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Evaluation of the aquifer characteristics of the basaltic terrain of Maharashtra in India

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ABSTRACT

The paper attempts to evaluate the permeability data obtained from 75 aquifer performance tests conducted on open wells tapping the water table aquifer of the basaltic lava flows spread over the three different basins of Maharashtra. The permeability has been computed by Thiem's formula and the modified Theis non-equilibrium formula. The statistical analysis of the permeability data of the study basins, *viz.*, Bhima, Godavari and Wardha, reveal a decrease in permeability range as one proceeds from the Bhima basin (low rainfall area) through the Godavari basin (assured rainfall area) to the high rainfall area of Wardha basin. The permeability frequency graphs of the three study basins reveal different hydrogeological characteristics for each.

INTRODUCTION

THE Deccan basalt is an important hydrogeological province of the Deccan peninsula in the Indian subcontinent extending over an area of about 0·5 million sq.km in the states of Maharashtra, Madhya Pradesh, Gujarat and Karnataka. In Maharashtra it occupies the largest arcal extent of about 0·24 million sq.km, constituting about 82 per cent of the total area of the state.

As the most extensive rock unit of the western sector of peninsular India, the Deccan trap has no doubt rceeived early attention of the geologists; but systematic groundwater study has been done only during the last decade and only a small portion of the vast and extensive Deccan basalt has been covered so far. Even so the results so far obtained throw considerable light on the hydrogeology of the terrain in Maharashtra.

We report here the results of our aquifer performance tests on select open wells in Bhima, Godavari and Wardha basins of Maharashtra, piercing the water table zone to a depth of 10 to 15 m in an area covering 13,000 sq.km.

Climate

Climatically the State of Maharashtra can be divided into three main zones: (i) The area of moderately high rainfall comprising partly six eastern districts of the Vidarbha region with Wardha sub-basin of the Godavari main basin forming the principal river basin and an average annual rainfall of 0·9 to 1·25 m; (ii) The area of assured rainfall comprising mainly the districts of Aurangabad and Parbhani of the Marathwada region with Godavari basin as the principal river basin and an average annual rainfall of 0·75 m; and (iii) The scarcity tract comprising the districts of Poona, Ahmednagar and Sholapur of Western Maharashtra with Bhima sub-basin of the Krishna main basin forming the principal river basin and an average annual rainfall of 0·5 to 0·625 m.

The aquifer parameters, including the coefficient of permeability, of the basaltic water table aquifer in different climatic zones depend upon the rainfall, topography, fillings in the vesicles of the vesicular units and the relative compaction of the rock material.

Geological Setting

The Deccan trap is a thick pile of basaltic lava flows, horizontally disposed and apparently more or less uniform in composition. It also includes other volcanic products, such as tuffs, breccia, ash beds and sediments deposited during the interval between two successive flows.

In geological literature the Deccan trap is presently divided into the following three groups (Krishnan 1968):

Areas	*Groups*	*Description*
C. Coastal areas	Upper traps (450 m thick)	Bombay and Kathiawar, with numerous intertrappean beds and layers of volcanic ash
B. Valleys of *Godavari*, *Bhima* and *Krishna*	Middle traps (1,200 m thick)	Central India and Malwa with numerous ash beds in the upper portion and practically devoid of intertrappeans
A. Valleys of *Wardha*, *Penganga*, etc.	Lower traps (150 m thick)	Central Provinces and eastern areas, with intertrappean beds and rare ash beds

Hydrological properties of the basaltic formation

The area under study constitutes a sequence of basaltic flows intervened by thin red bole or fresh water sediments. The individual flow in a typical section varies from porous weathered base to a massive middle unit becoming increasingly vesicular towards the top.

Each distinct part of the flow forms a unit and they differ in respect of their ability to receive, store and transmit groundwater as a result of their inherent physical characteristics like porosity and permeability. The vesicular and amygdular units have abundant vesicles that contribute to the hydrological properties, and thus have a high degree of porosity and permeability to serve as potential aquifers of groundwater. Weathering too augments this property of holding water and when favourably situated forms productive zones. The massive units are almost devoid of any openings and have low porosity and hence less productive, but closely spaced interconnecting joints in these units contribute towards fracture porosity, and thus form a productive zone of relatively low potential. When a fractured massive unit forms a hydraulic trough in a morphological depression, it holds far better promise.

Groundwater occurs under water table conditions in these basaltic lava flows, comprising the weathered and jointed zones in the massive units and the vesicular or amygdular units, which singly or collectively form the main water table aquifers of these lava flows.

The study area, being a succession of basaltic lava flows with a sequence of alternating massive and vesicular units, has a hydraulic continuity through the weathered and jointed zones to constitute a single aquifer system in a relatively low or level ground.

