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Understanding Shallow Basaltic Aquifer System Near West Coast of Maharashtra, India

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Abstract

Two-Dimensional (2D) Electrical Resistivity Tomography (ERT) and geophysical logging and injected tritium tracer studies with hydrogeological tests were carried out at selected location in an area of 5 km^2 near the coastal region of Tarapur, Thane district, Maharashtra. The area is in basaltic terrain, overlain by thin cap of alluvium formation and receives an annual rainfall of about 2000 mm. An integrated investigation method was adopted to delineate the subsurface lithological variations, understand the existing aquifer system up to 25 m depth, evaluate aquifer properties, recharge potential and also to monitor the groundwater flow characteristics. The investigation results showed a variable thickness of weathered zone of 1-3 m, existence of two basalt flows, low vertical natural recharge, high transmissivity, high hydraulic conductivity and high groundwater flow rates. The results also depicted that a combination of hydrogeological tests along with resistivity and tracer investigation is an effective tool in mapping and characterizing the shallow potential groundwater aquifer zone in Deccan traps. The integrated study carried out in the coastal area provided detailed subsurface information useful for planning specific water conservation strategies for sustainable groundwater supply.

Keywords: Deccan Traps, ERT, Tritium Tracer, Recharge, Groundwater Flow

Introduction

About two-thirds of the Indian sub-continent comprising the central, western and southern peninsula is covered with hard rock types such as basalts, granites, gneisses, etc. It is one of the most remarkable continental flood basalt provinces (CFB) of the world like those of Columbia River, North Atlantic, Caribbean, Panama, Karoo, Endeca, Ethiopia, Siberia, Emaishan, Ontong Java and Antarctica. The Deccan trap refers to the terraced appearance of the landscape of the Deccan Plateau. The word Trap comes to mean fine grained dark colored rock which is usually basaltic in composition. They are also called flood basalts because of their vast expanse and as plateau basalts as they standout as table lands. The Deccan Volcanics had erupted close to the Cretaceous-Tertiary (K/T) boundary at about 65 Ma. This stupendous volcanics is closely related to catastrophic events of mass extinction (like Dinosaurs) through bolide impacts and global climatic change (Vaidyanadhan and Ramakrishnan, 2010).

The Deccan trap flood basalts of the Paleocene age cover about 500000 km^2 of western and central India (Verma and Khosla, 2019). The estimated extent prior to erosion including their concealed extent as under the Arabian sea may be of the order of 15,00,000 km^2. The approximate composite thickness of the Deccan volcanics is about 3000 m. It occupies a vast terrain between 69°–79°E longitude and 16°–22°N latitude and they constitute one of the largest volcanic provinces on Earth (Pandey, 2016). The narrow coastal strip in the western part is covered by thin cap of alluvium over basalt and the same is characterized by heavy monsoon rainfall of 1700–2200 mm. In this area, dug wells tapping the shallow phreatic aquifers (sandy zone in thin alluvial formation / weathered zone of basalt) and semi confined to confined aquifers (fractures and vesicular zone) at moderate to deeper depth are common. Numerous geological, mineralogical, geomorphological, structural, tectonic, geochemistry and hydrological studies were carried out in Deccan Trap province since last few decades (Versey and Singh, 1982; Athavale *et al.*, 1983; Subbarao, 1988, 1994, 1999; Deshmukh, 1988; Deshmukh and Nair, 1996; Nair and Bhusari, 2001; Chandrasekharam *et al.*, 2003, Narayanpethkar *et al.*, 2008; Kulkarni and Deolankar, 2008; Limaye, 2010; Rai *et al.*, 2011). Rangarajan and Muralidharan, 2019)

Aquifer mapping in an inhomogeneous anisotropic medium has always been a challenging task to attempt. Several good and promising results have been reported all over the world for more than 4 decades in the past. An integrated hydrogeological investigation towards aquifer mapping, recharge rate estimation, aquifer characteristics and flow dynamics is necessary to develop numerical groundwater model study. Electrical Resistivity Tomography (ERT) is extensively used for mapping aquifer dimensions, geotechnical problems and contaminated sub-surface

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geological formations (Ratnakumari *et al.*, 2012; Rai *et al.*, 2013, 2015; Kumar *et al.*, 2016). The advantage of ERT is that it provides large amount of data (greater spatial coverage) in less time and cost. It represents the sub-surface lithological units in the form of an image; along the entire spread length with high resolution due to mapping of same location a number of times for different electrodes spacing.

Tracer technique is widely adopted to estimate natural recharge in point and catchment scale with merits and demerits (Allison, 1988; Athavale *et al.*, 1980, 1983, 1998; Rangarajan *et al.*, 2000, 2005, 2009, 2014b; Bhanja *et al.*, 2019). It is also useful in soil moisture transport (Rolland *et al.*, 2018), groundwater flow rate estimation and direction (Athavale *et al.*, 1992; Rangarajan *et al.*, 2014a). Extensive hydrogeological investigation has been carried out and reported in the recent past by Central Groundwater Board (CGWB) and Groundwater Surveys and Development Agency (GSDA) in Thane district, Maharashtra on a district level. Here in this paper, the authors have reported the investigation results pertaining to resistivity tomography along with aquifer and tracer studies carried out to decipher the subsurface pattern of basaltic flows and also to map the aquifer system up to a depth of 25m in an area in the west coastal zone of Tarapur, Palghar mandal, Thane District, Maharashtra.

