Chapter VI

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SUMMARY AND CONCLUSIONS

An attempt has been made in this thesis to present some general considerations governing the application of geoelectric resistivity method to study the ground water occurrance and its suitability for various purposes in the Bharatpur District of Rajasthan. The purpose of this work was to obtain a general picture of the sub-surface geology with the help of geoelectric resistivity method and its usefulness in identifying areas that can be further explored for the construction of new tube wells. Generally, electrical resistivity method fails in those areas where thick clay layer occurs, particularly in differentiating saline water from clay. The similarity in electrical conductivity of clay, saline water and brackish water in sandy aquifers limits resolutions by electrical resistivity method. The study area shows the presence of clay horizon ranging in thickness upto 90m within the alluvial aquifers. The variations in clay horizons are partly due to the pre-deposition lands surface with very strong relief, wherein the clay was deposited in basins by fluvial / aeolian processes. Within the clay horizon itself there are frequent changes of sedimentary facies, as it occurs partly as clay, partly as more or less sandy clay and occasionally as a series of alternating fine sand and clay layers. All these factors cause reduction in the number of possible fresh water bearing permeable horizons. These rather complicated problems lead to the question as to what extent electrical resistivity method can provide reliable results ? At this point, it was felt that vertical electrical sounding (VES) data coupled with other parameters such as, hydrogeological and geochemical data can give better result and hence keeping this in view this study was undertaken.

This concluding chapter gives a precise summary of the important results of field investigations and presents an account of the significant conclusions drawn at the end of the study.

The study area covering the Bharatpur district of Rajasthan is located in the easternmost part of the state and included within the Survey of India Topographic Sheet Nos. 54A, 54E and 54F on 1:250,000 scale, bounded by $26^{\circ}40'00''$N and $27^{\circ}50'00''$N latitudes, and $76^{\circ}53'00''$E and $77^{\circ}45'00''$E longitudes. Climatically, the study area forms part of the semi-arid to arid climatic region having extremes of temperatures and very low rainfall of about 600mm, and greater evapotranspiration. The area with altitudes ranging from 180 to 220m above mean sea level (MSL), typically represents an extensive level topographic flat with isolated hillocks of meta-sedimentary rocks belonging to the Proterozoic Delhi and Vindhyan Supergroup. Quaternary sediments occupy extensive alluvio - colluvial and aeolian landscape. In the southern part of the study area, the Great Boundary Fault separates the rocks of older Bhilwara, Aravalli, Delhi from those of the younger Vindhyan Supergroup . Most of the study area is covered by alluvium consisting mainly of sand, silt and clay. A few stabilized and drifting sand dunes exist in the northern and eastern parts of the study area. The sand dunes consisting of fine to medium textured sand mixed with silt and clay, lie in linear pattern trending in the NE-SW direction parallel to the most effective wind direction. The Drainage density varies from 0.2 to 0.3 km/sq km in the northern and central parts of the study area while the south western part and in southern part show 0.5 to 0.7 km/sq km and 0.3 to 0.5 km/sq km drainage density respectively.

The mean, standard deviation and occurrence of maximum and minimum rainfall in respect of the eight rain gauge stations of the study area have been computed and presented in Table 2.4. It is seen that highest rainfall (740mm), on an average, is recorded at Nadwai rain gauge station, whereas lowest rainfall (547mm) is noted at the Weir rain gauge station. Drought frequencies computed for these eight rain gauge stations are graphically shown in Figs. 2.10a to 2.10h. It is seen from these figures that the Bayana rain gauge station is the most prone to the droughts, while lower drought frequencies have been observed at the Roopwas and Weir rain gauge stations. Further, mild droughts are most frequently observed in the study area. The most severe drought frequency of 2.7% and severe drought frequency of 10% have been respectively observed at the Nadwai and Weir rain gauge stations. In general, the Bharatpur district witnessed frequencies of recurrence of mild (37.84%), normal (13.5%) and severe (2.7%)

droughts during the period from 1957 to 1993. The drop in rainfall has caused serious drought conditions in the study area.