EVALUATION OF AQUIFER PARAMETERS

For a quantitative estimation of most problems in hydrogeology, it is necessary to have an accurate knowledge of the aquifer parameters, notably P_f, the coefficient of permeability and T, the coefficient of transmissibility. The method, employed for the determination of aquifer parameters, is the aquifer performance test on open wells of the area, applying necessary formulae referred to by Ferris *et al*. (1962).

It is generally believed that the usual methods of analysis applied to soft rocks cannot be applied to hard rocks like basalt since the assumption of an infinitely homogeneous aquifer are not met with. However, Todd (1959) points out that aquifers composed of hard rocks exhibit homogeneous characteristics, if sufficiently large volumes are considered. On this basis, analysis of hydrological data as applied to soft rocks have yielded excellent results when applied to hard rocks like basalts. The authors too have applied such methods with good results. Evaluation of the aquifer parameter has been done by the following two methods:

(1) Well data analysis method (Groundwater hydraulics), and

(2) The statistical analysis method.

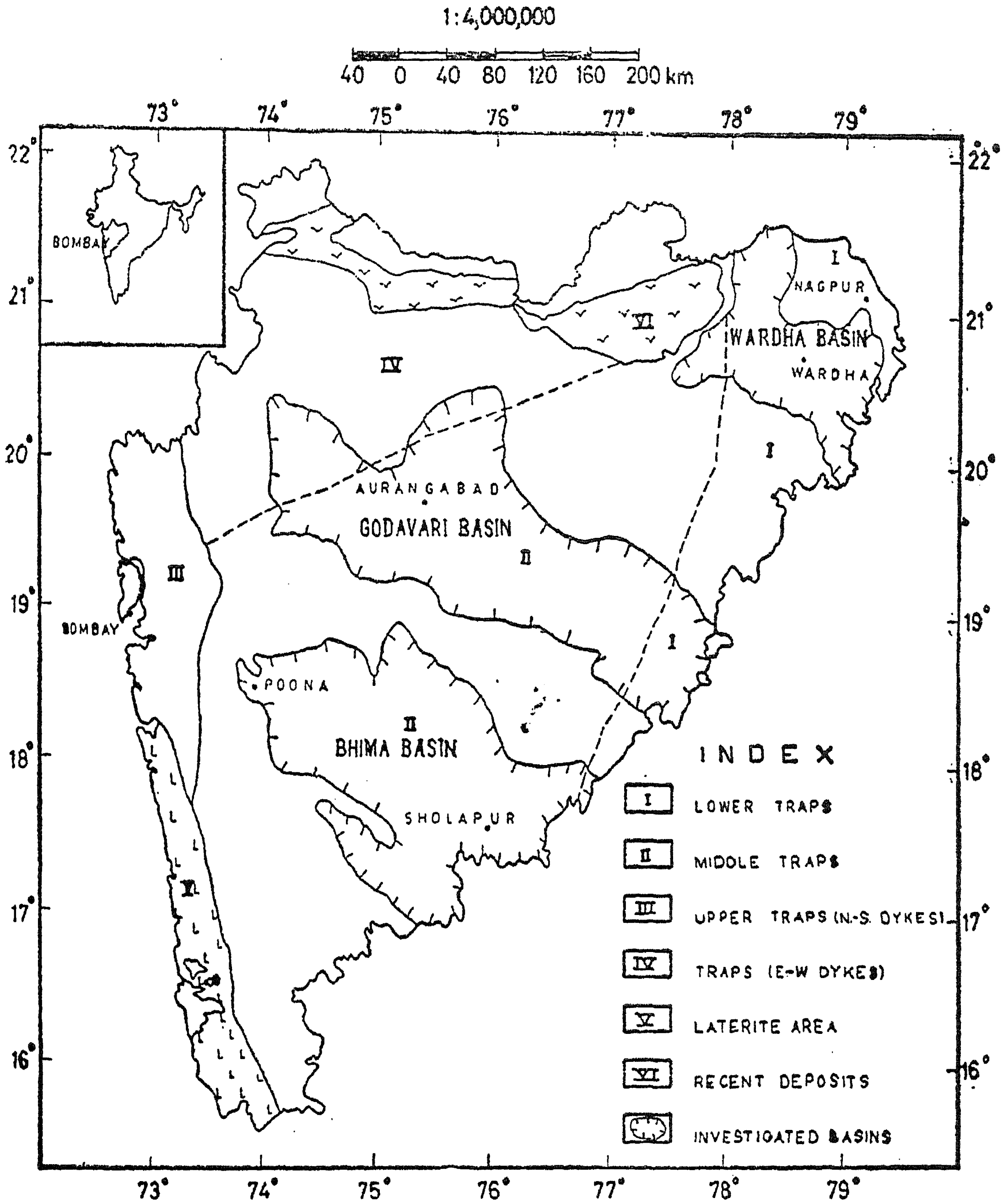

Figure 1. Hydrological zones in the basaltic terrain of Maharashtra.

