Site selection for artificial recharging of groundwater by application of geoelectrical method — A case study

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Abstract— To meet shortage of groundwater, the application of artificial recharge offers a great scope for the arid and semi arid regions as the water available in time of plenty can be stored in this manner for utilization in times of shortage. The choice of a particular method of recharge is governed by local geology, topography and soil conditions etc. The percolation of water into the zone of saturation is mainly dependant on the nature of lithology and thickness of the alluvial overburden. In this study, an attempt has been made to delineate different lithological conditions by the application of surface geoelectrical method at three different sites in the western part of Iran. The data obtained were interpreted and the results show that lithological mapping by resistivity method is a feasible factor in selection of recharge sites.

Keywords: artificial groundwater recharge, surface geoelectrical method, resistivity method

INTRODUCTION

With ever increasing demand on water resources, artificial recharge of groundwater is gaining importance as one of the strategies of water management. Artificial recharge is adopted to restore supplies from aquifer depleted due to excessive draft, to improve supplies from aquifers lacking adequate resources as in arid and semiarid areas, to store subsurface excess water for subsequent use, to prevent saline water intrusions in coastal aquifer, and to reduce land subsidence by increasing hydrostatic pressure conditions in artesian aquifers. The feasibility of artificially recharging groundwater is governed by the following factors (Karanth, 1994).

1 Availibility of suitable sites, mainly from topographical and cultural consideration.
2 Presence of suitable source of supply water.
3 Favourable lithological composition, thickness and permeability characteristics of geological formations.
4 Hydrodynamic conditions in the aquifer, and
5 Cost benefit considerations.

A number of methods have been formulated for estimating groundwater recharge, such as direct measurement, Darcian approach, tracer techniques, isotopes dating, chloride mass balance equation, analysis of base flow hydrographs and spring discharges, numerical modeling and water budgeting Naik & Awasthi (2003). Techniques based on groundwater levels are found to be the most widely used method for estimating recharge rates (Healy & Cook, 2002). However, prior to this the feasibility of artificially recharging groundwater is to be considered as is governed by the several factors like, presence of suitable source of supply water and lithological composition, thickness and permeability characteristics of geological formation etc.

GEOELECTRICAL METHOD IN SELECTING FEASIBLE RECHARGE ZONE

The geoelectrical, seismic, magnetic and gravity prospecting methods can be used to reduce substantially the amount of test drilling and in selection of sites for future exploitation of groundwater. Seismic prospecting provides fairly accurate estimates of the depth to different layers and bedrock, while gravity prospecting may be used successfully in determining broad and deep valleys and caverns in limestone. In direct current electrical prospecting two methods are used, the first one is electrical profiling, which provides information about the lateral variation of resistivity. The second method (vertical electrical sounding) provides information about the resistivity variation with depth.

Geoelectrical method is an effective tool for ascertaining the subsurface geologic framework of an area (Keller & Frischknechdt, 1966; Griffith & King, 1965; Zohdy *et al*., 1974). Researchers have also developed surface resistivity techniques for making quantitative estimates of water transmitting properties of aquifers Tizro & Singhal (1993), Tizro (2002) and Mazac *et al*. (1985).

The goal of this paper is to ascertain the subsurface geological framework by application of geoelectrical method at three selected sites (A, B, C) as shown in Figure 1 to determine thickness of layers and their corresponding resistivities and also to ascertain the success of this method in determining the contrast between appropriate physical properties of the geological materials present in the subsurface and finally to delineate feasible recharging zones.

BACKGROUND

Site location

The area is at the foot of the Alvand Mountain, located to the north east of Hamedan west of Iran. The area has a network of roads and is connected to Hamedan, the state capital. Three selected sites, A, B and C as shown in Figure1 were examined. The area A, located near Qareh Aqach River is underlain by alluvial deposits of varied composition which increases in thickness towards the south and forms an aquifer known as the Bahar and Lalejin Basin (Figure 1).

