Chapter - 7

DISCUSSION AND CONCLUSION

In this chapter the discussion is made on various aspects of the study including geology, structures, drainage pattern, drainage morphometry, geomorphic surfaces and hydrogeology of the area.

7.1 GEOLOGY:

7.1.1 Field Characters of Basalt flows:

Stratigraphic division of the lava pile in the study area is not possible on the basis of lithological characters because of the more or less uniform nature of the flows and absence of markers like giant phenocryst basalt (GPB) flows which help in division and long distance correlation of flow sequence. The maximum thickness of basalt flow is found to be 41m in the Southern part of the sub-basin.

The basalt flows in the study area are classified into two main types namely compact (aa type) and vesicular – amygdaloidal (Compound Pahoehoe type). The ‘aa’ flow normally consists of a thin vesicular zone on top, thick, massive and dense middle part and thinner rarely basal clinkers (flow breccia). These flows are extensive and show the jointing pattern (Photo 7.1). The ‘Compound Pahoehoe’ flow, on the other hand consists of a series of units in each of which a basal section of pipe vesicles/amygdules, middle massive and dense part and top vesicular part with reddened and glassy crust, with or without ropy structure are seen. The red bole bed (Tachylitic bed) occurs below the Compact basalt flows (Photo 7.2). The ‘aa’ flows are usually replete with several block joints (Fig.3.2).

The pahoehoe flows are formed by the outpouring of low viscosity and greater fluidity of lava through large number of outlets (Bondre et al., 2000, 2004, Duraiswami et al., 2003, 2008). Hence,
pahoehoe flows have large sizes, irregular forms and have greater lateral extent (Duraiswami et al., 2001, 2002). These flows consist of basal pipe vesicles/amygdules; middle simple part and top vesicular part with reddened and glassy part, with or without ropy structure.

The basalt flows, in general, are broadly horizontal in disposition and exhibit gentle gradients ranging between 1: 100 and 1: 200 in different directions. The marginal area to the northern and northwest of the watershed shows a general south-easterly gradient. The flows range in thickness from 4m to 26m and are essentially of simple type. Several simple flows exhibit fragmentary tops similar to ‘aa’ type (Deshmukh, 1980).

![Photo 7.1 : Extensive Compact Basalt Flow Exposed in Quarry at Bhoyar.](image-url)
7.1.2 Structures:

Lattman and Porizek (1964) established a relationship between the occurrence of groundwater and fracture traces for aquifers, particularly in lineaments underlain by zones of localized weathering, increased permeability, and porosity. Researcher’s interest in this relationship has grown most rapidly since the introduction of aerial photographs into geological studies (Caran et al., 1982).

The lineaments map for the Tawarja sub-basins was prepared using the topographic maps, satellite imageries and a field check to confirm the lineaments as geologic features of interest (Fig. 3.6). Several lineaments intersect one another and are associated with channel segments of the rivers. The majority of the lineaments correspond to stream channels which are of importance as the occurrence and movement of groundwater is controlled by these linear features.

Structural features like micro-lineaments are recorded in the area from remote sensing studies. There are five main sets of major and micro-lineaments trending in N-S, E-W, WNW-ESE, ENE-WSW and
NW-SE directions. The lineaments are found to be better repositories of groundwater (Murthy and Jayaram 1996, Muley et al 2000, Babar and Kaplay 2003 and Ravi Shankar and Mohan 2005).

7.2 GEOMORPHOLOGY :

7.2.1 Drainage pattern :

A drainage pattern is the planimetric arrangement of streams, etched into the land surface by drainage systems. The drainage pattern generally reflects the influence of factors such as initial slopes, inequalities in rock hardness, structural controls and geomorphic history of the drainage basin. Drainage patterns are extremely helpful in the interpretation of geomorphic features and their study represents one of the more practical approach for understanding of structural and lithologic control of land form evolution. Several authors (Zernitz, 1932, Laebeck, 1939, Von Engeln, 1940, Parvis 1950 and Howard, 1965) have described certain types of drainage patterns which are considered as basic parameters.

