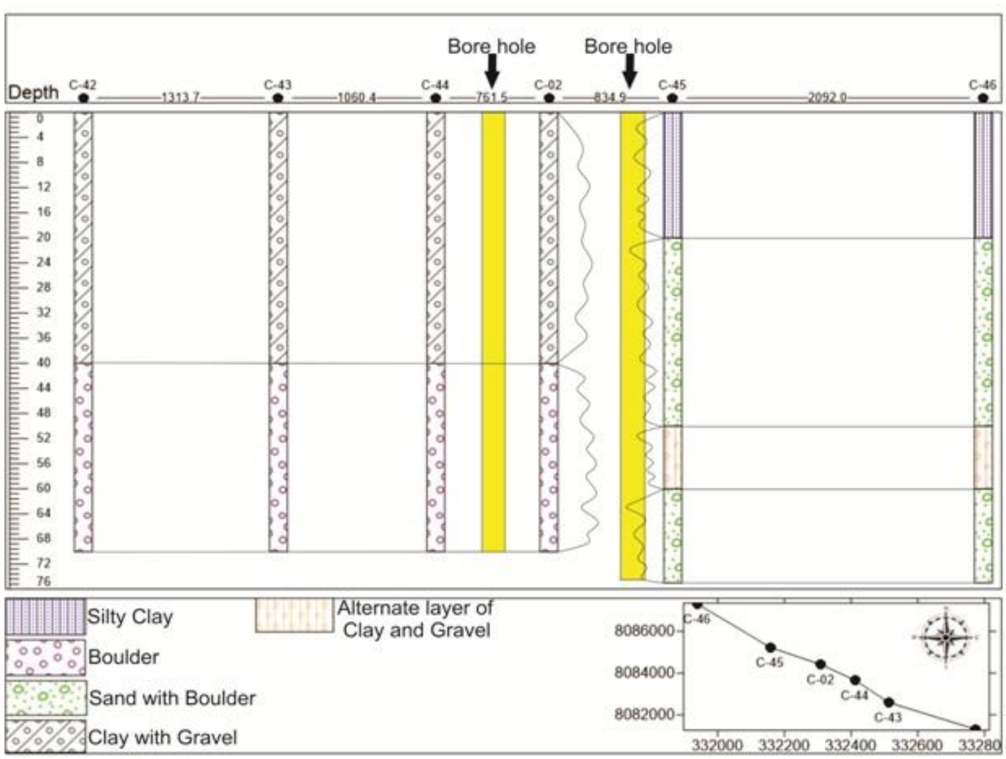

Fig. 6. Representing Cross Section G-G′ indicating aquifer lithologies at variable depth.

