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Influence of Geological and Geomorphological Characteristics on Groundwater Occurrence in Deccan Basalt Hard Rock Area of Tawarja river Sub-Basin Latur, Maharashtra, India

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Abstract: The entire study area is covered by Deccan basalt formations comprising nearly horizontal lava flows of late Cretaceous to early Eocene. There are eight flows of lava found in the area and these flows have been considered to be a result of fissure type lava eruption. The types of basaltic flows occurring in the area are simple basalt (aa type) and vesicular-amygdaloidal (Compound pahoehoe type) basalt flow and also red bole beds (Tachylitic bands) are observed in the exposures, quarries and well sections. The drainage pattern varies from dendritic to sub-dendritic and sub-parallel. The bifurcation ratio is moderate (3.00 to 4.67) and the lower values of drainage density (1.77 km/km^2) and stream frequency (1.74 streams/km^2) indicates the region is of permeable subsoil strata of the basin. Morphometric attributes like form factor (0.85), circularity ratio (0.37) and elongation ratio (0.63) reflects the early mature stage of erosional development. The groundwater occurrence with reference to hydrogeological and geomorphological characters of the sub-basin is discussed. The groundwater occurrence is good productive in the geomorphic surfaces like moderately dissected plateau and pediplains, moderate in highly dissected plateau and lateritic uplands and poor in denudational hills.

Key words: Deccan basalts, geomorphic surfaces, groundwater occurrence, hydrogeology, morphometric analysis

INTRODUCTION

The linking of the geomorphological parameters and geology with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behaviour of the different basins particularly of the unguaged basin in hard rocks like Deccan basalt. The hydrologic and geomorphic effects of nature and human process with in a basin are focused on its outlet. The techniques of geomorphometric analysis are useful in the quantitative description of the geometry of the drainage basins and its network which helps in characterizing the drainage network. The geomorphological landforms are important from the hydrological point of view and include the linear, aerial and relief aspects of the drainage basin. It has also been found that hydrogeological geomorphological investigations besides helping in targeting potential zones for groundwater exploration provides inputs towards estimation of the total groundwater resources in an area, the selection of appropriate sites for artificial recharge and the depth of the weathering (Babar, 2009; Babar *et al*., 2010; Muley *et al*., 2010).

In the present study geology and geomorphological analysis has been carried out in the Tawarja river sub-basin in Latur district of Maharashtra (Fig. 1). The area is bounded by latitudes 18º24′15″ N and 18º12′16″ N and longitudes 76º15′22″ E and 76º41′35″ E and is included in the Survey of India toposheet no. 56 B/7, B/8, B/11 and B/12. Tawarja river is a tributary stream of Manjra river and covers an area of 642.40 km^2 with the elevation range of 702 and 560 m.

Geology: Geologically, the entire study area is covered by Deccan basalt formations comprising nearly horizontal lava flows of late Cretaceous to early Eocene. The types of basaltic flows occurring in the area are simple basalt (aa type) and vesicular-amygdaloidal (Compound pahoehoe) basalt flow and also red bole beds (Tachylitic bands) as observed in the exposures, quarries and well sections (Fig. 2a).

Compact basalt flows are thick and having tabular form. In compact basalt flows there is variation in the field characters from its top to bottom. The top surface of compact basalt flow is rather undulating. Top of the flow up to some thickness is hydrothermally altered, purple or greenish coloured and vesicular. The middle and lower portions of compact basalt flows are free from vesicles and amygdules and they occur in true senses as compact (massive) basalt. Joints, which are contraction cracks developed during cooling and solidification of the lava, always occur in middle and lower portions of the flow (Fig. 2a). There is variation in the pattern of jointing and joint spacing (Fig. 2b).