Study Area

A 5 km^2 area was identified adjacent to the west coastline near Tarapur village in Palghar taluk of Thane district, Maharashtra state. The study area is adjacent to the Arabian Sea on its west and is underlain by Deccan Trap Basalt Formation with the thickness of about 1000 m (Fig.1). The area experiences a subtropical monsoon type of climate, with the rainy season persisting from June to September, which brings about 95% of the annual rainfall. Groundwater in the study area occurs under semi-confined to confined conditions with massive lava flows and thick red-bole layers tending to exhibit vertical movement of groundwater and thus act as confining aquicludes. The aquifer zones near the coast are mainly alluvium formation and are classified as shallow aquifer (< 10m). The bore holes yielding aquifer in basalt occur under semi confined condition at moderate to deep levels and are classified as deeper aquifer (>15m). The groundwater level fluctuation in the area during pre-monsoon varies between 2 to 6 m bgl. No systematic integrated studies were carried out in this

Rainfall

Based on data analysis for the period 2000 to 2011 the mean annual rainfall calculated was 2167 mm. The seasonal rainfall analysis for the study years (2010 and 11) was carried out based on data collected from IMD (Table 1). The rainfall data also indicates

Table 1: Seasonal rainfall analyses

Monsoon months	Av (2000-11)	2010	2011
June	497.8	484	228.1
July	731.8	1107	972.5
August	612.3	903.5	584
September	259.6	264	299.5
October	33.7	121.5	28
SW monsoon (June- October)	2135	2880	2112
Total	2167	2937	2210

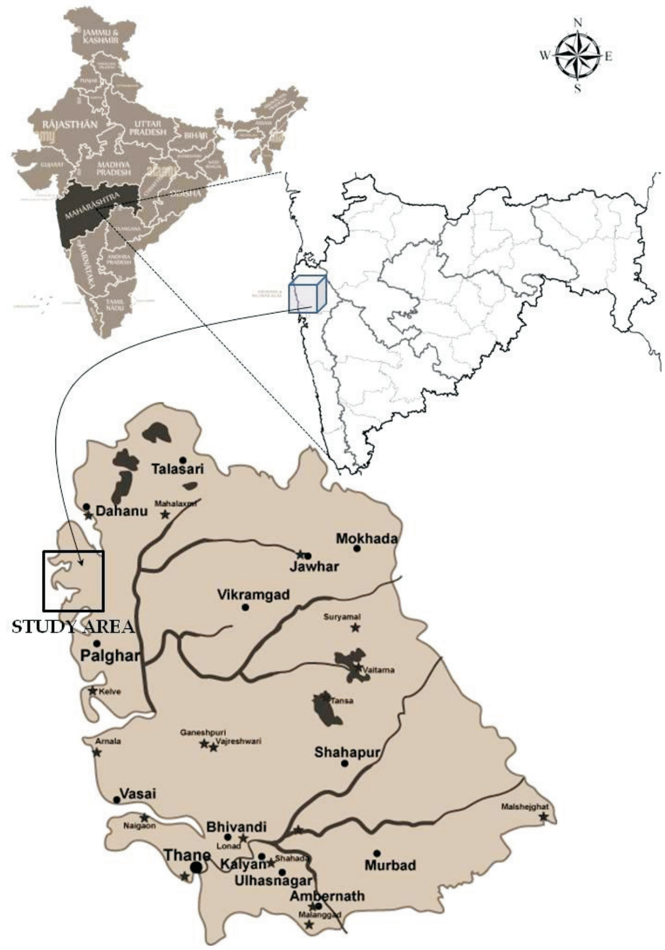

Fig. 1. Location map of the study area

that the monsoonal rainfall during the study years contributes more than 98 % of the total annual rainfall. Large number of moderate rainfall events (> 30 mm/d) and several moderate to high intensity rainfall events (>60 mm/d) and few high intensity rainfall events (> 100 mm/d) had occurred during 2011.

Material and Methods

A detailed study pertaining to subsurface lithological mapping was undertaken in the study area, adopting a systematic integrated approach, comprising of hydrogeological, geophysical and tracer techniques.

