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DELINEATING FRESH/SALINE INTERFACE AND FRESHWATER POCKETS USING VES SOUNDING & WELL LOGGING IN AGRA, UTTAR PRADESH

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ABSTRACT

Agra is situated in a semi-arid region on the bank of the Yamuna River. Agra is one of the major urban setups of western Uttar Pradesh. Deteriorated groundwater quality at variable depths is an intervening problem for groundwater development in Agra city and its nearby urban areas. The available fresh groundwater occurs in shallow pockets or brackish/saline sandwiched environments. Integrated VES (Vertical Electrical Sounding) studies for drilling sites and further Well-Logging Data analysis have provided suitable fresh groundwater zones. Initially, nine VES correlated with two well-log data. Based on nine VES results and two well-log data, fresh groundwater zones have been delineated in the study area. The study revealed the presence of fresh to moderate water zone limited to the above 70 mbgl (meter below ground level). Where freshwater delineated 40 mbgl and later on 40 mbgl to 70 mbgl moderate water quality was found. The discharge of both wells was more than 500 lpm (liter per minute). One sounding also delineated the presence of sandstone bedrock of nearly 170 mbgl. The present work proposes a prominent fresh-saline groundwater interface and freshwater pocket delineation using VES and Logging Data.

Keywords: *Groundwater, VES (Sounding), Saline-Fresh Interface, Well Logging, and semi-arid.*

INTRODUCTION

Groundwater is vital in fulfilling the area's drinking, irrigational and industrial needs, as it is a highly dependable and replenishable natural resource. As a critical tourist place in Agra, the need for drinking water in the metropolis has increased. Due to the occurrence of brackish to saline groundwater pockets at varying depths and increasing pollution on the surface. Surface water and groundwater resource scarcity are becoming a grave problem day by day, especially in urban areas. Groundwater resource management is essential for overall human development and sustainability Yadav et al. (2003) & Birendra Pratap (2006).

Geophysical methods provide a relatively low-cost approach to hydrogeologic characterization. Numerous papers illustrate the utility of geophysical methods in defining subsurface heterogeneity in aquifer properties (Kelly and Mares 1993). Combining geophysical methods help explore groundwater, Singh, Anirudh, et al. (2021).

In this following integrated geophysical study, we used four DC electrical surveys to clearly explore the fracture in hard rock with minimum ambiguity. Kearey and Brooks (1984) and Telford et al. (1990) has also discussed the geophysical survey geometries and array. Recently many researchers worked on composite geophysical investigation in different geological settings, Yadav and Singh (2007). Also, the correlations between electrical resistivity and geotechnical parameters were investigated by Devi et al. (2017).

The present study aims to delineate the freshwater zone in Agra, both urban and semi-urban setups. To figure out the general fresh and saline water interface and configure the bedrock depth. Resistivity surveys (VES) were conducted at nine places in the study area of Bichpuri Blok, comprising most of Agra City. Two Well Log data have been analyzed at the VES site recommended for exploration post Surface VES exploration.

STUDY AREA

The Agra district occupies the westernmost part of Uttar Pradesh, is bounded by the Rajasthan and Madhya Pradesh states in the west & south and by Mathura, Etah, Firozabad, Mainpuri, and Etawah districts from north to East, respectively. Agra comprises an area of 4027 sq. Km lies between latitude 26^0 44'10", to 27^0 24'30" North and longitude 77^0 30'15" to 78^0 51'30" East under the Survey of India topo sheet Nos. 54 E, F, I, and J (Figure-1).

GENERAL GEOLOGY AND HYDROGEOLOGY

The study area Agra district lies in the Indo-Gangetic plain, and its significant part (about 80%) is occupied by Quaternary alluvium. However, Vindhyan rocks (Bhander sandstone) are exposed in the western and southwestern parts of the area. The granular zones consist mainly of alluvial sands and gravels, forming the two-tier aquifer system in the area. (Chowdhary R. Sujatro & A.V. Singh, CGWB 2019)

The Agra district is mainly covered by a thick pile of Quaternary alluvial sediments with some patches of hard consolidated rock outcrops of the Bhander group under the Vindhyan supergroup. The Bhander Group consists of rocks viz. quartz arenite, sandstone shales, shale pebble