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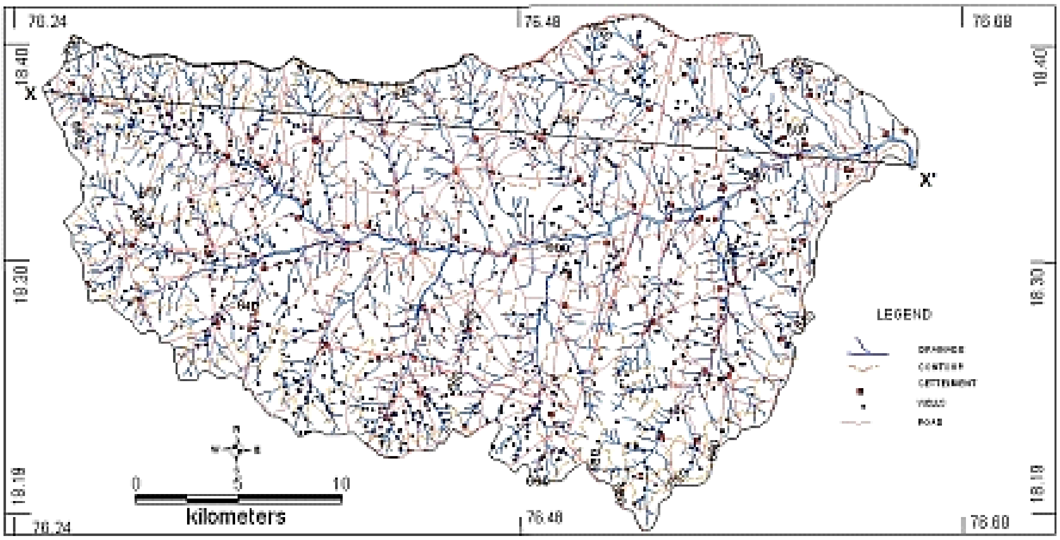

Fig. 1: Drainage and topographical map of Tawarja river sub-basin

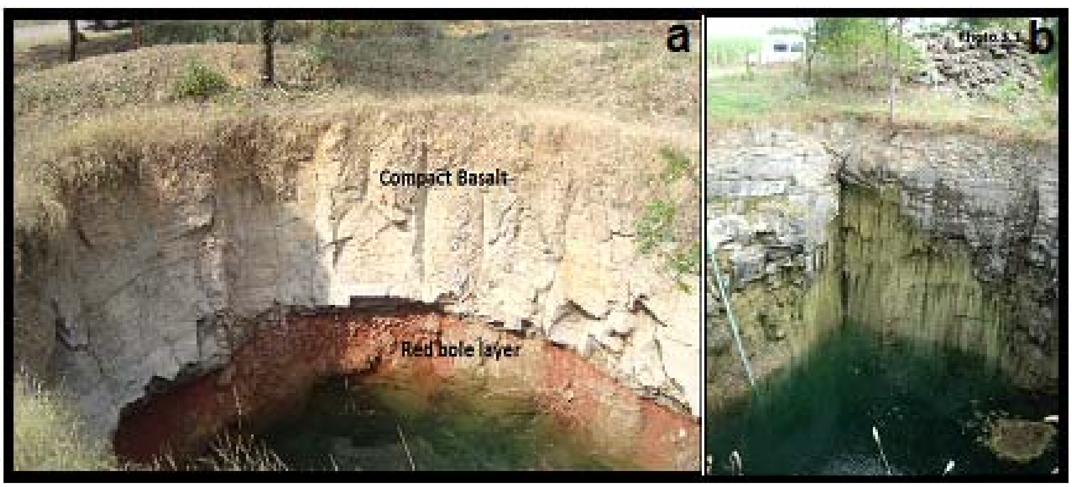

Fig. 2: (a) Compact basalt showing closely spaced jointing and red bole bed (b) Variation in the pattern of jointing and joint spacing in compact babalt

Table 1: Deccan basalt lava flows observed in the long section along the Tawarja river

