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Efficacy of Kumarswamy method in determining Aquifer Parameters of Large-Diameter Dugwells in Deccan Trap Region, Nagpur District, Maharashtra

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ABSTRACT

Since ancient times, withdrawal of groundwater in India is carried out from shallow level phreatic aquifers by the means of dugwells. These shallow unconfined/anisotropic aquifers, generally comprising weathered material, are tapped by the dugwells of large diameter. Such wells, specially penetrating the crystalline and basaltic terrain ensure large storage of groundwater in low permeability aquifer conditions. Therefore, proper understanding of the characteristics and behaviour of this almost omnipresent phreatic aquifer, being tapped by vast number of large diameter dugwells becomes imperative. In view of this, an attempt has been made here to analyze the pumping test data of ten (10) large diameter dugwells, falling under micro-watershed of WGKKC-2 of Kalmeshwar Tehsil, Nagpur district, Maharashtra. The drawdown and recovery data, generated through pumping tests were analyzed by the empirical formula given by Kumarswamy (1973). The transmissivity (T) and specific yield (Sy) values for the large diameter dugwells, tapping the phreatic aquifer of study area were found in between 22.43-385.60 m^2/day and 0.028-0.127 (fractions), respectively. The permeability (K) and specific capacity (C) values range in between 0.99-82.96 m/day and 68.45-526.37 lpm/m, respectively. Subsequently, these results were compared with 'T' and 'Sy' values, reported by various workers/departments elsewhere in the basaltic terrain of Maharashtra. The range of observed values of 'Sy' and 'T' of present study confirms to those values reported earlier by the previous workers. The overall study indicates the efficacy of Kumarswamy (1973) method in determining the aquifer parameters of large-diameter dugwells tapping the basaltic aquifers.

INTRODUCTION

The Deccan basalts occupy an area of about 500, 000 km^2 in central, western and southern parts of India (Singhal, 1997). In Maharashtra State (total area 307, 713 km^2), 81% of the area is occupied by basaltic lava flows (Deccan plateau). In this vast basaltic region, a total of 1.83 million wells have been reported by Central Ground Water Board (CGWB), Ground Water Surveys and Development Agency (GSDA) and other organizations. Out of these wells, 90% are dugwells, a majority of which are commonly used for irrigation purposes (GSDA & CGWB, 2005). The total depth and diameter of these dugwells vary from 5-20 mbgl and 2-12 m respectively. Such wells ensure large storage of groundwater in low permeability aquifer conditions and offer the only opportunity to test for hydrologic characteristics of the shallow aquifer systems (Chachadi and Mishra, 1989; Naik and Awasthi, 2007).

The recharge into the aquifer media takes place through infiltration of precipitation through ground surface and seepage from surface sources like lake, river, pond, irrigation return, *etc.* However, the availability of groundwater at any place depends upon the hydrological properties of an aquifer media, rates of withdrawal and the recharge conditions (Birpinar, 2003; Saha and Agrawal, 2006). Therefore, pumping tests are performed in the field to assess the aquifer parameters of sub-surface formations. These tests not only help to evaluate the hydraulic characteristics, yield and drawdown of an aquifer system but also provide an idea on designing of wells for future (Rao and Rao, 1985; Kruseman and Ridder, 1991; Bopche and Shastri, 2001).

Similar to other hard rock formations, the determination of aquifer properties from pumping test in volcanic rocks is problematic (Adyalkar and Mani, 1972; Deolankar, 1981; Singhal, 1997). The groundwater storage capacity in these rocks depends on the extent and thickness of the weathered layers, also called regolith, developed over the hard basement rocks. Similarly, the interconnection and extensiveness of voids/joints/fractures, discontinuities and permeability, *etc.* also control the occurrence and behavior of groundwater in these rocks (Raju, 1985; Agashe, 1994; Gopinath and Seralathan, 2003). Normally, primary and secondary fractures present in these rocks may not have the hydraulic inter-connection. Due to such vagaries in aquifer system, estimation of aquifer parameters is always a matter of approximation for hard rocks of Deccan trap basaltic terrain (Sammel, 1974; Singhal, 1985; Pathak, 1985).

