Characterization of aquifer parameter in basaltic hard rock region through pumping test methods: a case study of Man River basin in Akola and Buldhana Districts Maharashtra India

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Abstract Aquifer parameters transmissivity ‘T’ and storage coefficient ‘S’ are very important parameters to assess the groundwater potential either through mathematical modeling or any conventional methods. In early days, these parameters are estimated either by means of in situ test or performing test on aquifer samples brought in the laboratory. In recent times, the pumping test has become an important method to estimate these parameters. This is the only method that provides simultaneous information on the hydraulic behavior of the well (borehole), the reservoir and the reservoir boundaries, which are essential for efficient aquifer and well field management. The applicability of the result from the laboratory test has limitations while in situ tests give representative aquifer parameters. The most common in situ test is pumping test performed on wells, which involves the measurement of the fall and rise of water level with respect to time. Theis (American Geophysics Union Transcripts, 16th annual meeting, part 2, pp 519–524, 1935) was first to propose method to evaluate aquifer parameters from the pumping test on a bore well in a confined aquifer. Since then, several methods have been developed to analyze the pumping test data (time-drawdown) under different conditions. For the characterization of the aquifer parameters in Man River basin area, it is essential to know the Transmissivity ($T = Kb$ where, b is the aquifer thickness: pumping flow rate, $Q = TW (dh/dl)$ flow through an aquifer) and Stora-tivity (confined aquifer, $S = bS_s$, unconfined, $S = S_y$) so as to predict the rate of drawdown of the water table/

potentiometric surface during the pumping of an aquifer. The determination of aquifer’s parameters is an important basis for groundwater resources evaluation, numerical simulation, development and protection as well as scientific management. Pumping test is a main method for determining aquifer’s parameters. A study area shows that this method has rapid speed and high accuracy. The results of parameter’s determination are optimized so that it has important practical value for scientific research and engineering practice.

Keywords Pumping test method · Aquifer · Pumping well · Theis’s type curve method · Aquifer test 2014 software

Introduction

The water demand for industrial, agricultural, and domestic uses is continuously increasing and freshwater resources are shrinking. Against this backdrop, groundwater management is a critical issue for current and future generations. Groundwater management entails both quantity and quality-related groundwater resource management. Hard rock aquifer occupies the first few tens of meters from the top (Detay et al. 1989; Taylor and Howard 2000) that is subjected to weathering process (Wyns et al. 2002). Groundwater occurs in weathered and fractured layers under unconfined to semi confined conditions, which have specific hydrodynamic properties from the top to the bottom. Quantification of groundwater resources and understanding of hydrogeologic processes is a basic prerequisite for efficient and sustainable management of groundwater resource development and management (Sophocleous 1991; Vander Gun and Lipponen 2010). This is particularly

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vital for India where 80 % of Indian peninsula is covered with hard rocks coupled with widely prevalent semi-arid climate (Pathak 1984).

About two-thirds of the Indian Territory comprising the central, western and southern peninsula is covered by different types of hard rocks such as basalts, granites, gneisses, etc. Western and central India is occupied by tholeiitic basaltic lava flows of the Deccan traps sequence. The Deccan traps occupy a vast terrain between 69°–79°E long. and 16°–22°N lat. constituting one of the largest volcanic provinces on the earth. The Deccan traps sequence consists of multiple layers of solidified lava flows. The basaltic flows vary in color from dark grey to purple and pink. Each lava flow consists of an upper vesicular unit and a lower massive unit which may or may not be fractured/jointed. Two lava flows at some places are separated by inter-trappean alluvium area. Therefore, unlike other hard rocks, the Deccan traps behave as a multi-aquifer system, somewhat similar to a sedimentary rock sequence. Acute shortage of groundwater in hard-rock areas, such as the Deccan traps, is well known. Groundwater available in shallow, weathered mantle under unconfined condition above the Deccan traps is inadequate to meet the ever-increasing demand of water supply. Maharashtra too is occupied by hard rock's whose receptiveness of precipitation is restricted to the degree of weathering and secondary porosity, so also its capacity to store and transmit the water. As a result, even in high rainfall areas of the state, water scarcity is experienced in summer months. Hard rock's derive its status as an aquifer on the basis of secondary porosity that gets developed due to decompose and weathering processes over a period of time (Radhakrishna 1970). The aquifers in hard-rock are unconfined and their water table generally follows the surface topography. Therefore, there is a good match between the surface drainage (watershed) and groundwater system (aquifer geometry). Thus, it becomes imperative to understand the hard rock physiographic, its characteristics vis-à-vis availability of groundwater. The shallow aquifers are phreatic and found to be occurring up to the depth of 10–15 m underlain by massive rocks which forms the bottom of phreatic aquifer.