The principal study area selected is the Qareh Aqach River aquifer which is relatively small in width. The aquifer is made up of a thick veneer of alluvial formations and presently forms recharge sites.

Resistivity soundings were also made in the Asad Abad basin to furnish and locate fractures to obtain existing subsurface data in site B. The aquifer is bordered by metamorphosed schistose and partly crystallized rocks in the east and forming a broad plain in the west providing high-yielding wells for agricultural use. Groundwater occurs under water table conditions in the alluvial, weathered, fissured, jointed and fractured zones. Detailed study of borehole lithology data reveals that the depth to the basement topography ranges from 20 m to more than 75 m below ground level in site C.

Meteorological Conditions

The study area experiences a cold winter with a minimum temperature of -9 °C and moderate summers with a maximum temperature of 35 °C. Average annual rainfall in this region is about 350 mm. The entire catchment comes under the influence of Mediterranean front, and the major part of the precipitation is received between February (Bahman) and March (Farwarding). Demartin type of classification shows that the climate is semi-arid.

Physiographic Setting

Physiography here is concerned with the evaluation of topography, soil, vegetation, land use and stream network which are principal factors in hydrological processes. The area has well-defined physiographic features.

(1) The Lesser Alwand

The Lesser Alwand ranges from 2500 to 3000m in height. It has deeply dissected valleys which suggest that rivers are still actively at work. This belt can be further divided in to two regions:

(i) High batholithic mountains have been demarcated by the 3000 m contour. These consist of small snow-capped mountains. The Qareh Aqach, Bahadour Big, Saleh Abad, Soulan, Abas Abad, Dareh Morad Big and Yalfan which are sub catchments with asymmetrical slopes forming characteristic features of the region. The tributaries of these catchments are U-shaped valleys with moraines and are smooth with aggradational slopes.

Fracturing is caused by the tectonic and intrusive activity in country rocks and the debris from landslides accumulates at the base of escarpments.