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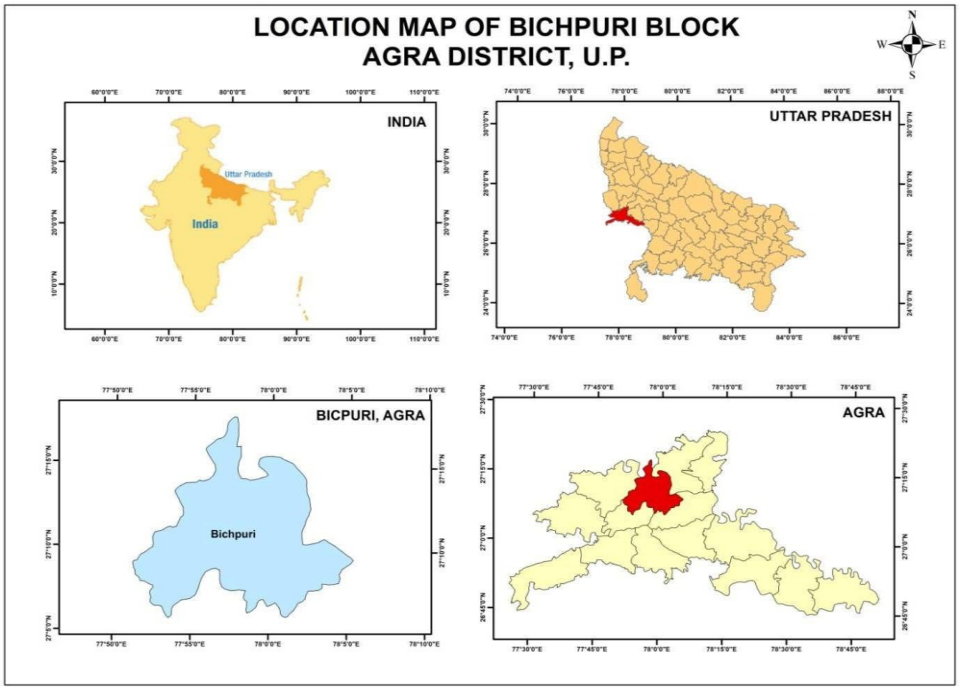


Fig. 1: Study Area Map and VES investigation site.

conglomerate, and siltstone. The Vindhyan supergroup belongs to the Proterozoic-III age.

The alluvium of the Quaternary age is based on its age and constituents, which can be further classified as Older Alluvium and Newer Alluvium. All these sedimentary formations were deposited as the valley fills unconformably on the Vindhyan Sandstones during the middle to late Pleistocene and Holocene times and are comprised of different grades of sands, silts, clays, gravels, and secondarily developed calcareous nodules known as kankar.

The older alluvium is represented by Varanasi Alluvium of middle to late Pleistocene age and is a polycyclic sequence of oxidized, brownish-yellow silty-clay with kankar disseminations and grey to brown fine to medium-grained micaceous sand. It has been further classified into silt-clay facies and sandy facies.

The Holocene age's Newer Alluvium comprises two units, viz. Terrace alluvium and Channel alluvium. The channel alluvium is confined to the present banks of the Chambal, Yamuna, and Gambhiri rivers, while the terrace Alluvium is exposed only along the Yamuna and Gambhiri rivers.

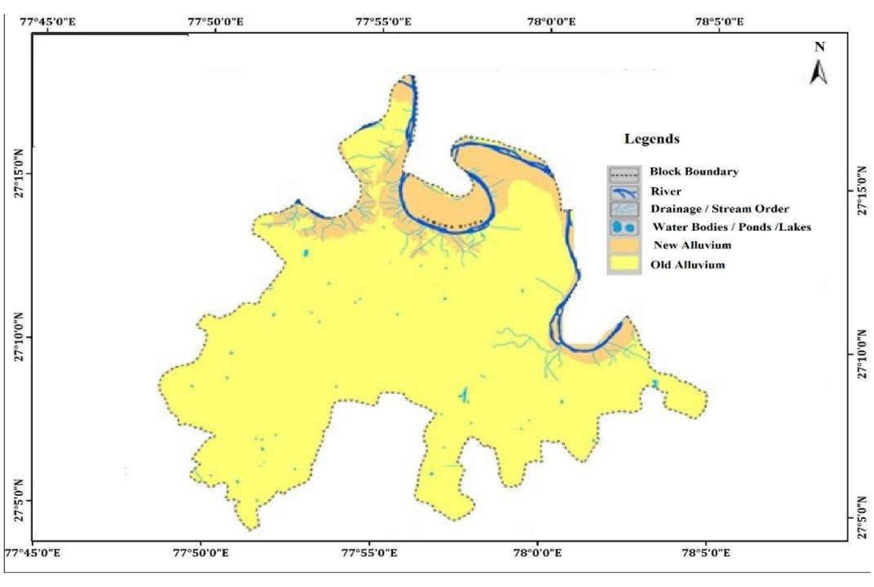


Fig. 2: Surface Geological Map of Agra City (Bichpuri Block).