PREVIOUS WORK

Till date, several attempts have been made by different workers to determine the aquifer properties of large-diameter wells, by analysis of pumping test data of the conventional methods. A review of these methods shows that most of them have theoretical and practical deficiencies (Sammel, 1974). Singhal (1997) has compared the transmissivity values of Deccan traps of India with some other volcanic rocks present in different parts of the world (Table-1). Similarly, the aquifer parameters for the Deccan trap basalts of Maharashtra State have also been studied by different workers/departments by using the methods proposed by Theis (1935), Jacob (1963), Papadopulos and Copper (1967), Kumarswamy (1973), Boulton and Streltson (1976), Mishra and Chachadi (1985), Singh and Gupta (1991), Water Balance Approach, etc. (Table-2).

Naik and Awasthi (2007) have given a detailed summary of applications and limitations of the methods of data analysis of dugwell pump tests in hard rocks. However, review of overall published work depicts a wide disparity in the 'T' and 'Sy' values of Deccan trap basaltic aquifer system. By keeping this in view, an attempt has been made here to determine the transmissivity and specific yield values for the basaltic aquifers of study area. The study was aimed at reducing the data gaps in 'T' and 'Sy' values for the basaltic aquifers.

THE STUDY AREA

Kalmeshwar Tehsil is located about 20 km north-west of Nagpur city of Maharashtra State. The study area falls in between longitudes 78°43′26″:78°57′50″E and latitudes 21°14′57″: 21°19′18″N, and covered under the Survey of India (SOI) toposheet nos. 55-K/12, 55-K/15 & 55-K/16 (Fig.1). It represents the micro-hydrological unit of Wainganga Sub-basin covering Kanhan-Kolar Sub-sub-basin and falls under the watershed WGKKC-2. Thus, the study area forms a micro-watershed of the main WGKKC-2 watershed.

Geologically, the watershed area is occupied by flat topped and terraced featured basaltic lava flows. Most of the area is plain and covered by black cotton soil. Outcrops of Deccan trap basalts are also exposed at some places. The large diameter dugwells of the study area tap the shallow phreatic aquifer comprising weathered, fractured, jointed, massive and vesicular types of basalt.

Aquifer Characteristics

Mainly, two types of hydrogeological units of basaltic lava flow have been identified in the study area *i.e.* vesicular unit (confined to upper part of the flow) and massive unit (confined to lower part of the flow). Out of these two, vesicular unit of the Deccan trap flow provides more

Table 1: A comparison of aquifer characteristics of Deccan traps with some other volcanic rocks

Country	Place/Area	Formation	Age	T ($m^2 day^{-1}$)
El Salvador	San Salvador	Lava flows	Pleistocene	1000-15000 (avg. 10000)
		Pyroclastics		100
Nicaragua	Pacific coastal region	Pyroclastics	Quaternary	120-3500 (avg.1200)
Afghanistan	Upper Truck Valley	Reworked tuffs		71
	Abe Istba Nahara basins	Reworked tuffs	Pleistocene	250-1000
Spain	Gran Canaria	Old basalts	Miocene	5-28
		Modern basalts	Post-Miocene	40-200
India	Karnataka	Deccan trap	Early Eocene	10-180
	Andhra Pradesh			1-198
	Maharashtra			0.1-500
USA	Snake River	Basalt		1×10^3 1.8×10^5 (avg. 1×10^4)
	Oahu, Hawaii	Tholeitic	Pliocene	15000 (in dyke free zone)
		Basalt		1500 in the marginal dyke zone
Mexico		Fissured basalt	Pleistocene to Holocene	605-865

(*after* Singhal, 1997)