S.No.	Flow No.	Lithology of the flow	Altitude range (m)
1	VIII	Jointed compact basalt flow (fine grained massive and moderately weathered)	702.00 to 685.00
2	VII	Highly weathered vesicular amygdaloidal basalt flow	685.00 to 675.00
3	VI	Jointed compact basalt flow (fine grained massive, grey to dark grey coloured and poorly weathered)	675.00 to 643.00
4	-	Red bole bed	643.00 to 642.00
5	V	Compact basalt flow (fine grained massive and moderately weathered)	642.00 to 634.00
6	-	Red bole bed	634.00 to 633.00
7	IV	Highly weathered vesicular amygdaloidal basalt flow	633.00 to 621.00
8	III	Jointed compact basalt flow (fine grained massive, dark grey coloured and highly to moderately weathered)	621.00 to 580.00
9	II	Poorly weathered/un-weathered vesicular amygdaloidal basalt flow	580.00 to 569.00
10	I	Jointed compact basalt flow (fine grained massive, dark brownish coloured and poorly weathered)	569.00 to 560.00

The vesicular amygdaloidal basalt (compound Pahoehoe) flows are formed by the outpouring of comparatively viscous lava in small quantities through a large number of outlets (Gupte, 1971; Kulkarni *et al.*, 1980). Therefore, amygdaloidal basalt flows have small sizes having irregular forms and limited lateral extent.

There are eight basalt flows in the Tawarja river sub-basin area occurring between the elevations of 702 to 560 m above msl. The flows vary in average thickness about 18 m. The characters of basalt flows are given in Table 1 and all the flows are given in Fig. 3. Out of eight flows of basalt five flows are of compact/massive (aa type) basalt

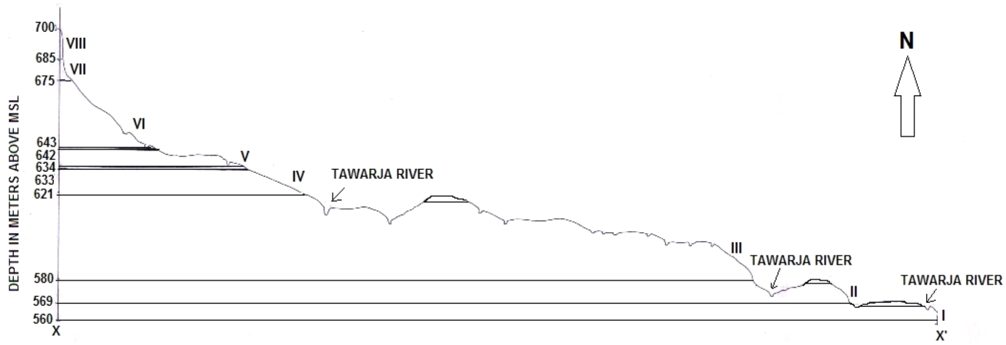

Fig. 3: Eight flows of basalt occurring along X-X’ section (location given in Fig. 1) of Tawarja River (I to VIII are numbers of lava flows)

Fig. 4: (a) Compact basalt and amygdaloidal basalt flows separated by red bole bed, (b) Compact basalt showing jointing with the spheroidal weathering

flows (Flow No VIII, VI, V, III and I), two flows of weathered amygdaloidal (pahoehoe type) basalt flows (Flow No. VII and IV) and one flow is poorly weathered/un-weathered vesicular-amygdaloidal (Flow No. II, Fig. 4a). Compact/massive basalt Flow No. VIII, III and I show the closely spaced joints, Flow No. VI shows jointing with the spheroidal weathering (Fig. 4b) whereas Flow No. V is compact basalt with non-inter connected and inconsistent joints.

The vesicular and amygdaloidal basalts also show weathering and development of sheet jointing. The red bole bed (Fig. 2a) occurs at the top of Flow No IV and having thickness varying from few centimetres to about 1m. In vesicular-amygdaloidal basalts the vesicles are filled with green chlorophaeite, zeolites and calcite.

Geomorphology: The drainage network of streams of Tawarja sub-basin (Fig. 1) shows dendritic to sub-dendritic and sub-parallel drainage pattern. The development of dendritic to sub-dendritic drainage in the sub-basin indicates the area of massive jointed rock types, gently sloping to almost horizontal terrain and low relief.

The morphometric analysis include the assessment of various parameters like bifurcation ratio, length and area ratios, basin configurations, drainage density, stream frequency, length of overland flow and relief aspects (Channel gradient, relief ratio, ruggedness number and hypsometric integrals) of the Tawarja sub-basin.