Well data analysis method

There are two main types of mathematical formulae which are used for computing aquifer parameters. The first of these is the older concept of the equilibrium formula (Thiem 1906) and the second is the more refined non-equilibrium formula of Theis (1935).

Thiem's formula is:

$$P \times m = T = \frac{527 \cdot 7\, Q \times \log r_2/r_1}{S_1 - S_2} \tag{1}$$

where

T is the coefficient of transmissibility;

P is the coefficient of permeability;

m is the thickness of the saturated zone;

Q is the rate of discharge in GPM;

r_1 and r_2 are the distances of the observation wells from the pumped well; and

S_1 and S_2 are the drawdowns created in the observation well at a distance of r_1 and r_2.

For purposes of ready usage, the above formula can be written as:

$$T = Pm = \frac{527 \cdot 7\, Q \times \log \frac{R}{r}}{S} \tag{2}$$

where R stands for the radius of influence. or the distance at which the drawdown in an observation well is negligible, and r and S stand for the effective radius of the pumping well and drawdown.

In the above case if S_1 is the drawdown in the pumped well itself, r becomes the effective radius of the well. The above formula reduces to

$$T = \frac{Q}{S_1} \times 527 \cdot 7 \log \frac{R}{r},$$

$$= \text{Sp. capacity} \times 527 \cdot 7 \log \frac{R}{r}. \tag{3}$$

In the above equation, if the value of R is assumed, the value of T can be obtained by multiplying the sp. capacity by an empirical factor $= 527 \cdot 7 \log (R/r)$. The average value of this factor in the basaltic terrain is about 400.

Non-equilibrium formulae

The original Theis non-equilibrium formulae required a graphical method to obtain a solution. However, Jacob (1947) recognised that for smaller values of r the distance from the pumped well and large interval of time, the original Theis equation can be reduced to the following formulae:

$$s = \frac{Q}{4T} \ln \frac{2 \cdot 25\, Tt}{r^2 S}$$

$$= \frac{264Q}{T} \log_{10} 0 \cdot 3\, Tt/r^2 S \qquad (4)$$

where

s is the drawdown;

T is the transmissibility;

t is the time in days since pumping started;

r is the distance from the pumped well in feet; and

S is the storage coefficient.

Cooper and Jacob (1946) showed that the above equation can be used to obtain the value of T and S by plotting drawdown (or recovery) data on a semilogarithmic paper. The resulting graph which should be a straight line is referred to as the time drawdown (or recovery) graph. If the values of time are selected against one log cycle $\log_{10} t/t' - 1$, then $T = (264\, Q/\triangle h)$, where $\triangle h$ is the drawdown over one log cycle. The method is most suited for wells which are situated in the vicinity of the pumped wells.

Assumptions implicit in the equation and their application to the basaltic terrains

The main assumptions of the non-equilibrium formulae are:

1. The aquifer is homogeneous and isotropic, and infinite in areal extent;
2. T is constant at all times and at all places;
3. Water removed from the storage is discharged instantaneously with decline in head; and
4. The well has an infinitesimal diameter.

The above assumptions may appear to prohibit the use of Theis equation for determining transmissibility. However, as pointed out by Todd (1959), it one considers a regional picture of the water table aquifer the local heterogeneity as in the case of the basaltic aquifer may be small and we can safely assume that the aquifer is homogeneous in its heterogeneity. Also, experience in other countries have definitely proved that normal laws of groundwater hydraulics can be applied to these hard rocks.

Assumption 2 states that the transmissibility is constant at all times and at all places. However, when water is withdrawn from an unconfined aquifer the transmissibility decreases as the aquifer is dewatered. This results in greater drawdown in water table aquifers than in the confined aquifers of equivalent transmissibility. Jacob (1963) has shown that adjustments can be made for the effect of dewatering.

The third assumption which affects the application of the Theis equation is that the water removed from the storage is discharged instantaneously with decline in head. Indeed, water drains slowly from the rocks through which the water table has fallen.

In case of water table aquifers in the basaltic terrain the wells are at present being developed by open wells, where the water discharged during pumping tests is mainly drawn from the storage of the well. The aquifer characteristics are not registered in the drawdown curve. Hence the authors have applied recovery methods, *viz*., time-recovery graphs, Slichter's formulae for determining the specific capacity of the wells multiplied by an empirical factor to arrive at the value of the transmissibility/permeability. Good agreement exists between the two methods confirming the reliability in applying groundwater hydraulics concept to the water table aquifer. The permeability values were arrived at by dividing transmissibility by the thickness of the saturated zone penetrated.

