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Hydrogeological investigations in Bonai area of Sundargarh district, Odisha: An integrated approach

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Abstract
An attempt has been made in the present investigation to understand the hydro geological parameters of the study area. The most common methods of groundwater exploration are Geological, Geophysical and Remote Sensing techniques. From the resistivity data it is evident that most of the 5-layered cases are confined to the areas underlain by Bonai Granite whereas 4-layered cases are observed in almost all the lithostratigraphic units. It is also clear that groundwater can be tapped from 2nd layer through dug wells, from 3rd layer through dug-cum-bore wells and bore wells and from 4tn layer through only deep bore wells. The ground truth studies reveal that better well yields are received from the area in the vicinity of NE-SW trending lineament. Also it is marked that the areas of intersection points of lineaments serve as potential zone of groundwater. The groundwater potential of the area is controlled by lineaments/ fractures. The area of extension of lineaments in buried pediment, pediplain and intermontane valley, alluvial plain etc. are to be considered during selection of well sites as such locations have good water potentialities.

Keywords: hydrogeology, groundwater, resistivity, lineament, remote sensing

1. Introduction
Groundwater is one of the most precious natural resources which supports growth of civilisation on the globe. The utilisation of groundwater for domestic and irrigation is as old as the humanity. The replenishment of groundwater constitutes a vital component of the hydrological cycle. Proper planning for the development and management of groundwater resources requires study of water bearing formations, sustained yield of aquifers, hydro geologic properties of aquifers and quality of water. As the development of groundwater intensifies due to increased demand for irrigation, industrial and domestic purposes, it is necessary to determine the response of aquifers to heavy pumping. Quantitative appraisal of the groundwater, economics and consequences of groundwater development has to be determined before the development of groundwater basin is made. There is some water under the earth surface almost everywhere but hydro geological investigation is needed to determine whether the water occurs under conditions that would permit its economic utilisation through dug wells or bore wells. Knowledge of geological conditions and hydrologic parameters also assume importance in deciding the well locations and the type of structure of the wells. Since groundwater system constitutes highly complex bodies, a systematic and integrated approach using different scientific techniques is the most effective way of achieving the best results.

The study area occupies the eastern part of the Sundargarh district, lying towards the northern extremity of Orissa. It is bounded by the north latitudes 21° 35' - 22° 10’ and east longitudes 84° 30’ - 85° 25’ and falls in the Survey of India Toposheet Nos. 73B/12, 73B/16, 73C/9, 73C/10, 73C/13, 73C/14, 73F/4, 73G/1, 73G/2 and 73G/5. It is delimited by the state of Jharkhand in the northeast, Keonjhar district of Orissa in the east, Deogarh and Angul districts in the south, Sambalpur district in the west and Panposh subdivision of Sundargarh district in the north. In ancient time i.e. during Samudragupta’s era, the present district of Sundargarh was a part of the territory of south Kosala and later on it was a part of the Gangpur Estate. The total geographical area of the study area is around 2200 sq.km. The Bonai subdivision is divided into 4 administrative blocks namely Bonai, Gurundia, Koira and Lahunipada.

An attempt has been made in the present investigation to understand the hydro geological parameters of the study area. The followings are the objectives for which studies have been undertaken.

1. To understand the nature of aquifers of the area.
2. To study the occurrence, movement and storage of groundwater.
3. To understand the role of lithology, structure and landform in the occurrence of groundwater.

2. Methodology
The most common methods of groundwater exploration are Geological, Geophysical and Remote Sensing techniques. Geologic methods, involving interpretation of geologic data and field reconnaissance represent the first important step in any groundwater investigation. Published geologic data concerning to an area supplemented by field reconnaissance provide much information regarding groundwater occurrence of the area. In electrical resistivity survey, a known current I is sent into the ground through a pair of current electrodes and the potential difference created in the medium between another pair of potential electrodes is measured. Vertical Electrical Sounding (VES) with Schlumberger electrode configuration using (AB/ 2) separation up to 100m were carried out at 44 locations throughout the study area (Fig.1).