In morphometric analysis of the sub-basin the stream order is determined following the method of Strahler (1957). Accordingly the Tawarja river is of Sixth order. The bifurcation ratio (Rb) is the ratio of number of stream segments of a given order (Nu) and the number of stream segments of next higher order (Nu + 1). Bifurcation ratios in general have a range from about 2.0 for flat or rolling areas to 3.0 to 5.0 for mountainous, hilly and highly dissected basins (Horton, 1945). Bifurcation ratio registers very small variation from region to region irrespective of structural control (Singh *et al.*, 1984). Strahler (1964) found that bifurcation ratio characteristically ranges between 3.0 and 5.0 in watersheds in which the geological structures do not distort the drainage basin. Bifurcation ratios of Tawarja river sub-basin ranges from 3.0 to 4.67 (Table 2).

Table 2: Bifurcation ratio, length ratio and area ratio of Tawarja sub-basin

Stream order	No. of streams	Bifurcation ratio	Stream length (Km)	Mean stream length	Length ratio	Stream area (Km^{-2})	Mean stream area	Area ratio
1	872		633.30	0.73		373.20	0.43	
		4.67			1.75			5.84
2	187		239.65	1.28		465.80	2.51	
		4.45			2.59			4.10
3	42		138.93	3.31		432.75	10.30	
		3.50			2.04			3.90
4	12		80.99	6.75		482.43	40.20	
		4.00			0.37			3.06
5	3		7.59	2.53		368.70	122.90	
		3.00			13.58			5.23
6	1		34.37	34.37		642.40	642.40	
Total	1117	-	1134.83	-	-	642.40	-	-

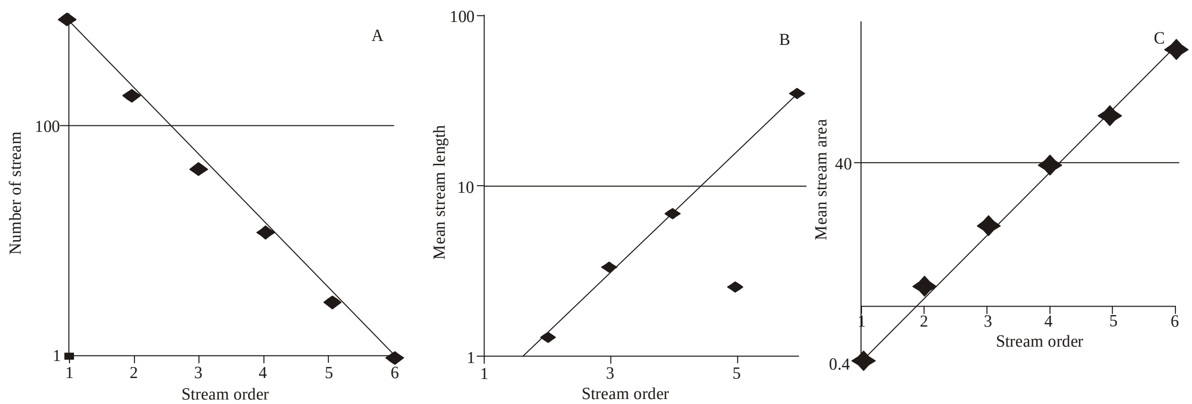

Fig. 5: (a) Semilog plot of stream order vs number of streams, (b) Semilog plot of stream order vs mean streams length and (c) Semilog plot of stream order vs mean streams area

The number of streams of each order is plotted against the corresponding stream order of the Tawarja sub-basin (Fig. 5a). The plot shows that the number of streams of given orders in the sub-basin forms an inverse geometric sequence by decreasing systematically with increasing order in conformity to the Horton (1945) 'law of stream numbers'.

The lengths of the various stream segments were measured order wise and the total lengths as well as the mean stream length for each order were computed. The length ratio, which is the ratio of the mean length of the streams of a given order to the mean length of the streams of the next lower order, was then calculated for each pair of order (Table 2). The plot of mean stream length of each order against stream order (Fig. 5b) gives exponential form around the regression line.

