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Altimetric and hypsometric analysis for soil and water conservation: A case study of Anjani and Jhiri river basin, Northern Maharashtra, India

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ABSTRACT

The present paper contains longitudinal profile, hypsometric analysis of river basin and geomorphological studies for future planning of soil and water conservation in Anjani and Jhiri river basin, Jalgaon district, Maharashtra, India (20°45' to 21°08'N Latitude and 75°09' to 75°27'E Longitude). The main aim of the present study is to recommend a suitable site for soil and water conservation in Anjani and Jhiri river basin, Northern Maharashtra, India. The study area is geologically covered by Deccan trap basalts of the Cretaceous to the lower Eocene age, and some part is covered by thick alluvium of the Quaternary age. Drainage map of the study area reveals two drainage patterns including dendritic and sub dendritic patterns, indicating that the uniform lithology of the basaltic landforms has uniform resistance to erosion. This condition has caused the Anjani and Jhiri River get little recharge from the rainwater and the surface drainage flows during only monsoon season and latter becomes dry. Therefore, water conservation is a prime need for minimize water scarcity problems in the study area. In the present study, landscape information, such as longitudinal profile and hypsometric integral, has been analysed. The longitudinal profile reveals the presence of nick points at three locations in Anjani river and two locations in Jhiri river. The nick points indicate that the rapids are formed due to different erosion, relief and presence of lineament (Joint).
The hypsometric integral values for the Anjani and Jhiri river are 0.52 and 0.51, respectively. The present research illustrates that both basins fall under equilibrium stage and are in a mature phase of development.

Key words: Longitudinal profile, hypsometric analysis, soil and water conservation structures, Anjani-Jhiri river basin, Deccan Trap, India

RESUMEN

El presente artículo contiene el perfil longitudinal, el análisis altimétrico de las cuencas ribereñas y los estudios geomorfológicos para la planeación a futuro de la conservación de suelos y aguas de los ríos Anjani y Jhiri, en el distrito Jalgaon, Maharashtra, India (20° 45' a 21° 08' N de latitud y 75° 09' a 75° 27' E de longitud). El objetivo principal de este estudio es la identificación de un lugar apropiado para la conservación de agua y de suelos en las cuencas de los Anjani y Jhiri, al norte de Maharashtra. El área de estudio está geológicamente cubierta por basalto de las Traps del Decán, en la era del Cretáceo al bajo Eoceno, y por aluvión espeso de la era Cuaternaria. El mapa hidrográfico de la zona de estudio muestra dos modelos de drenaje, el dendrítico y el subdendítrico, lo que indica que la litología uniforme de los accidentes geográficos basálticos tiene una resistencia uniforme a la erosión. Esta condición ha causado que los ríos Anjani y Jhiri tengan una pequeña recarga proveniente de las aguas lluvias y de los drenajes superficiales durante la única estación monsónica del año y que luego se secan. Es por esto que la conservación del agua es una necesidad primaria para minimizar los problemas de escasez en el área de estudio. En el presente trabajo se analizó la información del paisaje, como el perfil longitudinal y la altimetría integral. El perfil longitudinal revela la presencia de cambios de gradiente en tres puntos del río Anjani y en dos puntos del Jhiri. Los cambios de gradiente indican que los rápidos se formaron debido a la erosión diferente, al relieve y presencia de lineamiento (convergencias). Los valores de altimetría integral para los ríos Anjani y Jhiri son de 0.52 y 0.51, respectivamente. La presente investigación muestra que ambas cuencas se encuentran en un escenario de equilibrio y en una fase madura de desarrollo.

Palabras clave: Perfil longitudinal, análisis de altimetría, estructuras de conservación de agua y suelos, cuencas Anjani y Jhiri, Traps del Decán, India.

