Groundwater Potential Zone Identification in Unconsolidated Aquifer Using Geophysical Techniques around Tarbela Ghazi, District Haripur, Pakistan

Syed Muzyan Shahzad, Liu Jianxin, Asim Shahzad, Muhammad Sharjeel Raza, Sun Ya, Fanidi Meryem

***Abstract*—**Electrical resistivity investigation was conducted in vicinity of Tarbela Ghazi, in order to study the subsurface layer with a view of determining the depth to the aquifer and thickness of groundwater potential zones. Vertical Electrical Sounding (VES) using Schlumberger array was carried out at 16 VES stations. Well logging data at four tube wells have been used to mark the super saturated zones with great discharge rate. The present paper shows a geoelectrical identification of the lithology and an estimate of the relationship between the resistivity and Dar Zarrouk parameters (transverse unit resistance and longitudinal unit conductance). The VES results revealed both homogeneous and heterogeneous nature of the subsurface strata. Aquifer is unconfined to confine in nature, and at few locations though perched aquifer has been identified, groundwater potential zones are developed in unconsolidated deposits layers and more than seven geo-electric layers are observed at some VES locations. Saturated zones thickness ranges from 5 m to 150 m, whereas at few area aquifer is beyond 150 m thick. The average anisotropy, transvers resistance and longitudinal conductance values are 0.86 %, 35750.9821 Ω.m^2, 0.729 Siemens, respectively. The transverse unit resistance values fluctuate all over the aquifer system, whereas below at particular depth high values are observed, that significantly associated with the high transmissivity zones. The groundwater quality in all analyzed samples is below permissible limit according to World Health Standard (WHO).

***Keywords*—**Geoelectric layers, Dar Zarrouk parameters, Aquifer, Electro-stratigraphic.

I. Introduction

THE rapid development in Tarbela Ghazi, District Haripur and the associated increases in population demands excesses utilization of groundwater. Groundwater is a major source for agriculture and drinking in the study area. The ability to observe the subsurface environment and processes that occur within it remains challenge to many researchers. Tehsil Ghazi extends from 33° 52' to 34° 25' North latitude and from 72° 30' to 72° 55' East longitude (Fig. 1). Indus River and district Swabi bound study area on the northwest, in the southwest lies district Attock of Punjab province. The area has a semi-arid climate with hot summers and mild winters. The winter rains are generally of long duration and low intensity, whereas the summer rains come in short showers with high intensity due to their monsoon character, with population of 145,367 [4]. The area is well known for agriculture, and fertile soil condition with highest point Above Sea Level (ASL) about 2000 feet. The VES is one of the geophysical exploration technique to determine the true resistivities, thickness and lithological variations in the subsurface layers of earth by compiling apparent resistivity and well log data on a map [1], [8]. Vertical electrical resistivity method can provide depth of occurrence of groundwater zone, thickness of the aquifer system and the probable location for well sites [13]. The electrical parameters of the geoelectrical layers and the relation between the aquifer characteristics or properties have been studied by many researchers, e.g. [5]-[7], [9], [11]. The electrical properties of most of the rocks in the upper part of the Earth's crust mostly depend upon the amount of water in the rock, the salinity of the water in the pores spaces, and the distribution of the water within the rock [16].

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II. Hydrostratigraphy

The overburden comprises the top clays, sand and alternative layers of sand gravel and boulder mixed strata. The study area is part of Peshawar basin, stratigraphic sequence in the Peshawar basin is generally Precambrian to Devonian metasediments [15]. The Indus River is the main river which recharges the whole aquifer system in study area. References [3], [10], [14] studied the surface and subsurface stratigraphy and lithology of borehole data (tube wells) and determined aquifer conditions in the Peshawar basin. Water is present in abundance in the Peshawar valley, coming from glacial melts in the north and northwest, and is used for drinking and irrigation purposes [2].