(ii) Low to moderately high mountains occur in the

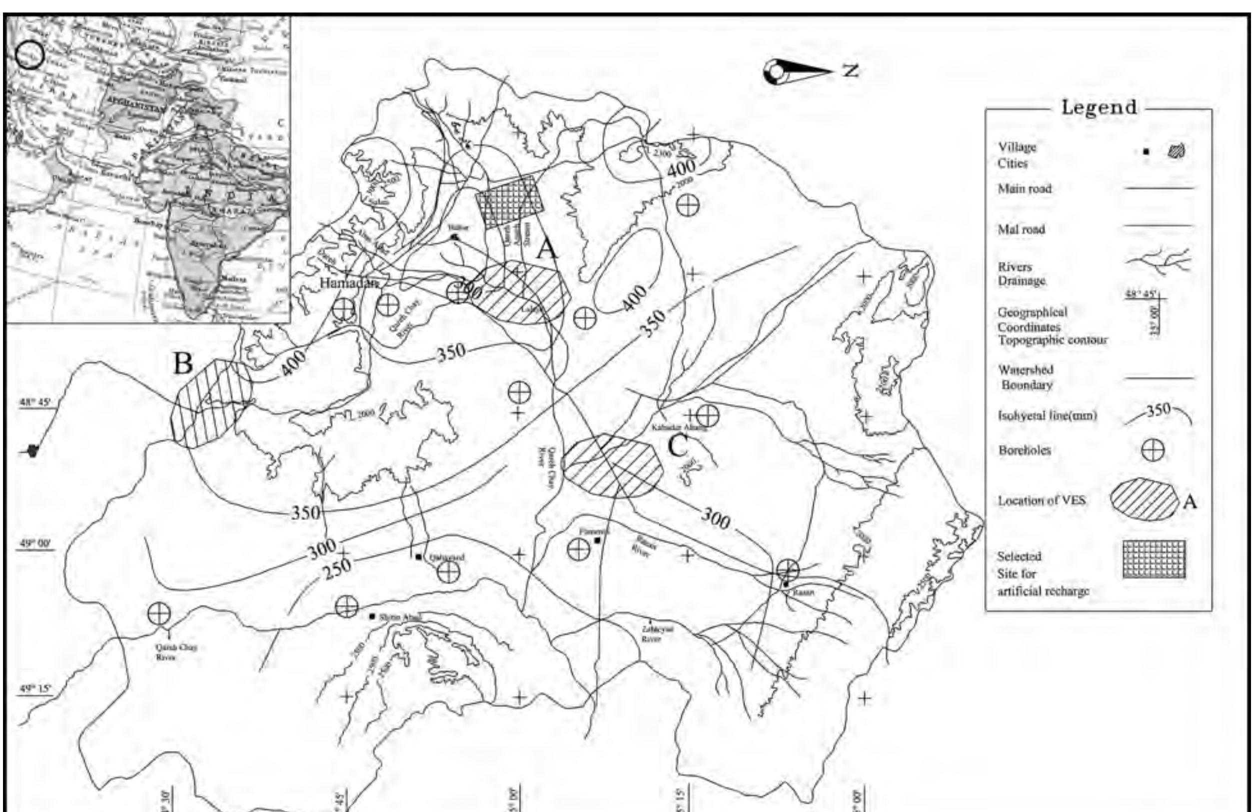

Figure 1: Index map of the study area.

altitudes of 1000 m and 2000 m above MSL. The massive mountainous tracts are underlain by metamorphic formations with series of ridges and spurs dividing river valleys. The slopes vary from 25 to 30 percent. The rivers and their tributaries form entrenched valleys at the higher reaches. The rivers form depositional terraces at a number of places and cause head-water erosion. The Harun Abad hills are formed as a result of intense dissection by fine-textured pattern drainage lines. They form long prominent ridges trending NW-SE with altitudes above 1500 m. The river is drained by numerous parallel to sub parallel streams flowing southwards.

(2) Depositional Features

These are alluvial plain, point bars and flood plains. The alluvial plain occurs in the central part, and are composed of sands admixed with other materials. Point bars have been observed at a few places but are not large and these represent gradational features, though their groundwater potential is likely to be moderately good.

(3) Drainage Pattern and Rivers

The drainage patterns are dendritic in character. In abnormal season the rivers have less runoff and in the dry period these rivers becomes non-entities with no water flow.

GEOLOGY

The area lies in between the tectonic zones of Alborz and Sanandaj-Sirjan, and is considered to be a tectonically active area. Intrusive (granites, granodiorites, diorites, gabbro), metamorphic (marble, schist, astrolite, andulusites) and sedimentary sequences (limestone, marl, shale, sandstone, dolomites) and volcanic rocks such as basalt, tuff are exposed in the area.

The area has been mapped on 1:250000 scale by the Geological Survey of Iran and the geology described by Braud (1970) and Boulourchi (1979). The following brief description of geology is intended to bring out only features of hydrogeological aspects. The reader is referred to the original references for more detail if needed. The geology of the area is shown in Figure 2. Table 1 represents the stratigraphical succession and gives broad descriptions of each formation.

GROUNDWATER OCCURRENCE AND CONDITIONS

The occurrence of groundwater in the area is controlled by diverse geological factors e.g. structures and geological sequences and stratigraphical disturbances of hydrogeological units. The occurrence of groundwater in the area can be studied in two parts.

Table 1: Stratigraphic succession.

Age	Formations
Quaternary	Recent alluvium
	Younger gravel fans
	Older terraces and fans
Oligo-Miocene	Limestone, marl, marly limestone, conglomerate
Cretaceous	Shale with intercalation of limestone, sandstone dolomitic
Jurassic	White limestone, partly crystallized and interceded with slate, shale slate and shcist
Pre-Jurassic	Metamorphosed shale, calcareous sandstone.