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Introduction

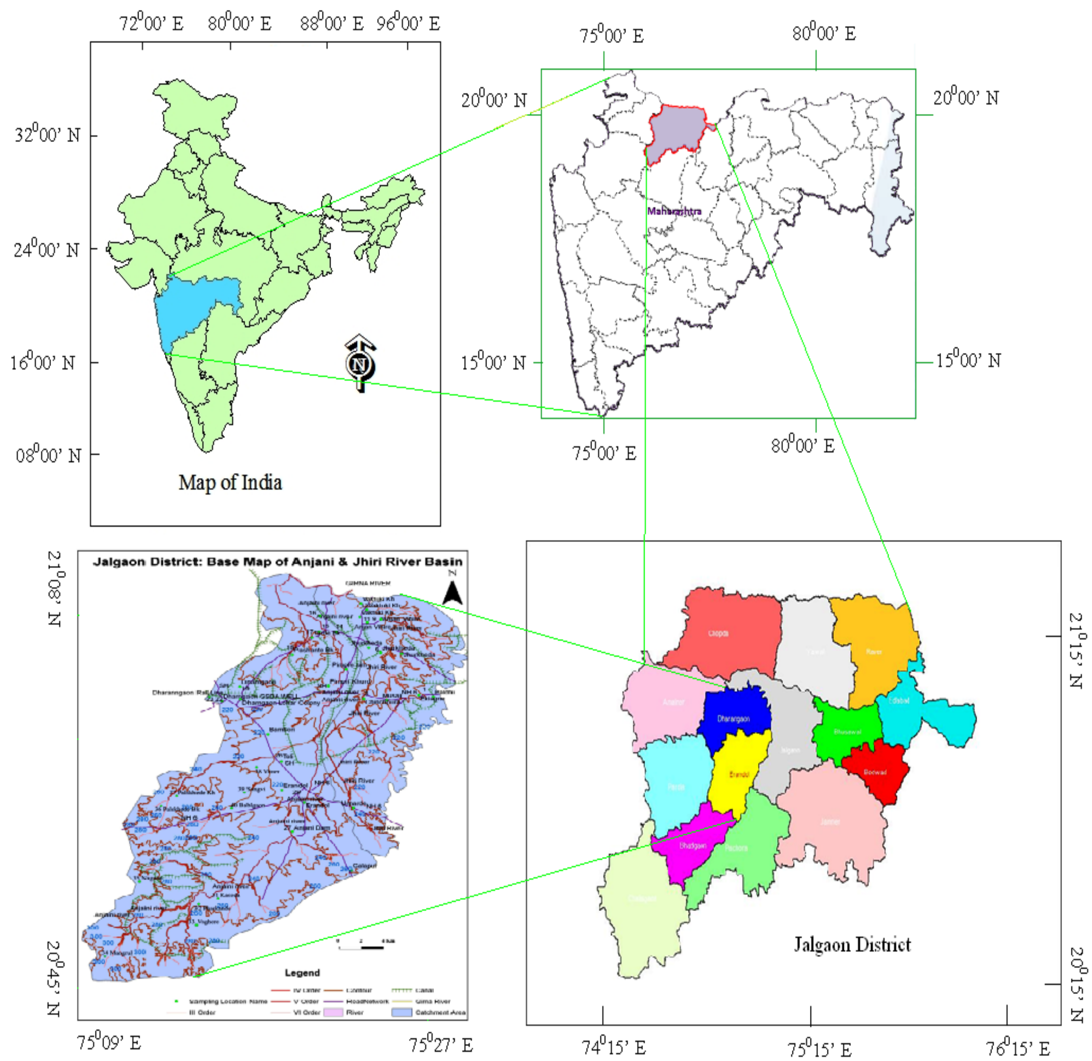
The Maharashtra state, with its peculiar geohydrological, geomorphological and climatic conditions, faces multifold problems in exploration, exploitation and development of its groundwater resource in a scientific and planned manner. The operation of groundwater on a large scale for meeting the demands of rapid industrialization, agricultural sector, and domestic purpose has further aggravated the problem. Currently, Maharashtra, especially in Marathwada and Northern Maharashtra regions, faces drinking water problem and supply for drinking water in this area depends on water tankers.

The Anjani and Jhiri river basin was chosen for catchment hydrogeomorphological studies, both of which are tributaries of Girna River. Girna is one of the major tributaries of River Tapi. Anjani and Jhiri river basin covers an area of about 1243.65 Km². The present study area is located in Jalgaon district (Fig. 1). It is confined to Latitude 20° 45' N to 21° 08' N and Longitude 75° 09' E to 75° 27' E, covering topographic maps NO. 46 P/1, 46 P/5 and 46 O/8 of the Survey of India. The data on Anjani - Jhiri river basin for the present study can serve as a pilot study based on hydrology and hydrogeomorphology.

The Anjani - Jhiri river basin is characterized by an arid to semi-arid climate, and its available water depends on the amount of rainfall in this basin. The water in the basin is used for agricultural and domestic purposes. Most of the domestic water supply is through common well in rural areas funded under rural water supply schemes of the State Government. People use water from unprotected open pits (dug) well, and/or depend on supply by tankers. The scarcity of water is also one of the main reasons that compel the farmers to cultivate their land under rain fed condition annually.

The Anjani - Jhiri river basin enjoys a hot and dry summer, cool winter and fair monsoon with an average annual rainfall of about 750 mm. The Anjani River has an elevation difference of 135 m, with the highest elevation (305m) at Titvi village located at the southern edge of the catchment, and drops to its lowest elevation (170m) at the northern edge where Anjani river joins Girna river. The Jhiri River has an elevation difference of 125 m, with highest elevation of 300 m amsl near Padamalay reserve forest, and the lowest being 175 m. amsl near its confluence with the River Girna. The contour map of this area (Fig. 2) shows elevation ranging from 300m to about 180m from southern part of the basin to the confluence of Girna river.

The hydrogeomorphological study helps to explore, plan and manage the water and the natural processes which produce landforms in association with their hydrological characteristics (Babar, 2005).



