Research Article
Khadri SFR, IJPRET, 2013; Volume 1(8): 315-332

ISSN: 2319-507X
IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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WATER RESOURCE MANAGEMENT OF ASIRGARH REGION, BURHANPUR DISTRICT, MP WITH EMPHASIS ON SUSTAINABLE MANAGEMENT OF GROUNDWATER IN BASALTIC TERRAIN

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Accepted Date:

27/02/2013

Publish Date:

01/04/2013

Keywords

Fluorides,

Drinking water,

Fluorosis,

Groundwater,

Sustainable development

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Abstract

Detailed water resource management analysis has been carried out in the Asirgarh region, Burhanpur district, Madhya Pradesh with emphasis on sustainable management of groundwater in basaltic terrain. In this study an attempt has been made to understand the role of water-rock interaction in the groundwater quality and its environmental management. Water and soil samples were collected from watershed and were analyzed for fluoride by AAS. The groundwater in Burhanpur district is being unsystematically explored by the farmers to meet the irrigation requirement of crops. In order to plan safe withdrawal of ground water in the Burhanpur district, the available geological, geomorphologic, hydrological and other related statistical data for the year 20010-2012 were analyzed and the groundwater inventory has been prepared. The further exploitation of ground water should to be done cautiously keeping in view the present stage of its development. The natural recharge from rainfall is the main source of ground water recharge in the area. The ground water budget and stage of development of the available ground water potential in the study area has been computed by utilizing statistical analysis. Net recharge is 80% of the gross recharge, while net draft is taken as 70% of the gross draft. The difference between net recharge and net draft would give the ground water balance. The ratio of net draft and net recharge gave the value of ground water status at present. Results reveal high concentration of fluoride in soils in western part of the watershed, which is comprised by hilly terrain. The concentrations vary from normal permissible levels to high concentrations of fluorine in some pockets which were found in rock samples indicating that high concentrations of fluoride in soils are derived from basaltic rocks. These high concentration levels may enter into the groundwater and in turn may enter into the food chain of the human beings as most of the area in the watershed is under active irrigation. Some elements are essential in trace amount for human being for the structural and functional built up of body. One of them is fluoride mainly necessary for the prevention of dental decay and can be provided through dietary sources or through drinking water however its higher concentration leads to several toxic effects; therefore the present study deals with the hydro geological investigation in the rural parts of Burhanpur district in Madhya Pradesh. Different water samples are tested for fluoride concentration; among which few samples indicate the toxic level of fluoride. Physico-chemical condition like decomposition, dissociation and subsequent dissolution along with long residence time might be responsible for leaching fluoride in to the ground water. Fluoride concentration in groundwater was estimated from places in and around Asirgarh region of the Burhanpur district, occurrence found within permissible limit in 83% of the samples and 17 % places showed a higher degree exceeding the normal levels. In this study, environmental assessment analysis for sustainable development of the region was made.

Introduction

Systematic mapping of hydro geological conditions is the prime task in the understanding of water bearing characteristics of basaltic rocks, since the water bearing characteristics of rocks are controlled by many factors, such as weathering, structural set up, and the nature of rock type. To understand the physical state of groundwater within their geological framework, mapping of shallow, unconfined aquifers are undertaken with a view to study the relationship between lithology and their aquifer characteristics.Determination of groundwater potentiality, movement etc, is possible only when one knows the characteristics of the rock formation in which it is occurring (Krusemam & de Ridder 1970, Karanth 1987, Walton 1989).

Pumping test is the best available method to evaluate the aquifer parameters, which involves the abstraction of 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 & Gupta 1999). During the past few decades several researchers have proposed their own methods of approach for analyzing pumping test data (Theis 1935, Cooper-Jacob 1946, Chow 1952, Hantush & Jacob 1955, Hantush 1960, 1966, Javandel & Witherspoon 1983, Thiem 1906, Pradeep Raj 2001). Analytical/conventional meth-ods involve either curve matching or finding inflection points or for special cases fitting straight lines to the pumping test data. Generally, in curve matching techniques the field results are plotted and matched against the results of analytical solutions. There are several alternative techniques for estimating aquifer parameters from the pumping phase (log-log plots or log-arithmetic plots) and further techniques for recovery phase. Comparatively, in the numerical method a single numerical model is used to obtain a best fit between the field and modeled results for both the pumping and the recovery phases using the different parameters. A trial and error technique is adopted to obtain a best fit (Rushton 2003). The entire computation procedure will be usually written in the form of computer programs to solve the hydrological equations. Each of these methods are based on some basic assumptions and holds good initially penetrated), diameter of the well (dug well, bore well). So it is important to choose a right method for the interpretation based on the field conditions (Krusemam & de Ridder 1970). In the present study an attempt has been made to interpret the pumping test data of large diameter wells in the basaltic terrain at the Chikaldhara region by two conventional methods viz, Papadopulos & Cooper method (1967), Mishra & Chachadi method (1985) and by one numerical method proposed by Singh & Gupta (1991). The results obtained by these methods are discussed in this paper.