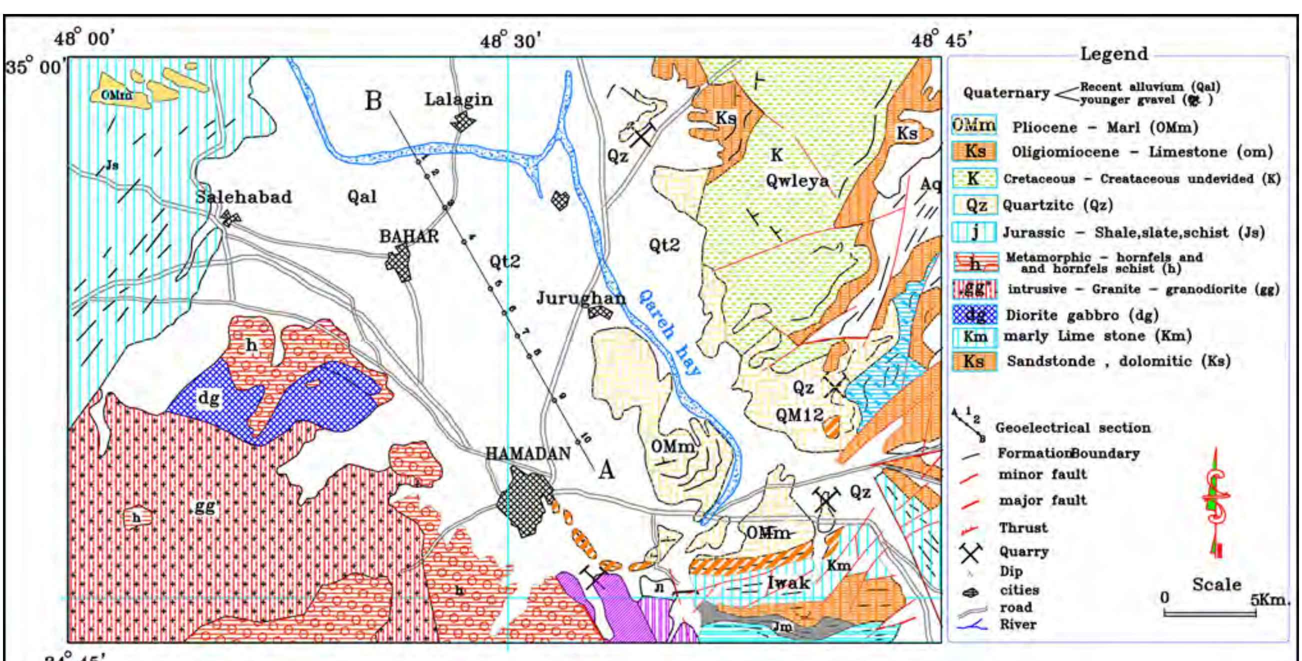

Figure 2: Geological map of the study area.

(i) The north east, eastern and south east parts where thick alluvial formations constitute the aquifer-aquiclude systems. Alluvial deposits, comprising silt, sand and gravel, occur along the major river tributaries and include good aquifer horizons.

Lithological data from the exploratory wells show that the thickness of aquifer increases in the central part of the basin and reaches up to 110 m, whereas in the periphery it is 40 m only.

The point bars, which consist of unconsolidated sediments of coarse to medium grain size, appear to form groundwater storage, but due to small size of river and its ephemeral nature, the groundwater potential of point bars are limited.

The erosional valleys, located in the eastern parts appear to possess good groundwater potential. The geological and hydrogeological studies have revealed the existence of deeper aquifer zone in the confined state as it is overlain by impermeable beds of considerable thickness in the eastern part of Bahar Basin. Limited numbers of deep bored wells have been drilled in the area. So existence of deeper zone in the confined state can be studied on the logs geoelectrical data and few available lithologs.