Location Map of study area

Figure 1. Location map of the study area

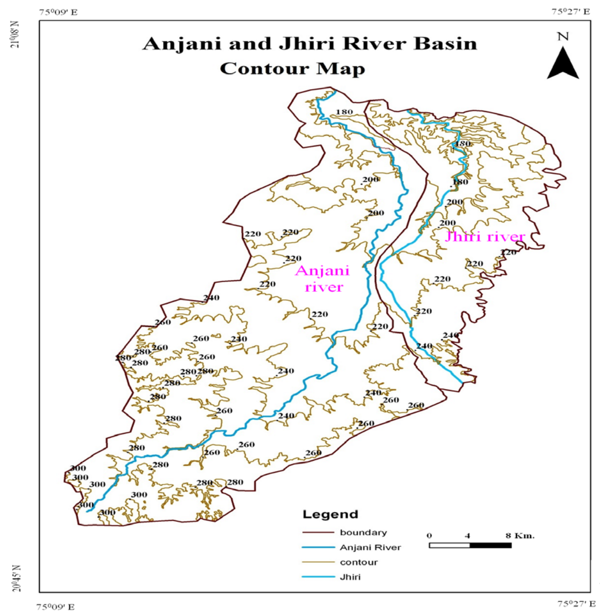


Figure 2. Contour Map and river flowing in the Study area

Figure 3. Dark grey massive basaltic flows.
(Location: 20°58' N 75°27' E)

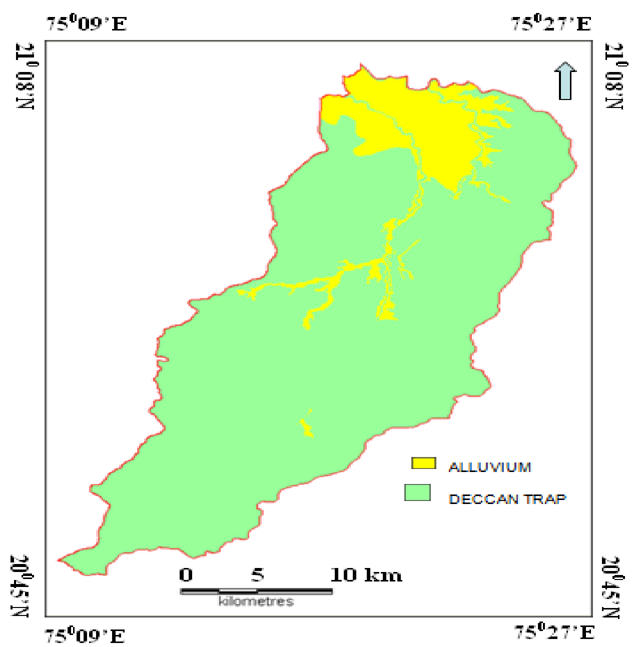


Figure 4. Geological map of study area (after Golekar et al., 2013)

Geologically, the major part of study area is covered by Deccan basalt of the Cretaceous to the lower Eocene age and the rest by alluvium of the recent period (GSI, 2000). The Deccan trap lava sequence is grouped under Sahyadri Group, which was formed during the Upper Cretaceous to lower Eocene. The lava assemblage of Sahyadri group consists of alternating sequence of Pahoehoe and 'aa' flows (GSI, 1976). Dark grey massive basaltic exposed in the study area has been depicted in Figure 3. Those parts that are covered by Deccan basalts consist of amygdaloidal and vesicular basalts.

Alluvial deposits can be observed along the lower reaches of river valleys and watercourses (Fig. 4). The thickness of the alluvium ranges from less than a meter to several tens of meters (10 – 100 m). Alluvium consists of unconsolidated to consolidated sand, brownish yellow silt and calcrete (locally known as kankar) along the Girna, Anjani and Jhiri rivers. In the study area, however, the alluvium is characterized by unconsolidated clays and silts that are associated with a very limited thickness (0.5-2.0m).

The soil cover in the study area is derived from the basaltic lava flows and is classified as a) Deep black soils b) Medium black soils c) Sandy soils and d) Black alluvial clay (CGWB, 2009).

A deep black soil covers the central part of the catchment area. Medium black soils occur within the valley and southern hills, and the alluvial basin soil (black alluvial clay) covers the northern part of the study area. Sandy soils are observed along the foothills of Satmala stretching near Padamalay hillocks. The gross and net water availabilities in the Anjani - Jhiri river basin were calculated by using equation 1 (Pilgrim and Cordery, 1993),

$$\text{Available water (in hectare)} = \text{Area (in ha)} \times \text{Rainfall (in mm)} \quad (1)$$

The gross and net water availabilities in the Anjani - Jhiri river basin have been presented in Table 1.