METHODOLOGY

VES-Schlumberger Sounding

The electrical resistivity of the earth material is a function of subsurface rock-making material quality, as well as the quality of groundwater present in the formation. The presence of clay contents, material size, and saturation of material of the formation skeleton affect the formation of true resistivity. Formation resistivity is considered an effective parameter to decide upon the suitability of a formation for groundwater availability and quality. The electrical resistivity of a formation increases with the granularity of aquifer material and the improvement in the water quality and decreases with the finer sediments and deterioration in water quality.

In the vertical electrical sounding (VES) Schlumberger method, an array of electrical currents and potential of electrodes in a straight line was used. Out of these, two outer electrodes are current electrodes used for injecting the current into the ground, while the inner electrodes, called potential electrodes, are used for reading the corresponding potential signal. Increasing the distance between the current and the potential electrode, the effect of the deepest zone gets pronounced. The potential difference and the current fed are measured for each changed current and potential electrode position. Thus, the obtained resistance is multiplied by the geometric factor of the arriving resistivity. The Apparent resistivity value is plotted against half of the current electrode separation. The analysis gives effective resistivity and (thickness) depth of different sub-surface formations, forming the layer parameters. In these layer parameters, one parameter is resistivity, and another is the thickness of the corresponding layer.

The mathematical expression for apparent resistivity ρ (a) in vertical electric sounding is given.

(2)

Where L is the distance between the center and current electrodes, X is the distance between the center and potential electrodes, ΔV is the observed potential difference, and 'I' is the input current.

A total of 9 VES were conducted out of these 4 soundings in Agra city and 5 soundings in the suburban area shown in figure-3.

The city area has two soundings conducted in Bhoor Ka Bagh and Kamla Nagar. In the available space, the space available was 80 m minimum and 200 m maximum. In the Suburban area, out of the 5 VES, 3 soundings were conducted around Patti Pachgain and one in Nagla Laljeet and Chor Nagaria.

Well-Logging

Exploratory drilling and geophysical well logging are the most practical solutions for executing exploration programs (Kwang et al., 2004).

Geologic formations with varying chemical quality of water present in their pore spaces offer

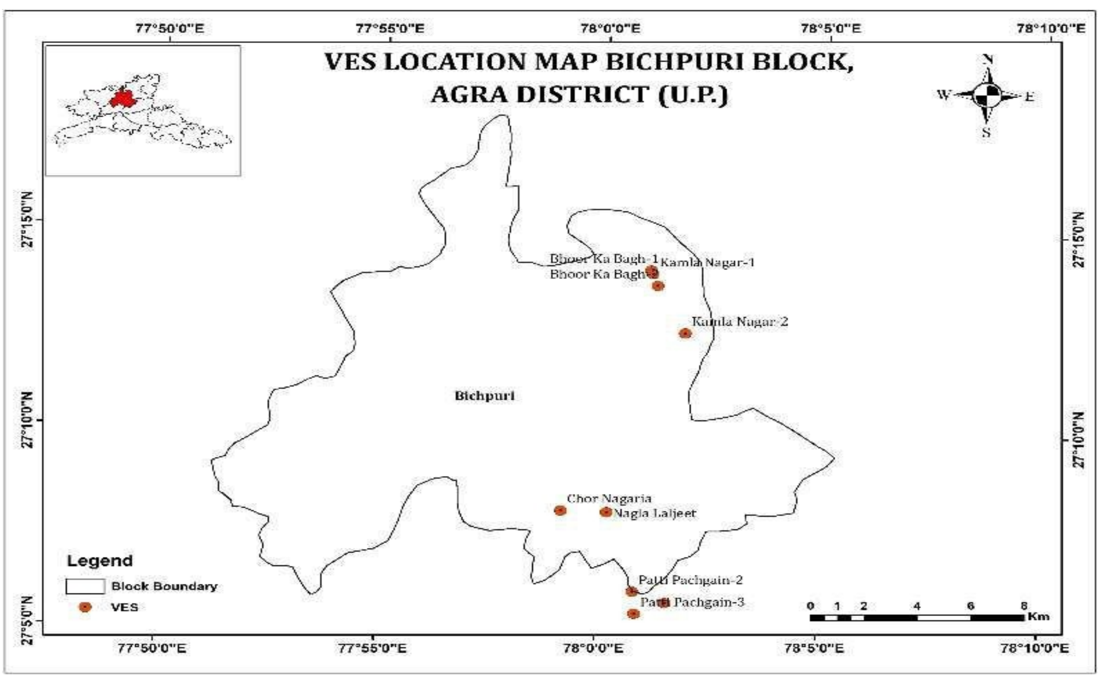


Fig. 3 : VES Location Map.

distinguishable resistance to the flow of electric current through them. Thereby came up with the idea of in-situ measurements of electrical potential. The resistivity of formations encountered during logging by a sensor-bearing current pumped in the ground and potential measuring points lowered in the un-cased mud/water-filled borehole. Electrical logging can be classified into the following two categories.