Climate

The climate of the study area is classified as semiarid, based on the Thornthvaite's scheme of classification (1948). Temperature is considerably hot. The difference between the maximum and the minimum temperature is moderate. The mean annual rainfall is 850 mm.

The evaporation rate ranges between 3.2 and 7.6 mm per day, and it is high in the month of May, June and July. The mean wind velocity ranges between 7 and 16 km per hour and it is high during June and July.

Hydrogeology

Water level

General behavior of groundwater is studied from water level data. In winter, water level is 12.02 m and the minimum is 6.54 m in the extreme west and central parts of the area. The water level during southwest monsoon shows that the maximum is 10.9 m and the minimum is 4.52 m, with respect to ground level. Likewise, the summer water level also shows that the maximum is 20.52 m and the minimum is 5.39 m. The water level during the northeast monsoon shows that the maximum is 10.29 m and the minimum is 4.16 m. The groundwater level varies greatly and not follows any rhythmic pattern. The water level fluctuations in the area are calculated at a maximum of 3.52 m and a minimum of 1.44 m, respectively. The fluctuation of water level is high in the villages Baraghat, Mahadev Barli, Mangrul and Borgaon Whereas, the fluctuation is low in the villages Bori Buzurg, Bilthad, Utambi, Davatiya and Gangapur.

Groundwater flow

From static water level data for 20 years (from 1972 – 1992) within a basin, an annual average water level map is constructed with respect to the above mean sea level. The flow system of these basins have revealed that the east – west movement, since it has a well defined relief, recharge area at the topographic high and adjacent discharge area. Further, the topographic elevation and groundwater level gradient decrease from west to east gradually and thus confirms the flow pattern. Further, it is observed that the central and eastern part of the area has more favorable permeability (low gradient of water level) than the other areas. Similarly, the areas of west, west – central and NW and SW corners have lower recharge (high gradient of water level) than discharge. The convex trend of flow indicates the presence of abduction zone in the western part of the study area and that too also a divide of basaltic – lateritic contact.

Aquifer parameter evaluation

Substantial contribution in the field of groundwater hydraulics has been made by several scientists. Although aquifer testing methods are routinely used to determine aquifer properties, their applications to fractured rocks are debatable. In addition, the effects of weathering process also exert a significant influence on aquifer heterogeneity at shallower depths. However, pumping test is one of most useful means of not only determining hydraulic characteristics of the aquifer but also in the determination of yield and draw down.

Storage Co-efficient

In an unconfined aquifer, the storage coefficient, also called specific yield. The storage coefficient is high in the northeast and southwest parts of the area and very low in the central part of the basin. The values range from 0.02 to above 0.22. Further, it could be seen that there is a progressive decrease of specific yield in the eastern to central parts and again an increase towards the west.

Transmissivity

Transmissivity result shows that it's value varies from 25 to above 100 m^2/day, following the general pattern of increasing value from east to west, that is, the values increases from the upper part of the basin to the lower. This shows a gradual increase of hydraulic gradient. The Transmissivity 100 m^2/day and above found to be coincided with areas of where fault zone occurs.

Specific Capacity

A decline in specific capacity may indicate declining S or T values due to declining water level or piezometric surface. It can also be used to determine the distribution of transmissivity of the aquifer. The spatial distribution of specific capacity reveals that the increase in values coincides with the storage co-efficient or transmissivity value. Values of specific capacity range from-6 to above 1pm/mdd/m^2. Specific capacity in pink granites are found in ranges from –3 to o 1pm/mdd/m^2 and also higher specific capacity are found to be coinciding with areas of extension fracture system.