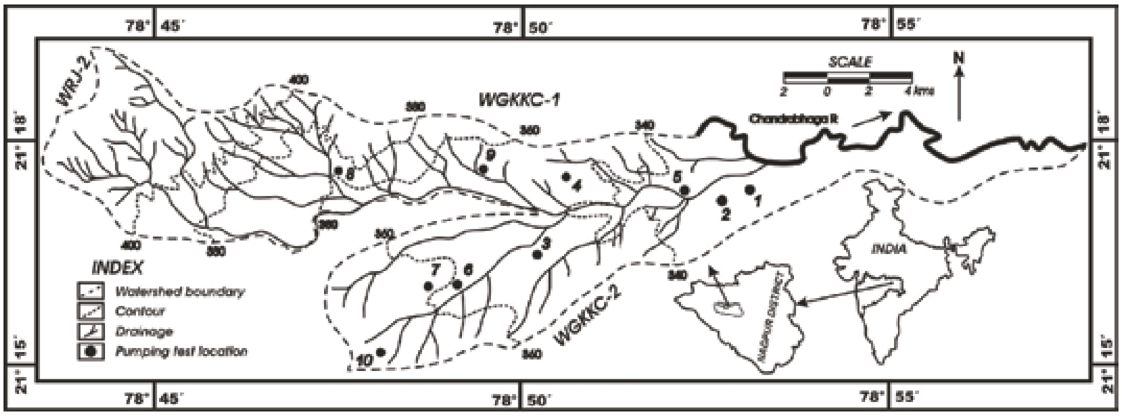

Figure 1. Index map showing location of dug wells in the watershed (WGKKC-2) area

Table 2: Aquifer parameters for the Deccan trap basalts of Maharashtra State

Authors/ Departments	Aquifer Parameters		
	Transmissivity 'T' (m^2/day)	**Specific Yield 'Sy' (Fractions)**	**Specific Capacity 'C' (lpm/m)**
Rao, 1975	VB: 50 - 70	VB: 0.01 – 0.04	VB: 110 - 200 WB: 80 - 170
Deolankar, 1978	FB: 20-60 WB: 90-200	FB: 0.008 - 0.01 WB: 0.02 - 0.10	-
CGWB, 1980	VB: 30 - 300 FB: 600 - 2077 WB: 100 - 600	VB: 0.02 – 0.03 FB: 0.01 – 0.03 WB: 0.015–0.05	VB: 20 - 180 FB: 50 - 200 WB: 80 - 150
Pathak, 1985	< 1-210	0.01-0.03 (Avg.)	-
Saksena, 1985	-	WMB: 0.018-0.025 WVB:0.016-0.0222 FMB:0.016-0.022 FVB:0.02-0.03 M/B:Almost nil VB: Insignificant	-
Singhal, 1985	0.10-507.30	-	-
Singhal, 1991	0.10- 500	-	-
Agashe, 1994	22-73.60	0.015– 0.06	-
Karanth, 1999	-	0.022– 0.026	12-202.65
Saha and Agrawal, 2006	-	MB: 0.0019-0.0022 VB*: 0.0121	
Naik and Awasthi, 2007	28-135	-	-
GSDA & CGWB, 2009	25-100	0.02	-
Mohanta and Shende, 2010	JMB: 3.73-21.30 JFB: 1.49-33.75 WB: 1.49- 41.89 JVB: 13.33-88.90	JMB: 0.009-0.062 JFB: 0.006-0.085 WB: 0.008-0.128 JVB: 0.016-0.071	JMB: 108.65-357.46 JFB: 131.41-545.35 WB: 93.39-304.22 JVB:115.85-517.36
Present Work	FMB: 22.43-120.22 FVB: 385.60 WMB:58.25-170.93 JMB:70.18 WVB:71.52	FMB: 0.058-0.103 FVB:0.040 WMB:0.028-0.127 JMB:0.083 WVB:0.126	FMB:201.03-526.01 FVB:317.73 WMB:261.87-369.13 JMB:269.33 WVB:68.44

Explanation: VB*-Vesicular Basalt dissected by sheet joints, **V**-Vesicular, **M**-Massive, **W**-Weathered, **F**-Fractured, **J**-Jointed, **B**-Basalt

Table 3: Dugwell inventory data of study area

Well No.	Village	Depth of Well (m bgl)	Diameter of Well (m)	Depth of Lining (m bgl)	Aquifer Type	Post Monsoon Depth to Water Level (2006) (m bgl)
1.	Wadhona Buzurg	19.3	3.5	15.30	FMB	17.00
2.	Sawali Khurd	17.4	3.2	7.10	FMB	9.70
3.	Wathoda	14.6	6.0	4.60	FVB	9.50
4.	Sawangi	19.0	2.4	5.60	FMB	12.10
5.	Wadhona Khurd	21.3	3.2	15.60	WMB	11.40
6.	Kohil	12.3	5.0	3.60	WMB	2.20
7.	Kohil	8.4	3.9	2.80	WMB	1.70
8.	Khairi	17.8	2.2	7.50	WMB	13.00
9.	Susundri	12.4	3.2	7.90	JMB	9.80
10.	Mohali	20.1	4.3	7.60	WVB	5.79