The selection of VES station was done keeping in view the geological complexity, accessibility and field layout feasibility. DC. Type of resistivity meter of JAKS, Hyderabad was used for acquisition of data in the field. The recorded data were plotted on a standard log-log paper and were interpreted by matching with those of the standard curves published by the European Association of Exploration Geophysicists (Rajakswater saat, Netherlands, 1975) [16] and auxiliary charts given by Orellana & Mooney (1966) [12] and Bhattacharya and Patra(1968). Also some of the field data were interpreted by the computer programme developed by Prasad *et al*. (1983) [15] and Zohdy (1989) [22]. The resistivity data is interpreted making the use of personal computer programming. IRS - IA (LISS-II) satellite imageries data have been used for preparation of different maps. Hydro geomorphological map of the area has been prepared to identify different landforms. Different litho units and lineaments have also been depicted. Groundwater potential of the geomorphic units and recharge potential of these units have been studied.

3. Results & Discussion

Geological Methods

Geologic methods, involving interpretation of geologic data and field reconnaissance represent the first important step in any groundwater investigation. Published geologic data concerning to an area supplemented by field reconnaissance provide much information regarding groundwater occurrence of the area. A preliminary evaluation with regards to groundwater occurrence and yield prospects can be drawn from the geological studies of the area. A detailed geological study with special reference to lithology, landform and structure help to understand the groundwater regime better and visualise the gross aquifer conditions like the nature of aquifer materials, types of aquifer, the type of wells suitable, their depth range, yield range, success rate, sustainability etc. in each unit. Knowledge of stratigraphy and structure is useful in understanding the order of superposition of various litho units and their continuity. Petro graphic description gives indications regarding consolidation, porosity of rocks and their water bearing and yielding characteristics. Landforms are important in delineating the lateral extent of productive and unproductive zones. A geologic investigation is carried out by examining natural exposures made in well digging, road cuts and vertical cliffs. From the study of outcrops, information can be obtained on the possible extent of weathering zone, rock types, frequency and attitude of fractures, faults and intrusive.