The groundwater in shallow aquifers gets replenished annually as the monsoon rainfall occurs only within a 4-month period (June to September). The pre and post monsoon water levels indicate the degree of saturation in the hard rock aquifer network of 20 observation wells has been calculated in Man River basin area and water levels are recorded since last 2 years. An analysis of water level data has indicated that declining of water level trends could occur even in the underdeveloped watersheds indicating that there are various factors influencing in declining of water level, time and Discharge data. During the drawdown phase of a pumping test on a large diameter well, most of the pumped water initially comes from well, most of the pumped water initially comes from well storage. It is only after some time

that the aquifer starts contributing to the pump age. The time gap between the onset of pumping and the beginning of an appreciable flow of water from the aquifer to the well depends mostly on the transmissivity of the aquifer. Other factors being the same the lower the aquifer transmissivity, the longer the pumping time required to produce pumping test data with a discernible signature which can be interpreted to determine the aquifer parameters (Fig. 1). Sometimes, in low permeability formations, this condition may not be attained during the drawdown period. One must, therefore, continue observations during the recovery phase (Singh and Gupta 1986). A cut off point for recovery observations in the well needs to be established. Due to a slow rate of recovery in a low permeability aquifer, one may be tempted to stop the observations too soon to capture the information contained in the later segment of the time recovery curve. This paper presents details of a few pumping test and data analysis which lead to a reasonable criterion for the extent of recovery that should be observed.

Study area

The present study is based on the hydrogeological data obtained for large-diameter dug wells tapping unconfined aquifers in various parts of Maharashtra and considers the potential of the above five groups as aquifers. The area under study is forming a part of the Akola and Buldhana District, Maharashtra, India, located close to the western margin of the Deccan traps terrain about 25 km SW of Chikali Taluka. 20°54'59"N latitude and 76°41'23"E longitude. The study area is covered by Survey of India toposheets 55D/7, 55D/9, 55D/11, 55D/13, 55D/14 and 55D/15 on 1:50,000 scale. The east to west monsoon (during middle June to September) contributes more than 70 % of the rainfall. Rainwater is the main source for recharging of groundwater. The location map of the study area is shown in Fig. 2.

Geology of area

Physiographically, the study area can be broadly divided into low lying plain towards the banks of the Man River in the northeast and horizontal Deccan Trap flows with multiple scarps and abrupt cliffs towards the southern parts. The study area consists of various erosional surfaces in step-like terraces. The horizontal dispositions of the lava flows with a fair degree of uniformity in lithology have considerably simplified the changes brought by the secondary processes like weathering and denudation. Differential weathering forces has resulted in wiping out of thick lava pile (Fig. 3).

Fig. 1 Illustration of a semi-confined aquifer condition pumping test

Rainfall

The area receives major part of the rainfall (about 45 %) during South-West-monsoon period there are eleven rain gauge stations in the area which have rainfall recorded for more than 50 years. The normal rainfall for Akola and Buldhana districts is 800–1200 mm (source IMD). It is minimum in the North-Western part of the district and increases towards the South Eastern parts of the district i.e. toward Washim district. The percentage of probability of receiving normal rainfall over the district has been studied.