III. Methods and Objectives

VES survey was carried out in 16 locations (Fig. 1) using Schlumberger array configuration with cooperation of Geolog International Pvt. Ltd., and the well log data have been attained during their recent project in Tarbela Ghazi. A regular direction of N-S azimuth was maintained in the orientation of the profiles. Alluvial cover is not as thick as to enlarge the more widen current electrode spacing for deeper current penetration, therefore maximum 150-180 m electrode spacing AB was taken as standard for all VES. During electrical resistivity data acquisition ABEM terameter (SAS 1000) geophysical instrument was used. The field data obtained have been analyzed using computer software (IPI2win) which gives an automatic interpretation of the apparent resistivity. Resistance readings observed from the Terrameter were converted into resistivity. The objective of this study is to find out the apparent resistivity of subsurface layers, thickness of each subsurface layers, marking of potential zone, type of aquifers and depth of the aquifers and quality of groundwater.

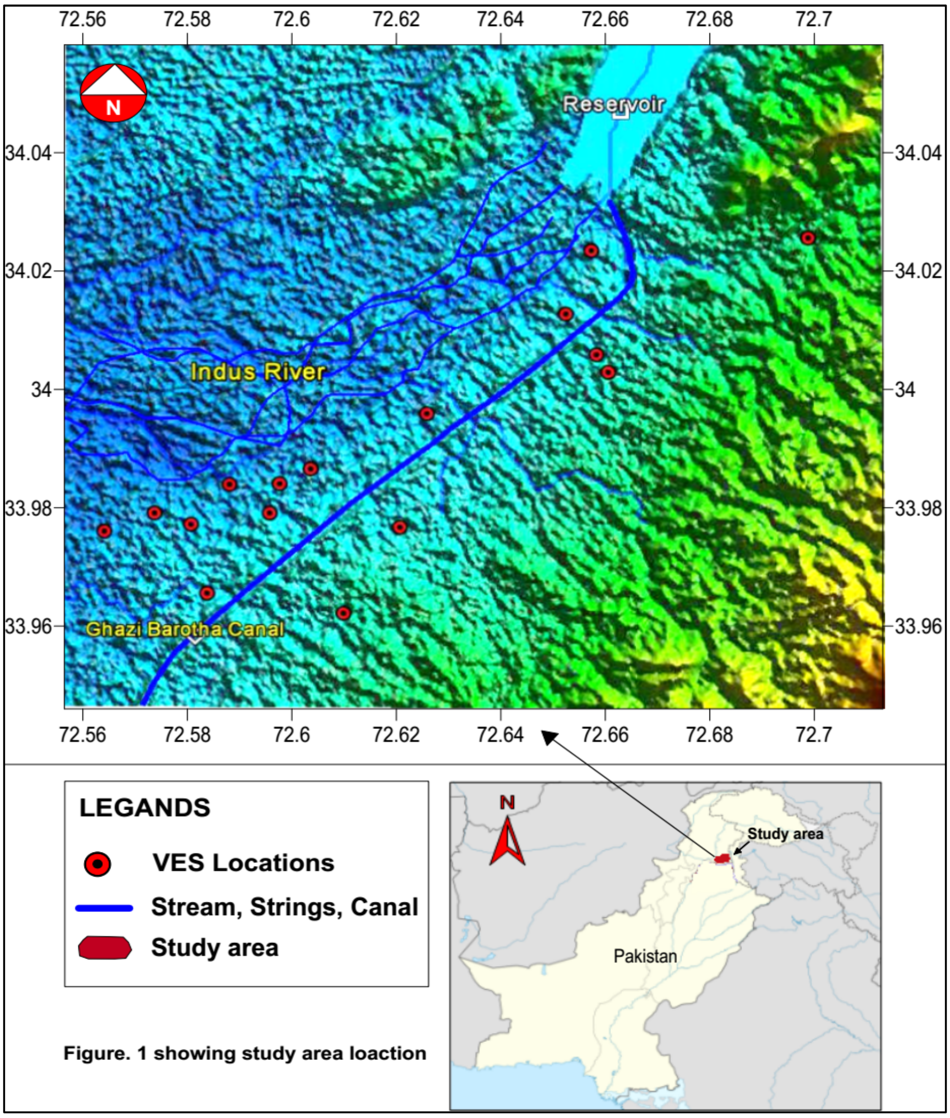

Fig. 1 Study area location map

IV. Parameters and Functions of Dar Zarrouk (DZ)

Dar Zarrouk parameters are described as the product of transverse unit resistance (Ohm-m^2) and longitudinal conductance (Siemens), whereas these parameters are basically important both in the data interpretation and modelling of stratified conductors in electrical prospecting. These units are quantitatively product of apparent resistivity and thickness of subsurface electro-stratigraphic model [12], [16].

