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Estimation of groundwater favorable zones in Pothohar region for management of water demand in area

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Abstract

In this study geophysical technique of electrical resistivity method was employed with integrated approach of using geospatial techniques for identification of groundwater favorable zones in the Pothohar region of Punjab, Pakistan. Favorable zones of groundwater occurrence in this area were delineated using resistivity survey datasets. Resistivity survey was conducted at about 240 different points in all the districts of the area. Schlumberger electrode configuration method was used and 2D resistivity survey technique was employed in this study for which adjoining borehole records were also collected. Area had presented up to five geoelectrical layers and geological units. Groundwater bearing rocks were evident at around depth of 100m and beyond with the resistivity values fluctuated between 100 Ωm to 250 Ωm. Whereas low resistivity values of less than 65Ωm in deep zones indicated the presence of clay mixed with shale which extended up to the depth of 180m and marked as no aquifer zones. Water favorability map was then generated by integrating the resistivity survey results with the geology of Pothohar region. Final groundwater prospect map exhibited the presence of two groundwater potential area found in third and fourth geoelectric layers. Shallow aquifers were found at the sites of alluvium deposition of quaternary period, with depth of 3 to 25 meters whereas deep water zones were demarcated at the depth of 70m and beyond 160 meters in the areas of sandstone formations.

Keywords: Groundwater; Geophysical survey; Geospatial techniques; Resistivity

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Introduction

In northern areas of Punjab, water availability is limited to groundwater, precipitation and runoff. Pothohar region present in this area is also facing water scarcity problem which can be aggravated in the future due to arid and semi-arid nature of the area (Shah, 2014; Khan et al., 2017). The advancement of groundwater in Pakistan began when the surface water supplies diminished and deficient water system brought about crop misfortunes (Basharat & Tariq, 2015). These water shortage patterns are presently clear in the Pothohar plateau and there are chances that it may result in a water crisis in future (Daniellpol et al., 2003 and De Stefano et al., 2012).

Groundwater is the type of water which is trapped in the voids and fractures of the geological layers. The surface layer of the earth acts as a channel for transmission and as a storehouse of water at subsurface regions by water bearing routes (Giordano, 2009). Viable regulation of groundwater resources is now a requirement due to its significance socio-economically and strategically, particularly in arid and semi-arid regions. Drilling test, water pumping test and stratigraphy analysis of the ideal place and aquifer thickness of the borehole are the most commonly used strategies for groundwater management, but they required skilled manpower, the cost and time (Mukherjee et al 2012; Mallik et al., 2015). However, integration of spatial analysis tools like Geographical Information System (GIS) has proved cost effective and time saving techniques to access the underground water resources and their management (Adiat, 2012; Verma & Singh, 2013; Duguma & Duguma, 2022).

Ayenew et al. (2013) carried out a study using geospatial techniques in the northern part of Ethiopia for the purpose of extension in the area for irrigation and tried to tap the possible groundwater zones in that area. Jaiswal et al. (2003) used the Geospatial methods for the demarcation of groundwater occurrence towards country advancement. Rana et al. (2022) has also presented a similar study to identify potential zones of groundwater in Dinajpur district of Bangladesh using geospatial approach. Srivastava et al. (2006) assessed the groundwater capability in southwestern state, Ogun where researchers had also used the geospatial technique in combination with the geoelectrical sounding method for groundwater assessment. Falebita et al. (2020) had conducted research to assess viable organization of groundwater resources of North-eastern Osun, by utilizing geophysical data and Remote Sensing data. Onawola et al. (2021) carried out a study for evaluating aquifer parameters using resistivity data in Northcentral Nigeria. A study was led by Abdulrazzaq et al. (2020) to evaluate potential groundwater areas in Imo state of Nigeria, utilizing geophysical data and employing fuzzy gamma operator model. Marko et al. (2021) focused on assessment of groundwater potential by employing magnetic methods and VES data in Adilo catchment, Ethiopia. Mohanty and Behera (2010) also utilized Geographical Information System (GIS) spatial analysis tool along with Remote Sensing data for demarcation of groundwater in Ganjam district of Orissa.

This study has been focused on recognizable facts about the water presence beneath the earth surface by applying geospatial techniques in combination with geophysical techniques. Thus, main objectives of this study were to demarcate the favourable zones of groundwater presence in the area by integration of geospatial and geophysical methods for future groundwater exploration and to unleash the water bearing subsurface lithology of the study area.