Agriculture

Agriculture plays an important role in the economic development of Akola and Buldhana districts of Maharashtra. Nearly 80 % of the total area is arable and most of the total population is engaged in different agricultural activities. The farmers' are harvesting two crops in a year. Ground water the most important natural source that is widely used in agricultural production amounts to nearly 80 % of the total irrigated area.

Methodology

Proposed research

In reality, more than one of the above factors could be responsible. To resolve the question as to whether current groundwater abstraction is sustainable requires an understanding of the groundwater system including a detailed

knowledge of the aquifer parameters. It should then be possible to predict how water levels in, and around, an irrigation well or group of irrigation wells, respond to pumping and whether the aquifer resources are sufficient to sustain that level of groundwater development. Further, and perhaps of greatest importance, it should indicate the likelihood of excessive abstraction by wells lowering water levels in public supply wells and in the worst case causing the latter wells to be abandoned. Once the sustainable resource is known then further investigations into the effects of reduced recharge due to climate change, water management strategies and agricultural practices can be carried out.

Pumping tests and methods

A pumping test is the best available method to evaluate aquifer parameters. This test involves extracting water from a well at a controlled rate and observing the water level changes in the pumped well and/or in one or more observation wells, with respect to time (Theis 1935; Singhal and Gupta 1999). During the past few decades, researchers have proposed several different methods to analyze the pumping test data and estimate the aquifer parameters (Theis 1935; Cooper and Jacob 1946; Hantush and Jacob 1955; Hantush 1960, 1966; Javandel and Witherspoon 1983; Theim 1906; Raj 2001). Among the main techniques are; analytical/conventional methods and numerical methods. Analytical/conventional methods involve one of the following: (1) curve matching, (2) finding inflection points, or for special cases, (3) fitting straight lines to the pumping test data. In curve matching

Fig. 2 Location map of study area

techniques, field results are generally plotted and matched against the results of analytical solutions. There are also several alternative techniques for estimating aquifer parameters from the pumping phase (like log–log plots and log–arithmetic plots), as well as techniques for estimating aquifer parameters from the recovery phase. Comparatively, the numerical method uses a single model to obtain a “best fit” between the field and modeled results for both the pumping and recovery phases (using different parameters). A trial and error technique is employed to obtain a best fit (Ruston 2003). The entire computation procedure and hydrological equations is typically written into a

computer program(s). Each of the methods described above are based on basic assumptions relating to the basic type of well such as well diameter, dug well, and bore well. Therefore, it is important to choose the right method of interpretation based on the field conditions (Kruseman and de Ridder 1970).

Current study, methods and results

In the study presented here, pumping tests were conducted on large diameter wells in basaltic terrain within the Chikali region of Maharashtra. An attempt was made to

Fig. 3 Geology map of Man River basin

interpret the pumping data by using two conventional methods: the Papadopoulos and Cooper method (1967) and one numerical method, as proposed by Singh and Gupta (1991). In this study, Aquifer test 2014 version software is being used including pumping test method which has proved to be a quick and easy way to interpret the data through the software program. It is specifically designed for graphical analysis and reporting of pumping test data. There are two types of methods in this software such as to create pumping test and slug test. In this present study, use of creating pumping test method through the software is being applied.

Details of pumping tests

A pumping test is the best available method to evaluate aquifer parameters. This test involves extracting water

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represent the aquifer as a homogeneous, isotropic porous medium, and adopt one of three basic geometries. Spherical flow models describe fluid flow toward a spherical cavity in a homogeneous porous medium of infinite extent in all directions (Fig. 4). Flow is three-dimensional, and equipotential surfaces are concentric spheres around the spherical cavity. Flow is two-dimensional, and equipotential surfaces are cylinders centered about the well axis. This geometry might also represent a horizontal fracture zone or a single horizontal fracture bounded by impermeable rock. Linear flow geometry describes flow that is unidirectional, such as linear flow towards a highly transmissive vertical fracture that intersects a well. Combinations of these three basic geometries are also possible (Table 1).