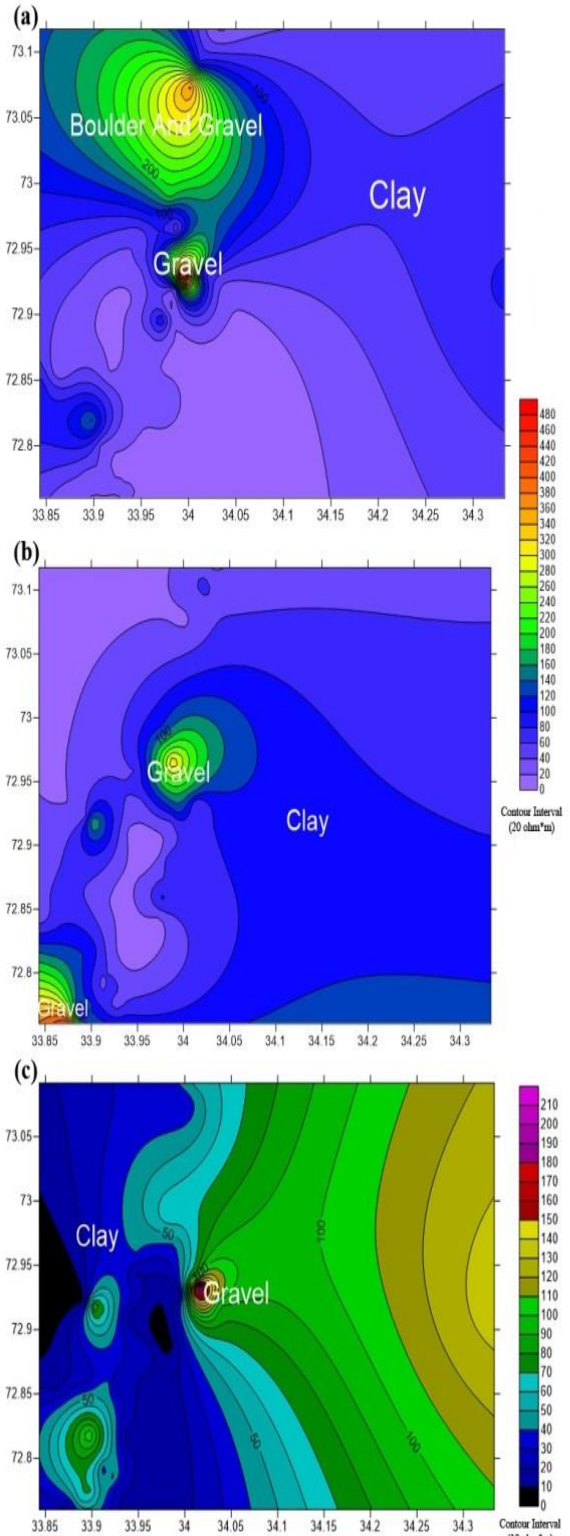

Fig. 7. a, b and c showing Iso-resistivity map drawn at 30m, 50m and 80m respectively representing low and high resistivity values.

Iso-resistivity map drawn at 50 m depth (Fig. 7b) shows moderate resistivity contours of 40-80Ωm representing finer sediments (sand, silt and clay) in south-eastern part of area indicating progressive loss in steam energy as it moves away from foothills while high resistivity contours 120-200Ωm indicating coarser sediments (clay with gravel and boulder) in south-western part of area. These coarser sediments are attributed to high stream energies associated with Gandghar ranges a large depositional source towards the west. The Iso-resistivity map drawn at 80 meter depth (Fig. 7c) shows low resistivity contours of 15-50Ωm indicating finer sediments (clay, fine sand, and silt) in south-western part of area, further away from Gandghar ranges, furthermore high resistivity contours of 100-170Ωm representing coarser sediments (clay with gravel, coarse sand, and boulder) in north-eastern part of area facilitated by Nathiagali and Margalla hills.

4.3 Depositional Models

Geo-electrical results integrated with borehole data were used in the construction of depositional models of the basin indicated by seven two dimensional profiles representing the distribution of sediments in various parts of the basin.

The depositional model C-C' (Fig 8d) is oriented in NE-SW direction and comprises of three boreholes and seven VES points. This cross-section covers the area from foothills of Havelian towards the center of the basin. The cross-section represents massive clay beds having a thickness of 100 m followed by massive gravel and sand beds. The deposition of massive clay indicates low energy conditions, however towards the eastern side presence of coarser sediments in the form of lenses having variable thickness indicate high energy conditions. The area towards the east represents foothills of Nathiagali, and Margalla hills provide a necessary slope for the stream to deposit coarser lithologies. That is why we can see coarser beds towards the east as the stream travels further down towards the center the deposition of coarser lithologies decreases which completely eradicates as we finally reach the central part of basin, generally the overall deposition in this cross-section can be divided into two episodes, first episode involves deposition of finer lithologies indicative of low energy conditions, while the second episode comprises of coarser lithologies attributed to high energy conditions, within both the depositional episodes there are small evidence of channel activity associated with seasonal rainfall.in term of aquifer distribution, shallow aquifers are identified in the eastern and western part of the cross-section.

The depositional model E-E’ (Fig. 8f) comprises of four VES points and two boreholes oriented in a north-south direction. The cross-section represents a single major episode of deposition contributing coarser sediments associated with high energy conditions. Furthermore, these high energy conditions are associated with topographic relief in the study area. Presence of rare finer sediments (clay lenses) indicates channel activity that has resulted due to seasonal rains in which finer lithologies were eroded and deposited by the stream. In terms of aquifer yield, this cross-section can provide an economic quantity of water to surrounding areas plus aquifer in these areas are at shallow depth and therefore are vulnerable to contamination due to the presence of conducting pathways (permeable lithologies) near the surface.