- Response of natural earth currents - **Self Potential (SP).** The potential development in a borehole column is measured, which is the product of mud resistance and ionic current.
- Response to external current input – **Resistance/Resistivity (N-16 & N-64)**

The logging sensor or probe imparts a preset constant current while traversing in the borehole, and given the present positions of potential and current measuring points, the developed potential is calibrated in terms of resistivity. The drilling sites have been logged to confirm and locate the freshwater zone with the help of Electrical Logs name SP Log (Red), Normal Resistivity N-16 (Green), and Normal Resistivity N-64 (Blue). The well log chart of both sites is shown in Figures. 5 and 6.

SP Log

Upon being penetrated by a borehole containing drilling fluid and dissolved salts different from that in the formation water, the sub-surface gives rise to voltage development at the contacts between shale/clay and granular zones. Consequent to potential differences, natural current flow occurs through four different media: the borehole, the invaded zone, then the invaded part of the Permeable formation, and the surrounding shale, clays sandy clays. In each medium potential drops in proportion to the resistance, and the total potential drop along a line of current flow is named self or spontaneous potential (SP). The development of SP is mainly a function of chemical activities between the borehole fluid and water formation. Besides, the clay type and lithology also play a role in developing SP. The electromotive forces driving the natural Currents are of two types

a) Electrochemical and b) Electro-kinetic

Resistivity Log

The simultaneous recording is done of the two types (N-16" and N-64") of resistivity measurements. For regular resistivity measurements, 3 openings or electrodes are provided in the probe. The bottom-most electrode is used for 16" potential measurements and is located 16" below the current pumping electrode. The other 'electrode is located near the top of the probe 64" above the current pumping electrode. Generally, for resistivity measurements, recorder channels 2 and 3 are used with different colors of pen inks. In the chart paper, the resistivity recording is conventionally done on the right track.

RESULTS & DISCUSSION

Surface Exploration- (VES Sounding)

The field VES curves for nine soundings (4.1 to 4.9) were interpreted using the partial curve fitting method and IPWIN software, shown in Figure 4.

The resistivities interpreted from the surface measurement are cumulative or weighted average resistivities of the formation. Thus the true resistivity value for a particular depth zone indicates the predominance of low and high resistivity material, and the value is not absolute in lithology characterization.

There for an interpretation, sub-surface electrical layers from the sounding curve comprise a number of thin layers of different resistivity and lithology. The resistivity of the geo-electrical layer would only indicate the maximum contribution of the prominent litho-unit.

Bhoor Ka Bagh: Two soundings (VES-1 & VES-2) at Bhoor Ka Bagh have been conducted for selecting the drilling point. The spread of VES-1 (Figure 4.1) was AB/2 500 m. The spread of VES-2 sounding was 200 m. At VES-1 resistivity of the first layer (Top Soil) was (391) ohm-m with a thickness of h1 (2.8) m, the second layer (Dry Sand) having resistivity (156) ohm-m with a thickness of h2 (7.3) m, the third layer (Fresh Water Bearing Sand) having resistivity (26.4) ohm-m with thickness h3 (10.8) m, fourth layer (Moderate Quality Water Bearing Sand) with resistivity (16) ohm-m with thickness h, (50.8) m, and finally, fifth layer (Slaine Water Formation) with resistivity (10.8) ohm-m has been found.

In VES-2 (Figure 4.2) the resistivity of the first layer (Top Soil) was (261) ohm-m with a thickness of h1

(5) m. The second layer (Dry Sand) had a resistivity of (515) ohm-m with a thickness of h2 (2.6) m, the third layer (Dry Sand with Clay) had a resistivity of (315) ohm-m with a thickness of h3 (8.7) m, fourth layer (Fresh Water Bearing Sand) with resistivity (22) ohm-m with thickness h, (58.75) m, and finally, fifth layer (Brackish Water Formation) with resistivity (3.6) ohm-m has been found. The curve of both soundings shows the same trends, and the depth of the fresh/saline interface is inferred to be around 70 mbgl,

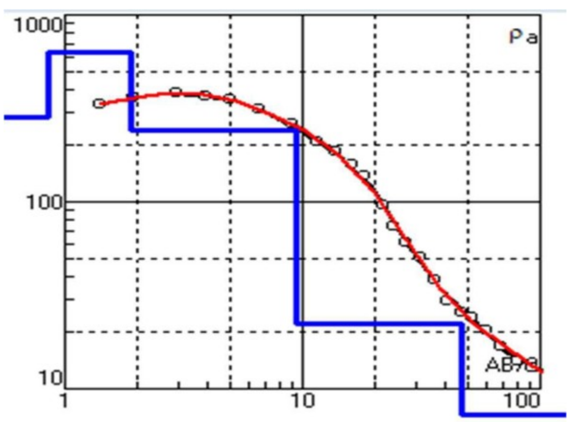
Kamla Nagar: The two soundings (VES-3 & VES-4) have been conducted. The spread of both VES was 100 m and 80 m only due to cultural noise; less spread was available.