Optimum Yield

The optimum yield indicates that only the western half of the study area gives substantial yields of water, whereas the southern and northern halve of the area shows uniformity in delivering yield of water.

The optimum yield ranges from 25 m3/d and more than 100 m^3/d. The high yield areas are close to extension fracture and also in where lineament intensities are high.

Recovery Rate

The spatial distribution of recovery rate of the area increases from east to west. The values of recovery rate range from 50 to 200 m^3 day. The areas which yields high recovery rate are close to areas of higher optimum yield.

Recuperation Rate

The recuperation rates indicted the period in hours or day taken in restoring the water from adjacent areas. The computed result shows that the recuperation rates ranges from 25 to above 75 hrs towards northern parts.

Saturated Aquifer Thickness

It represents the width of an aquifer saturated with water. The spatial distribution of saturated thickness indicates uniformity in thickness of aquifer saturated with water, values range from less that 3 m to 6 m found in the study area.

Aquifer parameter assessment

In order to evaluate the relationship between well yield, specific capacity, saturated aquifer thickness, well depth, recovery rate and transmissivity, the linear correlations analysis have been carried out and the regression line fit indicates to a steep negative relationship between depth and well yield in basaltic terrain. The lateritic horizons also shows results with respect to well yield with depth. The lines of regression are almost non informative indicating a near zero change in well yield with depth in increases. Transmissivity vs recovery rate shows very significant positive trends in fractured basalts (very steep), amygdaloidal basalts (least steep) and vesicular basalts (even less steeper) whereas in massive basalts the negative relationship between transmission and saturated aquifer thickness and between Transmissivity and optimum yields show similar trend of regression.

Hydro geophysical assessment

For the purpose of hydro geophysical assessment, the resistivity data have been collected from the public worked Department for 65 locations. In the hard rock terrains, groundwater occurs in fractures, fissures, crushed zones and joints. The objective of geophysical exploration is to locate such features. However, geophysical properties of water bearing zones depend on many factors. As such, the geophysical techniques used for groundwater prospecting in hard rock area must be selected with these different aspects in mind. Interpretations have been made through schlumberger inverse slope method. From the results, resistivity has been classified into four types as those of

10, 20, 30 and 40 meters iso-apparent resistivity. Iso lines have been drawn in order to assess the spatial distribution of these iso-apparent resistivity values used in demarcating favorable ground water locals.

As can be seen from the iso apparent resistivity is less than < 50 ohm meters in most of the basin area with increasing resistivity towards the central of the basin, about kulipirai. A torque of medium resistivities (of 50 – 100 ohm metres) extends into the east and central east. The pattern of iso apparent when considered less than 20 m type. The medium level iso apparent resistivity occupies the largest area, followed by high resistivity, However, low and high resistivity (less than 50 ohm meters and above 100 ohm meters) are now seen in pockets, High resistivity are more wide spread, mostly in the east and central east. At 30 mete type, again but except for medium resistivity's (50-100 ohms meters) other two classes are non-contiguous. It is in the spatial pattern of resistivity at 40 meter type that the high resistivity become more wide spread and large contiguous that either medium (50-100 ohm meters) or low resistivity (less than 50 ohm meters) or low as are characteristic of central south, central month and north east of the Bokad and Utavali river basins. The most favorable groundwater potential zones in the Midwest is in three pockets, about Asirgarh, Bokad and Burhanpur. A third of the basin area but mostly in the eastern half of the basins is less favorable with more favorable areas between. The west is more favorable than the east for integrated ground water development.

Groundwater recharge

In order to assess groundwater recharged into the aquifer system of the upper Bokad and Utavali basins, environmental isotope technique have been adopted to evaluate the amount of water recharged.

Tritium Isotope Techniques

Groundwater recharge rate is defined as net yearly increment to a groundwater body and is dependent upon the topography. Environmental tritium offers such better method of obtaining vertical recharge and also eliminates the necessary for the measurements of complex parameters like evapotranspiration. There are two ways in which environmental tritium can be utilized to evaluate vertical recharge. As mentioned earlier tritium is a built-in-tracer in water molecule, it just follows water. If water evaporates tritium also evaporates, If water runs off, so does tritium has percolated deep down i.e, after runoff and evaporation losses from the total precipitated since 1952. (taking into account of radioactive decay) one can directly determine the recharge for the past 25 years or so. Since the analyzed ^{3}H content for the upper Bokad, and Utavali basins water samples, shows almost similar range of less than or equal to 5TU. It indicates that the recharged water before the year 1953 and recharge of water from rainwater is accounted to 3 percent to the total annual average rainfall of about 878mm.