The depositional model F-F’ (Fig. 8g) comprises of four VES and three boreholes oriented in an east-west direction. This cross-section has a unique bedrock exposure that is influencing the multi-episode deposition. The first episode indicates deposition of coarser sediments with limited channel activity. The second episode indicates deposition of finer lithologies on both sides of exposed bedrock. Furthermore, this episode contains lenses of coarser sediments that can serve as shallow perched water aquifers (towards the east). Similar results were indicated by other cross-sections in the study area. The overall architecture indicated high stream activity towards the north, east and west as a result of elevation(foothill area) indicated by the presence of coarser lithologies accompanied by some finer domination (clay lenses) associated with seasonal stream variations. The aquifer lithologies with high yielding capacity occur towards the eastern side whereas on the western side the depth of aquifer increases as massive clays are deposited towards the western side of bedrock.

4.4 Geological field observations

The geological field observations were carried out at different geological sites to identify depositional architecture of Quaternary sediments. The results were found in accordance with the subsurface borehole and VES data sets. The geological field data sets revealed domination of coarser sediments towards the north, east and western parts, These sides represent high stream energy resulting in deposition of high yielding aquifer lithologies, furthermore due to high stream energy very less amount of finer sediments is deposited that tends to increase the yielding capacity of the aquifer. The conditions change towards the center and south of the basin where massive clays dominate, indicating considerable loss in stream energies, at some locations coarser lithologies also prevail but due to presence of clays that tend to reduce the water pathways (permeability) result in decreased yielding capacity of aquifer, however, these clays can act as better seal for aquifer decreasing the vertical and spatial flow of contaminants to underlying aquifer. Figure 9(a) represents deposition of alternating beds of clay with sand indicating channel activity near the center of the basin. Figure 9(b) depicts massive gravel, sand with clay beds towards the western part of the study area, this area lies close to the foothills of Margalla hills justifying the presence of coarser lithologies.