ERT Survey for Subsurface Lithological Mapping

A multi-electrode resistivity tomography (ERT) survey employed in the study area is used to obtain subsurface lithological information. The multi-core cable is connected to an electronic switching and transmitter unit, which is then connected to a laptop computer. The data acquisition is fully automatic and sequence of measurements depends on electrode array used for the study. The measured apparent resistivity is converted into true resistivity using RES2D.INV inversion program in order to produce the 2D resistivity cross-section image. ERT technique is accepted by many researchers for mapping of aquifer, saline water zones,

Table 2: Resistivity imaging investigation details

Sr. No	Site Name	Spread Length (m)	Direction	Depth Investigated (m)	Inferred Sub-Surface Lithology			
					Geo-electric Layer	Resistivity Range in Ohm-m	Depth Range in m	Inferred Lithology
1	Site 1	80	NE-SW	12.0	1	1 - 10	0 - 3	Moist silty clay soil
					2	10-80	3 - 5	Weathered vesicular basalt
					3	>100	> 5	Massive basalt
2	Site 2	160	N-S	25.0	1	1 - 10	0 - 3	Silty clay soil
					2	10-30	3 - 12	Highly Weathered vesicular basalt
					3	>30	> 12	Semi weathered vesicular basalt
3	Site 3	80	N-S	12.0	1	1 - 10	0 - 4	Silty clay soil
					2	10-30	4 - 7	Highly Weathered vesicular basalt
					3	>30	> 7	Semi weathered vesicular basalt
4	Site 4	120	N-S	12.0	1	1 - 40	0 - 7	Silty clay soil
					2	> 40	7 - 12	Highly Weathered vesicular basalt
5	Site 5	80	E-W	12.0	1	1 - 10	0 - 1	Silty clay soil
					2	50 - ~ 200	2 - 5	Semi weathered to massive basalt
					3	10 - 30	5 - 12	Semi weathered vesicular basalt
6	Site 6	120	E-W	12.0	1	100 -200	0 - 3	Silty clay soil
					2	5 - 20	2 - 5	Highly Weathered vesicular basalt
					3	20 - > 200	5 - 12	Semi weathered vesicular basalt
7	Site 7	160	N-S	25.0	1	1-10	0 - 12	Highly weathered vesicular basalt
					2	10 - 60	12 - 25	Moderately weathered basalt
8	Site 8	80	E-W	15.0	1	1-15	0 - 2	Dry silty clay soil zone
					2	15 - 150	2 - 7	Highly weathered vesicular basalt
					3	150 - > 600	7 - 12	Weathered to fresh basalt zone
9	Site 9	80	N-S	12.0	1	300 - 500	0 - 2	Dry silty clay soil
					2	20 - 70	2 - 6	Highly weathered vesicular basalt
					3	70-200	6 - 9	Moderately weathered basalt
					4	200-500	> 9	Fresh basalt
10	Site 10	80	E-W	12.0	1	1 - 10	0 - 4	Silty clay soil
					2	10-30	4 - 6	Highly weathered vesicular basalt
					3	>30	> 6	Moderately weathered basalt

groundwater - surface water interactions and other environmental impact assessment studies.

The ERT survey was carried out using ABEM SAS 1000 Terrameter instrument at 10 different sites in the study area, in order to understand the subsurface lithological setting (Table 2). The configuration adapted in the survey was Wenner 32SX, Wenner L and Schlumberger S. The total depth of investigation inferred from all the investigated sites were 12 m to 24 m with an inter-electrode spacing of 2 m.

The 2D resistivity pseudo-section at each investigated site depicted the depth variation of resistivity with respect to subsurface basaltic rocks (Fig.2). Long spread resistivity imaging for deeper investigation, beyond the depth of 25m could not be conducted due to lack of uninterrupted long stretch of space for laying cables. The resistivity images broadly indicate shallow (1-3m) thickness of moist and dry silt clayey soil followed by thick layer of moderate to highly weathered basalt. The subsurface resistivity pattern and corresponding values up to the maximum investigated depth of 25 m provides information about two basaltic flows in the study area. Based on the results of these resistivity images, suitable sites were identified for drilling of boreholes.

Drilling of Bore Holes and Lithological Study

In order to understand the aquifer characteristics and also to delineate potential aquifer zone(s), 10 boreholes (6.5" diameter) were drilled at each selected site. At the time of drilling at each site, the lithological information was gathered based on core samples collected at regular interval of time from different depth. The approximate yield of the wells varies from 0.5 to 2.5" (< 100 gph – 1150 gph). After completion of drilling, the bore holes were protected by casing made of mild steel. Locking arrangement and provision for hanging automatic water level logger was made at the time of fabrication.

Cadastral Survey and Electrical Logging

Cadastral survey was carried out using Theodolite in order to connect all the drilled bore wells with respect to mean sea level (MSL). After the boreholes were reduced to MSL, electrical resistivity logging was carried out at each observation well site using ABEM-SASLOG 200. A continuous record of resistivity variation with depth was acquired and the same is plotted for few boreholes along with the respective litholog (Fig.3). Taking into account the signature of depth measurement (vs) measured values of resistivity, Self potential and temperature, the aquifer position and thickness is estimated at different bore hole sites as tabulated (Table 3). In most of the cases, the aquifer is found to be thin (1-2 m) within the depth of 30 m. A 3D perception of the subsurface lithology and aquifer distribution in the study area was attempted with respect to litholog (Fig.3).