There are a number of reasons why pumping tests are unlikely to provide useful continuum estimates of aquifer hydraulic conductivity in fractured rocks. Firstly, the estimate of hydraulic conductivity is highly sensitive to the model chosen to analyse the data. Often none of the simplistic models represented by Fig. 3 are appropriate, yet this may not be obvious from test results. Observed hydraulic head data may still superficially resemble one of these models.

Interpretation of pumping test data

The pumping test is generally used to study the parameters like storativity, transmissivity and yield characters of the well (Table 2). These values define the aquifer characteristics. In Deccan traps, the large diameter dug wells, Papadopoulos and Cooper (1967) method is the right procedure to arrive at aquifer parameters (Karanth 1987; Kruseman and de Ridder 1970). In the present study

Fig. 4 Contrasting models of groundwater flow to a well that are used for interpreting single well hydraulic tests. **a** Flow to a short test interval in a bore hole that approximates spherical geometry (interval length! Bore hole radius); **b** Radial flow to a cylinder; and **c** linear flow to a well that intersects a highly transmissive vertical fracture. (Source: NRC 1996)

Papadopoulos and Cooper (1967) method is adopted to determine the aquifer parameters and also to analyze pumping test data.

In this method, plots of time draw down data on double logarithmic paper are prepared for all the pumped wells. These plots are matched with the Papadopoulos and Cooper (1967) type curves. This study has demonstrated the occurrence of mini basins showing specific groundwater flows in the area of investigation which is separated from each other by a permeability barriers or a high. Recharge experiment have also indicated the beneficial areas of irregular shape and eccentric outline with respect to recharge location. This study has given rise to the areal extent and depth of penetration, which in turn helpful in determining the volume. The storativity (S), transmissivity (T) and specific yield values have been computed. The location of pumping test from which the overall groundwater potential of the basins, present draft, net balance of water available and the stage of development of the basin have been determined. A numerical method (Singh and Gupta 1986), coupled with an optimization technique was considered appropriate for data interpretation as it fully takes into account the well storage effect. The method is valid for a confined aquifer which was true in case studied. The first step of this method consists of the computation of drawdown (s) and the residual drawdown (s') in the well after each time interval of 5 min for computing and s' , the following relationships as given by Papadopoulos and cooper (1967) are used. Here $\Delta\beta = [\beta J_0(\beta) - 2\alpha J_1(\beta) + [\beta Y_0(\beta) - \alpha Y_1(\beta)]]$. J_i and Y_i are Bessel functions of it order of the first and second kind, respectively. Values of s and s' may be computed by assuming some initial values of T and S the computed values of s and s' are then compared with the observed ones the computed and observed values of s and s' is the most significant step in the estimation of aquifer parameters.

Results, discussion and recommendations

The transmissivity values for well number 15,12,7 and 6 are found to be 22.91, 58.12, 22.81 and 24.68 sq.mt/day respectively. The standard value of transmissivity for Deccan trap is 30–100 sq.mt/day. The calculated value of transmissivity (T) are according to the standards the specific capacity values calculated for well numbers 5,12,7 and 6 are 22.22 33.72, 22.49 and 61.47 lit/min/m respectively. The storage coefficient values for well no. 15, 12, 7, 6 are 0.118, 0.220, 0.0290 and 0.20 respectively, which are relatively comparable to the standard values for Deccan trap aquifers due to compact and massive trap is at lower elevation in the study area. The values of safe yield (QS) for same wells are 35,500, 67.445, 22.939 and