It is apparent from the plots that the average length of streams of a given order forms a direct geometric sequence by increasing systematically with order and thus conforms to Horton (1945) 'law of stream length'.

The areas of each order were computed and calculated the mean stream areas of each order. Then taking pairs of stream orders, the area ratios were obtained between the mean areas of the basins of one order and that of the next lower order (Table 2).

The mean basin area of the streams of a given order is plotted against corresponding order in exponential form (Fig. 5c). The relationship shows that the mean basin area of corresponding order increases systematically with increasing order, which is in conformity to the Schumm (1956) 'law of basin area'.

Table 3: Morphometric parameters of Tawarja river sub-basin

S.No.	Parameters	Values
1	Total basin area (A) Sq. Km.	642.40
2	Maximum basin length (l) Km	45.25
3	Total stream length (L) Km	1134.83
4	Basin perimeter (P) Km	148.40
5	Radius of the circle with the perimeter as circumference (r) Km	23.63
6	Area of the circle with same perimeter (Ao) Km^2	1753.30
7	Form factor ($F = A/l^2$)	0.85
8	Circularity ratio (C = A/Ao)	0.37
9	Compactness ratio ($K = 4\pi A/P^2$)	0.37
10	Diameter of the circle of the area of the basin (lo) Km.	28.60
11	Elongation ratio (lo/L)	0.63
12	Drainage density (Dd = L/A) Km/Km^2	1.77
13	Total number of streams (N) 1117	
14	Streams frequency (Fs = N/A) streams/Km^2	1.74
15	Length of overland flow (1/2Dd) Km.	0.28
16	Infiltration number (If)	3.08
17	Maximum basin relief (H)m	136
18	Relief ratio	0.003
19	Ruggedness number (H/L)	0.24
20	Slope of the ground surface (Hx2Dd) m/km	0.48

The values of circularity ratio (0.37) and elongation ratio (0.63) (Table 3) indicates that the sub-basin is

Table 4: Well inventory and yield particulars of wells in Tawarja river sub-basin

Sr No.	Geomorphic unit	Observation wells Types	Nos,	Range of depth (m)	Range of depth to water (m bg1) Pre-monsoon	Post-monsoon	Water table fluctuation (m)	Range of yield (1pm)	Av. yield (l pm)
1	Highly dissected	DW	3	8.5-12.2	6.5-12.4	3.1-5.4	3.4-7.0	75-95	83
	plateau	BW	5	50.0-70.0	10.5-26.9	5.2-10.2	5.3-16.7	95-150	125
2	Moderately	DW	4	9.5-14.0	2.5-5.5	1.0-3.0	1.5-2.5	100-180	160
	dissected plateau	BW	7	32.0-60.0	4.8-9.5	2.0-4.5	2.8-5.0	150-185	170
3	Pediplains	DW	6	10.0-15.0	5.5-10.5	2.5-4.5	3.0-6.0	150-195	178
		DBW	5	15.0-20.0	6.8-10.6	3.8-5.2	3.0-5.4	165-206	185
		BW	6	40.0-65.0	8.5-15.6	4.5-5.8	4.0-9.8	210-315	270
4	Lateritic upland	DW	3	9.5-14.0	2.5-5.5	1.0-3.0	1.5-2.5	100-180	160
		BW	7	32.0-60.0	4.8-9.5	2.0-4.5	3.8-5.0	95-160	135
5	Denudational hills	BW	03	45.0-62.5	12.0-30.0	6.4-11.5	5.6-18.5	60-85	72