The dendritic drainage pattern is the network of streams of various orders and magnitudes joining the trunk/master streams and resembles the branches of a tree. The development of dendritic to sub-dendritic drainage in the sub-basin indicates the area of massive rock types, gently sloping to almost horizontal terrain and low relief.

In Deccan trap region, the development of streams is controlled by the pattern of the joints of the basalt rock. From the study of drainage density it is clear that the structure of the underlying rocks have affected the drainage pattern. The study toposheets reveals that the drainage density and the pattern are gradually organised in accordance with initial slope and underlying structure of Deccan basalt.

7.2.2 Morphometric Characteristics :
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 4.1) suggesting the apparently minimal structural control in drainage development. The values of stream length ratios are relatively low for first to fourth orders (i.e. between 0.37 and 2.59, Table 4.1) and higher for fifth and sixth order i.e. 13.58. The slightly higher values of bifurcation ratio for the lower order streams would mean that the streams have rapid networking of lower order streams resulting in the decrease in mean stream length. This is borne out by the lower values of stream length ratios, which suggests that the area is fairly well dissected and may have broad valleys (Badve et al, 1990).

The relation of number of streams against stream order in the Tawarja river sub-basin (Fig.4.1), mean stream length against stream order (Fig.4.2) and mean basin area against stream order (Fig.4.3) satisfies their respective laws of drainage composition as discussed earlier (Chapter 4). These relations also illustrate the fact that the sub-basin is not structurally controlled.

The values of circularity ratio (0.37) and elongation ratio (0.63) (Table 4.2) indicates that the sub-basin is moderately compact and more 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/km² and Fs = 1.74 streams/km², Table 4.2) 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 watershed (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.

7.2.3 Relief Aspects:

The relief measures of the watershed are higher i.e. maximum basin relief is 136m, 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.

7.2.4 Hypsometric Integral:

Based on hypsometric curves (Fig.4.5) the hypsometric integral obtained is 56.3%. This value of hypsometric integral indicate that the
sub-basin is in early monadnock stage i.e. early mature stage of erosion and the area below the curve is yet to be removed by erosion. Hypsometric curves confirm the inference drawn on the basis of basin configuration and relief measures that the watershed has reached early mature stage in erosion cycle.

7.3 GEOMORPHIC SURFACES:

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. 4.6) obtained are: Highly Dissected Plateau, Moderately Dissected Plateau, Pediplains, Denudational Hills and Lateritic upland. The groundwater potential of each geomorphic surface is discussed in this chapter.

7.3.1 Dissected Plateaus:

These are highly and moderately fractured and weathered surfaces and occurring in marginal and central part of the sub-basin. The land of these units is severely dissected by the streams of Tawarja river giving rise to a terrain consisting of flat-topped ridges and steep scarps.

The dissected plateaus are 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 and 1995). Dry deciduous medium density forest species, bushes and shrubs form the main vegetation in these areas. They are mostly dissected by monsoon gullies, detachment of the jointed blocks are seen (Photo 7.3), they are barren and can be classified as stony waste and wastelands. To restrict erosion, runoff and for preservation of the ecology of the area soil and water conservation methods like continuous contour trenches, percolation tanks, series of weirs, underground bandhara, afforestation and gully plunging must be implemented. The moderately dissected.. 153 ..
plateau of the area (Photo 7.4) has favourable sites 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).

Photo 7.3 : Close view of Highly dissected plateau area near Murud showing dissection of jointed Compact basalts.

Photo 7.4 : Moderately dissected plateau area near Murud along Tawarja river.
7.3.2 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 5.2 and 5.3). They are found in the central portion adjacent to moderately dissected plateau.

These geomorphic surfaces have good potential for agriculture (Photo 7.5), especially for crops/plantations like sugarcane, banana, grapes, chilies, sunflower and vegetables in addition to cotton, sorghum and wheat. Major problems of these surfaces are severe gully erosion, development of deep and wide cracks, water logging and soil salinity. These landforms have high potential of groundwater.