Table 1 Details of the pumping test data

Well no.	Location of well	Duration of pumping (min)	Maximum draw down (m)	Duration of recovery (min)	Residual draw down	Aquifer type
1	Padsul	140	18.82	190	0.42	WVB
2	Chatari	170	11.92	150	0.03	JMB
3	Sirla	170	9.25	180	0.17	VB
4	Wadali	170	10.05	90	0.78	JMB
5	Tarkhed	120	8.04	35	1.82	FMB
6	PimpariDhanagar	150	10.21	110	1.52	WSMB
7	Satargaon	130	16.68	80	0.81	JMB
8	Hiwarakhurd	120	6.35	115	0.08	FMB
9	Manegaon	160	21.00	80	4.50	FMB
10	Batwadibudruk	200	14.10	150	0.10	WVB
11	Ghuighui	170	19.40	200	0.07	WMB
12	Amdapur	210	8.70	205	0.40	WMB
13	Dastapur	105	13.70	90	0.05	FMB
14	Mohadari	280	9.00	250	1.60	FMB
15	Pardi	230	2.80	210	0.30	JMB
16	pimparkhed	110	15.9	100	1.62	WSMB
17	Songiri	250	10.5	120	1.72	WSMB
18	Tandi	200	11.4	170	0.15	VB
19	Uti	140	20.6	220	0.92	JMB
20	Wadali	160	18.23	90	1.92	FMB

S saturated, *B* basalt, *F* fractured, *J* jointed, *M* massive, *V* vesicular, *W* weathered

60.247 lts./day respectively. The result of 20 pumping test carried out in the study area follows that there are presence of three categories of wells having excellent, moderate and low productivity of wells. Well number 2, 3,4,5,8,9,10,11,13,14 and 1 show excellent potential for the groundwater exploration with higher safe yields. Whereas well numbers 6 and 12 showing moderate productively with medium safe yield well no. 7 and 15 show low potential with very low safe yield and poor recuperation and hence are not suitable for further development. The recommendation includes further development of well no. 2, 10 and 14 which can increase groundwater potential with upward rise with safe yields. Whereas well no. 1, 3, 5, 8, 9, 10, 11 and 13 does not require further development, as these have already reached optimum level of production (Table 3).

The results of pumping test data shows that in each basin, the transmissivity and permeability values are very similar to one another indicating free movement of groundwater within the basin limits with the presence of permeability barrier towards the 'high' where the values reduce drastically. These values will also be helpful in further determining the boundaries of the basin which differs from the other basin in these respects. Considering the free movement of groundwater within the limits of

basin, well location can be more accurately identified based on the shapes of the contours. The result of the pumping test data shows that there are limited groundwater prospects in the region which certainly needs careful planning and management of the available water resource (Tables 4, 5, 6, 7). The Time and Drawn Graph of villages are shown in Fig. 5a–c).

Theis's type curve method

Theis's type curve method is presented type curve which is the plotted values of $W(u)$ and $1/u$ on log–log sheet. The field values of drawdown and time are plotted on similar log–log sheet. The field curve is matched with the type curve keeping the axes of the curves parallel (Fig. 6). In the matched position a match point is selected. The values of $W(u)$ and $1/u$ for this match point is read from the type curve. Similarly the values of s and t are read from the field curve. Substituting these values of $W(u)$, $1/u$, s and t in Eq. (9) and (10) gives the values of T and S .

There are four types of Theis's curve method;