The fresh/saline interface has been calculated at around 18 m. Due to less depth of information, the site is not feasible to be recommended for drilling.

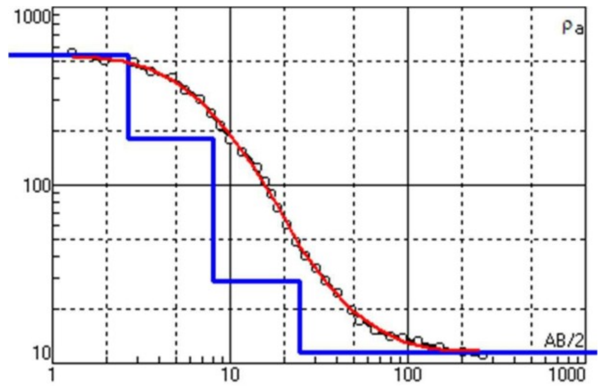
In VES-3 (Figure 4.3) at Kamla Nagar Site, four layers have been found; the resistivity of the first layer (Top Soil) was (54) ohm-m with thickness h1 (1.4) m, the second layer (Dry Sand) having resistivity (108) ohm-m with thickness h2 (5.1) m, the third layer (Fresh Water Bearing Sand) having resistivity (32) ohm-m with thickness h3 (15) m, fourth layer (Brackish Water Bearing Sand) with resistivity (6.5) has been found.

At VES-4 (Figure 4.4) at Kamla Nagar Site, four-layer has been found; the resistivity of the first layer (Top Soil) was (180) ohm-m with thickness h1 (1.3) m, the second layer (Dry Sand) had resistivity (72) ohm-m with

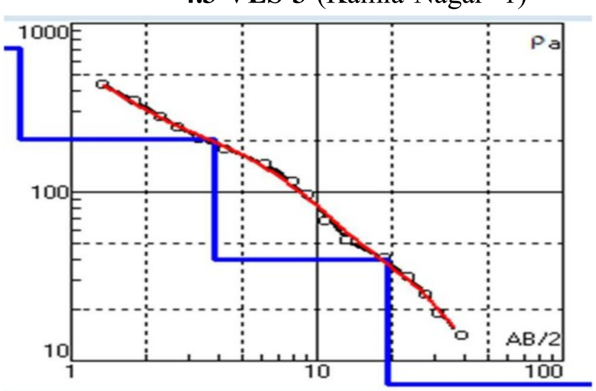
4.1 VES-1 (Bhoor Ka Bagh -1)



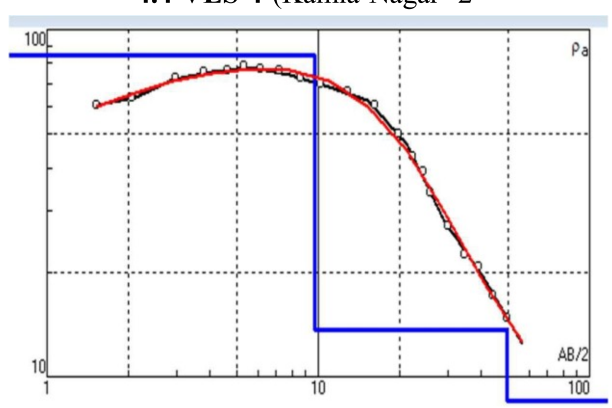
4.2 VES-2 (Bhoor Ka Bagh -1)



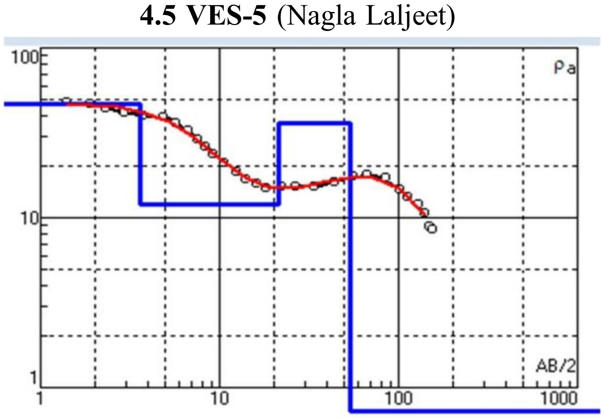
4.3 VES-3 (Kamla Nagar -1)