Materials and Methods

Study area

This study was conducted in the Pothohar region, which is in the Northern part of Punjab Province, Pakistan (Fig. 1). This region is comprised of four districts which are Jhelum, Chakwal, Rawalpindi and Attock. Pothohar region is situated at the coordinates of 32º - 30" N to 34º N latitude and 71º - 45" E to 73º - 45" E longitude. Pothohar Region of Punjab is ranked as the fifth largest area of Pakistan covering around 2.2 million hectares of area. This region is mostly rain-fed and in certain parts of the region ancillary canal system is available for irrigation purposes. Annual precipitation of this area is around 450 to 1750 mm, (Cheema & Bastiaanssen, 2012) where highest rainfall is witnessed in monsoon period and observed on hills of Murree (Yasmeen & Rahman, 2007). Pothohar is the plateau area mainly and this region is primarily a semi-arid zone of country where essential water demand is met through three sources including rainfall, runoff and groundwater resource.

Geophysical survey

Geophysical survey was carried out with the technical objective to estimate the sub-surface lithology/nature of material in terms of ground-water prospective sites for future groundwater exploration (Hewaidy et al., 2015; Ernstson & Kirsch, 2006; Cardenas & Wilson, 2006). During survey maximum depths of 180m at different selected sites were scanned by vertical electrical sounding (VES) using Schlumberger electrode configuration (Nejad, 2009; Hamzah et al., 2007). Using Schlumberger configuration, field data was recorded by electronic instrument i.e., Terra meter SAS-4000 ABEM. Apparent resistivity was calculated based on field observations plotted on log-log paper.

Principle and field procedure

Survey procedure was carried out by inserting two electrodes A and B in the surface of ground for transmitting the direct current into the ground as shown in Fig. 2. A and B were designated as outer electrodes and two other electrodes M and N which were the potential electrodes, set in between them to measure the potential variation within electrodes A and B. Resistivity was then calculated by the measurement of current (I) between A and B, and related probable difference (V) among the M and N electrode by using following Formula:

$\boldsymbol{\rho} = K * V/I$ …………………… (1)

K = Geometric Factor
Geometric factor for Schlumberger Electrode Configuration was given as:

$K = \boldsymbol{\pi} *(AB/2)2 – (MN/2)2 / MN$ ……………. (2)

For any material which was not homogeneous, calculated resistivity by equation 1, was denoted as apparent resistivity (Batte et al, 2008) and given as:

$\boldsymbol{\rho}\alpha = K * V/I$ ………………. (3)

V = Potential Difference in milli- volts (mV)
I = passing current in milli-amperes (mA)
$\boldsymbol{\rho}\alpha$ = Apparent resistivity in ohm meter

Apparent resistivity values were plotted against the depths to acquire the curve of resistivity. Smoothened curves of field data were registered in the computer for interpretation which was done by using the computer assisted software IXID Interpex (Interpex, 2008), which is USA based software. Iteration procedure was used for the calculation of layered models which had given the true resistivity of layers.

Use of Geo-Spatial Approach

Resistivity survey results were then processed and assessed through ArcGIS software for generation of a final map of groundwater favourable zones in the area after integration of the geological records of the Pothohar Plateau. Since resistivity data was available as point data, spatial interpolation method was employed to extend the resistivity range across the area (Mohamaden et al.,2017; Bakkali & Amrani, 2008; Shakir et al., 2016; Al-Khafaji & Al-Dabbagh, 2016). Interpolation technique of kriging was used in this study which assessed the values for unknown areas by assiging the weight to each known point where more influence was assigned to the nearest unknown points for prediction of the values in continuity (Jensen & Jensen, 2012).