DW: Dug well DBW; Dug: Cum bore well; BW: Bore well; lpm: Litre per minute

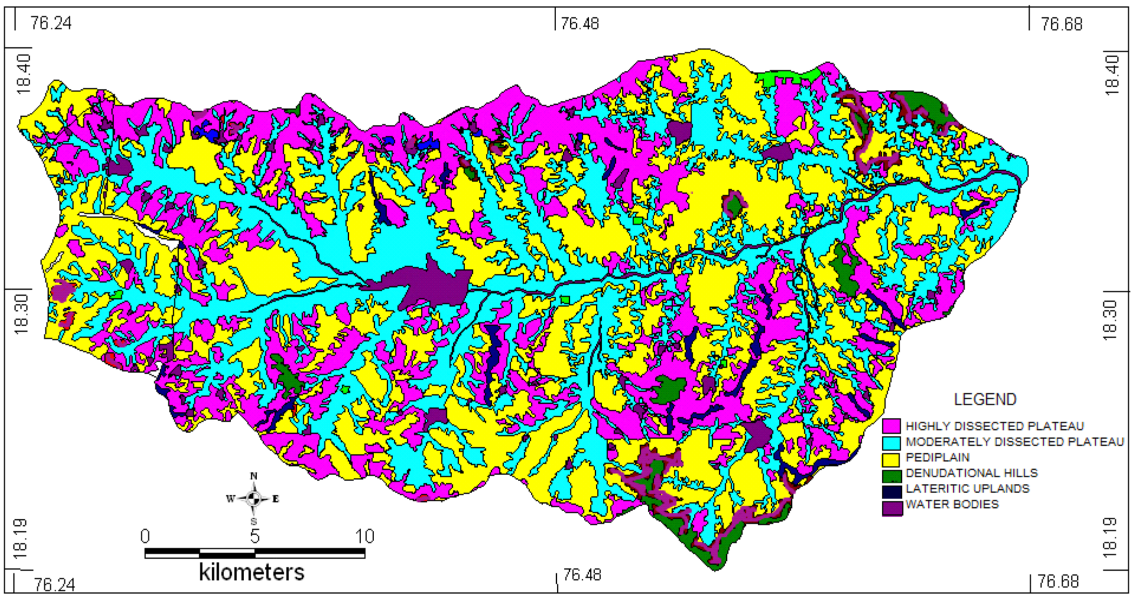

Fig. 6: Geomorphological map of Tawarja river sub-basin

moderately compact and elongated similar to that obtained by Jain (2006) in Sonar river basin. The shape of a drainage basin is significant since it affects the stream discharge characteristics (Strahler, 1968) and the sub-basin is in the late mature stage of erosional development.

The values of drainage density and stream frequency are lower indicating the characteristic of regions of incompetent and impermeable subsurface materials, sparse vegetation and mountainous relief (Strahler, 1964). In the study area the drainage density (Dd) and stream frequency (Fs) are somewhat lower i.e., Dd = 1.77 km/km^2 and Fs = 1.74 streams/km^2, Table 4) which correspond to the highly or moderately dissected plateau surfaces, denudational hills and lateritic uplands of the sub-basin with sparse vegetation and impermeable subsurface rocks in pediplains.

The length of overland flow is low for the sub-basin (0.28 km) indicating the less amount of water is to be run before concentrated in the stream channel. Melton (1957) related it with runoff process and concentration of time. The value of infiltration ratio for the sub-basin indicates that there is possibility of higher infiltration and lower run-off. It also suggests that the possibility of jointing/fracturing and deep weathering of the basaltic rocks present in the sub-basin. Field traverses corroborate this influence that lithology and geology of the area plays an important role in the development of drainage density and stream frequency.

The relief measures of the watershed are higher i.e., maximum basin relief is 136 m, channel gradient 3.01 m/km, relief ratio 0.003 and ruggedness number 0.24, which also reflect the fact that the sub-basin lie within hilly terrain. These relief measures also show that the sub-basin has early maturity stage of erosional development.

Geomorphology of an area is one of the most significant features in evaluation of the groundwater potential. Considering the importance, different geomorphic surfaces are mapped using the satellite imagery. The geomorphic surfaces (Fig. 6) obtained are: Highly Dissected Plateau, Moderately Dissected Plateau, Pediplains, Denudational Hills and Lateritic upland. The groundwater potential of each geomorphic surface is discussed.