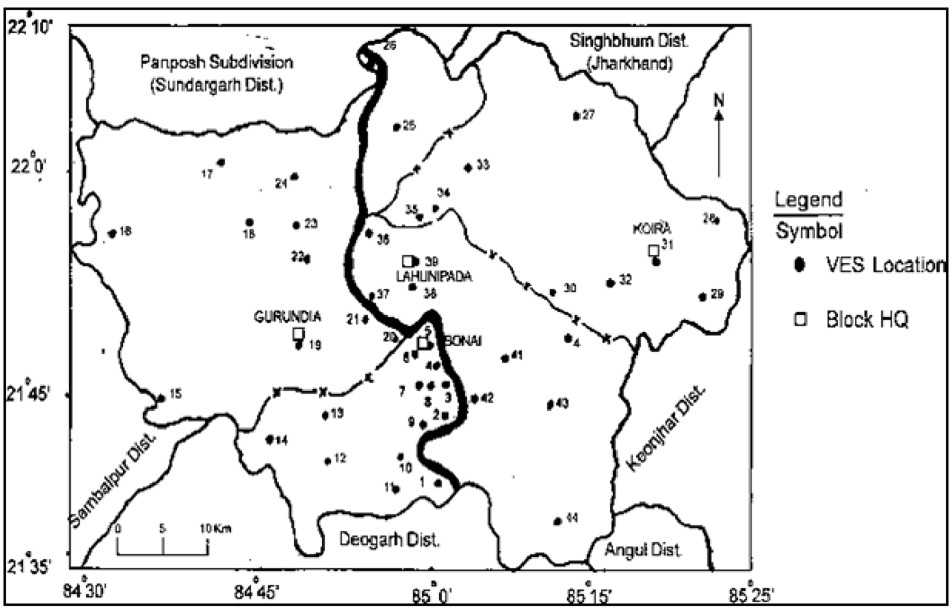

Fig 1: Location map of resistivity survey

The study area is underlain by rocks of Iron Ore Group, Darjing Group, Bonai Granite and Deogarh Group. Subjected to different phases of tectonics, the rocks are intensely folded, faulted and fractured and have been weathered to varying degree at different places. The maximum thickness of weathered zone is 20 m. The weathered layer profile is well developed in valley bottoms and low lands. The rock types in this area, being highly weathered and fractured, favour storage and movement of groundwater. The movement and occurrence of groundwater depends mainly on the secondary porosity resulting from structural discontinuities like lithological contact, fault, fracture, joint and foliation plane etc. These structurally weak planes act as a conduit for groundwater movement and introduce an element of directional variation in hydraulic conductivity. The erosional residuals, viz. inselbergs, residual hills etc. form upland comprising of massive and commonly sparingly fractured rocks, which are mostly runoff zone with very low recharge conditions. The dolerite dykes seen as linear ridge or humps of low relief, generally, form barriers for movement of groundwater resulting in compartmentalization of the groundwater regime. At few places in study area (i.e. Juniani), these intrusive are weathered and fractured which themselves serve as potential site for groundwater extraction. It is also found that the lateritic soil of considerable thickness is a good repository of groundwater due to their high porosity and permeability. This water can be utilised for domestic purpose through dug wells. In the study area weathered zone along with the fracture system constitute the important loci for groundwater development. The topographic low lands combined with of close to lineaments/fractures are best sites for well location. While the dug wells and dug-cum-bore wells depend on weathered and saprolite zone for yielding significant quantity of water, the bore wells depend on the fracture system of the deeper zone to yield significantly.

Geophysical Methods

The geophysical investigation forms a relatively quick and inexpensive way to gain subsurface information. In the study area the electrical resistivity method has been employed in groundwater investigation in which the electrical resistivity of formations is measured. This method is by far the most preferred tool in exploring for groundwater primarily due to its simple investigational operations, easy interpretational procedures and good results (Todd, 1980). Its application for siting bore wells in areas underlain by hard crystalline rocks is very popular (Ballukraya, 2001; Gupta *et al*. 2000 Hazell *et al*. 1988; Patangay *et al*. 1977 [13]; Sharma, 2000 and Vaidya *et al*. 2002) [5, 13, 19, 21]. The resistivity depends principally upon the amount and salinity of water present in the pores and interstices. The electrical resistivity method was employed to delineate weathered, fractured and alluvium zone in the study area for construction of suitable groundwater structures. In hard rock terrain, there is a good contrast in resistivity value among the bedrocks, the fractured zone, the weathered zone and the top soil comprising of sandy and clayey materials. Because of such variations Vertical Electrical Sounding (VES) have been conducted to assess the types and thickness of different layers occurring at a particular place and the finding is correlated with the nearest borehole data. Applying the knowledge of the geology of the area and the available borehole data through exploratory drilling and resistivity data, it is possible to give a fairly accurate interpretation of the general sequence of the layers and their hydro geological characteristics occurring at a particular site.

Interpretation of resistivity data

On the basis of resistivity survey 4 or 5 geoelectrical subsurface layers set-up is found in the study area. These layers are top soil, highly weathered zone, semi weathered zone, fractured zone and the bedrock. It has also been marked that in some cases the semi weathered and fractured zone are not distinguished clearly from each other because of similarities in resistivity values. The top soil layer of variable nature has resistivity value between 9 to 188 ohm-m whose thickness is less than 4.5 m. The top soil is followed by highly weathered, semi weathered, fractured and/or massive bedrock sequentially. The highly weathered layer is identified with resistivity value ranging from 55.2 to 155.5 ohm-m having a maximum thickness of 19.5 m. The semi weathered zone is indicated by resistivity value 130.0 to 384.0 ohm-m having a maximum thickness of 25 m. The fractured zone is indicated by resistivity value 305 to 450 ohm-m. However, the prominent fracture zones are restricted within a depth of 60 to 70 m. below the ground level.