As layered aquifer resistivity p_i and thickness h_i, the Dar Zarrouk parameters (longitudinal conductance **S** and transverse resistance **T**) are formulated as:

$$Si = \sum_{i=1}^{n} \frac{hi}{pi} \quad (Siemens) \qquad (1)$$

$$Ti = \sum_{i=1}^{n} pi.hi \ (Ohm.m^2) \qquad (2)$$

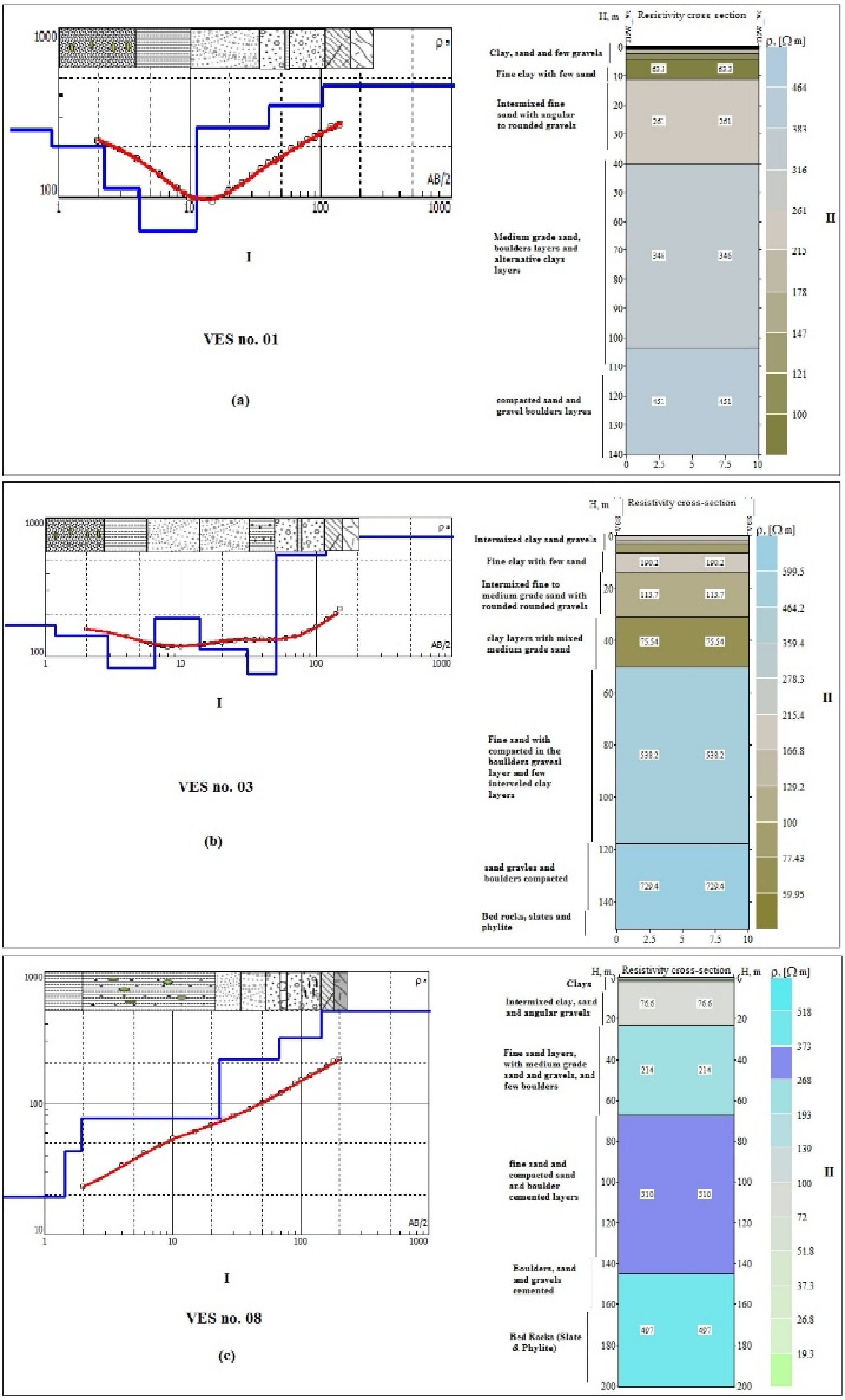

Fig. 2 IPI2win interpreted VES data, (I) resistivity block with lithological data, (II) electro-stratigraphic profile pf resistivity data

V. Result and Discussion

A. Vertical Electrical Sounding (VES)

The quantitative interpretation of the VES provided geoelectrical information which categorized through the assemblage of resistivity and thickness of layers. These geoelectrical units are characterized into electro-stratigraphic model. The interpretation of VES data was done using the software IPI2win. The average 2.1% error was obtained during final fitting between VES field data and model using IPI2win. Fig 2 detailed the field work that we acquired geophysical and geological data, and tube well lithological data in order to correlate amongst, and a particular relation between all parameters to develop and precise hydrogeological model. Groundwater model was determined to infiltrate between assembled high and low resistivity contrasts. This interpretation focused to determine the groundwater water table depth and differentiate between unsaturated sediments, and saturated sediments throughout the study area. Resistivity values for the unsaturated sediments fluctuate significantly (21.5 to 355 ohm-m), which is a representative sign for unsaturated sediments to saturated sediments resistivity values. Saturated sediments showed various subsurface resistivity face with interlinked to lithology, such as clay layers (resistivity < 40 ohm-m) and sand layers (resistivity $\geq$ 80 Ohm-m) because sand is compacted some location sand's resistivity values exceed to 120 Ohm-m. High resistivity anomalies beyond 50 -155 m depth at some resistivity locations were observed more then 300 (Ohm-m) marked bed rock dominantly slates and phyllites.

B. Geoelectric Layers