Table 1 Gross and net water availability in the Anjani and Jhiri river basin

Parameter	Anjani river basin	Jhiri river basin
Area (in hectare meter)	91170	33194
Annual rainfall (in meter)	0.7505	0.758
Gross Annual Water Availability	Crore Litres	Crore Litres
Surface Storages and Runoff (45 %)	41026.5	14937.3
Soil Moisture (40 %)	36468.0	13277.6
Groundwater (15 %)	13675.5	4979.1
Net Annual Water Availability	**Crore Litres**	**Crore Litres**
Surface Storages and Runoff (20 %)	18234.0	6638.8
Soil Moisture (35 %)	31909.5	11617.9
Groundwater (15 %)	13675.5	4979.1
Total Losses Cr. Liters	27351.0	9958.2

Methodology

The field work was carried out in the summer of 2012 for observing geomorphological units in the study area. After completion of the field work, we carried out the hypsometric analysis of Anjani and Jhiri river basin by Strahler methods (Strahler, 1964). The topographic maps numbered 46 P/1, 46 P/5 and 46 O/8 on 1:50000 scale from the Survey of India are considered. The SOI toposheet is geometrically rectified and georeferenced to world space coordinate system (WGS 1998) using digital image processing software (AutoCAD 2004 and Arc GIS version 9.0) and digitization work was carried out for entire basin. Percentage hypsometric curve (Strahler, 1952) that involves a ratio of relative height expressed in percentage (cumulative (hx100)/H) was plotted on ordinate, and the relative area expressed in percentage (cumulative (ax100)/A) was plotted on abscissa. Where 'a' and 'h' denote area and height between successive contours, and 'A' and 'H' denote total area and height of the basin, respectively. The areas between successive contours and their respective heights are the basic data required for the study of area-height relationship. The areas between successive contours were measured by digital planimeter, and contour heights were obtained from topographic maps used for this work. After plotting the respective value on simple arithmetic graph paper and joining all the points, a smooth line percentage hypsometric curve can be obtained. The hypsometric integral (HI) were calculated mathematically from the graph.

Result and Discussion

Hydrogeomorphological parameters

The delineation of a hydrogeomorphological parameter is aimed at demarcating the areas of groundwater recharge/discharge and potential zone for the development of groundwater (Raghu and Reddy, 2011). Alluvial plain represents the runoff zone while valley belongs to discharge zone, and the denudational hills constitute the infiltration area. It is classified into three zones on the basis of their groundwater potential zone as a) Very favorable zones b) Good to moderate zones and c) Poor zone.

The groundwater potential zones are identified with the help of geomorphological units. The morphometric data are enclosed in details and are described below (Table 2 and 3).

Dissected Plateau (DPT)

An extensive flat top and steep slopes formed over horizontally layered Deccan basalts that may be crossed by fractures, joints and lineaments are called as plateaus (Babar, 2005). These units can be expressed regarding the slope of the area, runoff characteristics, drainage density, stream frequency and relief ratio of the area (Babar, 2005). In the present study area, two plateaus were observed, i.e. moderately dissected plateau and un-dissected plateau.

Moderately dissected plateau

The soils covering in this plateau are moderately thick and well drained. High moisture capacity suggests that the irrigation requirement is moderate in the moderately dissected plateau area. The groundwater potential in these units is moderate to high.

Un-dissected plateau

The land of this unit is dissected by the streams of giving rise to un-dissected terrain consisting of flat-topped hills and steep scarps. The groundwater potential in these units is very poor (Babar, 2005). The runoff from these areas can be arrested through the construction of check dams and other strategies.

Hydrogeomorphological characters of Anjani river basin

Moderately dissected plateau

Moderately dissected plateau is presented in upper part of the Anjani river catchment (Fig. 4). This unit is observed between Denudational hills and Un-dissected plateau.

Un-dissected plateau

Un-dissected plateau is distributed in lower part of the Anjani river catchment (Fig. 4). This unit is observed between moderately dissected plateau and eroded lad by stream.

Valley fills (VF)

Valley fills are linear depression presented in between the Younger alluvium composed of cobbles, pebbles, gravels and sands. Valley fills are also observed in between the Denudational hills near Galapur, Khadke Bk, Mangrul and Palskhede Bk villages of upper part of the Anjani river catchment.

Denudational Hills

A group of hills with basalt as resistant rock are formed due to different erosional and weathering processes, and they occupy the low area. Denudational hills are observed in a few patches of the upper part of the Anjani river catchment (Fig. 4).

Alluvial Plains (Younger and Older alluvium)

Alluvial plains are composed of sand slit and clay layer. Fine to coarse sand layers form the potential aquifer zone. It is the most prospective hydrogeomorphological unit for groundwater exploration. Younger alluvial plain can provide sufficient amount of water than older alluvial plains. Older alluvium is distributed along the northern part of the Anjani river catchment area.

Hydrogeomorphological characters of Jhiri river basin

Moderately dissected plateau

Moderately dissected plateau is mainly distributed in the upper part of the Jhiri river catchment (Fig. 4). This unit is observed between Denudational hills and Un-dissected plateau.

Un-dissected plateau

Un-dissected plateau is mainly located in the lower part of the Jhiri river catchment (Fig. 4). This unit is observed between moderately dissected plateau and eroded lad by stream.

Valley fills (VF)

Valley fills are found between the Younger alluvium composed of cobbles, pebbles, gravels and sands. Valley fills are observed at Padmalaya and Umarde villages.

Denudational Hills

A group of hills with hard rock is formed due to different erosional and weathering processes and they occupy the region where the River Jhiri originates (Fig. 4).