Geological and hydrogeological setting

Laterites and basalts are the main litho types found in the area. The laterites are derived from the residual weathering or lateralization of basalts (Radhakrishna & Vaidyanadhan 1994). The basalts exposed on the surface belong to upper cretaceous age (southern flank of Deccan traps). Well-developed laterites are found overlying basalts in the central part of the city, while the basalts outcrop in the northern and southern part of the study area. The weathering of Laterites gives rise to red soil whereas basalts to black soil. The Laterites possess interconnected primary openings and also secondary fractures. The basalts are devoid of primary openings but possess secondary openings in the form of fractures and joints. These features in the litho units help in easy infiltration of surface water. The pores & fractures in laterites and fractures & joints in basalts act as reservoirs of groundwater. Thus, in the study area groundwater occurs under phreatic (unconfined) condition in laterites and basalts that are outcropping at surface. The groundwater found in the basalts below laterites occur under semi-confined to confined conditions. The groundwater is exploited by either dug well or bore well in the study area (Sarwade 2004). Dug wells are more popular in lateritic horizon, due to shallow water table (depth: 2.0-15.0 m) cost effectiveness, simplicity in construction and operation. The bore wells are drilled in both laterites and basalts where the water level varies from 35.0 to 45.0 m. So, all the dug wells are replenished by shallow aquifers (laterites) and the bore wells from deep aquifers (basalts).

Aquifer parameter estimation

In the present study three methods are adapted to estimate the aquifer parameters in a basaltic terrain. Out of three, two are conventional/analytical curve matching methods viz; Papadopulos & Cooper method (1967), Mishra & Chachadi method (1985) and one numerical method proposed by Singh & Gupta (1991). As the above-mentioned analytical methods are well known methods, only numerical method is discussed in detail.

Numerical Method (Singh & Gupta, 1991)

In the numerical approach to estimate the aquifer parameters, a method proposed by Singh & Gupta (1991) has been used. This method considers both pumping and recovery phase data for the interpretation of pumping test data. The method assumes the following conditions to be valid: a static water level in the well prior to the pumping test; pumping well fully penetrates the aquifer; the flow towards the well is radially symmetrical, implying isotropy and homogeneity of the aquifer; drawdown is much smaller compared to total saturated thickness and hence transmissivity is regarded as invariable during the pumping test; the system is linear which permits application of the principle of super-position.

The method involves analysis and computation of pumping duration into a number of equal time steps. The aquifer response is calculated for each time step through convolution of the abstraction with the impulse response function. The abstraction rate during each time step is assumed to be constant, while it could take different values during various time steps.

The drawdown for each time step is calculated considering guess values of aquifer parameters. The computed drawdown is then compared with the observed drawdown. The aquifer parameters are then progressively modified in an iterative manner until a satisfactory match is achieved between the observed and the calculated time-drawdown/recovery. The best-fit time-drawdown /recovery curve gives the representative aquifer parameters.

The entire computational procedure involved in this method is written in the form of an interactive, user friendly computer program, which takes into account the combined effect of all or any one of these field conditions Viz; variable abstraction rate, seepage face and the effect of nearby hydro geological boundary.

This computer program is used to compute the response of an aquifer for a given set of parameters as and when needed, instead of having a large number of type curves.

Data acquisition and interpretation

Twenty pumping tests were conducted on dug wells in Asirgarh region, a basaltic terrain to characterize the aquifer parameters. of these 8 were carried out in laterites and 12 in basalts. In the tests, pumping phase was of short duration (60 to 210 min.) and recovery phase was of long duration (90 to 300 min.). Details of pumping tests are given in Table 1. The discharge rate and drawdown vary from 12.74 to 307.13 m^3/day and 0.33 to 3.19 m respectively. The recovery was taken care upto 70 to 100% of the drawdown except at location no.11. The data has been analysed/ interpreted by the above said three methods. The results are shown in Table 2.