Explanation: FMB: Fractured Massive Basalt, **FVB**: Fractured Vesicular Basalt, **WMB**: Weathered Massive Basalt, **JMB**: Jointed Massive Basalt, **WVB**: Weathered Vesicular Basalt

inter-connected pore spaces for storage and movement of groundwater and therefore acts as a good aquifer. This unit is more susceptible to weathering and thus forms good potential aquifer, particularly at a shallow depth; whereas, the lower massive units of Deccan trap flow is basically hard, compact with less primary porosity and permeability. However, due to seismic/tectonic activities, the secondary porosity and permeability develop in such massive units of basalt, converting the massive unit into an excellent fractured basaltic aquifer system (Agashe, 1994; Naik and Awasthi, 2007).

METHODOLOGY

Detailed hydrogeological traverses in the study area were covered during 2006-2007 to delineate the Deccan trap basaltic flows, with their lateral and horizontal extensions. The well inventory details of the study area are presented in Table-3. During the well inventory studies, it was observed that all the pump-tested wells were installed with lifting device of 3 HP centrifugal pumps. The pumping test is a controlled field experiment to determine hydraulic properties of aquifer and associated rocks by observing groundwater flow in response to pumping, change of head along stream, changes in the rate of recharge in the pumped well with respect to time (Karanth, 1999; CGWB, 1982, 1986). For evaluating the hydraulic characteristic of the shallow basaltic aquifers of the area, pumping tests were performed on the large diameter dugwells tapping unconfined/ phreatic aquifers. For this purpose, ten (10) large diameter dugwells from different locations of the study area were selected.

Unavailability of regular electric power supply was a common problem in the area. Therefore, during the pumping tests, pumping durations were considered on the varied field conditions and related constraints. Short duration pumping tests were carried out on the dug wells with pumping time ranging from 55 to 200 minutes, while recuperation data was recorded from 70 to 200 minutes. The discharge of water during the pumping tests was calculated by applying 'Jet method' in the field itself (Karanth, 1999). The pumping test data so obtained was analyzed using Kumarswamy method (1973) and the respective ranges of various hydrogeological parameters *viz.* water level, specific yield, T, C and K are provided in Table-4.

Kumarswamy Method (1973)

Kumarswamy (1973) observed that the conventional method of determining the Transmissivity 'T' and storage coefficient 'S' cannot be applied to hard rock areas because of anisotropic nature and occurrence of flow in the well through fissure planes or conduits. He assumed that, open wells in hard rock have appreciable storage capacity, low inflow and no formation of cone of depression during pumping. The mathematical equation defining inflow of groundwater to the well and its behavior during recuperation was developed based on the following basic assumptions;

1. Flow into the well is only through very minute fracture conduits or fissure planes of very small cross section stacked horizontally over one another and no cross flow is assumed in between these fissure planes.

2. Water travels from an outer feed surface limited to short extents from the well.

3. The flow in the plane is laminar considering the Reynolds number and temperatures involved.

4. The operative depth of well is reckoned. Below the static water levels and no flow occurs above static water level. No flow is assumed to enter through the bottom of the well.

5. The static water level outside feed surface is not lowered during the period of test on account of the insignificant pumpages.

6. The following well parameters were recommended to be determined during the pumping test on open wells in hard rock areas : Hard rock well permeability 'K' expressed in m/hr, in which, a) Maximum inflow capacity of the well Q_{max} in m^3/hr, and b) Time taken for 99% recuperation t_R (max.).

The procedure recommended for the calculations is as follows:

Measure area of cross section of well 'a' and the static water column 'D'. Pump out such that the water column reduces to about 0.3D or say d1.

Observe the time taken (t_R) for water in the well to recuperate from d1 and d2.