1. Log–Log Method,
2. Semilog Method
3. Recovery method. Template

Table 2 Details of well design data for the study area

Well no.	Well location	Type of aquifer	Diameter of the well	Depth of the well	Static water level
1	Padsul	WVB	4.10	20.00	15.10
2	Chatari	SMB	2.70	12.00	8.25
3	Sirla	VB	3.15	10.30	7.30
4	Wadali	JMB	5.10	10.10	7.10
5	Tarkhed	FMB	4.60	8.50	5.08
6	PimpariDhanagar	WJMB	3.50	10.30	7.30
7	Satargaon	JMB	2.90	17.00	13.45
8	Hiwarakhurd	FMB	3.50	6.60	4.42
9	Manegaon	WVB	4.35	20.90	14.20
10	Batwadibudruk	WMB	3.60	15.00	12.10
11	Ghuighui	WMB	4.00	20.00	16.32
12	Amdapur	WMB	2.80	8.80	4.40
13	Dastapur	FMB	3.00	14.20	10.35
14	Mohadari	FMB	2.45	9.00	6.30
15	Pardi	JMB	2.30	9.20	6.40
16	Pimparkhed	VB	3.22	11.2	7.4
17	Sirla	FMB	3.32	8.90	10.20
18	Tarkhed	JMB	4.70	16.30	12.30
19	Uti	FMB	2.60	14.50	11.40
20	Wadali	WVB	4.80	20.20	5.60

S saturated, *B* basalt, *F* fractured, *J* jointed, *M* massive, *V* vesicular, *W* weathered

Table 3 Hydraulic parameters calculated from aquifer test

Well no.	Safe yield QS (Lts/day)	Specific capacity (min/mt of D/D)	Transmissivity T (m ² /day)	Storage coefficient S
1	1,36,125	92.08	35.11	0.036
2	9,382	38.12	37.42	0.044
3	1,06,503	50.18	74.43	0.101
4	1,23,694	113.80	34.92	0.021
5	1,14,557	75.00	43.73	0.022
6	50,257	62.47	24.58	0.030
7	23,849	23.49	22.87	0.0380
8	1,86,027	108.70	64.77	0.130
9	1,62,812	83.52	86.18	0.020
10	1,55,718	64.35	44.20	0.080
11	3,10,520	75.20	27.13	0.015
12	67,475	30.72	52.12	0.330
13	1,74,430	85.66	34.53	0.070
14	1,32,760	70.93	50.00	0.016
15	38,540	21.35	22.80	0.117
16	50,252	68.48	23.50	0.040
17	23,879	23.60	22.90	0.0400
18	1,85,022	108.90	64.74	0.125
19	1,62,716	82.56	86.15	0.030
20	1,55,728	64.46	45.20	0.060

Table 4 Details pumping test data of Man River basin

Time (min)	Water level (fit)	Ambeshwar village		Amdapur village		Change phal village		Dhanori village	
		Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)
1	4.12	1	4.2	1	7	1	5.6	1	9.1
3	5.11	3	6.3	3	8.7	2	7.2	2	9.4
4	6.8	4	7.8	5	8.6	4	8.4	3	12.4
5	7.2	5	8.9	10	7.1	5	6.12	5	10.3
8	8.4	10	10.11	20	5.2	8	7.6	8	9.75
10	9.6	20	12.4	50	8.62	10	8.14	10	4.9
25	10.1	50	9.6	100	12.15	18	9.2	20	9.6
30	11.2	80	8.12	200	6.4	20	10.11	30	9.12
50	12.6	100	10.6	500	6.1	30	9.6	50	10.1
80	10.5	200	11.8	800	8.6	50	10.5	100	9.85
100	11.3	500	12.6	1000	15	80	11.2	200	12.3
200	12.9	800	13.2	1500	9.5	100	8.6	400	10.87
500	13.2	1000	12.8	2000	5.8	500	12.8	500	9.93
1000	10.8	1550	13.4	2500	15	800	11.14	1000	8.63
1500	13.4	2000	12.12	3000	9.1	1000	13.2	2000	5.9