(ii) The south- western parts, where the weathered and fractured rock formations occur are likely to form aquifers. The occurrence and also movement of groundwater are controlled by the nature, depth and intensity of weathering.

A gently sloping horizontal well, known as Qanat, was dug through alluvial materials to lead water by gravity flow from beneath the water table at higher elevation to the ground surface outlets. Vertical shafts dug at closely spaced intervals provide access to the tunnel. The vertical collapsed wells persist to the present day and can be seen in the band across Lalejin regions. The collapse of Qanat wells was due to overdraft conditions in the region.

There are 2169 deep wells discharging 314 MCM of groundwater annually. The value of transmissivity is of the order 200 to 250 m^2/day in the periphery, and up to 900 m^2/day in central part of the basin.

The study of water level data of wells offers a useful technique for evaluating the subsurface geohydrological regimes. Different workers like Davis & DeWiest (1966), Freeze & Cheery (1987), Fetter (1988), and Karnath (1994) have dealt in detail about the methods of analyzing the water level data of wells tapping unconfined and artesian aquifers. From the depth to water table maps (DTW) of area it is inferred that, the depth to water table (Figure 3) is highly variable being shallow in the western part and greater than 50 m below ground level in the north and 36 below ground level in the south east.

The movement of groundwater is from recharge area of upper hills towards central part of the basin ultimately discharges into the Qareh Chay River.

The unit hydrograph analysis of observation well stations during the years 1981-2003 shows that there is average decline of about 20 m in the static water level in region. Figure 4 shows a selected hydrograph of the Bahar Basin. The quality of groundwater has also deteriorated and this can be alarming. These issues call for better water resources management including augmentation of groundwater through artificial recharge measures. For purpose of increasing the potential of groundwater supply in the area recharge well method can be very useful in the northern part as this area experiences highest decline in groundwater level. Selected site for artificial recharge is shown in Figure 2.

Studies based on available lithological data reveals that the thickness of the aquifer increases from the periphery to the central parts i.e. Bahar and Lalejin and it reaches up to 110 m.

The available lithologs have failed to provide a synoptic picture of the subsurface features especially in the central part of the area. Accordingly, attempts are made to decipher the subsurface picture from the interpretation of the generated geoelectrical data.

GEOELECTRICAL MEASUREMENTS AND INTERPRETATION

Measurements

Vertical electrical soundings (VES) were conducted with Schlumberger Configuration at three sites (Figure 1). The advantages of the Schlumberger method (Bhattacharya & Patra, 1968; Keller & Friscknechdt, 1966; Zohdy *et al*., 1974), particularly the interpretation techniques available, made it the choice for this study. The maximum current electrode spacing was kept between 400 m and 500 m. The apparent resistivity data for different values of AB/2 have been processed and sounding data for 55 VES locations were obtained. A selected VES field curve is presented in Figure 5.

Interpretation

The main purpose of interpretation of resistivity data is to determine the true resistivities and thickness of different layers purely on theoretical considerations. These results were subsequently used to obtain realistic picture of the geological framework. Therefore quantitative and geologic methods have been applied in the interpretation. The quantitative method is classified as indirect, and direct. Koefoed (1979) has described the techniques used in the indirect interpretation. A comprehensive account of various approaches of automatic interpretation of resistivity data has been given by (Zohdy *et al*., 1974: Zohdy, 1989; Sriniwas & Singhal, 1983).

The fast iterative method for automatic interpretation of sounding data (Zohdy, 1989) produces the interpreted depths and resistivities respectively and does not require any initial guess of the number of layers and their thickness. The number of layers in the interpreted model equals the number of digitized points of the sounding curve. This method has been utilized for the quantitative interpretation of VES data and the true resistivity values and the corresponding layer

Table 2: Result of interpretation of VES data.