Water Level Measurements

The aquifer behavior in the study area with respect to seasonal variation was assessed through continuous water level

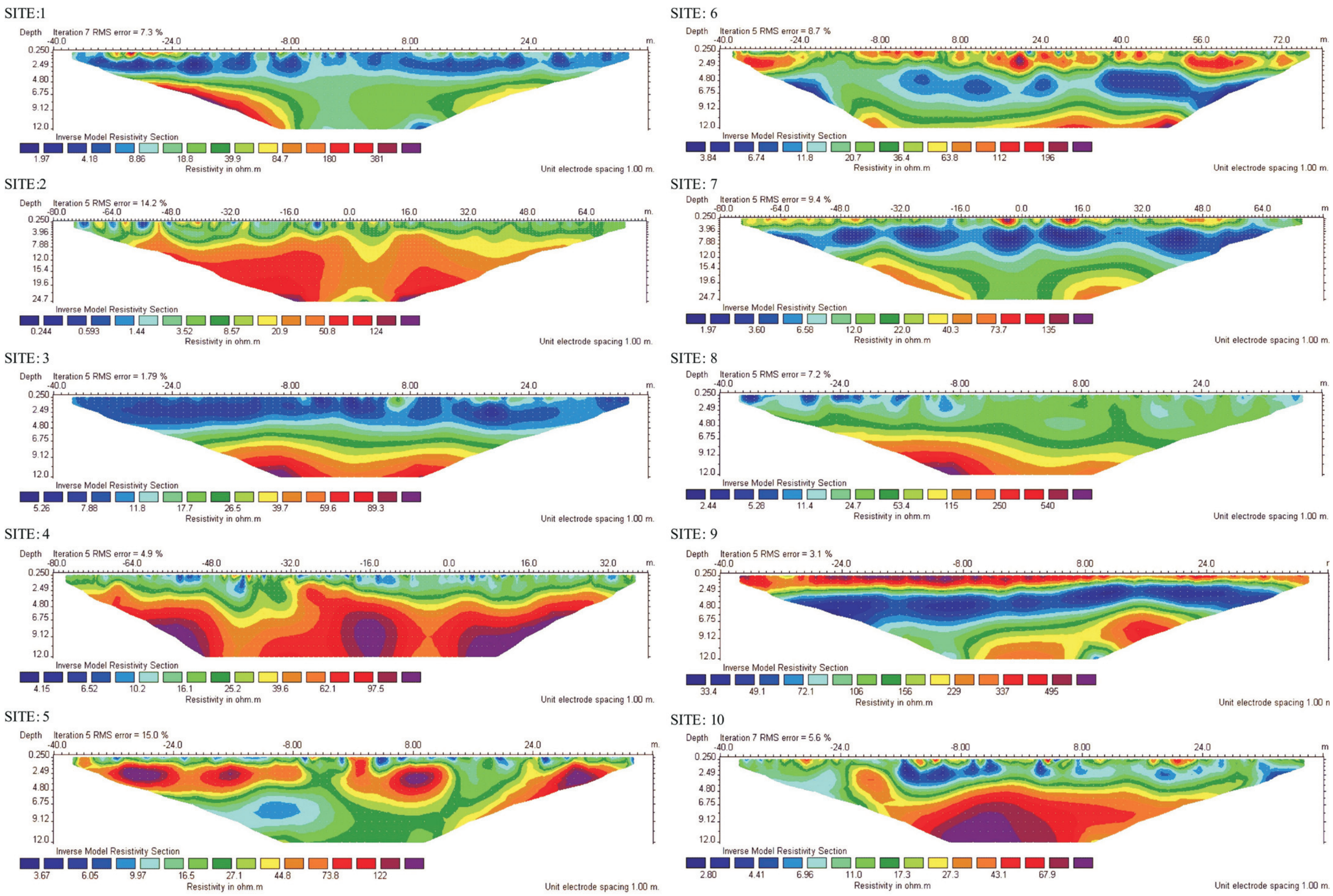

Fig.2. 2D Resistivity pseudo section at each investigated site depicting the lithologic variation with depth

measurement. Automatic water level recorder (data loggers) was installed in the bore wells for monitoring the changes in water level during 2011 and 2012 hydrological cycle. The continuous water level data of wells during the two hydrological cycles showed that the water level reaches the shallow level (1- 2m bgl) in the early monsoon and remains shallow during the monsoon. Later, the water level declines at a steady rate from the end of active monsoon season. The groundwater table contour map prepared based on reduced water level data of bore wells revealed that during pre-monsoon and post monsoon period, the groundwater movement is towards east, west and northern part. And during monsoon period, the predominant groundwater movement is towards west and southwestern side of the study area.