Alluvial Plains (Younger and Older alluvium)

Alluvial plains with fine to coarse sand layers form potential aquifer zone. Younger alluvial plain can provide sufficient amount of water than older alluvial plains. Older alluvium occurs in the northern part of the Jhiri river catchment, especially at Vaktuki, Anjan Vihire and Jhurkheda (Fig. 5).

Table 2 Linear aspects of the Anjani and Jhiri River Basin (after Golekar et al., 2013)

Stream Order (u)	(N_u) Anjani Basin	(N_u) Jhiri Basin	(L_u) Anjani Basin	(Lu) Jhiri Basin	(L) Anjani Basin	(L) Jhiri Basin	(Rb) Anjani Basin	(Rb) Jhiri Basin
1	613	283	640.96	264.34	1.05	0.93	3.93	3.98
2	156	71	262.12	101.26	1.68	1.42	3.9	3.55
3	40	20	104.43	63.86	2.61	3.19	3.33	4
4	12	5	79.13	41.05	6.59	8.21	4	5
5	3	1	12.4	24.37	4.13	24.37	3	
6	1		49.49	494.88	49.49	7.624		4.13
Total/Mean	825	380	1148.53		10.93		3.63	

Where, (Nu) = Number of Streams; (Lu) = Total length of Streams in Km; (L) = Mean Stream Length in Km; (Rb) = Bifurcation ratio

Table 3 Aerial and relief aspects of the Anjani and Jhiri River Basin (after Golekar et al., 2013)

Sr. No.	Morphometric Parameters	Symbol/ Formula	Anjani River	Jhiri River
1	Area (km²)	A	911.7	331.94
2	Perimeter (km)	P	181.6	133.67
3	Drainage density (km/ km²)	$D = L_u / A$	1.259	1.49
4	Stream frequency	$F_s = N_u/A$	0.904	1.144
5	Texture ratio	$T = N_1/P$	3.375	2.117
6	Basin length (km)	L_b	80.43	48.25
7	Elongation ratio	$Re=2 \sqrt{(A/ \Pi)} /Lb$	0.423	0.426
8	Circularity ratio	$Rc = 4 \prod A / P^2$	0.347	0.233
9	Form factor ratio	$Rf = A / Lb^2$	0.14	0.142
10	Drainage Texture (T)/ Infiltration rate	T = Dd X Fs.	1.138	1.704
11	Elipticity Index (E)	$E = \Pi L^2 /4 A$	5.566	5.505
12	Length of overland flow (lg)	Lg = 0.5 / Dd	0.397	0.335
13	Height of the highest point on the basin (m amsl)	H max	305m	300m
14	Lowest point of the River basin (m amsl)	H min	170m	175m
15	Total basin relief (m)	(Rr)	135 M	125 M
16	Relief ratio	Rh = H/ Lb	0.002	0.003
17	Ruggedness number (Rg)	Rg = H X Dd	0.169	0.186
18	Slope of ground surface (Sg)	Sg = H X 2 Dd	0.339	0.372
19	Channel gradient (m/Km)	-	5.566	5.505

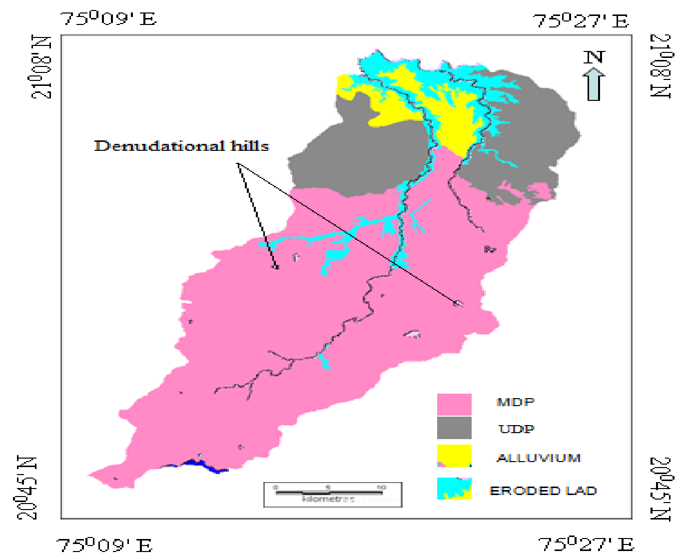


Figure 5. Geomorphological map of study area (MDP: Moderately Dissected Plateau, UDP: Un-dissected Plateau)