Highly dissected plateau: The highly dissected plateaus are fractured and weathered surfaces and occurring in marginal part of the sub-basin. The land of this unit is severely dissected by the streams of Tawarja river giving rise to a terrain consisting of flat-topped ridges and steep scarps. The dissected plateau is characterised by the shallow soil cover, moderately high relief, moderately steep slope, rocky and rugged terrain and hard and compact basalt bed rock, which makes them unsuitable for agriculture (Pofali *et al*., 1985, 1995). The area has favourable sties for development of reservoirs, which can be utilized to store runoff water for groundwater recharge as well as for irrigation of plains in its vicinity. The stony wastes and waste lands are by and large used for quarrying stones as building material and as grazing lands respectively (Singh, 1995).

In highly dissected plateau unit the groundwater potentiality is moderate. The water table fluctuations are ranging from 3.4 to 7.0 m bgl in dug wells and 5.3 to 16.2 m bgl in bore wells. The average yield in highly dissected plateau is 83 lpm in dug wells and 125 lpm in bore wells i.e., the yield is moderate.

Moderately dissected plateau: These are moderately fractured and weathered surfaces and occurring in central part of the sub-basin. The land of this unit is dissected by the streams of Tawarja river giving rise to a terrain consisting of gently sloping plateau surface. It is characterised by the moderately thick soil cover, moderate relief, gently sloping terrain and basaltic bed rock. It lies parallel to the stream course. It has low drainage density (1.5 to 2 km/km^2) and elevation range of 660 to 620 m above msl. The weathered zone thickness ranges from 5 to 15 m. Dug wells are commonly seen in this zone. The irrigation in this zone is mainly done through dug wells and bore wells.

Groundwater potential in moderately dissected plateau is good along fractures where groundwater can be obtained for domestic purpose. The water table fluctuations are ranging from 3.0 to 6.0 m bgl in dug wells and 2.8 to 5.4 m bgl in bore wells. The average yield of dug well is 160 lpm and of bore well is 170 lpm i.e., the yield is good.

Pediplains: These surfaces are formed by the weathering of the dissected plateaus. They are characterized by high porosity, permeability and infiltration rate and hence have the good yield of the groundwater (Table 3). They are found in the central portion adjacent to moderately dissected plateau. These geomorphic surfaces have good potential for agriculture, especially for crops/plantations like sugarcane, banana, grapes, chillies, sunflower and vegetables in addition to cotton, sorghum and wheat. Major problems of these surfaces are gully erosion, development of deep and wide cracks, water logging and soil salinity.

The irrigation in pediplain is mainly done through dug wells and dug-cum bore wells. Water table fluctuation ranges from 1.5 to 2.5 m bgl in dug wells 3.0 to 5.4 in dug cum bore wells and 4.0 to 5.8 m in bore wells. The average yield of dug wells is 178 lpm, dug cum bore well is 185 lpm and bore wells is 270 lpm. Hence the yield of groundwater in this area is good.

Lateritic uplands: These are the upland surfaces developed over highly dissected plateau areas occurring as capped rocks. They show reddish colour due to presence of the lateritic cap rock on the basalts. The vesicular type of basalts is highly altered which gave rise to laterites. In the study area there are 8 flows of traps of which the compact basalt flows are not weathered and are jointed, whereas the VII and IV flow are weathered vesicular amygdaloidal basalt and at some places altered to laterites. Thus laterites occur as cap rocks over vesicular-amygdaloidal basalt and form flat plateaus and tablelands at elevation range from 600 to 660 asl. They have cavities often filled with yellowish to reddish clayey material.

Water table fluctuation ranges from 2.5 to 3.5 m bgl in dug wells 3.8 to 5 in dug cum bore wells and 3.8 to 5 m in bore wells. The average yield of dug wells is moderate i.e., 140 lpm and bore wells is 135 lpm

Denudational hills: A group of massive hills with resistant rock bodies that are formed due to different erosional and weathering processes and occupying in northern and north-eastern part of the Tawarja river are denudational hills. The average elevation of these hill ranges is about 660 to 680 m above msl. These geomorphic surfaces have the very shallow soil cover and are of less potential for agriculture and groundwater. The yield of groundwater in this area is poor (i.e., 72 lpm in bore wells).