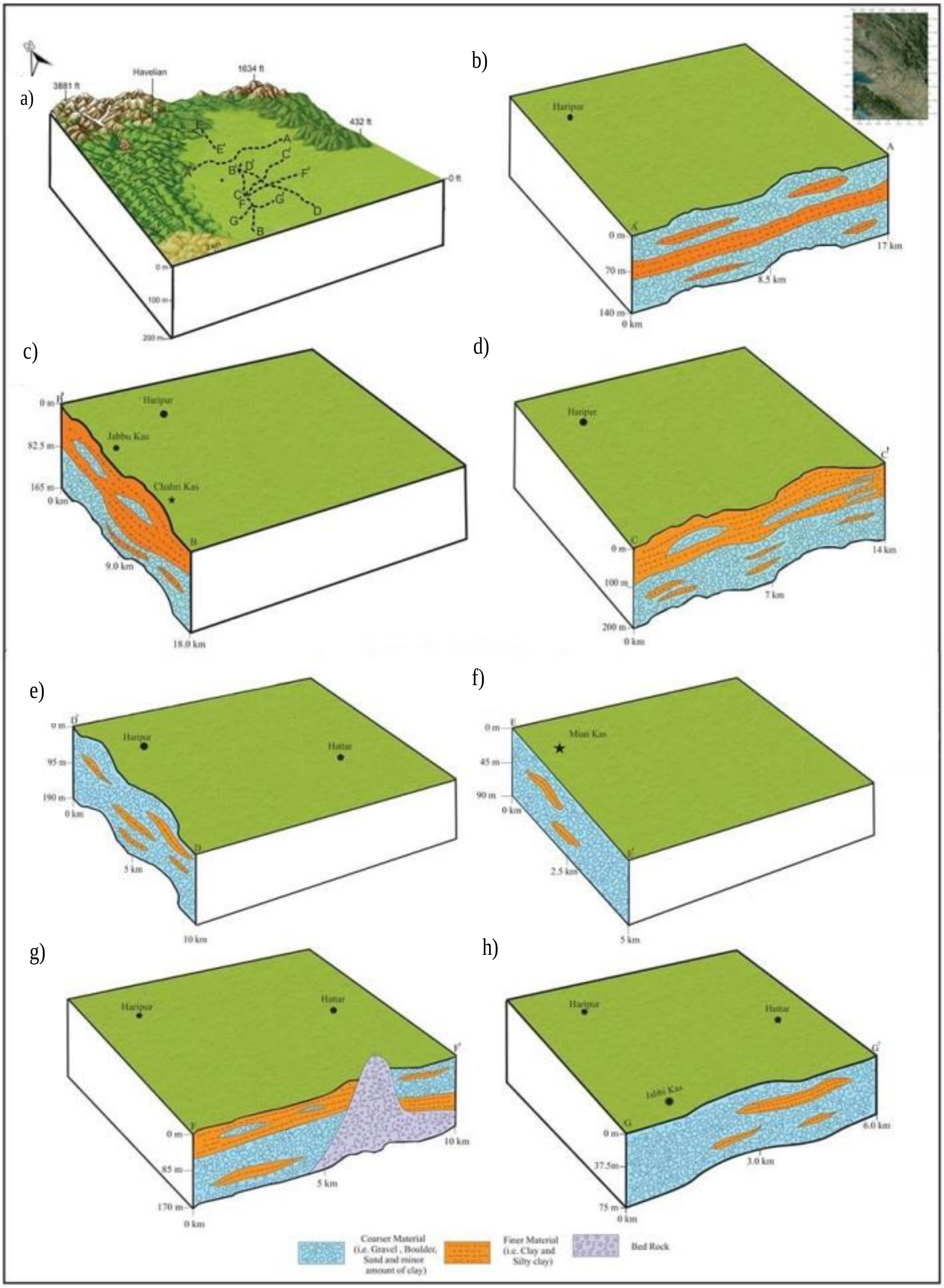

Fig. 8. (a, b, c, d, e, f, g & h) Showing depositional models of A′-A, B-B′ and C′-C, D-D′, E-E′, F′-F, and G′-G.