VES No	Top Soil		Unsaturated Zone		Aquifer		Bedrock	
	Resistivity (ohm-m)	Thickness (m)	Resistivity (ohm-m)	Thickness (m)	Resistivity (ohm-m)	Thickness (m)	Resistivity (ohm-m)	Thickness (m)
SiteA1	12	2	35-100	28	20-24	20	72	-
A2	15	2	40	25	25	22	>80	-
A3	12	1.5	30	28	30	28	>100	-
A4	10	1.8	28	30	28	30	>120	-
A5	11	1.5	30	28	25	28	>100	-
A6	12	1.5	28	25	31	30	>80	-
A7	10	2	25	32	22	32	>100	-
A8	10	2	22	30	13-40	65	>60	-
A9	10	1.5	20	31	44	60	>80	-
A10	11	2	30	28	20-25	65	>100	-
A11	55	2	46	28	40	60	>70	-
A12	50	2	52	25	39	60	>65	-
A13	65	1.8	43	24	33	62	100	-
A14	70	2	50	25	40	61	55	-
B1	105	2.8	120-260	38	130	40	214	-
B2	118	2.5	206-400	40	88	38	230	-
B3	200	3	>200	35	55-80	35	513	Fracture
B4	>300	2	267-300	35	127	30	378	-
B5	116	2	415	30	98	40	459	-
B6	200	2	158	35	40-60	40	496	Fracture
B7	103	1.5	>130	32	89	41	>300	-
B8	110	2	100	31	100	40	250	-
B9	200	2	>100	30	120	41	300	-
B10	150	2	210	30	130	40	350	-
B11	120	2	200	31	110	40	358	-
C1	40-50	1.5	70-80	40	50	35	35-100	Fracture
C2	40-55	2	70	40	60	30	168	-
C3	67	2	>20	55	55	25	110	-
C4	60	2	90	50	19	20	>100	-
C5	70	1.8	95	45	70	30	>150	-
C6	40	2	100	40	90	31	100	-
C7	75	2	>50	35	28	30	150	-
C8	77	2	80	30	>50	35	>80	-
C9	77	3	80	32	70	30	>90	-
C10	60	2	>100	31	80	31	>90	-
C11	37	2	135	30	80	31	32	Fracture

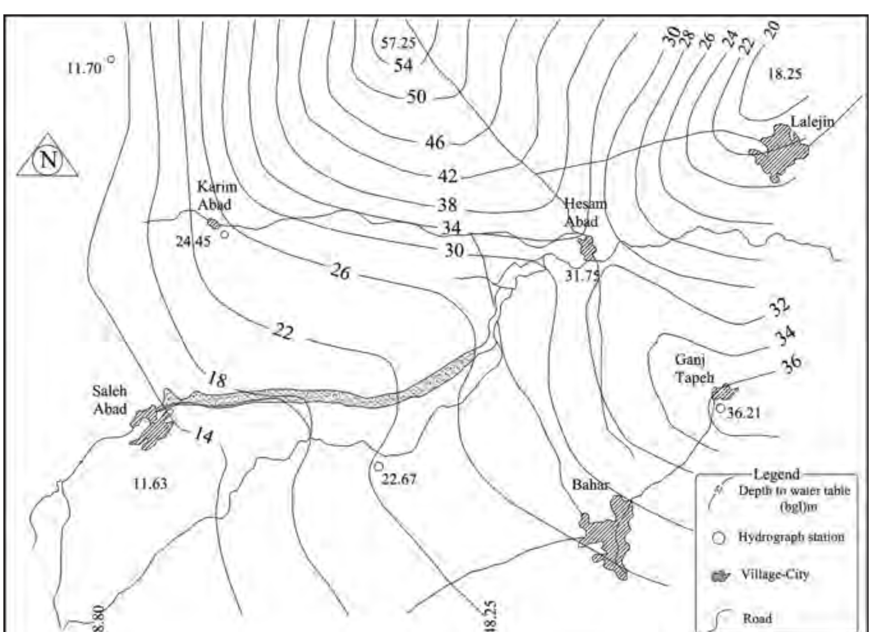

Figure 3: Depth to water table contour map (post monsoon in 2003).