The resistivity data acquired using Schlumberger array and interpreted results using IPI2win software are described in Fig. 2. These acquired interpreted results using IPI2win software VES1, VES 3 and VES 8, show in Fig. 2, give subsurface layer's thickness, resistivity and lithology, compiling electro-stratigraphic column shows the subsurface groundwater distribution, with respect to each layer. VES sounding shows prominent curves type values, which deepen upon resistivity of consecutive geoelectrical layers. These shapes are known as Q-type (or DA. descending Hummel), H-type (Hummel type with minimum), A-type (ascending) and the K-type (or DA, displaced anisotropic). During recent study VES soundings data interpretation and plotting results show all the possible curve types such as, Q, H, A and K. Table I illustrates different cure type relating to each VES sounding data, VES 1, VES 3, and VES 8 having KH, QQH and AA types, respectively.

C. Aquifer

As a whole, two sand layers were identified: one corresponding to the unconfined aquifer and another to the confined aquifer, between two gravel boulder cemented layers. During recent study, four well were used as evidence to identify the whole aquifer's system in the study area. Table I is describing the thickness of the aquifer which ranges between minimum 24.1 m to maximum 149.52 m. There are three main different types of aquifers which have been marked unconfined, semi- confined and confined by interpreting the resistivity data well log data and litholog chart verses depth of tube well, while comparison amongst three data parameters gives precise aquifers depths and type and boundary between each aquifer Fig. 3. 3D model of aquifer system described in Fig. 4, this aquifer model is prepared using VES well log data and litholog data, model shows the layers of aquifers in Fig. 4 (a), whereas Fig. 4 (b) displayed types of aquifer and their lithologies with respect to depth, Fig. 4 (c) labels a zone marked as Perched aquifer in aquifer model system, water table and subsurface strata through the water bearing zones. Tube well no. 1 interpreted result and defined aquifer system shown in Fig. 3, which demonstrates a detail model of tube well including well log (Spontaneous Potential (SP) and resistivity curves), depth of tube well, lithological layers setting, water table and unsaturated to saturated zone identification. Confined super saturated zone exist between depths 64 and 106 m, which yields high amount of discharge in tube well.