The VES conducted at different points in the study area revealed 4 layered and 5 layered situations. In a four layered case, the 2nd and 3rd layers are interpreted as the potential horizons from which a good amount of water can be extracted. In this case, the second layer represents weathered zone and the third layer represents partially weathered zone or fractured zone. The thickness of the groundwater potential zone varies from 10m to 50m. In five layered case, the 2nd layer is similar to that of the four layered case. The 3rd layer represents partly weathered zone whose resistivity value ranges from 130 to 384 ohm-m. The 4th layer generally shows resistivity value 305 to 405 ohm-m which is interpreted as fractured zone and is water bearing. However, the resistivity value of 4th layer is more than that of the 3rd layer. The 4th layer (in case of 4-layered case) and 5th layer (in case of 5-layered case) represents basement or bedrock. The hard rock layer shows very high resistivity value, usually greater than 500 ohm-m indicating devoid of water. The hard rock formation forming the basement at a depth ranging from 11.8 m to 64.8 m. Therefore, the 2nd and 3rd layers represent weathered and fractured zone in 4¬layered & 5-layered situation and 4th layer represents fractured zone in 5-layered cases are very important in locating well sites in the study area. The groundwater development through different kinds of groundwater structure may be carried out in this area based on resistivity investigations. The areas where depth to massive bedrock is less than 15m are suitable for only dug wells. The dug-cum-bore well along with dug well may be constructed in areas where depth to bedrock lies between 15 to 30 m and bore wells along with dug wells and dug-cum-bore wells are suitable in areas where depth to bedrock is more than 30m.On the basis of geophysical investigation and results obtained it is inferred that the area has high potentiality for exploitation of groundwater through different kinds of groundwater structures. Depending upon the depth to bedrock suitable groundwater structures may be developed.

Variation in depth to fresh bedrock

The variation in depth to bedrock in the study area is variable. The depth to bedrock is more than 30m in most part of the area. In small patches of Bonai, Koira and Lahunipada block the depth to bedrock ranges between 15 to 30 m. The bedrock is very shallow (i.e. less than 15m in depth) in only one location (Lamsi).

Variation in thickness of aquifer

The variation in thickness of aquifer of the study is shown in Fig.2. which has been prepared based on VES results. In most part of the study area, the thickness of the aquifer material is more than 30m. In small patches of Bonai, Koira, and Lahunipada blocks, the thickness of aquifer is between 15 to 30m. The thickness of aquifer having less than 10m is observed near Lamsi of Lahunipada block. The potential aquifers are confined to weathered and fractured granitic rocks of Bonai and Lahunipada blocks. The aquifer systems of IOG and Darjing Group are relatively less productive than that of the Bonai Granite.

Isoresistivity map

The resistivity data has been used for the preparation of isoresistivity maps for 1st, 2nd, 3rd and 4th layers of the whole area. The isoresistivity map of the 1st layer reveals that the top layer is a mixed sediment layer with varying proportion of sand, silt and clay with resistivity ranging from 9 to 188 ohm-m. About 60% of the area is covered with sandy loam whose resistivity value ranges between 15 to 50 ohm-m. In small patches of Bonai, Koira and Lahunipada blocks the 1st layer has the resistivity value ranging between 51 to 200 ohm-m corresponds to lateritic soil whose thickness vary between 2.1 to 4.0m. The top layer with resistivity value less than 15 ohm-m corresponds to clayey sand or sandy clay which occurs in few pockets.

The second layer shows resistivity value of wide range (55.2 to 155.5 ohm-m) due to varying degree of weathering and their water content. The layers with resistivity value between 50 to 100 ohm-m are interpreted as completely weathered zone. These are mostly found in Bonai and Lahunipada blocks which are the most favourable zones for groundwater occurrence. The 2nd layer with resistivity value between 101 to 150 ohm-m are found mostly in Koira and Gururidia blocks corresponds to weathered zone. However, the degree of weathering is comparatively low. In small patches of Koira and Lahunipada block the second layer having resistivity value between 151-200 ohm-m corresponds to relatively less weathered zone.