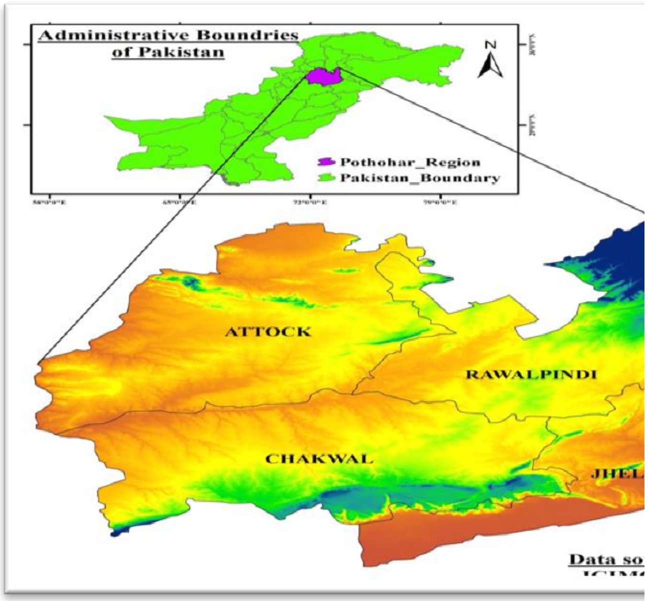

Fig. 1 Map of study area

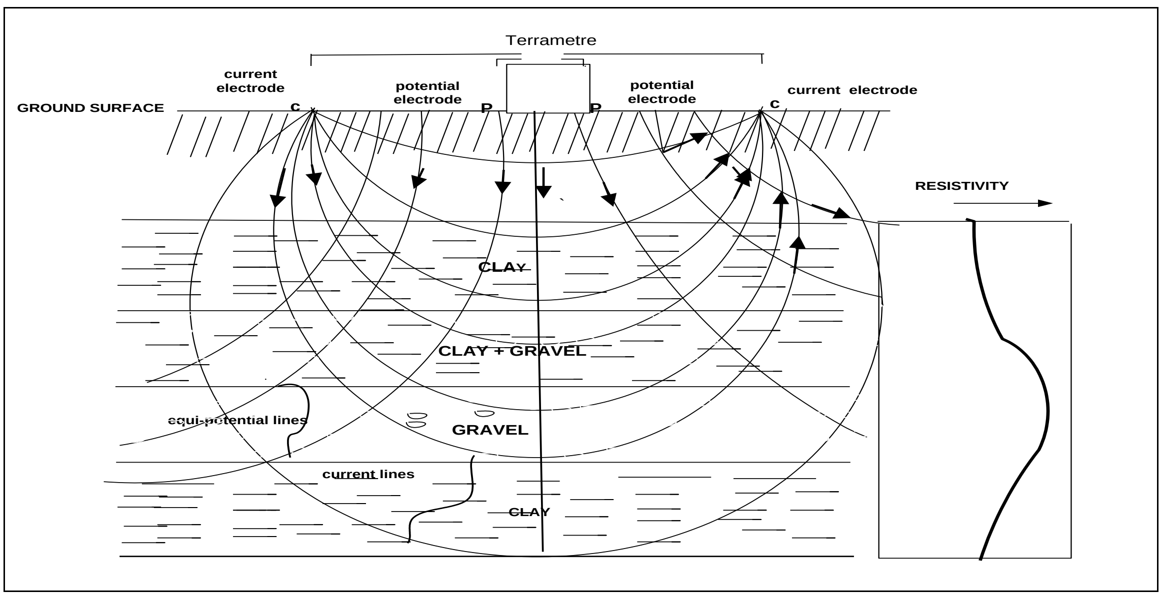

Fig. 2 Setting of electrodes spacing

Results

Interpretation of resistivity survey results

Measured resistivity values in the subsurface geoelectric layers were correlated with the hydrogeology of the area. Using 2D resistivity survey technique recorded resistivity values were interrelated with the lithology of the area (Table 1) based on the available data of boreholes and tube wells in the area (Santos et al., 2006; El-Galladi et al., 2007; Abbas et al., 2008; Mohamaden & Shagar, 2008; Sultan, 2010). Interpretative resistivity results exhibited that aquifer material extended down in the various depositional patterns in the study area. Layered strata were found in the area in form of inter-beddings, mixtures and as an individual thick bed where groundwater favorability areas could be identified. (Shahid et al., 2002; Oseji et al., 2005).