D. Dar Zarrouk Parameters

Dar Zarrouk Parameters play a vital role in interpretations and modeling of geoelectric parameters. Mostly these DZ constituents are related to various acquaintances of the thickness and resistivity of each geoelectrical layer in the subsurface profile, anisotropy, transverse resistance and longitudinal conductance values have key impact in hydrological distribution. Anisotropy results ranges upto 0.63% VES no. 1, while VES- 8 shows maximum anisotropic value 1.314%, Table I. Transverse resistance a layer's thickness dependent parameter having minimum result 20523 Ohm-m^2 at VES 13 location and maximum value 39416 Ohm-m^2 observed on VES 3 site. Longitudinal conductance ranges between 0.42 Seimens at VES 1 and maximized up 1.567 Seimens at VES 8.

E. Groundwater Quality

Groundwater quality data show up reasonable results for various chemical analysis of different parameters and substances like Temperature, pH, Electrical conductivity (EC), Total dissolved solids (TDS), Bicarbonate (HCO_3), Chloride (Cl), Sulphate (SO_4), nitrate (NO_3), calcium (Ca) magnesium, (Mg), Sodium (Na), potassium (K) and total hardness (TH) in Table II. Fifteen groundwater samples were analyzed considering physiochemical parameters. Temperature for all groundwater samples range between 24.6-26.2 °C, pH ratio stays in standard permissible limit (6.7-8), electrical conductivity exceeded up to 336-668 µS/cm, Total dissolved solids values ranges between 165-450 mg/l, Carbonates percentage in the groundwater samples varies between 56-160 mg/l, bicarbonates come about hosting proportion up to 12–80 mg/l extent, chlorine test indicates the variegated qualitative values between 12 and 39 mg/l, sulfate examination indicates comes about values between 34-59. 3 mg/l, nitrate showing extent percentage between 9-46 mg/l, calcium values broke down outcomes indicate varies between 21-68 mg/l, magnesium reveals to up reach the middle of in admissibility breaking point (3-17 mg/l), sodium analyzed samples indicates the proportion (20-38 mg/l), potassium presenting different amount (25-43 mg/l), while aggregate hardness proportion remained in permissible limit (35-198 mg/l). The groundwater quality examined thorough tested samples indicates quality remains below permissible limit of WHO.

TABLE I
INTERPRETED VES DATA AQUIFER THICKNESS AND DAR ZARROUK PARAMETERS

	Resistivity (Ohm.m)							Thickness of subsurface layers (m)						
VES no.	*p*1	p2	p3	p4	p5	p6	p7	h1	h2	h3	h4	h5	h6	h7
1	249.7	250	199	113	63.3	261	346	0.335	0.533	1.35	1.92	7.1	28.8	63.4
2	241	234	204	61.6	192	355	-	0.5	0.75	1.88	7.63	14.4	99.3	-
3	169	142	83.9	190	114	75.5	538.2	1.18	1.7	3.53	7.3	17.4	19.1	67.6
4	159.4	109.6	251.6	173	487	-	-	1.597	5.8	24.23	31.13	45.82		-
5	162	204	80.7	280	154	302	-	2.04	1.32	9.02	5.64	18.6	54.27	-
6	114	56.1	106	166	192	313.4	-	2.1	1.57	7.89	12.3	21.2	72.7	-
7	156.2	113	289	117	342	262	-	1.2	2.8	4.32	14.9	27.7	55.6	-
8	19.3	43	76.6	214	310	-	-	1.45	0.483	21.3	44.4	77.12	-	-
9	31	125	39.6	131	336	-	-	1.78	4.08	11.6	29.3	89.4	-	-
10	159.1	96.35	171.3	78.55	366.9	-	-	2.271	6.035	22.17	46.64	62.58	-	-
11	64	134	170	132	74	339	-	1.74	1.8	4.03	26.2	47.7	62.1	-
12	47.2	102	157	93.94	320	-	-	3.02	6.14	17.3	50.5	59.8	-	-
13	166	112	316	-	-	-	-	3.76	4.48	29.4	-	-	-	-
14	39.7	21.5	87	227	397	-	-	1.369	1.15	16.2	45.9	69.9	-	-
15	71.04	89.23	321.7	128.5	-	-	-	3	13.35	58.56	51.3		-	-
16	57.7	104	174	132	314	-	-	1.34	17	9.412	46.8	57.4	-	-