Photo 7.5 : Pediplain geomorphic surfaces having thick soil cover and potential for agriculture at Bhusani village.

7.3.3 Denudational Hills :

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A group of massive hills with resistant rock bodies that are formed due to different erosional and weathering processes and occupying in northern and northeastern 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.

7.3.4 Lateritic uplands:

These are the upland surfaces developed over highly dissected plateau areas occurring as capped surfaces. They show reddish coloured 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. Laterites have a typical reddish brown colour (Photo 7.6). They have cavities often filled with yellowish to reddish clayey material. A zone of lithomargic clay marks the contact between the traps and the laterites. The lithomarge is siliceous and exhibit brown to brownish green colour with soapy touch. It is slightly hard to break.
7.4 HYDROGEOLOGY:

The behaviour of the groundwater level conditions in 62 bore wells has been studied from Tawarja sub-basin. The wells have been selected in such a way as to give representation to highly dissected plateau, moderately dissected plateau, pediplain, lateritic uplands and denudational hills. The data on pre and post monsoon water level depth for 2008 to 2010 is given in tabular form, represented in the figures and discussed with reference to the influence of geology, geomorphology and climatic condition of the area.


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 of basaltic units. 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 the present area of Tawarja river sub-basin.

The compact basalt subunit overlying 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 (Fig. 3.1 and Photo 3.1).

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, 1991; Kulkarni et al 2000). The groundwater systems of the study area are constituted by such a lithological setup.

Like other hard rock formations the determination of aquifer properties from pumping tests in volcanic rocks is problematical. However, attempts have been made by various workers to determine aquifer properties by using conventional methods of pumping test data analysis.

Walton and Stewart (1961) used the Theis method for determining aquifer parameters from pumping tests in the Snake River basalts of USA. The data curve did not match fully with the Theis type curve on account of the effect of delayed drainage and boundary conditions. T was found in the range 840 to 1080 m²/day" and S was computed to be about 0.02. Fernandopulle (1974) and Custodio (1985) have given the results of pumping tests on basaltic aquifers from the Canary Islands, Spain (Table 7.1). The time-drawdown data indicated effects of well storage and boundary condition of both recharging and discharging type. Leaky aquifer and double-porosity models are also used to estimate aquifer properties (Singhal and Singhal, 1989).

In Deccan traps, the transmissivity is found to vary with wide limits depending on the aquifer type. Deolankar (1981) has concluded that the transmissivity of weathered basalts, vesicular basalts and fractured basalts of the Deccan trap area range from 90 to 200 m²/day, 50 to 100 m²/day and 20 to 40 m²/day respectively. The specific
capacity of large diameter dug wells (average 5 to 10 m diameter) $10^{-3}$ to $3 \times 10^{-3} \text{ m}^2 \text{s}^{-1}$ and $3 \times 10^{-4}$ to $1 \times 10^{3} \text{ m}^2 \text{s}^{-1}$.

Specific capacity of well has been used widely to estimate the transmissivity of hard rock aquifers (Huntley et al., 1992). Adyalkar and Mani (1972) used specific capacity data to compute transmissivity of Deccan trap aquifers. Computed specific capacity of wells in Deccan trap formations of central India are in the range of $5 \times 10^{-4}$ to $2 \times 10^{3} \text{m}^2\text{s}^{-1}$ (Adyalkar and Mani 1972).

Singhai (1973, 1974) suggested that in large diameter dug wells in basalts and other hard rock formations, the specific capacity values may be divided by the total surface area of the aquifer ($2c rh$) tapped by the well where $r$ is the radius of the dug well and $h$ is the saturated thickness of the aquifer tapped by the well. Such a property will give a better idea of the yield characteristics of different rock types in hard rocks as it would take into consideration the variation in well diameter and also its depth.

Table 7.1: A comparison of aquifer characteristics of Deccan traps with some other volcanic rocks.

