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HYDRO-GEOLOGICAL SETTING AND IMPACT OF SUGAR INDUSTRY EFFLUENT ON QUALITY OF AQUIFERS OF PANCHAGANGA RIVER BASIN, KOLHAPUR, MAHARASHTRA

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ABSTRACT

Panchanganga river basin is dominated by basaltic rocks which are altered to laterite and bauxite at higher altitudes and black cotton soil in flat areas. NE-SW and NW-SE trending lineaments have controlled drainage net work and moment of ground water of the area. Well inventory carried out during summer season shows different lithounits alluvial soil, fractured / weathered basalt, jointed basalt are good aquifers at different locations with moderate to good yield. Vertical Electric Sounding taken to a depth of 100 to 150 m, indicated that ground water in the entire river basin occur at four different depth level in the ground depending the topographical conditions with an average yield of 3000 to 10000 liters per hour. Efforts are made to correlate resistivity values of litho units with electric conductivity of ground water. Resistivity values supported by electric conductivity of ground water showed that shallow aquifers in the vicinity of sugar industries are polluted due to seepage of effluents to a confirmed depth of 8 to 10m and there is good evidence of pollution of ground water upto a depth of 35 m to 45 m. in the vicinity of sugar factories. Unlined dug wells are more polluted as compared to the lined dug wells. Utilization of such water has reduced the yield of sugar cane.

KEY WORDS: Aquifers, Lineaments, Resistivity, Litho units, Electrical conductivity, Pollution

INTRODUCTION

Ground water is one of the main sources of water for agricultural, domestic and industrial sectors. Ground water has number of advantages over surface water in terms of quantity, quality and availability at given point throughout the year depending upon the aquifer yield. Ground water is present everywhere but at different depths depending upon the topography and rainfall conditions. In the absence of surface irrigation system, ground water is the only source of irrigation throughout the year. Panchanganga river basin covers part of five talukas (segments) of Kolhapur district, i.e Gagan Bavada, Radhanagari, Panhala, Shahuwadi and Radhanagari tauka. According to Gupta (2013), for the part area falling in Panchanganga river basin spread over part of Gaganbawada, Karveer, Panhala, Radhanagari and Shahuwadi has Net Ground Water Availability of 114.7629 Million Cubic Meter for Future Irrigation Development. The study area has tremendous potential of ground water to meet the requirement for irrigation, domestic and industries. However, ground water should be utilized taking into account the balance between recharge and discharge. In some cases, over-exploitation has caused declining groundwater levels and has consequently limited groundwater flow to deeper weathered/fractured zones (Rai *et al.*, 2011; Kumar *et al.*, 2011, and Maiti *et al.*, 2012). At places, there are evidences of subsidence of land due to over exploitation. Objective of the study was to identify the depth of occurrence of ground water and also correlate the impact of depth wise pollution of ground water due to seepage or direct recharge of wells by sugar factory effluent.

MATERIALS AND METHODS

Base Geological map was prepared by using toposheets of Survey of India and aerial photographs on 1: 40,000 scale. Field work was taken up for the identification and confirmation of lithounits. Well inventory was carried out by selecting 75 dug wells to identify the type of aquifer, diameter of the dugwells, depth of water level, pumping test and fluctuation in water level during summer season. Based on the geomorphologcial, hydrological and geobotanical features, the location for Vertical Electrical Sounding (VES) was selected. The presence of groundwater in geological formation leads to distinctive reduction in the resistivity value. This characteristic of geological formations makes the geoelectrical survey more suitable than any other geophysical method for delineation of potential groundwater zones. Electrical surveys are conducted to find out variation of resistivity with depth called vertical electrical sounding (VES). Many configurations have been developed to carry out profiling and VES. Wenner and Schlumberger configurations are widely used for profiling and VES respectively (Telford *et al.*, 1976, Chandra *et al.*, 2004 and Yadav and Singh, 2007).

In the present study, twenty Vertical Electrical Soundings (VES1 to VES20) were taken in the study area by Wenner configuration of Equal electrode spacing to a depth of 100m to 150m. In order to confirm the results of vertical electrical sounding seven bore holes were drilled (BH1 to BH7). The VES's study was done by using 'Aquameter "Minitronix" A.C. type and "DDR3 " – D.C. meter by using Wenners equal electrode spacing method. The data was interpreted by inverse slope method of Sankar Narayan (1967).