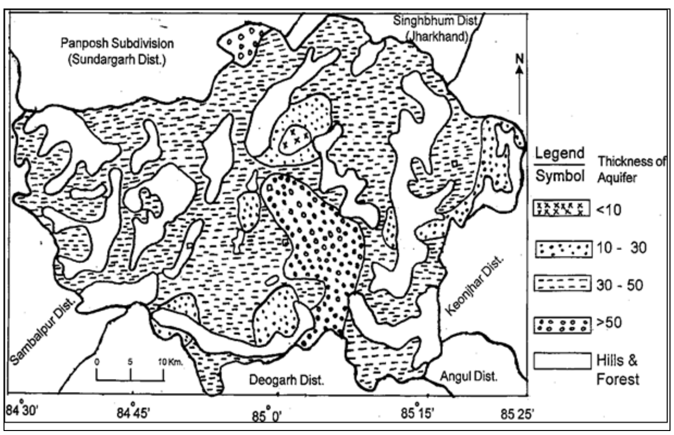

Fig 2: Thickness of aquifer in the study area

From the isoresistivity study it is revealed that the 3rd layer having resistivity value ranging between 183 to 384 ohm-m corresponds to semi weathered and / or fractured zone. The 3rd layer having resistivity value less than 230 has been generally interpreted as partly weathered zone but resistivity value between 230 to 384 ohm-m corresponds to fracture zone. At some places like phulijhar, K. Balang, Koira, Barsua, Jamkei, Satkuta, Kantapali, Baneikela and Tamda, the partly weathered zone and fractured zone are not clearly distinguished due to similar type of resistivity value. From the Isoresistivity map of 4th layer (Fig.2.7) it is clear that the resistivity value ranges from 305 to 500 ohm-m. Resistivity value of fourth layer ranging between 305 to 400 ohm-m is interpreted as due to moderate to highly fractured zone which continues up to considerable depth in Bonai and Lahunipada blocks. This zone acts as a potential zone for groundwater storage and movement. The area having resistivity value between 400 to 500 ohm-m has been identified as party fractured zone covering parts of Bonai and Lahunipada blocks. Resistivity value greater than 500 ohm-m of 4th layers are interpreted as hard rock which is seen in major portion of Koira and Gurundia blocks.

From the resistivity data it is evident that most of the 5-layered cases are confined to the areas underlain by Bonai Granite whereas 4-layered cases are observed in almost all the lithostratigraphic units (IOG, Darjing Group and Bonai Granite). It is also clear that groundwater can be tapped from 2nd layer through dug wells, from 3rd layer through dug-cum-bore wells and bore wells and from 4tn layer through only deep bore wells.

Remote Sensing Techniques

The advent of remote sensing has opened up new vistas in groundwater studies. Being hidden resources, groundwater is not directly amenable to remote sensing. However, remote sensing data provide integrated information on several factors which directly or indirectly control the movement and occurrence of water below ground. The synopticity of the satellite data helps in mapping different lithological, structural and morphological units in their correct spatial relationship. The repetitive coverage provides information on time-variant features and phenomena that are very important from hydrologic point of view. Then the satellite data provide information on different factors that control the groundwater regime and offers a common data base for integrated study of all the factors to evaluate the groundwater potential and prospects. During last decade, remotely sensed data have been increasingly used in groundwater targeting exercises (Behera *et al*.2000 [2]; Brahma, 2000 ; Harinarayana *et al*. 2000 ; Kar,2000 ; Mabee *et al*. 1994 ; Mahapatra, 2000 ; Per Sander *et al*. 1997; Sankar, 2001 and Sankar *et al*. 2002) [2, 4 ,6 ,8 ,10 , 11, 17] Remote sensing has become an indispensable tool for groundwater exploration in hard rock areas because the topographic expression and terrain characteristics have a direct relation to the geological characteristics of the rocks and their structural set-up. Geomorphology exercises a significant control over groundwater regime. The combination of landform-cum-lineament mapping and electrical resistivity investigations is very successful in areas where the overburden and/ or weathered rock as well as partly weathered/ fractured rock contain adequate quantities of groundwater. In view of the above facts the remote sensing technique has been applied to the present area to study the geology and geomorphology of the area and their significant role in groundwater regime and to demarcate the different hydro geomorphic units.