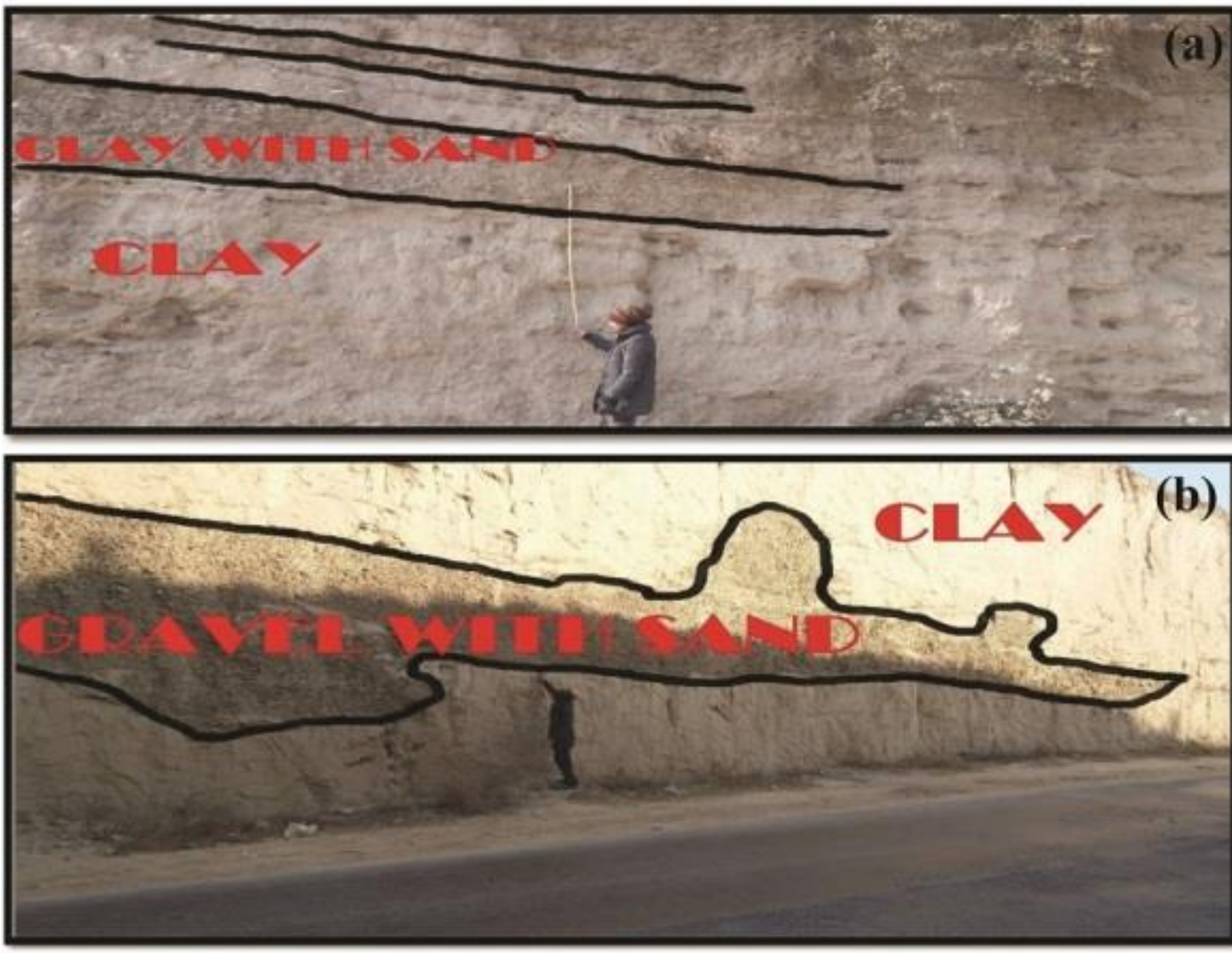

Fig. 9. a) Showing low energy depositional environment representing alternating beds of clay and sand. b) Showing the alternating beds of clay and gravel with sand representing high energy conditions.

5. Conclusions

Northern, eastern and western part of the area is mostly composed of boulders, gravels, and coarse sand. Whereas, central and southern part of the study area is dominated by clay particularly as a top layer. This lithology distribution indicates high energy conditions in the north, east, and west whereas low energy conditions towards center and south of basin.

Confined aquifers have been identified in all cross-sections at an average depth of 25-80 m, having an average lateral extent of approximately 600 m. These aquifers are associated with coarse lithologies that exist in north, east and west of study area. The central part of the basin is dominated by saturated clays that although porous but cannot transmit economic quantities of water. The Iso-resistivity maps also confirmed the presence of aquifer lithologies at different depths located in the north, east and western direction.

The VES and borehole data represented periodic episodes of deposition with coarse lithologies mostly in the vicinity of foothills and depositional mouths separated by lenses of finer lithologies. These finer lithologies get massive towards the center and southernmost part of the basin due to increase in distance from a depositional agent.

The depositional models indicated three possible depositional directions .i.e. from north, east, and west. These directions are initially dominated by coarsening up trends associated with the high energy deposition and then convert to finning up trends as the energy of deposition subsides. Geological fields carried out during this study have confirmed fluvial deposition environment. The size of the grains comprising the sediments fines upward, indicating a progressive loss of river energy, through time, within the river channel. In this way, finer and lighter weight grains could be deposited as the flow velocity decreased progressively. In north, east and west of the basin more stream activity is observed in the form of channels whereas, massive clays in the center and south of basin indicate possible flood and/or loss in energy of depositional agent.

Authors' Contribution

Umair Bin Nisar initiated concept of the project, did technical writing, data processing and interpretation. M. Rustam Khan supervised the project and provide financial support through institute of geology UAJ & K for field work and also helped in data interpretation. Sarfraz Khan technically reviewed the paper. Syed Saqib Razzaq Helped in field data acquisition and geological field. Muhammad Rizwan Mughal helped in map productions, Muhammad Farooq in field data processing set and interpretation, Khawar ishfaq in technical writing and Abrar Niaz in field data acquisition and geological field.

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