Results and Discussion

Transmissivity (T) value obtained by Papadopulos & Cooper method varies from 17.81 to m^2/day in basalts and 6.54 to 102.22 m^2/day in laterites as shown Table 2. Storativity (S) values vary from 1.4 X 10^{-5} to 6.8 X 10^{-3} in basalts and 9.9 X 10^{-5} to 72.0 X 10^{-3} in laterites. Similarly 'T' values obtained by Mishra & Chachadi method varies from 17.67 to 38.86 m^2/day and 6.64 to 99.20 m^2/day in basalts and laterites respectively, whereas 'S' values varies from X 10^{-5} to 9.9 X 10^{-3} in basalts and 10.0 X 10^{-5} to 78.0 X 10^{-3} in laterites. In general the results of Papadopulos & Cooper and

Mishra & Chachadi methods resemble each other (except at some locations for 'S' values). The results of numerical method show that 'T' value varies from to 43.25 m^2/day in basalts and 8.6 to 112.0 m^2/day in laterites. 'S' value varies from 0.05 X 10^{-5} to 2.0 X 10^{-3} and 0.10 X 10^{-5} to 30.0 X 10^{-3} in basalts and laterites respectively. The results of numerical and theoretical methods are compared with each other in terms of ratios, which are shown in Table 3. This table shows that T values obtained by theoretical methods are underestimated by 6-15% in basalts and 3-42% in laterites than the values obtained by numerical method. S values obtained by theoretical methods are overestimated by 45% in basalts and 52% in laterites than the numerical methods. Percentage of error is calculated considering the total drawdown and residual drawdown obtained for the above said methods, in comparison with the field observations (Table 4). Table 4 shows that the error of 21% in total drawdown and 30% in the residual drawdown are involved in the results of theoretical method, whereas the error involved is <1% in total drawdown and <3% in residual drawdown in the results of numerical method for basalts. In case of laterites, the percent of error involved for total drawdown is 29% and for residual drawdown is 35% in the results of theoretical method. For numerical method it is < 1.0% for total drawdown and < 4.5% for residual drawdown. As stated above the percentage of error involved in the results obtained from numerical method proposed by Singh & Gupta (1991) is less than 5% both in basalts and Laterites. Hence the numerical approach is found to be more accurate over the theoretical curve matching methods in determining the aquifer parameters by pumping test in the basaltic area.

Conclusions

The hydrogeology of the study areas is characterized by a steep gradient of water level, generally indicating low permeability and therefore having lower rate of recharge capacity. It is found that the central and western parts of the study area have more favorable permeability than other areas. The water level fluctuations in the basin follows that the familiar seasonal rhythmic pattern. Seasonal variation in the water level reflects the general climatic balance between rainfall and evaporation. The optimum yield in the area ranges from 25 and 100 m^3/d. The high yield areas are close to extension fractures and too lineaments. The saturated aquifer thickness is between 3 and 6 meters. The recuperation rate is between 25 to 75 hours. The average transmissivity rate in massive basalts is 38.65m^2/day, in amygdaloidal basalts is 52.27m^2/day, in vesicular basalts is 60.46m^2/day and the maximum is found in highly fractured basalts is about 76.99 m^2/day. The average optimum yield is 35m^3/d in both fractured basalts and vesicular basalts; whereas in massive basalts it is very low about 19.95 m^3/d and maximum of 46.96 in lateritic horizons. The average recuperation rate of all rock types are about 18 hours. Resistivity show different spatial patterns and it is found that the western parts of the basins are more favorable than the eastern parts for integrated groundwater development.

Table 1. Pumping test results obtained at the Asirgarh Region

Well no.	Depth of well (m)	Diameter (m)	Water Level(m)	Q (m^3/d)	DD recorded (in min)	Max. DD observed	REC recorded (in min)	% of REC observed
1	24.72	2.04	4.40	26.09	140	1.41	160	78.72
2	32.19	1.37	6.13	20.07	180	0.54	270	63.37
3	21.72	1.07	7.64	13.77	150	0.53	180	96.23
4	19.14	1.28	4.57	21.00	210	0.55	250	100.24
5	25.85	1.98	5.88	307.13	60	3.19	120	54.23
6	16.76	1.12	6.25	21.85	182	0.39	180	97.44
7	12.19	1.26	7.03	26.71	154	1.46	240	70.55
8	15.24	1.73	8.95	42.39	186	0.33	92	102.00
9	22.25	1.14	14.07	12.74	160	0.60	240	80.00
10	18.29	1.60	15.15	22.69	170	0.58	300	98.28
11	20.76	2.59	6.38	91.76	150	0.49	300	100.78