Alluvial Plain

It is a level or gently sloping and slightly undulating land surface produced by extensive deposition of alluvium found near the bank of Brahmani river. The groundwater potential is excellent which can be tapped through dug wells.

Weathered Pediplain

These units are characterised by the presence of relatively thicker weathered material. Depending upon the depth of weathered materials, these are broadly classified as shallow (up to 5 m), moderate (5 -20m) and deep (>20m). These hydrogeomorpic units are developed mostly upon Bonai

Granite and rarely over metasediments of Darjing Group. Depending upon the thickness of the weathered zone the groundwater potential is moderate to good and important for construction of dug well and dug-cum-bore well. Most of the area under this unit is mainly agricultural land.

Pediment

It is a gently sloping rocky surface with or without a thin veneer of soil cover. Part of Bonai and Gurundia blocks come under this unit. The area under this unit is generally considered to be the poor groundwater potential zone. The presence of fractures represented by lineaments over pediment indicates some groundwater potentiality.

Intermontane Valleys

These are almost flat valleys surrounded by hills all around and mostly observed in Koira and Gurundia blocks. Owing to their position, these units are highly favourable loci for groundwater occurrence and important for dug well.

Inselbergs

These are isolated hills made of up quartzite of Deogarh Group with limited areal extension surrounded by plain land all around observed in Bonai block. Groundwater potential is very poor in these units.

Structural Hills

These are group of curvilinear folded hill ranges. Compositionally these hills consist of BIF in Koira block and metasediments in Gurundia block. These units are intensely folded, jointed and fractured. They act as runoff zone with poor recharge condition.

Residual Hills

Residual hills of quartzite are seen in central part of the area. They act as runoff zone and the groundwater potential is poor.

Denudational Hills

These are massive hill ranges interspersed with intermontane valley. They also act as a runoff zone.

Lineament

Structural features such as lineaments are of great importance, since they could be zone of high porosity and permeability (Kukillaya *et al.*1999) [9]. The lineament map of the study area (Fig. 2.9) depicts the fact that fractures control the movement and storage of groundwater in the area. Lineaments of NE-SW, N-S, NW-SE and E-W trends are observed in the area. However, the NE-SW trending lineament is dominant over the study area. However, it is inferred that lineaments may be responsible for large- scale migration of groundwater of the area resulting in the partial dry zones.

4. Conclusion

The study area is underlain by rocks of Iron Ore Group, Darjing Group, Bonai Granite and Deogarh Group. The maximum thickness of weathered zone is 20 m. The weathered layer profile is well developed in valley bottoms and low lands. The rock types in this area, being highly weathered and fractured, favour storage and movement of groundwater. The movement and occurrence of groundwater depends mainly on the secondary porosity resulting from structural discontinuities like lithological contact, fault, fracture, joint and foliation plane etc. From the resistivity data it is evident that most of the 5-layered cases are confined to the areas underlain by Bonai Granite whereas 4-layered cases are observed in almost all the lithostratigraphic units (IOG, Darjing Group and Bonai Granite). It is also clear that groundwater can be tapped from 2nd layer through dug wells, from 3rd layer through dug-cum-bore wells and bore wells and from 4tn layer through only deep bore wells. The “ground truth studies” reveal that better well yields are received from the area in the vicinity of NE-SW trending lineament. Also it is marked that the areas of intersection points of lineaments serve as potential zone of groundwater. The groundwater potential of the area is controlled by lineaments / fractures. The area of extension of lineaments in buried pediment, pediplain and intermontane valley, alluvial plain etc. are to be considered during selection of well sites as such locations have good water potentialities. Finally, it is concluded that the integrated approach of “satellite image- aerial photo-interpretation-geophysical survey-drilling -geological survey” should be applied for successful groundwater exploration since it reduces time factor, risk and expenditure on groundwater development.

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