Pumping Tests for Aquifer Parameter Determination

Short duration pumping tests were carried out using low discharge pump (1 HP), in seven observation wells to estimate the aquifer parameters *i.e.*, transmissivity and storage coefficient. The discharge during the test was monitored and kept constant. Data loggers were used for monitoring the drawdown. The aquifer in the study area is considered to be confined without boundary effect and the same was considered for analysis using GWW software applying Theis/Jacob method. The GWW (1995) software is a data base and field data processing package. Four typical pumping test results with field and fitted curve matching through GWW software is shown in Fig.4. The aquifer parameters determined by pumping tests in observation wells indicated that the Transmissivity and Storage Coefficient varies in the range of 74 m^2/d - 260 m^2/d and 6.7×10^{-4} - 1.4×10^{-6}, respectively. The discharge rates measured at the time of drilling and pumping test indicate that the aquifers are low to moderately yielding.

Injected Tritium Tracer Studies for Natural Recharge Estimation

The tritium injection method (Zimmermann *et al.*, 1967; Munnich, 1968), for natural recharge measurements assumes a piston flow model for movement of water infiltration in the vadoze zone. It means that the soil moisture moves downwards in discrete layers. Any fresh layer of water added to the near surface soil layer due to infiltration after precipitation or irrigation, percolates down by pushing an equal amount of water beneath it further down. In the tritium injection method, the moisture at a certain depth (60-80 cm) in the soil is artificially tagged with tritiated water. For estimating recharge due to rainfall, the injections are made below the root zone and before the onset of monsoon. In the fallow un-ploughed and non-irrigated areas, the tritium is normally injected at the depth of 60 cm below ground level (bgl).

The tracer moves downwards due to infiltration of a fraction of precipitation or irrigation water. Soil cores are collected from the injection site after the monsoon and the moisture content and tracer concentration is measured in samples from successive depth intervals. The displaced position of the tracer is indicated by the peak in its concentration in a plot of depth versus tritium activity.

Table 3: Natural Recharge at tritium injected sites

Site No.	Site name	Depth of sample collection (cm)	Displacement of tracer peak from injection depth(cm)	Natural recharge computed (mm)	Effective rainfall (mm)	Recharge (%)
1	Site 1	150	85	273.7	2840	9.6
2	Site 2	170	85	112.8	2840	4.0
3	Site 3	150	90	175.7	2840	6.2

Table 4: Saturated Permeability / hydraulic conductivity of soil samples

Site Name	Depth cm	Position No	V (ml)	L (cm)	A cm^2	t (min)	H (h2-h1) in cm	K mm/hr / (m/d)
Site 1	5-10	1	40	5	19.62	305	2.3	8.7 (0.2088)
Site 2	5-10	2	40	5	19.62	49	1.9	66.0 (1.584)
Site 3	5-10	3	40	5	19.62	16	2.3	166.0 (3.984)

The peak may be broadened because of other factors such as diffusion, irregularities in water input and streamline dispersion. The moisture content of the soil column between the injection depth and displaced (peak) depth of the tracer in the soil core is the measure of moisture influx in the unsaturated zone over the time interval between injection of tritium and collection of soil core. As per the piston flow model, the moisture influx will reach the groundwater system as recharge flux. This methodology was used for natural recharge measurements in several Watersheds and Basins of India (Rangarajan *et al.*, 2000).

The recharge value for each site is calculated first by determining the peak of the tritium versus depth profile and the volume moisture content of the displaced zone. The displacement of the tracer from the depth of injection is the distance between injection depth and center of gravity or peak of the tritium concentration in the profile. The recharge is calculated by

$R_e = m \times d$

where R_e = recharge in mm, m = moisture content of the displaced zone in 1 sq. mm, d = displacement of tracer from the depth of injection

R_e is the height of an imaginary water column over 1 mm^2 in the soil profile between the depth of injection and peak in tritium activity. As per the piston flow model, this amount is finally added to the groundwater as recharge. Assuming this Re is due to rainfall R during time t (period between dates of injection and soil core collection), the percentage of rainfall R contributing to the recharge is given as,

$R_e (\%) = 100 \times d \times m/R$

In the study area, Tritium tracer was injected at 3 sites in fallow land covered by bushes /shrubs during the month of June 2010. The depth of tracer injection was at 60 cm below ground level and depth soil core samples were collected in 10 cm section from tracer injected locations, using recovery pipes up to maximum depth of 1.7m (Fig. 5). The displacement of tritium peak and moisture content of the displaced zone were used for estimating