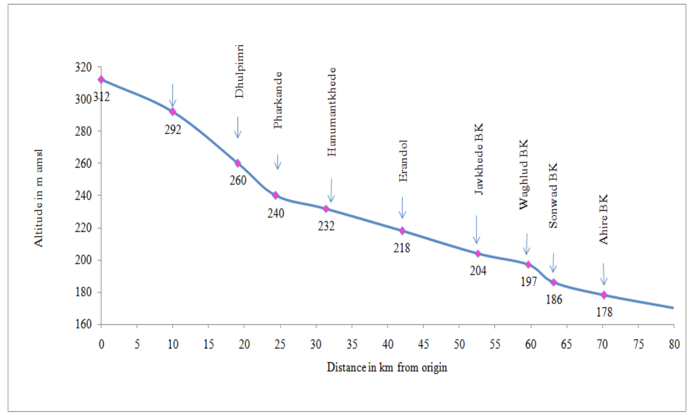


Figure 6. Longitudinal profile of Anjani river

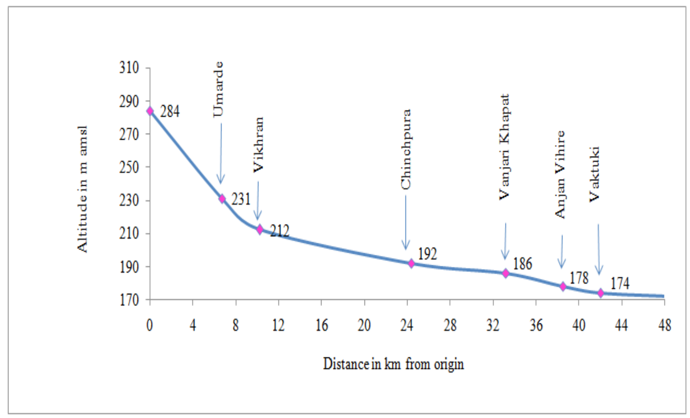


Figure 7. Longitudinal profile of Jhiri river

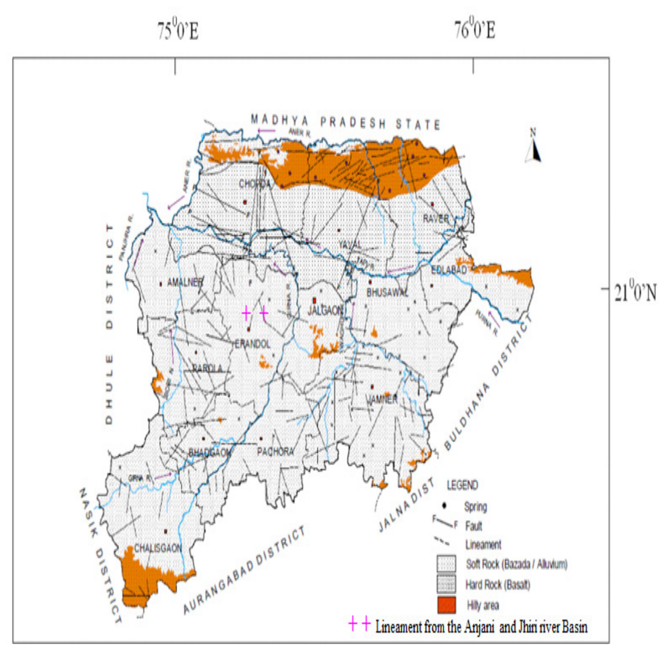


Figure 8. Lineament map of Jalgaon district
Source: Central Ground Water Board (CGWB, 2009)

Profile analysis

Profiles drawn from the contour map is an image observation of the real environment of the landscape. The longitudinal section of the valley is called as longitudinal profile. The entire distance from source to the mouth of a particular river is considered. The graph drawn reveals the relief impact of the river course (Singh, 1997).

The longitudinal profile provides breaks in the longitudinal course of the river flow. These breaks may indicate nick points, and helps in examining the nature and control of landform development (Singh, 1997). Longitudinal profile gives geomorphologists an insight of relief and topographical impact on river flow (Babar, 2005).

Longitudinal profile of the Anjani river basin

The Anjani river originates from the Titvi village at 305 m amsl, and flows almost straight towards NE. The slope is gentle with a drop in elevation from 292m to 240m, spreading over 25 km. At the village Pashtane Budruk, it turns toward NE. After that, the channel gradient decreases steadily till its confluence with the River Girna at village Babhulgaon (Fig. 6). A study of longitudinal profile reveals the character of Anjani river. It suggests the presence of nick points at locations Chorvad (292m amsl), Pharkande (240m amsl) and Waghlud Budruk (197m amsl). The difference in elevation suggests that the river has developed “rapids”. It is formed due to different erosion, relief and presence of lineament (joints). Lineament map of Jalgaon district has shown in figure 8.

Longitudinal profile of the Jhiri river basin

Jhiri river originates from village Padmalaya at 300m amsl, and it runs almost parallel with Anjani river and at Anjan Vihire village at 176m amsl it takes a NW turn and meets Girna river. The longitudinal profile curve for Jhiri river basin indicates the presence of nick points at Vikhran (212m amsl) and Vanjari Khapat (186m amsl).

The Jhiri river has a steep gradient in its earlier course with a drop from 284m to 231m up to village Umarde (8 kms away from the origin of Jhiri river), and thereafter the slope become gentle up to village Vikhran and Vanjari Khapat. There is a drop in elevation at Vanjari Khapat and the river becomes gently sloping after village Anjan Vihire. Longitudinal profile of the Jhiri river channel has shown in Figure 7. The nick points indicate that the rapids are formed due to different erosion, relief and presence of lineament (Joint).