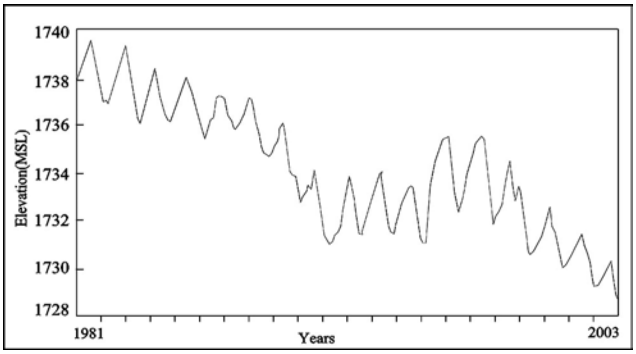

Figure 4: Unit hydrograph of Bahar well station.

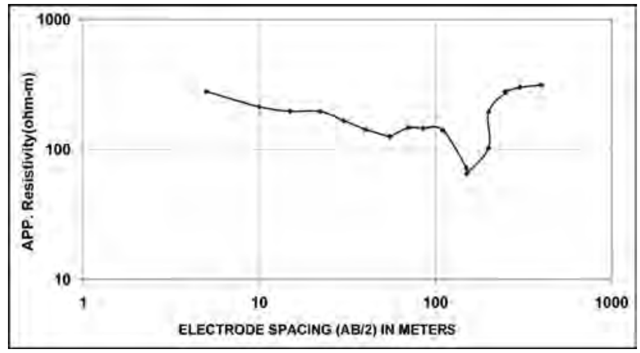

Figure 5: Selected field curve (B-6).

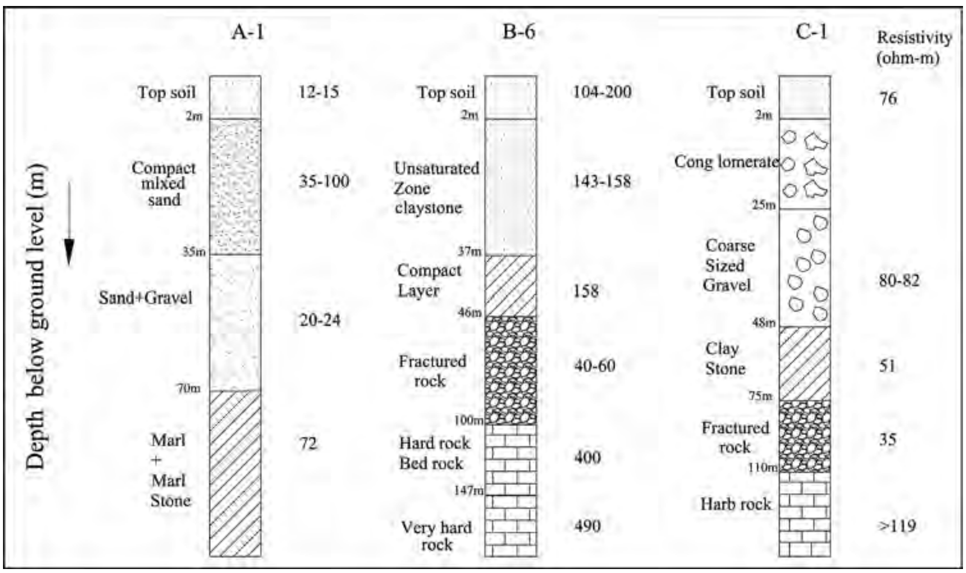

Figure 6: Schematic geoelectrical sections of selected sites.

thickness interpreted are given in Table 2.