The lithounits identified based on the resistivity values were further confirmed by drilling seven bore holes. To correlate the relationship electrical resistivity of the ground and quality of ground water , twenty six dug well samples (Fig.1) were collected winter and summer season in the Panchanganga river basin. Water samples were collected and analyzed only for electrical conductivity according to standard methods evolved for examination of water and waste water (APHA, 1989 and Trivedy and Goel, 1986). The term conductivity denotes the response of a medium to the passage of current. The specific conductance is the conductance of a cubic centimeter of a substance at 25 °C and is reported in mhos/cm. When reported in mhos/cm, the conductivity of natural waters is less than unity. For convenience conductivity is, therefore, expressed in micromhos/cm or Siemens. Conductivity - a temperature-dependent parameter, increases approximately 2% for each degree increase in temperature (Hem,1970). Conductivity of water increases with the dissolved constituents and is therefore indicative of ionic strength of water (Snosynk and Jenkins, 1980). The location of Vertical Electrical Soundings and bore holes drilled is shown in Figure 1.

RESULTS AND DISCUSSION

Geological Setting

The Panchanganga river basin lies in the area bounded by 16^0 27'N and $16^0$50'N latitudes, and 73^0 47'E and 74^0 18'E longitudes. The river basin has been carved out in basalt flows of the Deccan Volcanic Province. Regional geology fall under Deccan Trap of Upper Cretaceous to Lower Eocene age. These rocks now form the valley side, hills and ridges within the basin. At higher altitudes they have been altered to laterites that contain pockets of bauxites by insitu residual enrichment process of bauxitisation. The soils derived from basaltic rocks form a thin veneer on the valley floor. Panchaganga river basin which is formed due to the confluence of

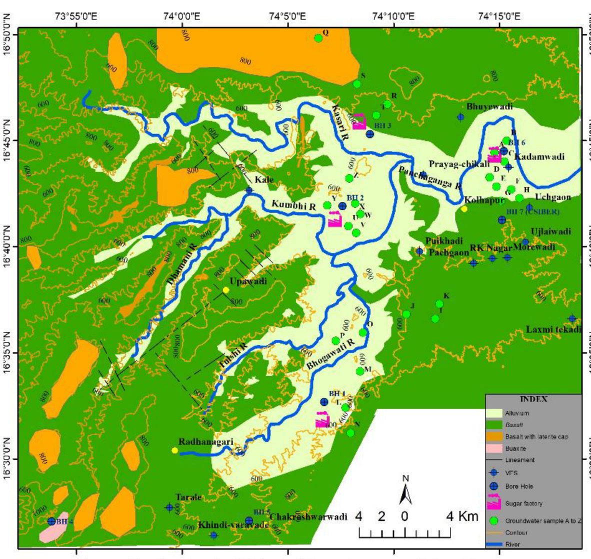

Fig. 1. Geological Map of Panchaganga River Basin

five rivers i.e Bhogawati, Tulsi, Kumbi, Dhamni and Kasari exhibit typical dendritic drainage pattern. The spatial distribution of these rocks is shown in the geological map (Fig.1) of the greater part of the basin, prepared from the toposheets of Survey of India, aerial photographs of scale 1:40,000 and digitized in ArcGIS 10.3 platform.

Alluvial Deposits: Because of the intensive weathering of parent rock and their transportation downstream, well developed alluvial deposits are formed on the banks of rivers. The thickness of the alluvial soil varies from 5 to 10m in the valley portions of the Panchanganga river basin. Black cotton soil is well developed in the north and north-western part of the basin and all along the bank of the river Bhogawati. Reddish brown lateritic soil is well developed on the plateau in the western and central part of the basin. In the southern part of the Kolhapur city a thin layer of coarse soil is developed on weathered basalts.

Basalts : The basalt flows of the Panchanganga river basin have been grouped into two Formations i.e. the Mahabaleswar (Kolhapur Unit) and Panhala Formation by Lightfoot *et al.* (1990). The flows of Mahabaleswar Formation (Kolhapur Unit) occur between altitudes 550 to 850m and are overlain by those of the Panhala varying from 5 to 30m. The different units of the flows are bun shaped to tabular in form. Spheroidal weathering is commonly observed and the boulders impart a gentle slope to the topography. The basal parts of thick basalt flows are normally marked by pipe amygdales, the middle portions are hard and compact and often contain phenocrysts of plagioclase. The upper portions of the flows are highly jointed or vesicular/ amygdaloidal in nature.

Red Boles/ Beds : These are more commonly observed between 550 to 700m altitudes in the Kolhapur Unit of Mahabaleswar Formation. They separate different flows and are of variable thickness ranging from few centimeters to about few meters in thickness. The reddish brown coloured red bole is best exposed in the dug well near Kasaba Bawada .