The authors have utilised only the permeability values (P_f) from 75 tests since the wells tested tap different thicknesses of the saturated zones and are of different diameters. The determined values of the principal water table aquifers in the three basins studied are given below for comparison:

	Basin	*Field permeability values (P_f) in Klpd/sq.m.*	*Remarks*
1.	Bhima	8·00 to 92·00	High range
2.	Godavari	2·80 to 40·00	Moderate range
3.	Wardha	1·30 to 18·00	Small range

Statistical Analysis

The above values have been subjected to statistical analysis to test if significant variation exists. Walton (1962) employed specific capacity data for dolomite wells for a similar purpose. The authors have used the field permeability data instead of the specific capacity values in the basaltic terrain as the latter do not represent the true aquifer characteristics.

The P_f values of the basaltic water table aquifer were segregated basin-wise and the permeability values for each basin were tabulated in order of magnitude and frequencies by the Kimbal method referred to by Walton (1962).

$$F = \frac{m_0}{n_w + 1} \times 100 \quad (5)$$

where F is the percentage of sites, where the permeabilities are equal to or greater than the permeability of the order number m_0; and n_w is the total number of wells tested for permeability.

The values of permeability were then plotted against the percentage of the well sites on a logarithmic probability paper as shown in figure 2. The slopes of the straight lines of the three basins vary, confirming thereby the differences in their aquifer characteristics.

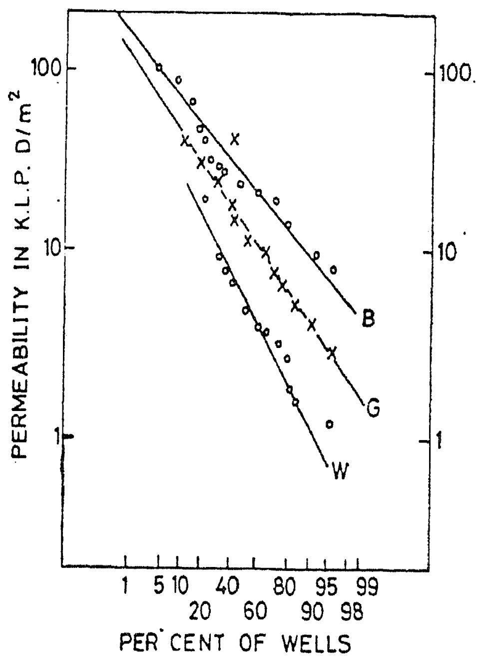

Figure 2. The frequency graph.

Discussion

The salient features of the frequency graph (figure 2) are:

(*a*) the permeability values show a progressive decrease from the Bhima basin in the west to the Wardha basin in the east;

(*b*) the steep gradient for the Wardha basin indicates less consistency of productive zones than both the Godavari and the Bhima basins, which are indeed more productive.

From the present study the Deccan basaltic lava flows of the state of Maharashtra may be grouped into three different domains, each with its own climatic, geological and hydrogeological characteristics:

Basin	*Climate*	*Geology*	*Hydraulic characteristics*
Bhima ..	Low rainfall	Basaltic flows with red bole beds (Middle Traps)	High permeability
Godavari ..	Assured rainfall	do.	Moderate permeability
Wardha ..	Moderately high rainfall	Basaltic lava flows with fresh water deposits (Lower Traps)	Low permeability

It can be seen that there appears to be a progressive decrease in the permeability of the principal water table aquifers of the basaltic lava flows as one proceeds from the Bhima basin in the west to the Wardha basin further eastwards, while there is a progressive rise in the rainfall. Such a phenomenon appears to be contrary to the prevalent belief that high rainfall increases productivity consequent to increased weathering of the aquifer material. However, in the present case the higher intensity of weathering due to higher rainfall has decreased the inherent physical characteristics like porosity and permeability of the aquifer in the Wardha basin area in contrast to the Bhima and the Godavari basin areas of lower rainfall. This may be explained by the fact that increased weathering of basalt results in greater amount of clay formation in the water table zone resulting in decreased permeability.

CONCLUSIONS

To sum up, it can be stated that the Deccan basaltic plateau can be safely grouped into three distinct domains, each with its distinct hydrogeological characteristics. This has been confirmed by the application of statistical method of analysis of the permeability data in the principal water table aquifers of the basaltic lava flows in three different river basins in this state. Negative correlation does exist between the climatic and hydrogeological characteristics of these domains.

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