Transverse resistance (Ohm.m^2)	longitudinal conductance (Seimens)	Anisotropy (%)	Curve Type	Aquifer thickness (m)	Water table (m)
21936.4	0.42	0.63	KH	109.2	5
38930.45	0.495	0.71	KHA	121.2	6
39416.68	0.6304	0.9455	QQH	111.4	6.5
34562.41	0.4531	0.738	HA	100.95	5
24130.93	0.4446	0.663	KH	83.87	4
30133.39	0.538	0.85	HA	105.7	4.3
26467.12	0.458	0.82	HK	101.15	4.4
35089.13	1.567	1.314	AA	141.52	4.1
35325.78	0.8464	0.43	KA	117.7	8.2
29830.64	0.994	0.572	HA	115.22	12
29077.76	1.091	0.77	AH	117.8	14
29281.56	0.9742	0.74	AH	110.3	13.5
20523.72	0.15725	1.11	A	29.4	6.8
39448.38	0.6539	0.7126	AA	115.8	7.2
35232.45	0.677	0.92	AH	123.21	5.4
27684.22	0.7685	0.63	AH	105.9	6.8

VI. CONCLUSION

This study, which will be pointed throughout investigating the groundwater potentiality, additionally aquifer characteristics from examining Tarbela Ghazi area, displayed fascinating resulting geoelectrical and hydrogeological techniques. Recent project describes there is huge volume of groundwater potential which is recharged accompanying through River Indus and precipitation. The groundwater quality remains under WHO standard, deep groundwater system zones nearly depth upto 45 meter is more permissible for drinking because the aquitard acted as boundary between unconfined to confined aquifer zones. The aquifer depth in the area was obtained to range between 5 to 150 m while determined the depth to the water level, defining: (1) unsaturated sediments, and (2) saturated sediments. Resistivity values for the unsaturated sediments varied considerably (21.5 to 355 ohm-m). For the saturated sediments, the following sequence can be defined for the locations studied: clay layers (resistivity < 40 ohm-m) and sand layers (resistivity ≥ 80 ohm-m) because sand is compacted some location sand's resistivity values exceed to 120 ohm-m. The aquifer is un confined to confined in nature, and compacted sand gravels boulders layers act as aquitard, a perched aquifer marked in area, aquifers system is developed at the alluvial deposit of Indus river, and piedmont deposits, whereas near mountainous area, aquifer is distributed in cracks and fissures of metamorphic rocks, such as slates and phyllite. The results of the hydrogeological parameters investigated also show that the groundwater is of good quality while the yield is adequate to provide the needed quantity desired by the people of the area.

3D hydrological model of area describes the well-developed aquifer system which is recharged by Indus River, at the vicinity of study area.