Laterites and Bauxites: Laterite occur as capping on basalt at higher altitudes (>850m) in the western portion of the basin around Radhanagari, Dhangarwadi and Gagan Bawada. These areas receive an annual rainfall between 3000 to 6000 mm. Sufficient rainfall, high temperature and humidity, and pH of rain water (between 7 to 8) facilitate the formation of laterite deposits by in situ weathering of the parent material basalt. Under favorable environmental conditions, the pockets of bauxites are formed within laterites. Such pockets of bauxites are developed around Dhangarwadi and Radhanagari. At present these areas are commercially mined for bauxite.

Structural Fabric

In the study area two sets of lineaments are identified on aerial photographs. One set trends NE-SW and the other trends NW-SE. The displacement of the lineaments because of intersection of these two sets is observed near Upavade. The fractures have controlled the drainage pattern and have given rise to nearly right-angled turns. The sharp turns of the river Kasari near Bazar Bhogaon can be attributed to NW-SE trending fractures. The river Dhamani flows along the NE-SW trending fracture.

Ground Water

In the present study it is observed that the vesicular, fractured and jointed basalts, and also alluvium constitute good aquifer. Most of the dug wells yielding water occur under unconfined conditions.

Preliminary well inventory was conducted in the river basin by selecting only 75 dug wells. The purpose of the well inventory was to know type of aquifer, dimensions of the dug wells, depth of the water level, seasonal fluctuation in the water level, and the quantity of water available for irrigation purpose. The results of the well inventory in summarized form are as follows:

The well inventory data also revealed that the shallow dug well situated in thick alluvial soil are flowing wells under unconfined conditions. This is mainly due to either the infiltration of irrigation water into the dug well or due to the infiltration of the effluent through the thick soil cover into the dug wells. This is facilitated by the fact that most of the dug wells are unlined. The infiltration of the effluent from the sugar factory or distillery lagoon is evidenced by the change in colour i.e reddish colour of dug well water.

The regional water table as a rule follows topography. Field experience and the well inventory data indicate that in same litho units for some aquifers is high yielding. While in a few cases they are totally dry or very poorly yielding. This is because in the former cases, the movement of groundwater is facilitated by the structurally weak zones. The occurrence of groundwater at different

Aquifer type			**Diameter**			**Depth of wells**		
Alluvial deposits	:	40%	7m to 10m	:	70%	< 7m	:	20%
Vesicular basalt	:	25%	10m to 12m	:	20%	7m to 10m	:	30%
Fractured basalt	:	20%	>12m	:	10%	>10m	:	40
Highly jointed basalt	:	15						

Fluctuation in water level (Winter – Summer)			**Pumping capacity during summer (5H.P. motor)**		
< 2m	:	25%	> 3hrs	:	20%
2m to 4m	:	28%	2 hrs to 3hrs	:	42%
4m to 8m	:	32%	<2hrs	:	38%
>8m	:	15%			

depth in the same litho unit over a small area indicates that the regional water table is not uniform throughout the river basin, in spite of similar surface topographical conditions.

Electrical Resistivity Survey

Hydrogeological characteristics of Deccan traps have been described in detail in the literature (Singhal, 1997; Ghosh *et al.*, 2006 and Limaye, 2010). When electric current is passed in the ground, the presence of groundwater in geological formation leads to distinctive reduction in the resistivity value. The electrical resistivity of a rock formation limits the amount of current passing through the formation when an electric potential is applied. The resistivity of a rock formation varies over a wide range depending upon the material, its density, porosity, pore size and shape, and water –content and also quality and temperature (Keller and Fushkencut, 1966). There are no fixed limits for resistivity's of various rocks; igneous and metamorphic rocks yield values in the range of 10^2 to 10^8ohmm; sedimentary and unsolidated rocks 10^0 to 10^4ohmm. Thigale (1984) attributed the variation in the resistivity values of the basaltic rocks to the degree of weathering, joining as well as to the vesicularity of basalt. The prospective groundwater zone delineated in the resistivity model is observed beneath the weathered/jointed compact basalt. It has been reported by Deolankar (1980) that the weathered basalt shows highest aggregate porosity (34 %) in DVP, whereas the specific yield is less (around 7 %). Though the porosity is high, the specific yield is very small signifying higher specific retention of the weathered basalt. This may be caused due to the presence of clay minerals in the weathered basalt which has higher water retention capacity. Details of Vertical electrical Sounding done in the study area with respect to coordinate and altitude is given in Table 1.