<table>
<thead>
<tr>
<th>Country</th>
<th>Place/area</th>
<th>Formation</th>
<th>Age</th>
<th>$T(\text{m}^2/\text{dayA})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Salvador</td>
<td>San Salvador</td>
<td>Lava flows</td>
<td>Pleistocene</td>
<td>1000-15 000 (average 1200)</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>Pacific coastal area</td>
<td>Pyroclastics</td>
<td>Quaternary</td>
<td>120-3500</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>Upper Truck Valley Abe Istaba Nahara basins</td>
<td>Reworked tuffs Reworked tuffs</td>
<td>Pleistocene</td>
<td>71 250-1000</td>
</tr>
<tr>
<td>Spain</td>
<td>Gran Canada</td>
<td>Old basalts Modern basalts</td>
<td>Miocene Post-Miocene</td>
<td>5-28 40-200</td>
</tr>
<tr>
<td>Country</td>
<td>Place/area</td>
<td>Formation</td>
<td>Age</td>
<td>$T(m^2/dayA)$</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>India</td>
<td>Karnataka, Andhra Pradesh, Maharashtra</td>
<td>Deccan trap</td>
<td>Early Eocene</td>
<td>10-180, 1-198, 0.1 to 500</td>
</tr>
<tr>
<td>USA</td>
<td>Snake River Oahu, Hawaii</td>
<td>Basalt, Tholeiitic Basalt</td>
<td>Pliocene</td>
<td>$1 \times 10^3$, $1.8 \times 10^5$ (av. $1 \times 10^4$) 15 000 (in dyke free zone) 1500 in the marginal dyke zone</td>
</tr>
<tr>
<td>Mexico</td>
<td>Fissured basalt</td>
<td>Pleistocene to Holocene</td>
<td>605-865</td>
<td></td>
</tr>
</tbody>
</table>

Davis (1974) showed that well productivity (specific capacity index divided by the saturated thickness of the aquifer) in Deccan traps is much less than that of basalts of the Washington area in the USA. This is attributed to low permeability of Deccan traps which is of older age as compared with the basalts from the Washington area in the USA. From the present study area the pumping test is carried out at six localities including Almala, Bhoyar, Dhakni, Katpuri, Yakatpur and Sirsi. Out of these six wells, 3 wells (Almala, Katpuri and Sirsi) are located in PDP (pediplain) areas, 2 wells (Dhakni and Yakatpur) are located in MDP (moderately dissected plateau) and one well at Bhoyar is located in HDP (highly dissected plateau) (Table 5.6 to 5.11). The aquifer of wells for pumping test at Almala and Sirsi is weathered amygadaloidal basalt (WAB), for Bhoyar and Katpuri is jointed compact basalt (JCB) and for Dhakni and Yakatpur is vesicular-amygadaloidal basalt (VAB). The details of the pumping data is given in table No 5.6 to 5.11 and the values of the capacity, discharge, transmissivity, storage coefficient and specific yield are given in Table 7.2.
Table 7.2 : Parameters of Aquifer performance test.

<table>
<thead>
<tr>
<th>Parameters for Aquifer performance test</th>
<th>Names of Villages where Aquifer performance test of wells is carried out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almala</td>
<td>Bhoyar</td>
</tr>
<tr>
<td>Geomorphic Surface</td>
<td>PDP</td>
</tr>
<tr>
<td>Type of Aquifer</td>
<td>WAB</td>
</tr>
<tr>
<td>Capacity (C) lpm</td>
<td>529.51</td>
</tr>
<tr>
<td>Discharge (Q) m³/day</td>
<td>335.50</td>
</tr>
<tr>
<td>Transmissivity (T) m²/day</td>
<td>181.96</td>
</tr>
<tr>
<td>Storage Coefficient (S)</td>
<td>0.0160</td>
</tr>
<tr>
<td>Specific Yield %</td>
<td>1.60</td>
</tr>
</tbody>
</table>

From the above data it is observed that the discharge, transmissivity and specific yield is greater in pediplain surfaces as compared to moderately and highly dissected plateau surfaces. Similarly, the discharge, transmissivity and specific yield is greater in weathered amygdaloidal basalt and jointed compact basalt as compared to vesicular-amygdaloidal basalt and compact (massive) basalt.