12	19.64	1.52	6.25	24.83	120	0.45	248	86.00
13	15.85	1.98	4.88	307.13	80	3.19	140	54.23
14	16.76	1.82	6.89	21.85	190	0.39	190	97.44
15	12.19	1.76	5.82	26.71	130	1.48	220	70.55
16	16.24	1.78	6.98	42.39	164	0.33	98	100.21
17	20.65	1.44	12.05	12.74	182	0.66	240	80.00
18	18.23	1.86	14.12	22.69	186	0.52	321	98.28
19	19.76	2.24	6.86	91.76	148	0.59	306	100.56
20	18.84	1.82	6.85	24.83	134	0.44	242	98.00

Well no. & location: 1.; 2.; 3.; 4., 5. 6.; 7. ,; 8. 9., ..; 10.; 11. 12.; Q = discharge rate (in m^3/day); DD = Drawdown (in m);. REC = Recovery

Transmissivity values are in sq.m/day and Storativity value is dimensionless

PAC = Results obtained from curve matching method of Papadopulos and Cooper (1967)

MAC= Results obtained from curve matching method of Mishra and Chachadi (1985)

NUM = Results obtained from numerical method proposed by Singh and Gupta (1991)

Table 2. Comparison of pumping test results obtained by different methods

Well	**Lithology**	**Transmissivity value**			**Storativity value obtained by**		
		PAC	MAC	NUM	PAC	MAC	NUM
1	Basalt	16.82	17.84	18.52	0.000084	0.000071	0.000042
2	Basalt	18.34	18.82	20.74	0.00078	0.00099	0.00034
3	Basalt	17.96	17.62	19.25	0.00064	0.0098	0.00032
4	Basalt	40.84	41.44	41.98	0.00026	0.00043	0.00014
5	Basalt	16.21	16.88	19.72	0.000072	0.000068	0.000018
6	Basalt	19.42	18.84	21.25	0.00068	0.00099	0.00028
7	Basalt	17.96	17.67	19.35	0.0063	0.0095	0.0035
8	Basalt	36.	37.	38.2	0.000044	0.000063	0.000024
9	Basalt					0.0000	
10	Basalt						
11	Basalt						
12	Basalt						

		75	86	5	0.0000072	081	0.0000024
		23.81	22.62	24.78	0.00065	0.00092	0.00023
		29.34	28.94	31.71	0.00083	0.0064	0.00012
		24.94	25.68	26.65	0.00006	0.00007	0.00003
		38.64	38.86	40.02			
Min		16.21	16.88	18.52	0.00008	0.00006	0.00004
Max		40.84	41.44	41.98	0.0083	0.0058	0.0018
13	Laterite	26.04	22.44	24.06	0.000034	0.00066	0.000024
14	Laterite	34.82	36.80	40.64	0.00048	0.00064	0.00012
15	Laterite	16.54	16.64	18.60	0.000062	0.000098	0.000024
16	Laterite	98.24	99.28	108.02	0.00086	0.00098	0.00032
17	Laterite	19.22	17.24	18.28	0.0046	0.0059	0.0016
18	Laterite	20.46	18.44	22.54	0.00064	0.00086	0.0033
19	Laterite	62.54	64.46	68.52	0.0078	0.0086	0.0042
20	Laterite	42.03	41.16	44.45	0.00042	0.00062	0.00016
Min		16.54	16.64	18.28	0.000094	0.000068	0.000046
Max		98.24	99.28	108.02	0.0078	0.0059	0.042

Transmissivity values are in sq.m/day and Storativity value is dimensionless

PAC = Results obtained from curve matching method of Papadopulos and Cooper (1967)

MAC= Results obtained from curve matching method of Mishra and Chachadi (1985)

NUM = Results obtained from numerical method proposed by Singh and Gupta (1991)

Table 3. Comparison of results of numerical method with theoretical method (in-terms of ratio)