Table 5 Details pumping test data of Man River basin

Mohadari village		Mundephal village		Pardi village		PimpalKhuta Village		Pimparidhangar	
Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)
1	6.7	1	5.2	1	5.8	1	5.5	1	5.2
2	8.9	2	4.38	2	6.1	2	6.8	2	6.4
3	10.12	3	6.4	5	12	3	7.9	3	7.6
4	9.5	4	5.6	10	11.5	5	8.12	5	8.8
5	10.32	5	7.8	20	12.8	10	10.15	8	9.2
10	9.8	10	8.8	30	15.5	20	10.5	10	10.11
20	11.5	20	9.2	50	7.2	30	9.6	15	8.4
30	10.62	30	8.12	100	8.18	40	11.4	20	11.6
50	11.55	40	10.11	200	9.8	100	9.12	30	11.7
100	12.3	50	9.4	500	11.7	150	11.6	40	10.5
200	10.4	80	10.18	800	10.9	200	10.18	50	9.6
500	12.8	100	11.5	1000	11.5	500	12.6	100	12.2
800	13.5	200	12.2	1500	11.38	900	11.8	200	11.8
1000	11.6	500	11.8	2000	11.88	1000	12.4	500	12.5
2000	13.8	1000	12.8	2500	12.2	2000	13.6	1000	13.4

4. Time Drawn Method (Log Log Method) (Figs. 6, 7, 8, 9).

Cooper and Jacob (1946) modified the Theis method and suggested an easy method to determine aquifer parameters. The method does not require curve matching. The time-

drawdown data is plotted on semi-log paper (time on log axis and drawdown on linear axis). The additional condition required to use this method is that the test should be conducted for enough time so that the value of u should be

Table 6 Details pumping test data of Man River basin

DhatraNaik village		Ghuti village		HiwaraKhurd village		Isoli village		Karkhed village	
Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)
1	6.1	1	5.2	1	4.12	1	3.8	1	4.3
4	8.5	2	6.12	3	6.8	2	4.2	2	6.2
5	7.6	5	8.35	5	8.9	3	5.11	5	8.4
6	8.8	10	10.4	10	10.12	4	6.8	10	9.5
7	6.4	15	11.6	25	10.42	5	7.4	20	8.6
8	10.2	20	11.45	35	11.9	10	8.11	30	9.3
10	9.3	50	12.5	55	10.6	20	9.12	40	8.6
20	10.5	80	10.7	80	11.14	30	10.5	50	10.2
30	9.5	100	7.8	100	12.2	40	11.14	80	9.7
40	11.1	150	9.9	200	11.8	50	10.8	100	10.11
100	10.8	200	10.25	500	12.5	100	11.15	150	12.6
200	11.5	500	12.9	650	13.4	200	9.15	250	11.12
500	12.6	800	13.8	800	12.8	500	12.8	300	12.8
1000	10.4	1000	13.73	1000	13.2	800	13.2	500	11.6
1540	12.12	1500	12.11	1440	9.91	1000	13.9	1000	13.2

Table 7 Details pumping test data of Man River basin

Pimparkhed village		Sirla village		Tarkhed village		Uti village		Wadali village	
Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)	Time (min)	Water level (fit)
1	5.6	3	4.8	1	6.9	1	4.9	1	6.9
3	6.8	5	5.2	2	12	2	5.32	3	7.8
5	7.11	8	6.4	3	16	3	8.2	5	10.5
8	6.12	10	7.2	4	15.15	5	11.5	10	12.1
10	8.14	20	8.6	5	6.6	10	10.4	20	13.6
20	7.22	30	9.1	10	8.18	20	11.7	40	14.3
30	9.13	40	10.12	20	13.63	50	12.2	60	14.48
50	10.11	50	11.7	30	7.2	80	9.46	100	15.4
80	8.5	100	10.6	40	10.5	100	7.8	300	13.1
90	10.4	400	11.12	80	10.2	200	12.9	500	13.63
100	11.2	500	12.2	100	8.71	500	13.5	800	12.8
250	12.5	800	10.6	200	6.17	800	15.6	1000	12.2
300	11.8	1000	13.2	300	7.3	1000	8.4	1440	13.55
500	12.9	1440	12.4	500	8.9	2000	10.7	1500	10.4
1000	13.4	2000	13.8	1000	7.6	3000	12.5	1550	10.75

less than 0.01 (Figs. 10, 11). A straight line is drawn through the data points and the slope (Δs) of the straight line is determined. The time (t_0) is also noted where the straight line intercepts the time axis (i.e. at $s = 0$).