7.5 WATER RESOURCE MANAGEMENT:

In view of the limitations of the total water resources availability due to peculiar agro-climatic and hydrogeological conditions prevailing in the area it is essential to plan out a systematic and scientific programme of development of water resource through an integrated approach of water harvesting conservation and augmentation by artificial recharge as well as by conjunctive use of surface and groundwater resources. The water resources management and conservation should be planned on micro-watershed basis laying emphasis on capturing the water in-site for its optimum use within the watershed itself.

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GIS based site suitability analysis by giving weightages to individual parameters of different thematic layers which are favourable for artificial recharge is recommended prior to implementation stage (Maggirwar and Umrikar 2009). Technical guidelines for selecting suitable sites for conserving water are given by the Integrated Mission for Sustainable Development (IMSD, 1995).

Considering all the preceding discussion, it is imperative that the natural resources like land, soil and water are used optimally in a planned self sustaining manner so that the natural environmental balance is not adversely affected. This necessitates systematic micro-level delineation of different geological, geomorphological and hydrogeological parameters. The monsoon runoff in the area invariably goes waste. Construction of stream barriers and filtration wells will help checking this and recharging the groundwater. These artificially developed percolation wells and pits can conserve great deal of water. The construction of underground bandhara (Fig.5.6) is necessary to arrest subsurface flow from watershed to protect and conceive base flow runoff from superficial zones Masoom, 1990 a and b. The increased storage of groundwater thus created is expected to cater domestic, agricultural and industrial water requirements of the area and promote multidimensional human activities. The additional benefits of water conservation would be minimal soil erosion, flood control and conservation of ecology of the region.

Drainage density of <2 km/km² has been considered to be course (Singh 1998 and Jain 2006). In the area the drainage density calculated is course (1.77 km/km²), which means that for every square kilometer area 1.77 km long channel is available. Such situation is conductive for rainwater harvesting as the runoff from large number of channels can be arrested by check dams and bunds. It is now essential to increase the
rate of recharge of groundwater by developing micro-watersheds. Such micro-watershed development can be taken up around Neoli, Kond, Dhakni, Bheta, Ekurga, Kalmatha, Almala, Bheda, Hasala, Dhanora and Kutegaon villages.

7.6 CONCLUSION:

In order to delineate the groundwater potential zones, different thematic layers such geomorphology, lineaments, soil and land use are used. This provides a broad idea about the groundwater potentiality of any area.

The groundwater potential zone map (Fig. 5.20) generated through this model is verified with the yield data to ascertain the validity of the model developed and found that it is in agreement with the bore wells yield data. This illustrates that the approach outlined has merits and can be successfully used elsewhere with appropriate modifications. The above study has demonstrated the capabilities of using remote sensing and Geographical Information System for demarcation of different groundwater zones, especially in hard rock geological setup like various basalt flows (Compound pahoehoe and simple). This gives more realistic groundwater potential map of an area, which may be used for any groundwater development and management programme.

The present research work is carried out using the below mentioned aspects:

1. Topographic maps
2. Satellite imageries and GIS maps
3. Well inventory data
4. Lithologs from the area
5. Vertical Electric Soundings
6. Pump test data
Considering the foregoing discussion, it is concluded that :