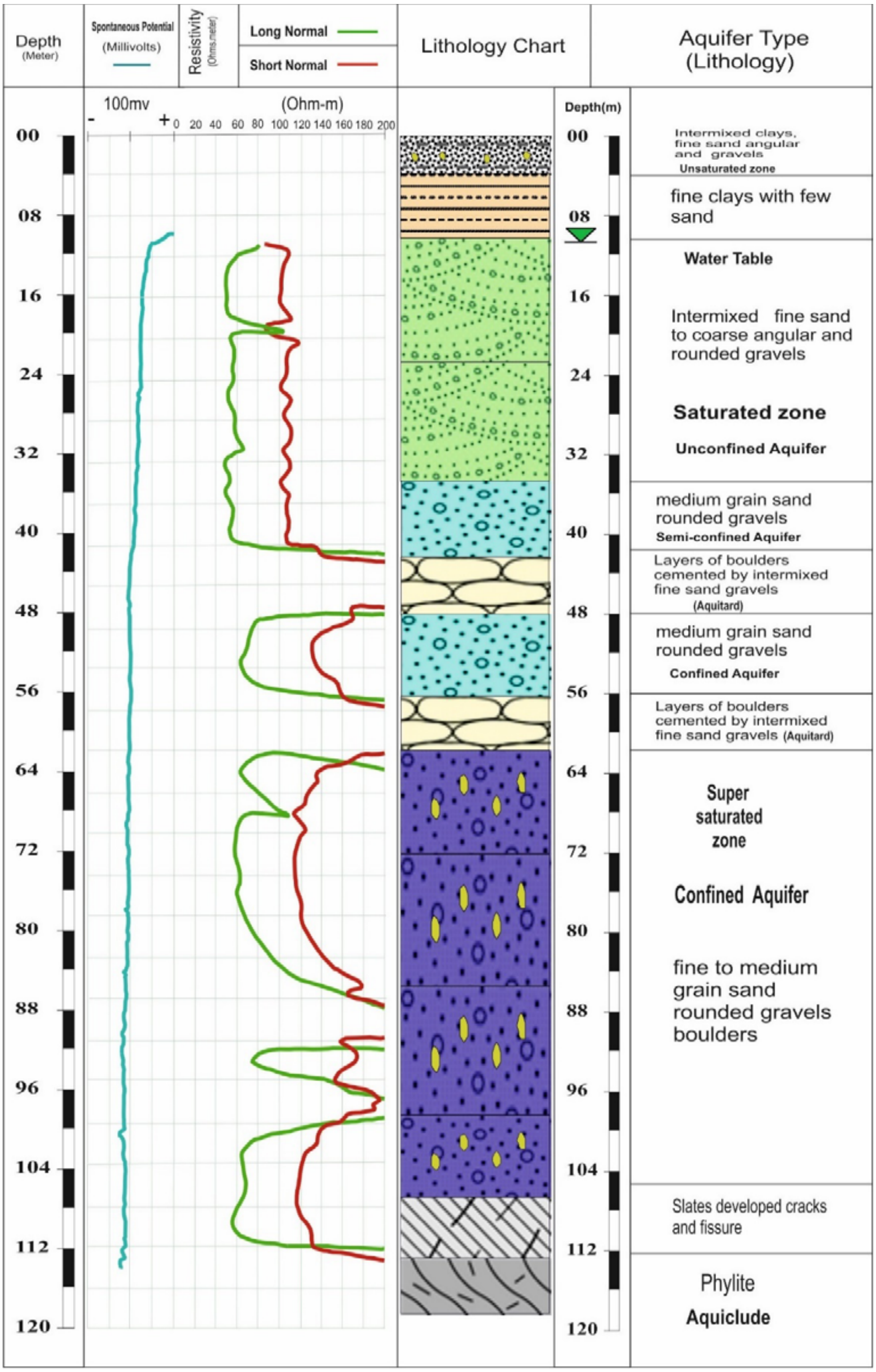

Fig. 3 The tube well no. 1, resistivity and SP log comparison with litholog and aquifer types with respect to depth