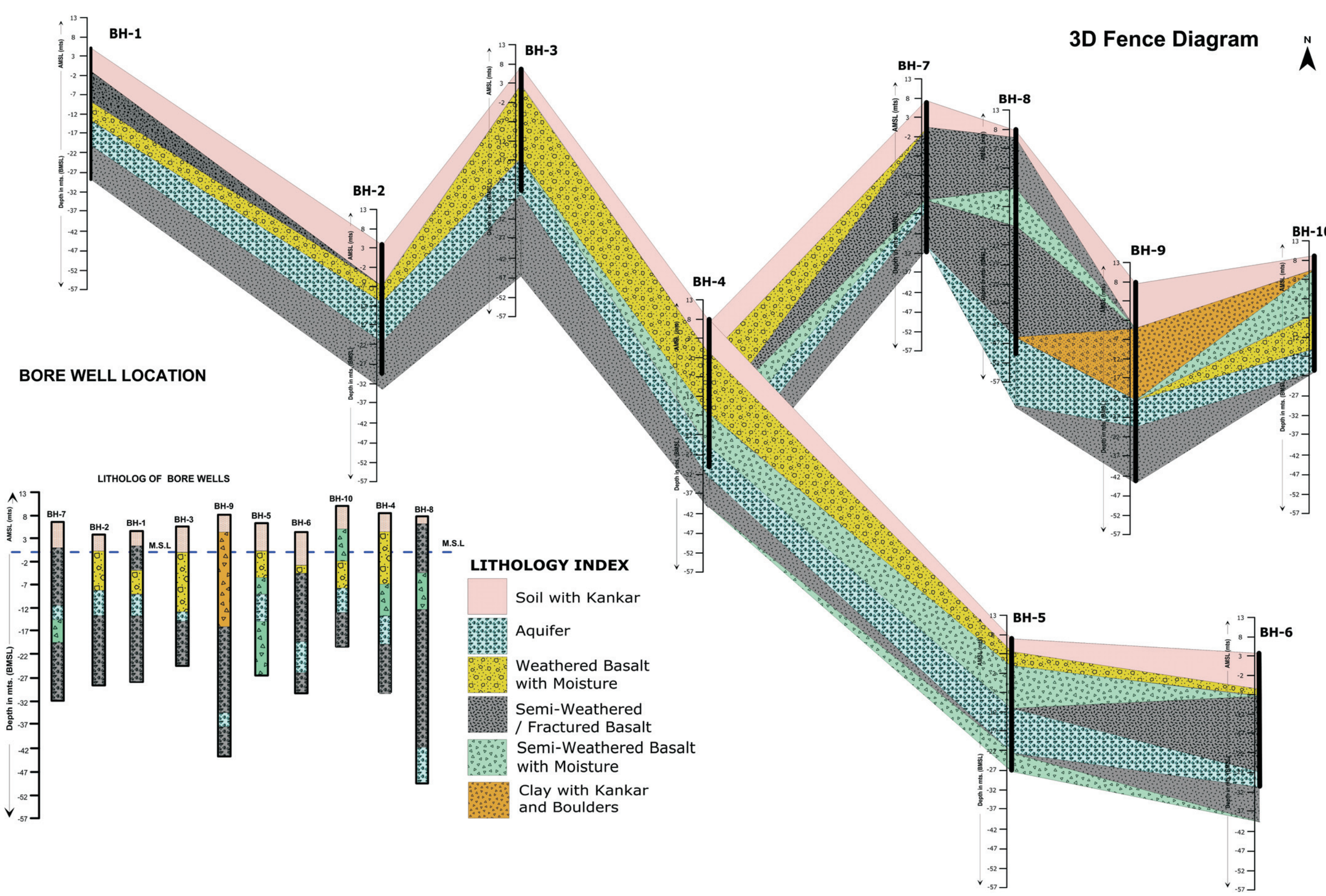

Fig.3. 3D perception of the subsurface lithology and aquifer distribution in the study area

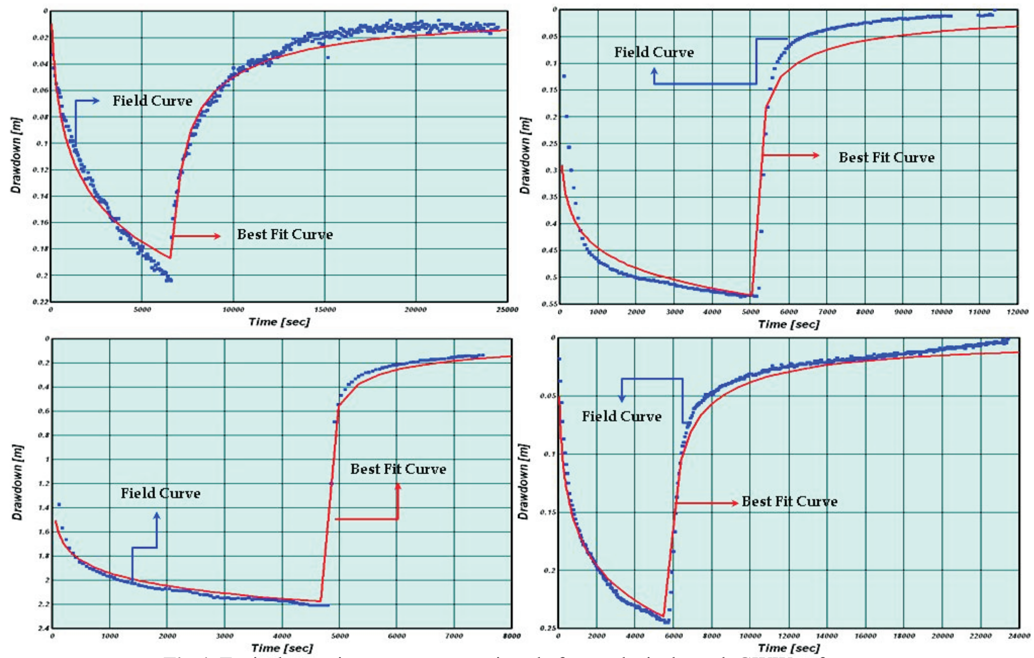

Fig.4. Typical pumping test curves retrieved after analysis through GWW software

natural recharge at each site (Table 3). The natural recharge values estimated varies from 112.8 – 273.7 mm, which is equivalent to 4.0-9.6 % of rainfall.