Table 1 Correlation among resistivity values and hydro-geological formations

Zone	Resistivity (Ohm-m)	Correlation with Hydro-Geological Formation	Interpretation
Low Resistivity Zone	0-30	Clay with rare layers of sand/sand-stone or gravel/boulder	Occasionally holds any water bearing formation
Medium Resistivity Zone	31- 100	Intermix of sand-stone / grave, sand, boulder and clay layers	Good quality water with possible yield
High Resistivity Zone	101-250	Alternative bedding of shale with hard and some impervious material like clay, silty clay.	Hardly yield any appreciable amount of water due to absence of required permeability
Very High Resistivity Zone	>250	Dry boulders, gravels/conglomerate with dry sandstone above water table and hard rock if below water table	Hardly yield any appreciable amount of water

Geoelectrical layers in study area

Three to five geoelectric layers were recorded in the Pothohar region (Table 2) which were interpreted according to their range of resistivity values in these respective layers and existing geological rock material. This horizontal profiling or 2D resistivity method employed in this study gave the good estimation of the subsurface rock lithology of the area by complimenting the electrical resistivity method with the existing borehole data (Ernstson & Kirsch, 2006; Bery et al., 2017; Rolia & Sutjiningsih, 2018).

Table 2 Geoelectric layers of the study area

Depth Range (m)	Resistivity Range (Ohm-m)	Litho-Units in layers	Hydrological Nature
0.2 – 140	1.2 – 30	clay/shale with minor sand particles/sandstone	____
1.2 – 160	31 – 100	Intermix of sandstone / gravel, sand, boulder with alternate clay layers	Shallow to deep Aquifers
3 – 160	100.12 – 250	boulders, gravels and sand with some impervious material	Deep Aquifers
6.8 – 180	253 – 903	dry boulders and hard rock	Bed rock area
120 – 160	14.2 – 16.98	Dominance of clay with sandstone layer	___

Using the GIS software, resistivity survey points were mapped rendering on the changing resistivity values in the survey area with changing depths in different geoelectric layers.

Interpolation of survey points

Survey points were interpolated using Empirical Bayesian kriging method and results (Fig. 3) had shown that depth range in first geoelectric layer was 0.2 m to 13.5 m deep with resistivity values of this layer was ranged from 2 Ωm to 504 Ω where 15 sites which showed the unusually very high resistivity of more than 250 Ωm were found in the northwestern part of the study area. Depth of the second resistivity layer ranged from 6m to 117 m in this area with highest resistivity value was 903 Ωm and lowest value was 4.7 Ωm. In this layer low to moderate resistivity values of around 40 Ωm to 150 Ωm were predominant in the central part of the area with very high values were found extended towards southeastern and northwestern parts of the Pothohar region. Third layer was extended from 50m to 160m deep and resistivities were ranged around 10 Ωm to 491 Ωm with lowest values in the central part and depicted the increasing trend towards northwestern and southwestern parts of the Pothohar. Whereas fourth layer of this area was having the depth of 70 m to 160 m with resistivity range of 2.1 Ωm to 250 Ωm, in this layer significant range of resistivity values (32 Ωm to 170 Ωm) were observed from central part of the Pothohar to the northeastern part of the study area, mostly belonged to the Rawalpindi district of the Pothohar region.

Integration of geological records

Aquifer water bodies are usually rock bounded, and their presence is highly dependent upon the geology of area and embedded rock material nature (Table 3). Therefore, a map of groundwater favourable zones was generated by integrating the resistivity layers with the lithology of rocks present in the area (Fig. 4). Lithology of an area is the important measure for the presence of groundwater since certain rock materials have good water holding capacity due to their permeable and porous nature. Areas of alluvium (Radulović et al., 2022), sandstone and limestone usually proved the water bearing rocks in this area depending upon their permeability and porosity (Khan et al., 2022). Final resultant map was shown in Fig. 5, which displayed the favourable and unfavourable trends of groundwater availability in the Pothohar region of Pakistan.

Table 3 Geological Formations and Lithology of Pothohar Region

Formation	Group	Age	Rock Type
Alluvium		Recent	Silt, Sand, Gravels, clay
Lei Conglomerate	Siwalik	Pleistocene	Conglomerate, siltstone, sandstone, clay
Soan			Rare conglomerate with siltstone and sandstone
Dhok Pathan		Pliocene	Claystone and siltstone with minor sandstone
Nagri			Claystone with siltstone
Chinji		Miocene	
Kamlial	Rawalpindi		Sandstone with intermix bedding of shale