The groundwaters from the study area have exhibited characteristics of fresh to saline water. From the chemical data for groundwaters (Appendix 3) from the study area, it is evident that more than 50% of the waters are saline. The semi-arid climatic conditions prevailing in the area under study seem to have played an important role in imparting salinity to the groundwaters. Low rainfall in the study area during the monsoon season appears to be insufficient to leach out the soil system off the soluble salts from the clay horizons bed. The concentration of salts in the sub-soil, thus, ultimately appear to have resulted into the development of evaporate deposits. It has also been observed that good to potable water predominates mostly in the shallow aquifers of the southern part of the study area (Ec $<$ 1000 micro-siemens/ cm). While potable to brackish water has been reported from the northern part, the central part has mostly saline to brackish water in its shallow aquifer (Fig. 3.2). Similarly in deeper aquifer, good quality of water has been reported from the southwestern part; relatively good to brackish quality of water from southeastern part and saline water from central and northern parts (Fig. 3.3). Further, it has been observed that the dugwells with maximum concentration of Ca^{2+} in their waters are located within the SE-NW trending belt parallel to the Bharatpur depression. However, the dugwells with maximum concentration of Mg^{2+} in their waters are scattered all over the study area except in its southernmost part (Fig. 3.4). Higher nitrate values (More than 100 mg/l), have often been locally observed for the shallow aquifers (Fig. 3.5) especially from the northeastern and central parts of the study area. Similarly, in the central and southwestern parts, the deeper aquifers contain waters with high nitrate values. Further, the groundwaters from the shallow aquifer pockets show more fluorid concentration at a number of places (Fig. 3.7). The deeper aquifers in the areas around Kaman, Nadwai and weir townships (Fig. 3.8) contain waters with higher fluoride concentration. Thus the groundwaters from both the shallow and deeper aquifers, especially in the central part of the study area are unsuitable for human consumption and other domestic purposes. It is also evident from the chemical data that the water from dugwells located in the alluvial tracts especially in the central and northern parts of the study area shows higher concentration of various chemical constituents during the pre-monsoon period and lower concentration during the post-monsoon period, thereby indicating dilution effect during the post-monsoon period. On the contrary, water from dugwells in the hard rock areas of the southern and southwestern parts shows higher values for various constituents during the post-monsoon period. Hem (1970), has pointed out that satisfactory relationship between the conductance and ionic concentrations can be developed from the record of major ionic concentrations and conductivity measurements of water samples over longer period of time. The average conductivity values and the average concentrations of the major ions in the groundwaters of 233 wells in the study area for the period from 1986 to 1990 have been used to find out the relationship between the conductivity and various ions and it was found that the average concentrations of Cl^-, HCO_3^-, Mg^{2+}, Na^+ and TDS exhibit good correlation with electrical conductivity.

The Vertical electrical sounding (VES) curves obtained in the study area are mostly of QH, KH, KQH and HKH types. The first layer invariably corresponds to the soil cover which is underlain successively by semi-weathered layer, weathered or fractured rocks and/or hard and compact rocks. Analysis of the data indicates the presence of four to five layers in general. From the interpretation of the data for QH, KH, KQH and HKH type curves, it is noticed (from the Spectrum of resistivity values) that the resistivity of the first layer (soil) has a range of 12 to 320 ohm-m for QH type curves, 4 to 200 ohm-m for KH type curves, 20 to 198 ohm-m for KQH type curves and 6 to 170 ohm-m for HKH type curves respectively. The second layer (semi-weathered) has a resistivity range 5 to 138 ohm-m for QH type curves, 8 to 342 ohm-m for KH type curves, 34 to 570 ohm-m for KQH type curves and 1.2 to 35 ohm-m for HKH type curves. The third layer (weathered) has a resistivity range 1.7 to 28 ohm-m for QH type curves, 1 to 125 ohm-m for KH type curves, 6 to 36 ohm-m for KQH type curves and 5 to 75 ohm-m for HKH type curves. However, the fourth layer has high resistivity value for QH and KH type curves, whereas it has 2 to 14 ohm-m for KQH type curves and 2 to 18 ohm-m for HKH type curves. The fifth layer resistivity for KQH and HKH type curves shows high resistivity value indicating the presence of hard rock. The interpretation of arithmetic mean curve gives an average thickness of the weathered layer of 95.8m for QH type curves, 101.5m for KH type curves, 87.5m for KQH type curves and 100.7m for HKH type curves respectively. The VES results are compared with the geological sections wherever available and it is noticed that the interpreted depth of the weathered layer based on VES data includes partly the semi-weathered layer as well.