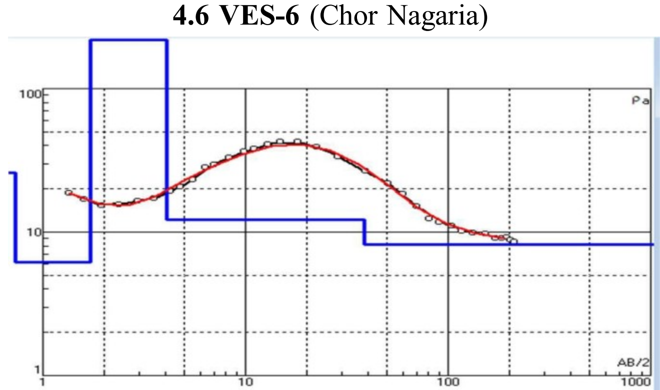
4.4 VES-4 (Kamla Nagar -2



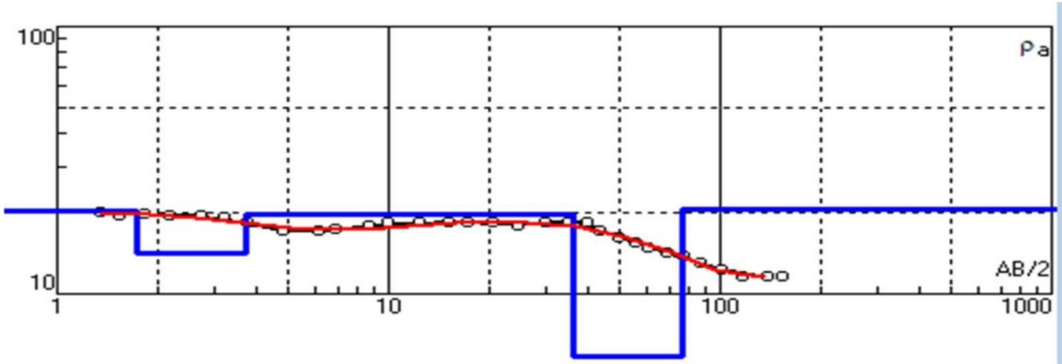
4.5 VES-5 (Nagla Laljeet)



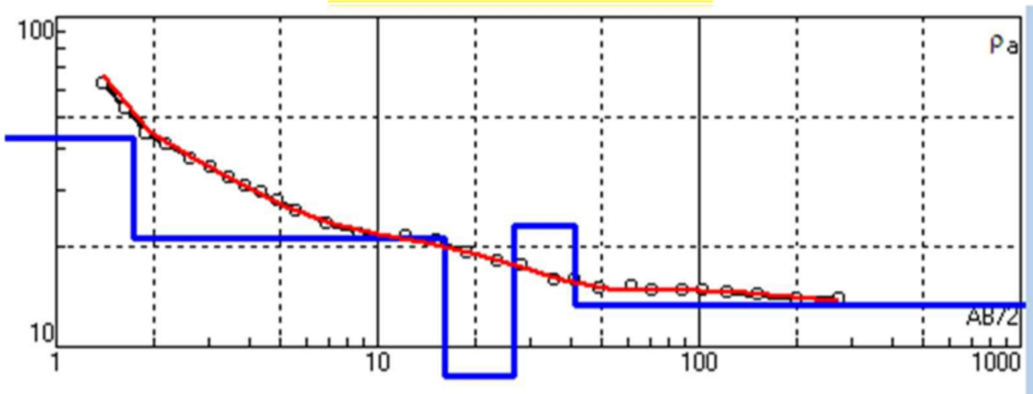
4.6 VES-6 (Chor Nagaria)



4.7 VES-7 (Patti Pachgain-1)



4.8 VES-8 (Patti Pachgain-2)



4.9 VES-9 (Patti Pachgain-3)

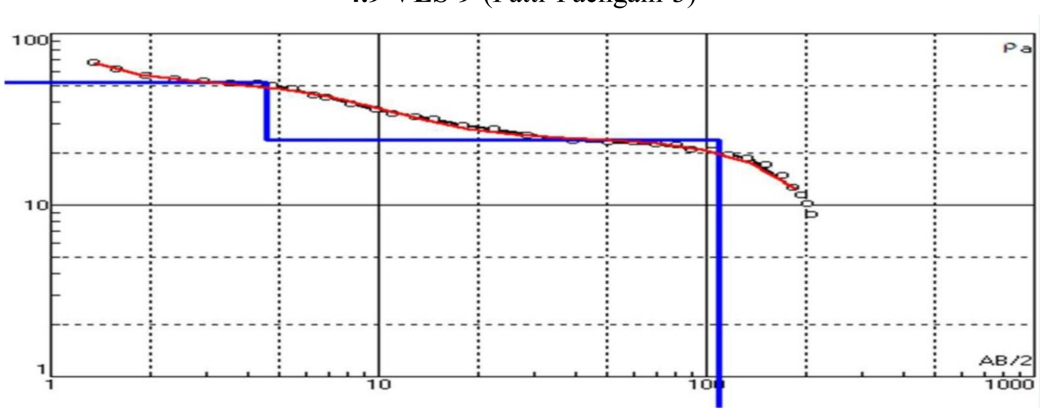


Fig. 4 : Vertical Sounding curves at VES-1 and VES-8 are recommended for drilling.