Hypsometric (area-altitude) analysis

The hypsometric curve is a normalized cumulative frequency distribution of elevation (Strahler, 1964). This curve is constructed by summing the number of data points higher than incremental thresholds of elevation, starting at the maximum elevation. Classically, hypsometric analysis has been used to differentiate erosional landforms at different stages of their evolution (Strahler, 1952; Schumm, 1956). The hypsometric analysis is necessary to determine the runoff, recharge, and storage conditions of the ungauged basins and is helpful for hydrogeological investigations. Hypsometric curves show the relationship between relative heights (h/H) and relative areas (a/A).

The relative area is a ratio of the area above a particular contour to the total area of the basin. According to Sarangi et al. (2001), the relative elevation is calculated as the ratio of the height of a given contour (h) to the maximum basin elevation (H). Hypsometry reveals the relationship between altitude and basin area to understand the degree of dissection and the stage of the erosional cycle (Strahler, 1952; Schumm, 1956). Area height curve, hypsometric curve, and percentage hypsometric curve are used to obtain the relationship between altitudes and area of the basin.

Convex-up curves with high integrals indicate typical youth, un-dissected (disequilibrium stage) landscapes, while smooth, s-shaped curves crossing the center of the diagram represent the characteristics of mature (equilibrium stage) landscapes and concave curves with low integrals exhibit old and deeply dissected landscapes (Strahler, 1952).

Hypsometric (area-altitude) analysis of the Anjani river basin

The Hypsometric curve of Anjani river (Fig. 9) suggests that the larger part of the area is moderate to gentle sloping. The curve can be characterized as mature/equilibrium stage of landscape development. The curve shows 1) elevation in 15 % of the area ranges between 300m -280m 2) 50 % between 280m -240m and 3) 35 % between 240m-180m. These results indicate that about 85% of the study area is moderate to gently sloping and about 15 % area is steep sloping (Fig. 6).

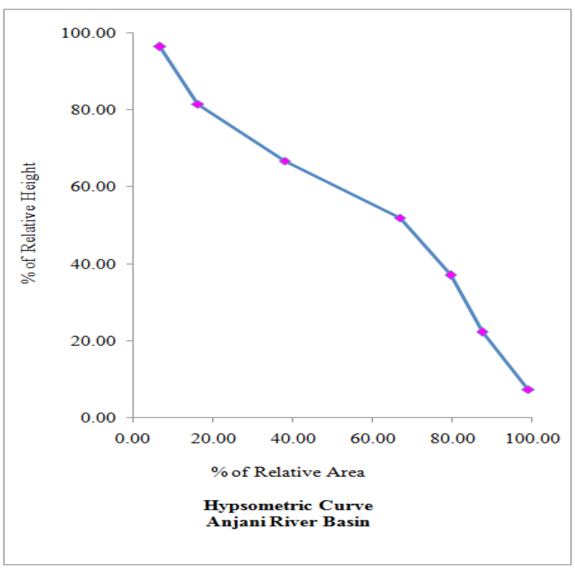


Figure 9. Hypsometric Curve (Anjani river)

Hypsometric (area-altitude) analysis of the of the Jhiri river basin

Hypsometric curve of Jhiri river (Fig. 10) shows 5 % are of steep slopes (300m -260m)), 80 % are of moderate slope (280m- 220m) and 15 % are on gentle slope (220m-180m), suggesting that Jhiri river flows over moderate slope to gentle slopes. This indicates a mature (equilibrium) stage of river development (Fig. 7).

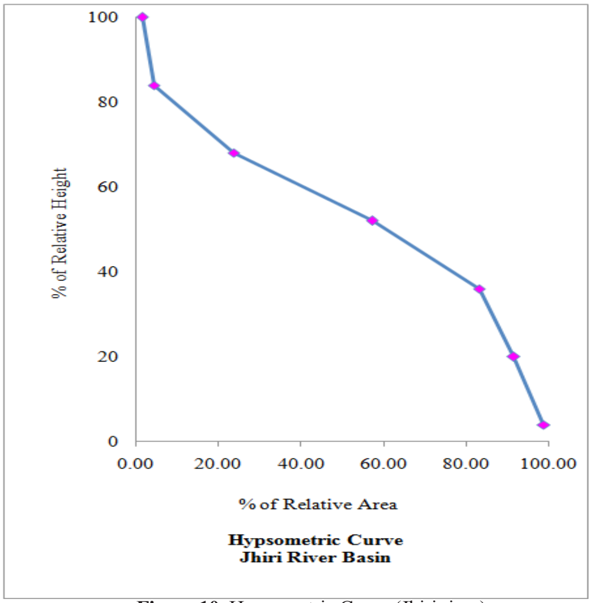


Figure 10. Hypsometric Curve (Jhiri river)

Hypsometric Integral (HI)

The hypsometric integral (HI) is the area beneath the hypsometric curve which relates the percentage of total relief to its cumulative percentage. This provides a measure of the distribution of landmass volume remaining beneath or above a basal reference plane.