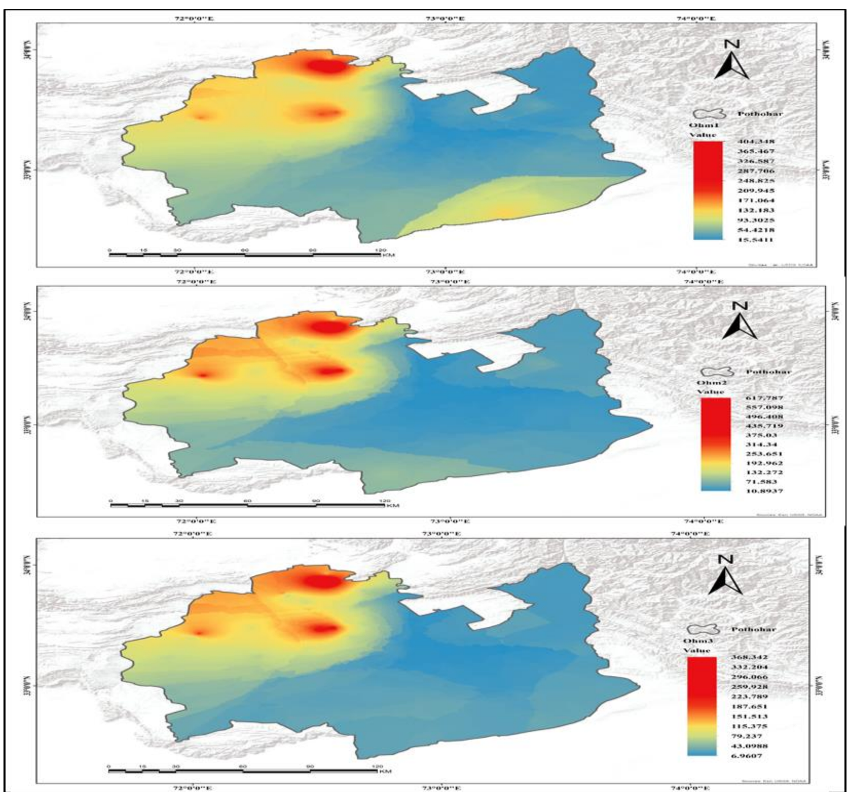

Fig. 3 Resistivity values range in different layers

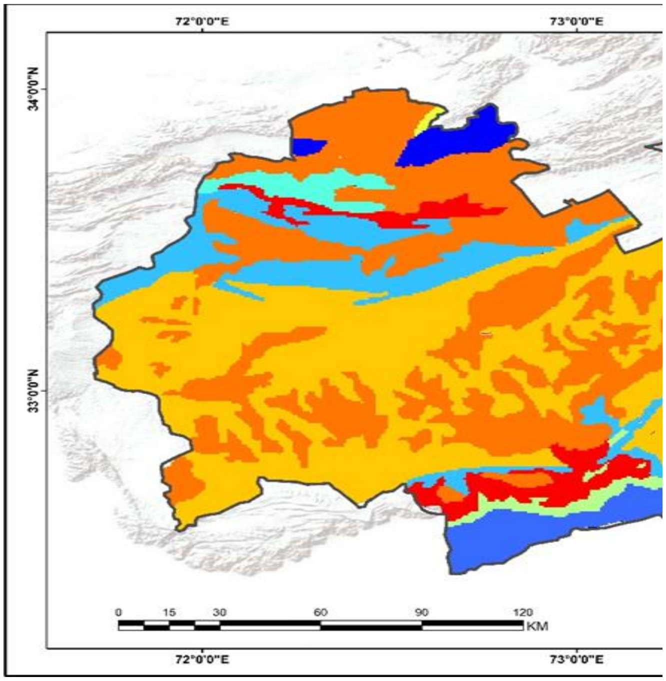

Fig. 4 Lithological map of Pothohar Plateau

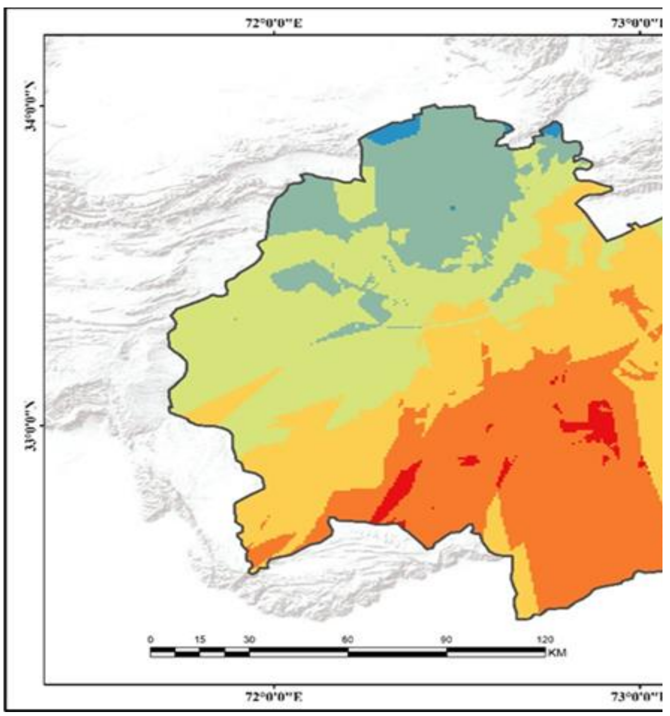

Fig. 5 Groundwater probability map using resistivity survey

Discussion

Construal of observed resistivity values were helped in the identification of water bearing rocks in the area. Resistivity survey technique when integrated with the geospatial method of interpolation in Geographical Information System (GIS) also gave a good estimation of lithological units of the study area. Low resistivity values in upper layers indicated the presence of clayey material, however, increase in resistivity beyond the depth of 100m indicated the presence of sandstone in the depth which formed the good groundwater reservoirs and possible sites of fresh groundwater aquifers. This study has also shown the decreasing trend of resistivity values across the depth of 180m, these low resistivity values (30Ωm to 12 Ωm) indicated the presence of clayey material mixed with shale. Porous and permeable sandstone and limestone areas made good potential zones for occurrence of groundwater.

Substantial depth in the study area was marked based on the measured resistivity values in different layers and their integration with the geological structure of the study area. Many areas depicted the dominance of fractured stone (gravel/boulder) at the depth of 40m, which was revealed by the very high true resistivity values173 Ωm. The porosity and drainage capacity of such areas was good due to dominance of gravel/boulder or fractured stone (Shabani et al., 2022). Therefore, rock materials of such layers could hold the high chances of groundwater yield capacity. However, the underground formations beyond the depth of 120m consisted of alternate layers of sandstone or sand with gravel and thin layers of clay containing water in some areas. Such areas reflected the moderate or high chances of groundwater presence depending upon the values of resistivity.