- The area of Tawarja river sub-basin belongs to Deccan Basalts of Late Cretaceous to Early Eocene period.
- Field characters of basalt revealed that there are two types of basalt flows viz., vesicular amygdaloidal basalt flow (Pahoehoe type) and compact basalt flow (aa type).
- Weathered, sheet jointed amygdaloidal basalt and highly jointed compact basalt flows are the good aquifers.
- Compact basalt with non-interconnected and inconsistent joints and unweathered amygdaloidal basalt (free from joints) are poor and less yielding aquifers.
- The majority of fracture lineaments are trending N-S, E-W, WNW-ESE, ENE-WSW and NW-SE directions.
- The Tawarja river stream is a sixth order stream with dendritic and sub-parallel drainage pattern.
- Bifurcation ratio, length ratio and area ratio of streams of the watershed indicate that there is no structural or tectonic control on the drainage development.
- Morphometric attributes like form factor, circularity ratio and elongation ratio reflects the early mature stage of erosional development.
- Relief measures also conform the fact that watershed is in early mature stage of erosional development.
- Slope, channel gradient and ruggedness number is indicative of region with moderate to high relief.
- Hydrogeomorphologically, the Tawarja river sub-basins divided into areas occupied by valley fills, pediplains, pediments, highly dissected plateau and denudational hills.
- Studying the hydrogeomorphological conditions of the Sub-basin it is possible to decipher the groundwater potentiality.
- The fractured zones in the moderately dissected plateau and pediplains are very good potential zones of groundwater and has shallow groundwater level (< 6m bgl) after the rainy season.
• Geomorphic units like highly dissected plateau and denudational hills has poor groundwater potentiality and the water level depth in the wells is found to be greater than 6 m bgl.
  Dug wells are favourable in moderately dissected plateau and pediplain areas whereas bore wells and dug cum-bore wells are suitable in denudational hills and highly dissected plateau.

7.7 RECOMMENDATIONS:

Determining the above parameters present study is intended to suggest following recommendations for the area in question:

➢ Wherever possible the percolation tanks are to be located close to lineaments so that infiltration to the subsurface is enhanced.

➢ The capability of integrated GIS in suitability analysis of artificial recharge and groundwater exploration sites in the area as well as establishing a relationship of landuse with consequent changes in groundwater regime.

➢ By studying the hydrogeomorphological conditions of the basin, it is possible to decipher the groundwater potentiality.

➢ It essential that, while selecting the site for the construction of water conservation structure, proper geological studies should be carried out and favourable geological conditions are to be located.

In addition to the development of water resources of the area, meticulous management of the available groundwater is very much essential and utilizing modern techniques of providing water, like drip irrigation and by using the available water judiciously.

In view of the limitations of the total water resources availability due to peculiar agro-climatic and hydrogeological conditions prevailing in the area it is essential to plan out a systematic and scientific programme of development of water resource through an integrated approach of water harvesting conservation and augmentation by

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artificial recharge as well as by conjunctive use of surface and groundwater resources. The water resources management and conservation should be planned on micro-watershed basis laying emphasis on capturing the water in-site for its optimum use within the watershed itself.

An attempt is also made to suggest the suitable water resources management measures which are as follows:

- The entire watershed programme should be planned and implemented on the micro watershed basis.
- Both natural resources inventory and farmers socio-economic conditions should be given equal consideration for programme planning and execution.
- For sustainable crop production on long term basis, due priority should be given to soil conservation work with active participation of government machinery and beneficiaries.
- Both mechanical and vegetative measures should go hand in hand for effective soil and moisture conservation.
- Merits of traditional systems should also be kept in view while planning the watershed programme particularly at micro-level. The new management techniques should not be a burden to the farmers. In general, creation of awareness among the farmers regarding the watershed programme is a pre-requisite. People’s active participation is also vital for greening most of denuded lands and degraded resources.
- Geomorphic units like highly dissected plateau and denudational hills may be utilized for development of forest based industries for the economic development of these rocky uplands.
- The terrace areas i.e. Pediplains at Almala, Bheta, Kalmatha, Chincholi, Dhanori, Gangapur and Bhunsi and Lateritic uplands at Korangala, Ausa and Yerandi are best suited for additional development of agriculture and for locating new industrial establishments.
- Detailed aspects of water balance studies, aquifer performance test, success of existing engineering structures and agricultural
output should be taken into consideration on the micro-watershed level.

➢ In view of the limited regional extent and poor potential of the deeper aquifers in the sub-basin, it is recommended that the ground water exploitation from the deeper aquifer should be restrained and limited to drinking water supply only.