Groundwater occurrences in deccan basalt hard rock: Water table depth in Deccan trap region generally varies with topography and the nature of aquifer (Agrwal, 1987; Patil, 1990; Bhatt and Salpekar, 1990; Agrwal, 1995; Adyalkar *et al*., 1996; Khadri *et al*., 1988).The rainfall also plays an important role in the water level fluctuation. The inherent low porosity and low hydraulic conductivity of basalts implies that the Deccan basalts possess low to moderate storativity and transmissivity (Kulkarni *et al*., 2000). Their potential, mainly the transmissivity is enhanced, if the basalts are transacted by fracture zones. Typical un-jointed compact basalts do not have the ability to store groundwater, whereas the vesicular-amygdaloidal basalts due to presence of vesicles (open gas cavities) and amygdales (gas cavities filled by secondary minerals) tend to be more deeply weathered and jointed. However, the presence of vesicles and amygdales is not only the deciding factor, but also a combination of weathering; jointing and fracture patterns over a particular lithology often enhance the potential of basalt aquifers on a local scale.

The study area is constituted by an alternate sequence of compact (massive) and vesicular-amygdaloidal type basaltic flows. Though all the subunits from each flow were differentiated in the field, they could not be separated out on the map due to their highly spatial variability. However, well sections and stone quarries expose the geometry of these subunits and this was taken into consideration and recorded in the well-inventory data. Each flow can actually be subdivided in an upper vesicular-amygdaloidal subunit (highly heterogeneous in nature) and a lower, sub-vertically jointed compact basalt subunit. This division is in accordance with the lithological model (Kale and Kulkarni, 1992) and the conceptual hydrogeological model (Kulkarni *et al*., 2000) that is commonly used in many parts of the Deccan volcanic province. In a typical basalt flow in the area the vesicular-amygdaloidal subunits are overlain by red tuffs with sheet jointing, grading downwards into somewhat massive amygdaloidal basalts. At places, entire vesicular-amygdaloidal subunit is extensively sheet jointed. On account of its heterogeneity and presence of sheet joints, vesicular-amygdaloidal basalt is likely to possess a higher specific yield and hydraulic conductivity than its underlying compact basalt counterpart.

The compact basalt subunit underlying the vesicular-amygdaloidal basalt is sub vertically jointed. Compact basalts are denser and more homogeneous than vesicular-amygdaloidal basalts. The upper portions show a larger frequency of jointing than the lower parts. Most of the times, the lower parts of compact basalts may be devoid of any joints.

It can be visualized that a large component of groundwater accumulation and flow occurs within the weathered and jointed-fractured portions of alternating sequences of basaltic units. The openings facilitating groundwater storage and movement are the sheet joints of the vesicular-amygdaloidal basalt and the vertical and sub vertical joints of compact basalt subunits.

Groundwater systems in Deccan basalt are a result of the alternate arrangement of sheet jointed vesicular-amygdaloidal basalts and the sub-vertically jointed to unjointed compact basalts (Kulkarni and Deolankar, 1995; Kulkarni *et al*., 2000). The groundwater systems of the study area are constituted by such a lithological setup.

CONCLUSION

Tawarja river is a sixth order stream with dendritic to sub dendritic and sub parallel drainage pattern. Geologically, the area is occupied by Deccan Basalts of late Cretaceous to early Eocene period. As the primary porosity is limited to gas cavities (vesicles), the groundwater in the area is therefore concentrated in the zone of secondary porosity developed in the rocks due to fractures, joints and amount of weathering.

Geomorphologically, the Terna river sub-basin area is divided into areas occupied by highly dissected plateau, moderately dissected plateau, pediplains, lateritic upland and denudational hills. By studying the hydrogeological and geomorphological conditions of the sub-basin, it is possible to decipher the groundwater potentiality. It is productive in the geomorphic surfaces like moderately dissected plateau and pediplains, moderate in highly dissected plateau and lateritic uplands and poor in denudational hills.

Dug wells are recommended in the weathered areas of moderately dissected plateau. Some of the dug wells in the pediments and in moderately dissected plateau dry up during pre monsoon period hence bore wells and dug-cum bore wells are recommended for these areas.

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