Well no	**lithology**	**Transmissivity**		**Storativity**	
		NUM / MAC	NUM/ PAC	NUM/ MAC	NUM/ PAC
1	Basalt	1.04	1.10	0.59	0.50
2	Basalt	1.10	1.13	0.34	0.05
3	Basalt	1.09	1.07	0.33	0.50
4	Basalt	1.01	1.03	0.32	0.54
5	Basalt	1.17	1.22	0.26	0.25
6	Basalt	1.13	1.13	0.28	0.41

7	Basalt	1.09	1.09	0.37	0.55
8	Basalt	1.01	1.04	0.38	0.54
9	Basalt	1.09	1.04	0.29	0.33
10	Basalt	1.09	1.08	0.25	0.35
11	Basalt	1.04	1.07	0.02	0.14
12	Basalt	1.03	1.04	0.43	0.50
Minimum		1.01	1.03	0.66	0.50
Maximum		1.17	1.22	0.31	0.21
13	Laterite	1.07	0.92	0.36	0.70
14	Laterite	1.10	1.17	0.19	0.25
15	Laterite	1.12	1.12	0.24	0.39
16	Laterite	1.09	1.10	0.33	0.37
17	Laterite	1.06	0.95	0.27	0.35
18	Laterite	1.22	1.10	0.38	0.52
19	Laterite	1.06	1.09	0.49	0.54
20	Laterite	1.08	1.06	0.25	0.38
Minimum		1.06	0.92	0.68	0.48
Maximum		1.22	1.17	0.03	0.05

Transmissivity values are in sq.m/day and Storativity value is dimensionless

PAC = Results obtained from curve matching method of Papadopulos and Cooper (1967)

MAC= Results obtained from curve matching method of Mishra and Chachadi (1985)

NUM = Results obtained from numerical method proposed by Singh and Gupta (1991)

Table 4.Percentage of error in the results obtained by different methods

Well no	lithology	PAC		MAC		NUM	
		DD	R-DD	DD	R-DD	DD	R-DD
1	Basalt	16.95	11.97	0.64	0.07	1.13	1.37
2	Basalt	4.76	3.96	7.35	6.89	0.00	2.14
3	Basalt	8.26	19.27	21.34	30.78	0.00	2.12
4	Basalt	1.18	10.00	5.56	16.00	0.00	2.95
5	Basalt	16.95	11.97	0.64	0.07	1.13	1.37
6	Basalt	4.76	3.96	7.35	6.89	0.00	2.14
7	Basalt	8.26	19.27	21.34	30.78	0.00	2.12
8	Basalt	1.18	10.00	5.56	16.00	0.00	2.95

9	Basalt	16.95	11.97	0.64	0.07	1.13	1.37
10	Basalt	4.76	3.96	7.35	6.89	0.00	2.14
11	Basalt	8.26	19.27	21.34	30.78	0.00	2.12
12	Basalt	1.18	10.00	5.56	16.00	0.00	2.95
Minimum		1.18	3.96	0.64	0.07	0.00	1.37
Maximum		16.95	19.27	21.34	30.78	1.13	2.95
13	Laterite	8.18	7.40	5.08	6.88	0.22	0.98
14	Laterite	26.59	34.84	5.49	14.08	0.00	2.07
15	Laterite	4.32	13.38	4.11	12.77	0.75	2.17
16	Laterite	17.52	33.19	5.12	14.84	0.21	4.43
17	Laterite	4.48	5.67	13.03	17.17	0.12	0.10
18	Laterite	0.14	14.44	7.66	21.77	0.10	3.63
19	Laterite	9.57	20.85	5.33	17.98	0.06	3.10
20	Laterite	28.73	29.95	17.11	17.12	0.04	0.49
Minimum		0.14	5.67	4.11	6.88	0.00	0.10
Maximum		28.73	34.84	17.11	21.77	0.75	4.43

Transmissivity values are in sq.m/day and Storativity value is dimensionless

PAC = Results obtained from curve matching method of Papadopulos and Cooper (1967)

MAC= Results obtained from curve matching method of Mishra and Chachadi (1985)

NUM = Results obtained from numerical method proposed by Singh and Gupta (1991)

DD&R-DD=Total drawdown & Residual drawdown respectively

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