Hydraulic Conductivity Measurements

Laboratory permeameter with constant head method was used to measure the saturated permeability of soil samples collected from the tritium injection sites. Permeability refers to the capacity of the soil to drain off water and its coefficient is the measure of permeability which is determined on one hand by the geometry of the complex of pores, depending on the texture and structure of the soil and on the other hand on the intrinsic features of the soil solution. Saturated soil is referred to as saturated permeability. Constant head method is normally used for high permeability soils.

Constant Head Method (for High Permeability Soils)

$K = V * L / A * t * h$

Where, K = Permeability coefficient in cm/d, V = Volume measured in the burette in ml, L = Length of the sample in cm, A = Area of cross section in cm^2, h = water level difference inside and outside the ring holder in cm, t=length of time in hrs

The undisturbed soil zone samples (5 cm section, 2 cm below ground level) were collected using hand auger from 3 selected over the study area. The samples collected in rings are loaded in the laboratory permeameter. The constant head method was used for measuring the saturated permeability of the samples. The results are presented in Table 4. The values range from 0.2-3.9 m/d.

Bore Hole Tracer Studies for Groundwater Flow Rate Assessment

Borehole tracer experiments in hydrogeological studies provide information on hydraulic connectivity, velocity and direction of groundwater flow. Natural groundwater flow is usually laminar, which implies that the velocity of flow is proportional to the hydraulic gradient. There are basically two methods namely (a) Single well and (b) Multi well used for estimating groundwater velocity (Drost *et al.*, 1974). In the single well method, the groundwater column of a filter tube / bore well is labeled with a tracer solution. The decrease in the concentration of this solution in time scale is a function of groundwater flow across the well. It can be expressed as,

Groundwater filtration velocity (V^*) is given as

$$Q = V/T \;\; In \; C_0/C \quad (1)$$

$$V^* = V/At \;\; In \; C/C_0 \quad (2)$$

$$V^* = pn^*v \quad (3)$$

Where,
Q = groundwater discharge from the filter tube
V =volume of labeled water column
C_0 = concentration of the labeled water column at time t=0
C = concentration of the labeled water column at time t
A= flow cross section area of the tube
v^* = filtration velocity
pn = effective porosity of the aquifer
v = distance velocity of groundwater

In the multi well technique, a labeling substance is added to the groundwater at an injection point (*donor well*). Detection is carried out in the direction of flow at acceptor wells. The measured parameter is the time taken by the labeled water when the flow from the donor well to the acceptor well. From the flow time (t) and distance (a), the velocity is given by

$$v = [a/t] \quad (4)$$

Borehole tracer experiment was carried out at selected sites within the study area during January 2012, after the end of 2011 monsoon season. Artificial chemical tracer bromide in the form of potassium bromide was used through single and multi-well dilution technique. The experiment was conducted at 5 bore hole sites, after

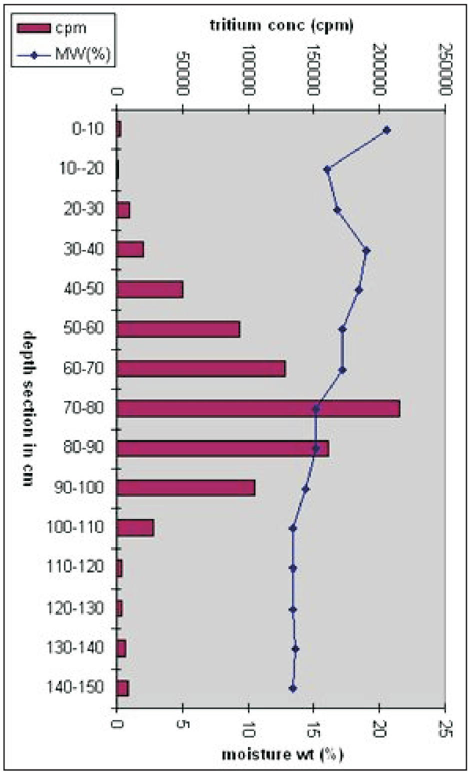

Fig.5. Tritium depth concentration plot of a site condition

measuring the depths of well and the static water level. In each well 5 kgs of potassium bromide (KBr) dissolved in 10 liters of water in a bucket and was injected in to the bore hole water as a single slug within time period of 30 seconds using PVC tubes and funnel. Using a conductivity meter and ion selective electrode system, the transient change in in-situ water conductivity and bromide concentration before and after the initiation of tracer injection was analyzed at every 15min interval.