Apparent resistivity maps for $\frac{AB}{2}$ equal to 10m, 50m, 100m and 200m have been prepared from the VES data. Though it does not represent for actual variations of resistivity at a depth equal to that of the electrode spacing but it is interesting to note that all the maps with half current electrode spacing ($\frac{AB}{2}$) more than 50m have similarity in apparent resistivity distribution indicating thereby corresponding similarities in distribution of geological strata in the entire study area.

The high porosity zone (Fig. 5.13) may be considered as clay dominant, mostly present in the central portion of the study area whereas, in north, southeast, southwest and in parts of central portion, there are low porosity areas indicating the presence of granular zones. The Archie's equation could give a reasonably fair picture of variation of porosity for mixed formations, which are encountered in the study area. Clay layers may be differentiated from the sandy aquifers and layers enriched in saline water. Clay layers with saline water delineated in central part where porosity is high, are characterised by very low to low resistivity in contrast to those observed in medium porosity zone. The comparatively high resistivities obtained for these clay layers are due to their sand contents.

Generally, thin water bearing zones indicated in the lithologs or electric logs within thick clay formations do not appear in the geoelectric sections of VES. Presence of even somewhat comparatively thick zone of sand at a greater depth may not be detected with the help of resistivity investigations as the resolving power decreases with depth and hence, proper correlation is not possible. Under the above conditions, the quantitative interpretation becomes difficult at times. The Dar Zarrouk parameters, that is, transverse resistance (T) and longitudinal conductance (S) have been calculated. The iso-transverse resistance and iso-longitudinal conductance map (Fig.5.14) for the alluvium column 10-40m indicates that the contour of T values (above 300 ohm-m) has higher percentage of water bearing strata, whereas the same for S values show that areas falling within 4 mhos have better quality of water. In central part of the study area there is no possibility of finding granular zone, and groundwater is highly saline in 10-40m alluvium column. In case of deeper aquifer (Fig.5.15), 40-120m alluvium column, southern and north-eastern parts of the study area indicate that the quality of groundwater is comparatively better than in areas falling within high value of longitudinal conductance. In central and northern parts of the study area, groundwater is highly saline.

Useful relations can be developed between aquifer hydraulic and electrical properties, where the entire saturated thickness comprises the aquifer. Although the aquifers are composed generally of several layers, the equivalent resistivities of these layers are useful parameters for predicting aquifer permeabilities. Electrical properties of individual layers within the aquifer can not be obtained without bore hole control because of the principle of equivalence and suppression. Porosity and hydraulic conductivity with formation factor for eight locations in the study area show excellent relationship (S.D.) (Fig 5.19). Formation factor and porosity are inversely related, and there is a trend of increasing hydraulic conductivity with increasing formation factor although agreement with Croft's line (1971) is not satisfactory. This could be due to geological situation as site 4 is situated in higher porosity zone while site 6 is in low porosity zone. But the plot of formation factor against hydraulic conductivity satisfies the Croft's line when formation factor is calculated with actual aquifer resistivity. The correlation between hydrogeological parameters and the VES data in the study area indicate VES is useful for estimating hydrogeological parameters. Estimates of hydraulic conductivity from surface resistivity measurements are feasible and can be made by developing semi-empirical relationship between formation factor of aquifers and hydraulic conductivity from pump test data.

In view of this excellent correlation between hydraulic and geoelectric parameters. the regressions can be used for estimating the transmissivity, hydraulic conductivity and discharge of tubewell from geoelectric parameters before selecting a new tubewell site having similar geological setting with more confidence. The method can also be used in other geological environs.

Geoelectrical resistivity method when used in conjunction with other methods, can partially replace the more expensive method of extensive drilling in groundwater exploration. This study combining hydrometeorological, satellite imagery, hydrogeological, hydrochemical and geophysical concepts has thus been useful for estimation of porosity and boundary between saline and fresh water zones; and the regressions obtained can be used to find out the hydrogeological parameters in Bharatpur district of Rajasthan for economical, rapid and efficient exploration of groundwater resources.