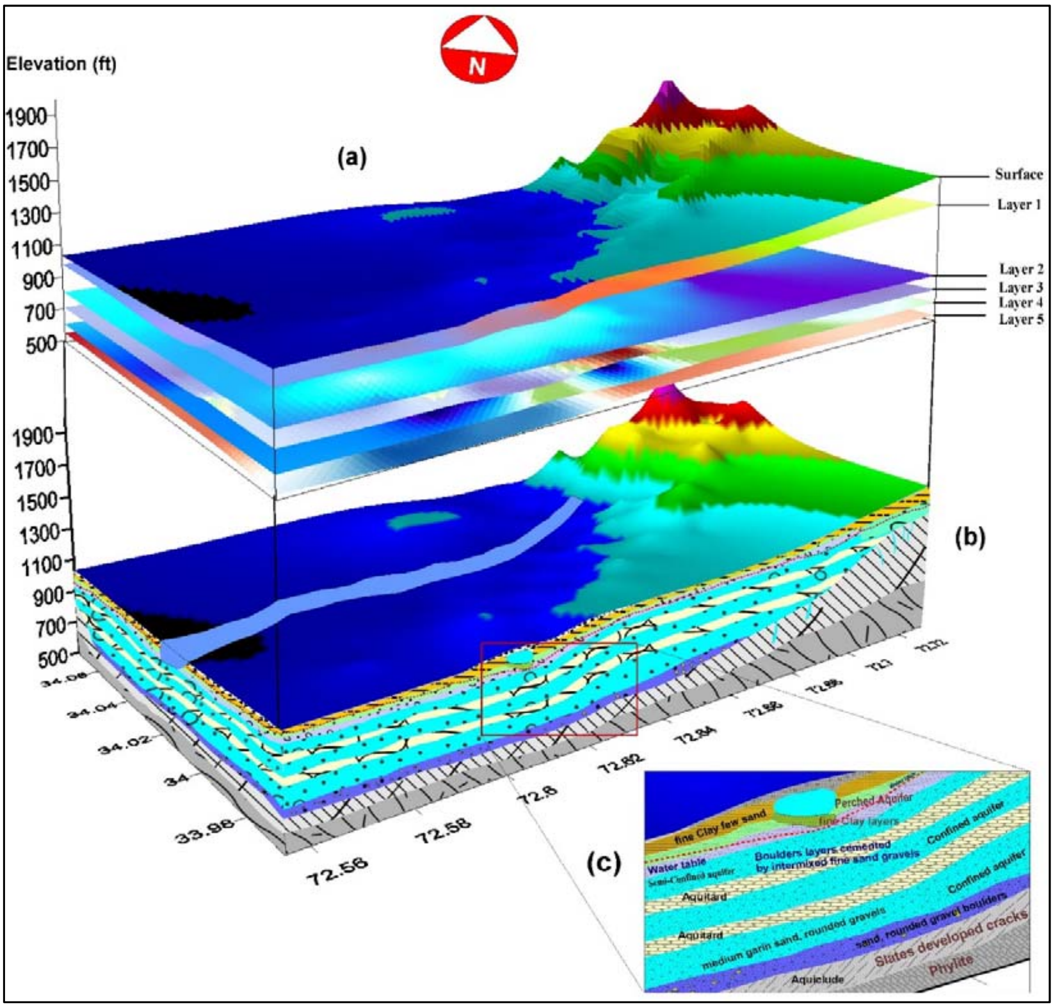

Fig. 4 3D model of Tarbela Ghazi area, (a) layers of aquifer and surface elevation and depth, (b) hydrogeological model, (c) subsurface lithological face at unsaturated zone to saturated zone, aquifer type, perched aquifer marked

TABLE II
CHEMICAL RATIO IN GROUNDWATER SAMPLE

Parameters	Minimum	Maximum	WHO standard (2011)
Temp (C°)	24.6	26.2	-
pH (on scale)	6.7	8	6.5 – 8.5
EC (µS/cm)	236	688	1500
TDS (mg/l)	165	450	‹ 1000
CO_3^{2-} (mg/l)	56	160	-
HCO_3^- (mg/l)	12	80	250 mg/l
Cl^- (mg/l)	22	39	< 250
SO_4^{2-} (mg/l)	34	59.3	250 mg/l
NO_3^{2-} (mg/l)	9	46	50 mg/l
Ca^{2+} (mg/l)	21	68	75 mg/l
Mg^{2+} (mg/l)	3	17	50 mg/l
Na^+ (mg/l)	20	38	50 mg/l
K^+ (mg/l)	25	43	-
TH (mg/l)	35	198	500mg/l

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