thickness h2 (4) m, the third layer (Fresh Water Bearing Sand) having resistivity (24) ohm- m with thickness h3 (12) m, fourth layer (Fresh Water Bearing Sand) with resistivity (7.8) has been found.

Nagla Laljeet: At Nagla Laljeet, VES-5 (Figure-4.5) has been conducted. The spread of VES-5 was AB/2 300 m. The fresh/saline interface has been calculated at around 54 m. At VES-5 resistivity of the first layer (Top Soil) was (48) ohm-m with a thickness of h1 (1.3) m, the second layer (Dry Sand) having resistivity (37) ohm-m with a thickness of h2 (2.3) m, the third layer (Sand) having resistivity (16) ohm- m with thickness h3 (8) m, fourth layer (Fresh Water Bearing Sand) with resistivity (27) ohm-m with thickness h, (43) m, and finally, fifth layer (Slaine Water Formation) with resistivity (7) ohm-m has been found.

Chor Nagaria: At Chor Nagaria, VES-6 (Figure-4.6) has been conducted. The spread of VES-6 was AB/2 300 m. The fresh/saline interface has been calculated at around 53 m. At VES-5 resistivity of the first layer (Top Soil) was (22) ohm-m with a thickness of h1 (1) m, the second layer (Clay) having resistivity (17) ohm-m with a thickness of h2 (1.1) m, the third layer (Sand) having resistivity (50) ohm- m with thickness h3 (9.2) m, fourth layer (Sand) with resistivity (13) ohm-m with thickness h, (42) m. Finally, the fifth layer (Saline Formation) with resistivity (5) ohm-m has been found.

Patti-Pachgain: The three soundings (VES-7, VES-8 & VES-9) have been conducted at Patti Pachgain sub-urban area, VES curve shown in figure (4.7, 4.8 & 4.9). The spread of VES varies from 400 m to 600

m. The fresh/saline interface has been calculated at around 45 mbgl for VES-7, 85 mbgl for VES-8, and 72 mbgl for VES-9. Thus due to the deeper fresh-to-saline water interface and availability of more freshwater sites, VES-8 and VES-9 are both suitable for drilling. At Patti-Pachgain VES-8 (Figure-4.8) fresh/saline interface has been calculated at around 85 m. At VES-8 resistivity of the first layer (Top Soil) was (114) ohm-m with a thickness of h1 (1) m, and the second layer (Clay) had a resistivity of (26) ohm-m with a thickness of h2 (9.4) m, the third layer (fine sand) having resistivity (14) ohm-m with thickness h3 (75) m, fourth layer (brackish sand) with resistivity (8) ohm-m with thickness h, (85) m. Finally, the fifth layer (Hard formation) with high resistivity has been found. Thus, drilling was carried out at VES-8. Two locations of the nive VES sites have been selected for drilling sites; VES-1 and VES- 8 are preferable, so they are kept for backup purposes. Therefore the VES sounding elaborated on the application and feasibility of carrying out the geoelectric survey in saline hydrogeology. The drilling results successfully corroborate the survey results.

Parameter Standardization of Geo-electrical parameter

The interpreted Geo-electrical layer parameters have been compared with the lithological, VES sounding, and electrical log of the borehole drilled at Bhor ka Bhag and Patti-Pachgain. With the standardization of the resistivity values, the following resistivity range is assigned (Table 1) to the litho-units in the area study.

Table 1: Interpreted Geo-electrical layer parameters.

S. No	Lithology	Resistivity Range
1	Top dry soil occurring above the water table	75 ohms.m and above
2	Finer sediments, finer sediments like clay silt, and very fine Sands are associated with deteriorated quality of water	Less than 10 ohms.m
3	Fine to medium sands with relatively good-quality groundwater	10 to 15 ohms.m
4	Medium to the course and with gravel and Kankar having fresh groundwater	15 to 50 ohms.m
5	Bedrock-Vindhyan basement.	High

Subsurface Exploration- (Well Logging)

Based on the study of geophysical logs, the following granular zone was delineated for the construction of the tubewell. In the electrical log Bhoor ka Bagh shown in (Fig. 5), the major granular zones are identified as shown in Table 2, along with the respective water quality. The clay cum clayey sand zones in the depth range from 25 to 39 and 81 to 93 mbgl. Below the depth of 93.0 mbgl, the logs with comparatively higher self Potential development (>-9 mv) and lower resistivities (<4 ohm/m) have inferred a very poor quality of groundwater down to 110 m. The discharge of the well was recorded to be 552 lpm, and the water was found to be fresh with EC 1500 micro Siemens/cm, well within the permissible limits of Agra.