The resistivity values of the flows were actually confirmed with the existing litho units in the dug wells and actual bore holes drilled at seven places (BH 1 to BH7). The generalized ranges of resistivity values for different flows obtained from VES's and corresponding litho units are as follow :

5 – 15 ohms - Black Cotton soil / Lateritic soil
15 - 20ohms - Red bed
20 – 40 ohms - Vesicular or Zeolitic basalt
40 – 70 ohms - Jointed basalt
>70 ohms - Hard & massive basalt.

These resistivity values more or less match with the results of Zambre & Thigale (1980) and Pawar (1985). In Kolhapur City, the vesicular and zeolitic traps act as good aquifers. The yield of these aquifers varies in the range of approximately 3000 to 10,000 liters per hour. In some cases yield is about 50,000 liters per hour.

After the Vertical Electrical sounding, bore holes were drilled at seven locations and lothologs prepared from bore hole data to confirm resistivity values of different lithounits.

The electrical resistivity result indicate that in Panchanganga river basin groundwater occurs at four different depths : the first zone range between 8m to 12m, second zone is between 35m to 60m and the third zone is beyond 90m – 100m and the fourth level between 125 to 145m depth. Thickness of aquifer varies between 5m to 25m. Amongst the four zones, generally the second zone is comparatively high yielding in low lying of the river banks whereas, in higher elevation the fourth zone is good yielding. This is further observed that some of the dry dug wells or with poor discharge, yield large quantity of water, if a bore is taken upto a depth of 35m to 60m in the floor of the dug wells. At few places water oozes out by itself because of sufficient confining pressure in the aquifers, for such dug-cum-bore wells.

Anomalous behavior in terms of low resistivity

Table 1. Location of Vertical electrical Sounding (VES), and bore holes drilled in the study area

VES/Bore Hole no. .	Village	Latitude (N)	Longitude(E)	Top RL (M)
VES1/BH.1	Bhogawati SSK	16^0 31′ 58.25"	74^0 6′37.50"	665
VES2/BH.2	Kumbhi – Kasari SSK	16^0 41′ 21.52"	74^0 7′15.45"	572
VES3/BH.3	Dalmia Sugar (Datta SSK, Asorle Porle)	16^0 45′ 57.01"	74^0 8′19.42"	567
VES4/BH4	Durgmanwadi (Hindalco Mines)	16^0 27′ 6.71"	73^0 58′55.59"	1000
VES5/BH5	Chakreshwar wadi	16^0 28′ 3.57"	74^0 5′10.84"	798
VES6/BH.6	Panchaganga SSK (Kolhapur)	16^0 42′ 44.21"	74^0 26′31.35"	572
VES7/BH7	CSIBER, Kolhapur			
VES8	Tarale (Near Radhanagari)	16^0 26′ 43.17"	74^0 1′44.42"	558
VES9	Khindi Vharawade	16^0 27′ 6.37"	74^0 3′20.58"	566
VES 10	Ujlaiwadi	16^0 40′ 12.98"	74^0 16′13.23"	596
VES 11	Puikhadi- Kolhapur	16^0 39′ 46.48"	74^0 11′13.61"	617
VES 12	Pachgaon (Kolhapur)	16^0 39′ 13.64"	74^0 13′46.16"	601
VES 13	R.K. Nagar (Kolhapur)	16^0 39′ 26.41"	74^0 14′39.64"	615
VES 14	Uchagaon (Kolhapur)	16^0 41′ 50.54"	74^0 16′24.66"	553
VES 15	Kadamwadi (Kolhapur)	16^0 42′ 36.06"	74^0 15′4.04"	556
VES 16	Morewadi (Kolhapur)	16^0 39′ 29.68"	74^0 15′21.89"	631
VES 17	Kale (Gaganbavada Road)	16^0 42′39.87"	74^0 3′9.80"	550
VES 18	Prayag Chakhali	16^0 43′ 23.72"	74^0 11′23.91"	545
VES 19	Bhuyewadi	16^0 46′ 6.63"	74^0 13′9.84"	579
VES 20	Laxmi Tekdi	16^0 36′ 36.56"	74^0 18′25.56"	614

values were observed around sugar factories for lithounits as compared to other units exposed in the well sections or drilled bore hole data. In this paper an effort is made to correlate low resistivity values with higher electrical conductivity of ground water samples from dug well. Electrical conductivity recorded in twenty six dug well water samples (Fig 1, Sample No. A to Z).

According to U.S.D.A (1953), the groundwater with conductivity values less than 500 micromho's/cm are grouped as low conductivity waters, 500-1000 micromho's/cm as medium conductivity waters and greater than 1000 micromho's/cm as high conductivity waters. In accordance with this classification, the groundwater of the Panchanganga river basin can be grouped into medium to high conductivity water. Dug wells close to the sugar factories showed very high electrical conductivity (825 to 1805.1 micromhos/cm).