After integration of the geological records (Bender et al., 1995; Moghal et al., 2007; Kazmi & Abbasi, 2008; Shah, 2009; Hasany & Saleem, 2012) of the area against the resistivity values, results have suggested the presence of two main water holding formations in the Pothohar region. Shallow aquifers which could be found at the sites of accumulation of quaternary period Alluvium and Lei Conglomerate with a depth of 3m to 25meters whereas deep water zones could be found at the depth of 70m to 160m and beyond in the areas of sandstone formations, due to highly porous and permeable rock structures. Since the two basic requirements for presence of an aquifer are permeability and porosity of rock formations in an area. Some portions depicted the semi-favourable zones in study area, these were the sites with moderate possibility of groundwater presence.

Favourable geological sandstone formations in this area belonged to the Siwalik group of Pothohar region in northwestern groundwater favourable zones. Siwalik group is characterized by the intermix bedding of conglomerate, sandstone and siltstone ((Critelli & Ingersoll, 1994; Wandrey et al.,2004; Barry et al., 2013; Kimura et al., 2017). Kamlial formation of Rawalpindi group have also been reported among the groundwater favourable zones based on the resistivity results but according to the geology of this area sandstone of Kamlial formation has low permeability and low porosity therefore water bearing capacity is low in this area and manifested among the semi-favourable groundwater zones in final prospect zones map. At the southeastern portion of the study area piedmont deposits across the salt range (Ahmed et al., 2005) were composed of inadequately placed sand and gravels which were graded to silt and clayey sand. Coarse detrital material eroded from adjacent high lands was also found in this portion. Sandstone presence with clay or limestone could be the prospective water bearing formations in this part of the study area.

Conclusion

It was concluded from the study that significant layers in various parts of this region started from the depth of around 4.8m (16feet). Above this depth layer of surficial material and dry clay existed which was not water bearing lithology. This study has also found that more groundwater favourable zones were evident at the northern and eastern side of the study area and more poor potential areas are at western tip.

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