On this site, the N-16 and N-64 resistivity curves well developed up to 27 m, but the SP log confirms the presence of moderate quality water up to 68 m.

Table 2: Interpretation Granular zone analyzed from Well Log at Bhoor ka Bagh, and respective groundwater quality.

Location Bhoor Ka Bagh			
Sl. No.	**Depth range of granular zones (mbgl)**	**Thickness (m)**	**Quality of formation water (as per E. log)**
1	20.0-25.0	5	Fresh
2	39.0-42.0	3	“
3	44.0-47.0	3	“
4	52.0-58.0	6	“
5	59.0-68.0	9	Moderate
6	73.0-76.0	3	Brackish to saline
7	104.0-107.5	3.5	“

In the electrical log of Patti Pachgain (Figure-6), major granular zones are identified, shown in Table 3, along with the respective water quality. The major clay or clayey sand zones in the depth range from 32 to 42 and 51 to 70 mbgl. Below the depth of 93.0 mbgl, the logs with comparatively higher self Potential development (>-10mv) and lower resistivities (<5 ohm/m) have inferred a very poor quality of groundwater down to bedrock. The discharge of the well is 615 lpm, and the water was with EC 1605 micro Siemens/cm within the desired limits.

Table 3: Interpretation Granular zone analyzed from Well Log at Patti-Pachgain, and respective groundwater quality.

Location Patti-Pachgain				
Sl. No.	**Depth range (mbgl)**	**Thickness (m)**	**Resistivity of Formation (N 64”)**	**Quality of formation water (as per E. log)**
1.	19 - 32	13	32	Fresh
2.	42 - 51	9	16	Moderate
3.	70 - 77	7	15	Moderate

In this study, VES and well-log data of saline aquifers are explored, compared, and analyzed. The analysis facilitates the identification of resistivity (r) and thickness by the VES method and identifies and correlates with well-log data, such as the freshwater and saline water zones. Thus VES and Well-Log technique coupled with lithology inputs are efficient in identifying the saline and freshwater interface, easy to carry out, and relatively free from ambiguity and uncertainty of the saline aquifers systems.

CONCLUSIONS AND RECOMMENDATION

In the present study, nine Vertical Electrical Soundings (VES) have been conducted to select the two exploratory drilling sites. The first Bhoor ka Bagh and the second Patti Pachgian in the Bichpuri Block of Agra District have been explored, analyzed, and finalized to provide safe and fresh drinking water. The drilling sites have been Well logged to confirm and locate the freshwater zone with the help of Electrical Logs name SP Log (Red), Normal Resistivity N-16 (Green), and Normal Resistivity N-64 (Blue).

The VES sounding has been successfully used to delineate the freshwater zones and fresh/saline water interaction in the study area. Post-drilling, the results were also confirmed and pinpointed by the well- log data analysis. Thus the depth of freshwater depth in the study area ranges from 16 to 70 m. Moreover, the VES-8 also confirmed the presence of underlying bedrock Vindhyan Sandstone at Patti Pachgain-2. The bedrock Vindhyan Sandstone arrives approximately 170 m below ground level.

No feasible site has been recommended due to shallow fresh/saline water & drilling possibility in Kamla Nagar, Nagla Laljeet, and Chor Nagaria. But these sites like Kamla Nagar (VES-3), Kamla Nagar-2 (VES-4), Chor Nagaria (VES-6), and Patti Pachgain (VES-9) have coarser granular zones at shallow depths predominantly. Thus, these sites have the privilege of groundwater infiltration and storage and are suitable for artificial groundwater recharge.

Both drilling sites (VES-1 & VES-8) recommended lie on the outskirts of the Bichpuri block, i.e., in the suburban area, and the VES soundings at Kamla Nagar, Nagla Laljeet, and Chor Nagaria falls in the urban area where the groundwater draft is higher due to higher population, and thus the availability of groundwater is low. Moreover, groundwater feasibility is higher in the outer suburban regions compared to urban areas.

The geoelectric surface exploration and sub-surface exploration in the form of logging coupled with lithological input is a promising combination to pinpoint the freshwater water zone in a problematic saline area like Agra. Calculative use of these approaches will surely be helpful for the researcher to delineate the freshwater pockets and zones in such hydrogeological terrains.

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