Most of the wells are shallow aquifers situated around Sugar factories in the Panchanganga river basin. Water level is about 2 to 6 m below ground level. Average Electrical Conductivity values around Kolhapur Sugar Mill was 1269.30 micromhos/cm. and Bhogawati Shakar Sakhar Karkhana was 861.10 micromhos/cm. Average Electrical Conductivity values between Parite and Kolhapur was 728.17 micromhos/cm. Similarly, average Electrical Conductivity values around Dalmia, Asurel-Porle and Kumbhi-Kasari SSK was 904.17 micromhos/cm. and 622.92 micromhos/cm. respectively. The dug well (Sample no. Q) situated away from the Dalmia sugar factory showed comparatively low Electrical Conductivity (i. e 675 micromhos/cm) than the average of 904.17 micromhos/cm which are in the close proximity of the sugar factory. This clearly indicates that the shallow ground water upto a depth of 8 to 10m are polluted due to the percolation of effluents flowing from factory to river through nalla and at places formers are directly pumping treated / partially effluent into dug wells anticipating to get better productivity because of higher potassium and sulphate. This is further, evidenced by the reddish colour of dug well water in the vicinity of sugar factories. Depth wise pollution of ground water is also observed in deeper strata because of lower electrical resistivity as compared to same strata in other places. Further, unlined dug wells are more polluted than lined dug wells in terms of higher electrical conductivity and reddidh colour of dug well water.

A red bole of 6m is exposed below the soil cover of 3 m, around the Kolhapur sugar mill. This red bed has shown resistivity value as low as 10 ohmm and the water sample has shown very high electric conductance (>1000 micromho's/cm). Most of the dug wells in the vicinity of sugar factories are polluted upto a depth of 8 to 10 m. Hard jointed basalt showed electrical resistivity of 35 ohmm (standard value is 45 to 70 ohmm) at a depth of 40m, vesicular and amygdaloidal in the range of 17 to 25 ohmm (against standard value of 25 to 45 ohmm) at depth of 35 to 45 m. In the same area vesicular and amygdaloidal encountered above 70 m depth showed higher resistivity value of 30 to 45 ohmm. This clearly indicates that ground water is also polluted by the percolation of effluent upto a depth of 35 to 45 m. However, this needs to be substantiated by the collection and analysis of ground water from depth of 35 to 50 m. Formers use such quality of dug well water for irrigating sugar cane. Personal communication with formers indicated that sugar cane yield has substantially reduced from 80 tonnes per acre to 50 tonnes per acre.

The VES not only gives information regarding depth of occurrence of ground water, but also highlight the quality of the groundwater to a certain extent.

CONCLUSION

The Geological map (Fig.1) indicate that at higher altitude i.e above 1000m MSL there is residual enrichment of bauxite with lateritic capping at places due to differential weathering process of parent basaltic rock. Typical geological section at the altitude is latertic capping 0 m to 5 m, followed by bauxite of 5 to 10 m and then by lithomarge clay of about 35 to 40 m and finally unaltered jointed basalt as parent rock. At this altitude, jointed basalt acts as a good aquifer. On the slope portion of the river basin laterite is exposed upto 800 m MSL elevation. On the banks river alluvial soil and rest of the area Deccan volcanic basalt is exposed. Jointed basalt, fractured basalt, Vesicular basalt and alluvial deposit act as good aquifers at different levels in the river basin. Well inventory, vertical electrical resistivity sounding and actual drilled bore hole data indicate that groundwater occurs at four different depths: the first zone range between 8 m to 12m, second zone is between 35 m to 60 m and the third zone is beyond 90 m – 100 m and the fourth level between 125 to 145 m depth depending upon hydro geological set up at that point. Average thickness of an aquifer varies between 5m to 25m. Effort was made to correlate quality of ground water by measuring electrical conductivity and vertical electrical resistivity values. Most of the dug wells are classified into medium to high conductivity water. The litho units showed low resistivity values and higher Electrical conductivity values of ground water in the area that is affected by the percolation of treated or partially treated effluent upto a depth of 35 to 45m as compared to same lithounits observed in the lithologs of uncontaminated zone at higher altitude. Pollution of deeper aquifers is further required to be confirmed by depth wise water sampling. Unlined dug wells are more polluted as compared with lined dug wells in the same area upto a depth of 8 to 10m. Irrigating sugar cane by such quality of ground water has reduced the crop yield. Farmers should not use of treated effluents for recharging or storing of dug wells and proper lining wells advised.

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