Calculate the hard rock permeability "K" by applying the following equation;

$$Q_{max} = K \times D^2 \qquad \text{------- } a$$

Where,
Q_{max} - Maximum inflow capacity of the well,
K - Hard rock permeability,
D - Static water column

The time taken for 99% recuperation of well is given by equation;

$$t_R \text{ (max.)} = 2645 \text{ a and } D/Q_{max} \qquad \text{--------} b$$

Where,
t_R (max.)-Time taken for 99% recovery
a - Area of cross section
D - Static water column
Q_{max} - Maximum inflow

Formulae for Pumping Test

The formulae for the pumping test data analysis is as under;

$$K = \frac{\frac{a}{D}\left(\ln\sqrt{\frac{1 + d_2/D}{1 - d_2/D}} - \ln\sqrt{\frac{1 + d_1/D}{1 - d_1/D}}\right)}{t_R} \qquad \text{-------} c$$

Where,
K- Hard rock permeability
'a' (Cross sectional area) – (Π) (r_w^2), where 'r_w'- radius of well
'D" (Aquifer thickness i.e. static water column) = Total depth – Static Water Level (SWL)
d_2 (Water column at t_R minutes) = Thickness – Residual Drawdown (RDD)
d_1 (Water column when pumping stopped) = Thickness- Drawdown (D/D)
t_R- Time taken for 99% recuperation

$$\textbf{Transmissivity (T)} = K \times D^* \qquad \text{-------} d$$

Where,
D^* = Thickness x (Drawdown – (Drawdown) ^{2} /2 × Thickness) = Saturated thickness of aquifer

Specific Capacity (**C**) =
$$\text{Discharge per unit drawdown} = \frac{\text{Discharge (lpm)}}{\text{Drawdown (m)}} \qquad \text{--------} e$$

$$\textbf{Specific Yield (Sy)} = \frac{0.0028 * ((LogT) * Pt)}{\left(r_w^2 * 10^{\left\{\frac{T/C + 65.5}{264}\right\}}\right)} \qquad \text{--------} f$$

Where,
T = Transmissivity (m^2/day)
Pt = Pumping duration (min)
C = Specific Capacity (LPM/m)
r_w^2= well radius (m^2)

OBSERVATIONS AND DISCUSSION

On the basis of well inventory details and the actual pumping tests carried out at different locations of the study area, following observations are drawn;

The depth of the wells in the study area ranges between 8.40 and 21.30 mbgl, while the diameter varies from 2.20 to 6.00 m. The post-monsoon depth to water level (2006) shows wide variations between 1.70 and 17.0 mbgl. The shallow to deeper overburden of weathered material have been noted from 2.80 to 15.60 mbgl readings of depth of lining.

Discharge of dugwells during the pumping test, calculated by jet method ranges between 243 to 479 lpm for a total drawdown of 0.91 to 6.53 m of water column.

Pumping tests were conducted on 10 dugwells tapping different aquifers of Deccan trap basalt. In most of the dugwells (40%), aquifer tapped was weathered massive basalt (WMB), followed by fractured massive basalt (FMB) aquifer in 30% of dugwells. Similarly, fractured vesicular basalt (FVB), jointed massive basalt (JMB) and weathered vesicular basalt (WVB) aquifers (10% each) were observed in the dugwells of Wathoda, Susundri and Mohali villages respectively.

The specific yield values in fractured massive basalt, fractured vesicular basalt, weathered massive basalt, jointed massive basalt and weathered vesicular basalt were found in between 0.058 to 0.103, 0.04, 0.028 to 0.127, 0.083 and 0.126 fractions respectively.

The lowest transmissivity value (T, minimum) of 22.43 m^2/day was noted in fractured massive basalt, while maximum T value of 385.60 m^2/day has been observed in the fractured vesicular basalt aquifer.This confirms the fact that the inherent nature of massive basalt is not conducive

Table 4: Results of pumping test data analysed by Kumarswamy Method (1973).