The data has been carefully compared with the lithologs of boreholes located in the vicinity of the corresponding sounding for sites A, B and C. The general distribution of resistivity response of the formations is obtained from these soundings. Table 2 illustrates the range of resistivities for different geological formations. It is observed that resistivity for sandy horizon varies from 35 to 100 ohm-m whereas for predominantly clay zones, it ranges from low to high resistivity. The rock formations exhibit a wider range of resistivity i.e.150 to 400 ohm-m respectively. The low values of resistivity for these formations imply their friable and weathered nature.

Geoelectrical sections prepared from the interpreted VES data are shown in Figure 6. From this figure it can be concluded that the site A1 can be considered as a favorable site for artificial recharge, as the area possessing alluvial formation, whereas at sites B6 and C1, the subsurface layers are characterized with the compact zones at top and weathered nature of hard rock formations can be favorable sites for recharge. To ascertain the geological framework the general distribution of resistivity response of the formation has obtained and a geoelectrical section along AB line have been prepared (Figure 7) to study variation in lithology in north to southern direction. The location of the section and position of respective sounding points are shown in Figure 2. The thickness of the alluvial burden increases in central parts of the basin.

CONCLUSION

The unit hydrograph analysis of observation well stations during the years 1981-2003 shows that there is average decline of about 20 m in the static water levels in region. The quality of groundwater has deteriorated and this can be alarming. These issues call for better water resource management including augmentation of groundwater through artificial recharge measures. The feasibility of recharge depends on availability of hydrogeologically suitable sites. Nature of subsurface layers and their characteristics can be identified by the application of geoelectrical method.

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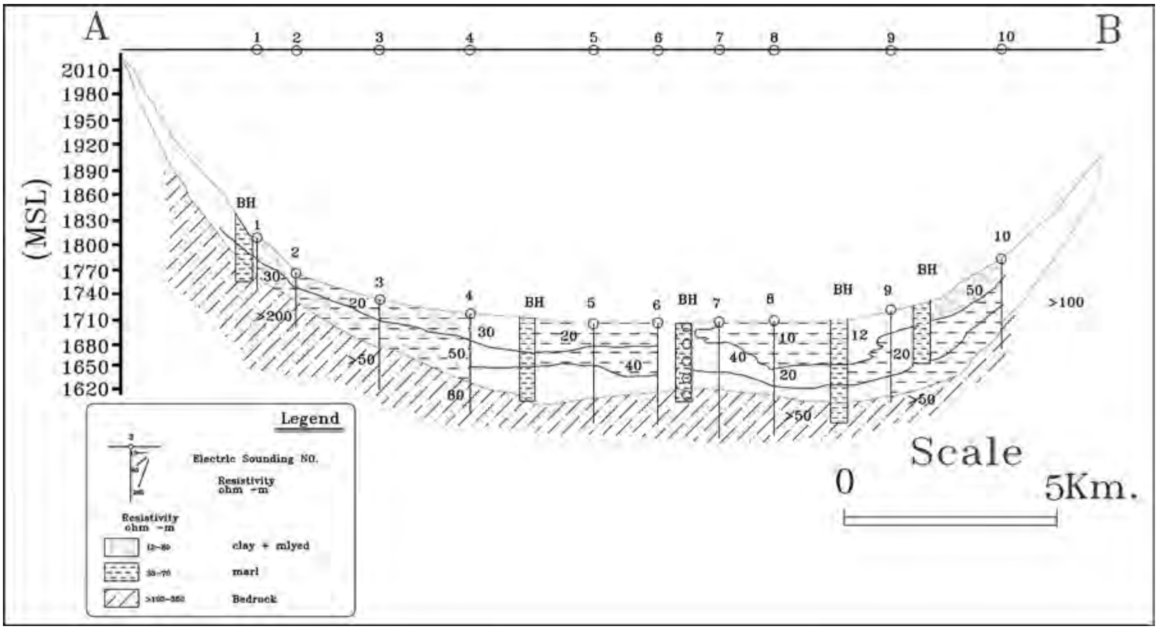

Figure 7: Comparison of boreholes lithologs and geoelectrical sections.

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