The following formulas are used to calculate the aquifer parameters.

$$T = 2.3 \frac{Q}{(4\pi\Delta s)}, \quad S = 2.25 \frac{Tt_0}{r.r}$$

Fig. 5 a Time and Drawn Graph of (i) Ainkhed, (ii) Ambeshwar, (iii) Amdapur, (iv) phal, (v) Dhanori, (vi) Dhatra Naik, (vii) Ghuti, (Viii) Hiwara Khurd pumping test by using aquifer software 2014. **b** Time and Drawn Graph of (ix) Isoli, (x) Karkhed, (xi) Mohadari, (xii)

Mundephah, (xiii) Pardi, (xiv) Pimpal Khuta, (xv) Pimpari Dhangar, (xvi) Pimpar khed pumping test by using aquifer software 2014. **c** Time and Drawn Graph (xvii) Sirala, (xvii) Tarkhed, (xix) Uti, (xx) Wadali of pumping test by using aquifer software 2014

Fig. 5 continued

Fig. 5 continued

Fig. 5 continued

Conclusions

The recent trend in increased abstraction from the Deccan Basalt aquifer to meet, in particular, the rising demand for irrigation is likely to continue. This has heightened concern in India that current groundwater abstraction from the shallow aquifer in certain areas may be exceeding that which is sustainable from limited groundwater resources and that water levels are declining as a result. The possible reduction in recharge due to climatic changes would exacerbate this problem. The cost implications of over abstraction and depletion of groundwater resources are potentially very serious, both in terms of wasted investment in agricultural development and in loss of cheap potable water supplies to many rural communities. Few studies have been undertaken on the shallow aquifer within the Deccan Basalts to understand the groundwater system, to quantify recharge or to assess the influence of pumped irrigation wells on the regional water table. There is a clear need for such research if sensible planning for sustainable development of groundwater and agriculture is to be made. Well storage effect is found to be significant during pumping tests in hard rock aquifers of low permeability.

The conventional interpretation technique gives rise to ambiguous results if well storage is ignored. In order to take into account the well storage effect, a radial flow model is suggested which yields a reliable estimation of aquifer parameters. For sustainability of water resources in Gurgaon district, extensive research plan was worked out. Recharge due to irrigation and rainfall has been estimated in accordance with CGWB methods. Irrigation recharge has been estimated using return flow factor method and rainfall recharge has been estimated using rainfall infiltration factor method as well as water table fluctuation

Fig. 6 Thesis Log Log method using aquifer software 2014

Fig. 7 Thesis Semilog Method using aquifer software 2014

method. Recharge quantities has been normalized according to standard recommendations of respective methods. The Proposed simple procedure appears robust in dealing

with the reproduction of the hydraulic head distribution in the Man River basin. Various automatic procedures or different manual calibration procedures would be expected

Fig. 8 Recovery Template
using aquifer software 2014

Fig. 9 Time Drawn Method
using aquifer software 2014;
Jacob's semi log (slope) method

Fig. 10 Thesis with Jacob correlation using aqifer software 2014

Fig. 11 Jacob's semi log using aqifer software 2014

to derive a similar result. The proposed structured procedure is expected to be useful not only for the manual approach but also for automatic models. However, the manual approach based on our procedure allows modelers to easily incorporate geological study and experience at calibration process. Finally, we would like to emphasize the fact that any calibration procedure may not necessarily lead to exact boundary conditions, transmissivity distribution, and other parameters for a field aquifer due to our incomplete knowledge of the complexity of geology, simplification of models, errors in observations, etc.

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