Well No	Village	Aquifer Type	Well %	Dia (m)	Depth (m bgl)	SWL	Q (lpm)	Pt (min)	Rt (min)	Rw (m)	$(rw)^2$	A (m^2)	D/D (m)	RDD (m)	D (m)	d_1	d_2	K (m/day)	T (m^2/day)	C lpm/m	Sy (Fractions)
1	Wadhona Buzurg	FMB	30	3.5	19.3	15.06	362	60	90	1.75	3.06	9.62	1.11	0.44	4.24	3.13	3.80	18.37	75.13	326.13	0.058
2	Sawali Khurd	FMB		3.2	17.4	13.11	479	80	80	1.6	2.56	8.04	0.91	0.13	4.29	3.38	4.16	34.45	120.22	526.37	0.103
4	Sawangi	FMB		2.4	19.0	12.58	243	55	150	1.2	1.44	4.52	1.21	0.5	6.42	5.21	5.92	3.19	22.43	200.83	0.082
3	Wathoda	FVB	10	6.0	14.6	10.58	445	90	110	3.0	9.00	28.26	1.4	0.27	4.02	2.62	3.75	82.96	385.60	317.86	0.040
5	Wadhona Khurd	WMB	40	3.2	21.3	14.64	362	60	90	1.6	2.56	8.04	0.98	0.11	6.66	5.68	6.55	21.78	131.67	369.39	0.078
6	Kohil	WMB		5.0	12.3	2.63	453	56	175	2.5	6.25	19.63	1.73	0.89	9.67	7.94	8.78	5.94	90.46	261.85	0.028
7	Kohil	WMB		3.9	8.4	2.05	410	80	70	1.95	3.80	11.94	1.49	0.56	6.35	4.86	5.79	20.47	170.93	275.17	0.074
8	Khairi	WMB		2.2	17.8	13.2	440	55	150	1.1	1.21	3.80	1.57	0.16	4.60	3.03	4.44	9.73	58.25	280.25	0.127
9	Susundri	JMB	10	3.2	12.4	9.85	428	73	200	1.6	2.56	8.04	1.59	0.24	2.55	0.96	2.31	25.15	70.18	269.18	0.083
10	Mohali	WVB	10	4.3	20.1	5.79	447	200	175	2.15	4.62	14.51	6.53	5.41	14.31	7.78	8.90	0.99	71.52	68.45	0.126

Explanations:
SWL: Static Water Level during the time of pumping test
Q: Discharge in LPM
P_t: Pumping duration in minutes
R_t: Recovery duration in minutes
rw: Radius of well in meter
A: Area in square meters
D/D: Drawdown in meters
RDD: Residual drawdown in meters
D: Aquifer thickness in meters
d_1: Water column at last D/D
d_2: Water column at last RDD
K: Permeability in m/day
T: Transmissivity in m^2/day
C: Specific Capacity in lpm/m
Sy: Specific Yield (as a factor)

to the flow of water through it. Whereas, in vesicular basalt the transmissivity value is invariably high compared to massive basalt due to the interconnected nature of vesicles/ void spaces/openings.

High transmissibility values and low specific yield indicate conduit of flow. This is mainly because of differential weathering due to structural variation.

The minimum aquifer permeability (K) of 0.99 m/day was observed in case of weathered vesicular basalt of Mohali village, which indicates that the vesicles are not properly interconnected in the aquifer tapped by this dugwell. Similarly, due to weathering process, the clay content of the basaltic rock increases thereby reducing the porosity as well as permeability of the aquifer. The maximum value for permeability was observed in the fractured vesicular basaltic aquifer of Wathoda village, which is attributed to the combined effect of fractured and vesicular nature of the aquifer media.

The specific capacity (C) of the different basaltic aquifer units in the study area ranges between 68.45 to 526.37 lpm/m. The highest specific capacity observed in fractured massive basalt can be attributed to high density of fractures in the aquifer, whereas the minimum value observed in weathered vesicular basalt of Mohali village validates that the vesicles in this aquifer are not interconnected.

CONCLUSIONS

During the study, it was observed that all the 10 large diameter dugwells of study area show appreciable storage capacity, low inflows, and absence of cone of depression during pumping. The groundwater flows into these wells were only through very minute conduits or fissure/fractured planes opening into the inner surface of the wells. The transmissivity (T), Specific yield (Sy) and Specific capacity (C) values determined using empirical formulae of Kumarswamy (1973) falls within the reported value range of basaltic aquifer, estimated by various other researchers. Therefore, it is concluded that the Kumarswamy method can be effectively used in the determination of aquifer properties in shallow, unconfined and anisotropic aquifers of hard rock Deccan trap basaltic terrain. This study will be useful for management of groundwater resources in the basaltic region, which is mostly affected by scarcity of water.

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