The bromide values obtained from conductivity sensor is more or less same as that of the analytical data. Bromide data of injection wells obtained from the conductivity sensor, well specification, aquifer zone thickness and water level data were taken in to account for determining the filtration velocity. The filtration velocity calculated ranges from 1.48 m/d to 1.94 m/d under pumping / induced condition and 0.106 m/d under natural condition. The actual velocity of groundwater flow is calculated, wherein the effective porosity of weathered / vesicular / fractured basalt formation is considered within 5-20 % (CGWB 1997). The actual velocity of groundwater flow for different sites is calculated.

Results and Discussion

The integrated studies were carried out to assess the hydrodynamics of shallow groundwater regime for sustainable groundwater supply for drinking and other needs. Though the area receives more than 2000 mm of annual rainfall, there was shortage of supply during dry period. This is due to groundwater outflow from the area towards coast. Based on the analysis of resistivity imaging survey and lithologs of drilled bore holes, the interpretation of subsurface lithology up to maximum depth of 25m was successfully done, which indicated the occurrence of thick weathered zone up to the depth of 15m followed by aquifer zones which ranges from 1 to 3 mts. The resistivity pattern and values up to the maximum investigated depth of 25m indicates two basalt flows in the study area. Static water level measurement showed that the water table in the study area is less than 6 m bgl before monsoon and reaches very shallow level (1-2m bgl) during and post monsoon period. The hydrographs indicate that after the onset of monsoon the water level in the entire complex area rises up to near surface level of 1-1.5m bgl. Transmissivity and storage coefficient calculated are 74 m2/d-260 m2/d and Storage Coefficient in the range of 6.7x10-4-1.4x10-6. The yield of the wells is 100–1150 gph. Natural recharge study using tritium injection method showed that the mean recharge rate is 187mm or 6.5 % of the effective rainfall. Hydraulic conductivity of shallow soils is in the range of 0.2-3.9 m/d. The mean velocity of groundwater flow taking into account 20% effective porosity of aquifer formation is calculated as 0.53 m/d under natural condition and 8.75 m/d under induced condition.

Lower recharge rate (6.5% of rainfall) is mainly due to presence of shallow water table condition during the monsoon period. The groundwater level remains at shallow level throughout the period of monsoon. Due to shallow water table condition during monsoon, the aquifer storage space is negligible which is reflected by lower recharge rate (6.5 % of rainfall). Most of the water infiltrated on the surface moves laterally as interflow and goes as rejected recharge in spite of moderate to high saturated hydraulic conductivity of surface formation. This is reflected by high Transmissivity of aquifers and high hydraulic conductivity of shallow soil formation in the study area.

Assessment of groundwater aquifer system towards creation of drinking water source or artificial recharge strategy development for sustainability measures needs a thorough understanding of the study area. The detailed investigations in the basaltic terrain (Tarapur area near Palghar in the west coast line of Maharashtra) lead to assess the aquifer behavior, occurrence, flow *etc.*, which is mandatory before implementation of any sustainable groundwater recharge scheme.

With the prevailing excessive rainfall during monsoon, high runoff and interflow phenomenon, low recharge rate, high flow rate of aquifers, it was recommended to construct few large capacity lined storage structures at suitable locations for storing the runoff and subsurface flow water for use during dry period. Such detailed study for any given terrain and geology will suffice all the necessary parameters required to frame an appropriate recharge strategy.

Conclusions

The average seasonal rainfall received in this part of coastal area for two year study period is 2496 mm. Higher average annual rainfall and shortage of groundwater supply due to observed reduction in yield of some wells during dry period shows that the groundwater after recharge is going out from the area. The resistivity survey indicated 1-3 m thickness of moist and dry silt soil and maximum 15 m thickness of moderate to highly weathered basalt. Existence of 2 flows could be inferred from the resistivity data. Hydraulic conductivity of shallow soil zone at three sites ranges from 0.2-3.9 m/d. High hydraulic conductivity of soil zone and maximum 15 m thick weathered zone formation indicates potential of high infiltration and percolation rates. However, due to the attainment of shallow water table condition during the middle of monsoon itself (about 1 – 1.5 m bgl), further recharge was not taking place in this area due to rainfall in the later part of monsoon. In spite of high rainfall and high hydraulic conductivity of vadose zone, natural recharge, *i.e.,* recharge through soil and weathered zone is very low of the order of 6.5 %. This clearly indicated rejected recharge phenomenon in this area. Higher transmissivity rate of aquifer zone (max. 260 m2/d) and higher groundwater flow rate 0.53 m/d under natural condition and 8.75 m/d under induced condition indicates large quantum of groundwater moving out from the area as outflow. Though favorable conditions exist for recharge and higher groundwater potential, the area suffers from sustainable groundwater supply. Rainwater harvesting through runoff collection in structures at suitable location will alleviate the shortage of drinking water supply.

Authors' Contributions

R. Rangarajan: Conceptualization, Investigation, Formal Data Analysis, Reviewing and Editing. **Rolland Andrade:** Investigation, Data Curation, Writing-Original Draft Preparation.

Conflict of Interest

The author declares no conflicts of interest.

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