Integration of the hypsometric curve gives the hypsometric integral. Pike and Wilson (1971) has mathematically defined the elevation-relief ratio E as

$$E \approx HI = \frac{\text{Elev (mean)} - \text{Elev (min)}}{\text{Elev (max)} - \text{Elev (min)}}$$

Where, E is the elevation-relief ratio equivalent to the hypsometric integral HI; Elev mean is the weighted mean elevation of the basin estimated from the identifiable contours of the delineated basin; Elev min and Elev max are the minimum and maximum elevations within the basin, the hypsometric integral is expressed in percentage units.

The hypsometric curves and HI values give valuable information about the geological stage of the development of a basin. According to Strahler (1952) and Kusre (2013), it can be classified as

a) $HI \geq 0.6$ = The basin is in-equilibrium (youthful) stage.

b) $0.35 \leq HI < 0.6$ = The basin is at equilibrium stage.

c) $HI < 0.35$ = The basin is at monadnock stage.

In in-equilibrium (youthful) stage, the basin is still under developed. The equilibrium stage is the mature phase of basin development, and the monadnock phase occurs, particularly when isolated bodies of resistant rock from major hills (monadnock) are found above the subdued surface. It is a rejuvenation stage controlled by structural features (Kusre, 2013).

Narayanpethkar et al. (1991) and Sable et al. (2009) used the hypsometric integrals for understanding groundwater recharge in different basins of basaltic terrains. The characteristics of hypsometric integrals of the watershed were also reported by Vivoni et al. (2008). They stated that the watershed with higher HI values indicated higher soil moisture, whereas a watershed with lower HI values is characterized by soil moisture being concentrated at the shallow depth. This means that watershed with lower HI values has less total runoff contributed from surface runoff. Whereas, watershed with higher HI values shows subsurface runoff is major process contributing the total runoff.

Hypsometric Integral (HI) for Anjani river basin

The hypsometric integral value of the Anjani river is 0.52. According to Strahler classification (Strahler, 1952), the value falls under the equilibrium stage and that the basin is in a mature stage of development.

Hypsometric Integral (HI) for Jhiri river basin

The hypsometric integral values of the Jhiri river is 0.51. According to Strahler classification (Strahler, 1952), the value also falls under the equilibrium stage and is in a mature stage of development.

The values for both rivers are similar. The river has attained mature stage since it has been controlled by climate, lithology, and relief. The nick points observed for both of the rivers (Figure 5 and 6) do not show any indication of structural control or rejuvenation of the river.

Conclusion and Recommendation

Drainage morphometry data of the area suggests that the maximum number of streams is of the first order (Table 2). It is also observed that there is a decrease in stream frequency as the stream order increases. The total and mean lengths of stream segments are maximal in first order streams and decrease as the stream order increases. An exception to this is Anjani river basin that shows the 6th order stream has more length then the 5th order stream (Table 2). This is due to the moderate to steep slope. Topography and also shows nick points at Pharkande where the 5th order stream begins. The average bifurcation ratios of Anjani and Jhiri river are 3.63 and 4.13, respectively, suggesting low runoff, high recharge and somewhat elongated basin (Table 2). Drainage density values of Anjani river (1.25/ sq.km) and Jhiri river (1.49/ sq.km) suggest that the Jhiri river is flowing through more weathered basalts than Anjani river (Table 3). Elongation ratios of the both basins are categorized as more elongated suggesting the areas has a high infiltration capacity and low runoff (Table 3). Both rivers flow through basalts with moderate slope and low relief. The ruggedness number for both river basins show lower value due to the presence of hard resistant basalts (Table 3).

Longitudinal profile results reveal the presence of nick points at Chorvad (292m amsl), Pharkande (240m amsl) and Waghlud Budruk (197m amsl) in Anjani river and at Vikhran (212m amsl) and Vanjari Khapat (186m amsl) in Jhiri river (Fig. 7).

The hypsometric curve of Anjani river suggests that a larger part of the area is moderate to gently sloping. The curve can be characterized as mature/ equilibrium stage of landscape development whereas the hypsometric curve of Jhiri river shows 5 % steep slopes (300m -260m)), 80 % moderate slope (280m- 220m) and 15 % gentle slope (220m-180m) suggesting that Jhiri river flows over moderate to gentle slopes. This fact indicates a mature (equilibrium) stage of river development. The hypsometric integral values of both the Anjani and Jhiri rivers fall into the equilibrium stage and that the basins are in a mature phase of development. The area, therefore, suggests relief, topography and climate controlled development.

Following are preventive measures recommended for the protection of the groundwater resources in the study area.

I. Cement Concrete Bandhara (bunds) is most feasible for water conservation structures in the moderately dissected plateaus and construct it across the 3rd and fourth order streams of both the Anjani and Jhiri river basin.

II. Nala bunding, gabion structures and vegetative bunds feasible structures for soil and water conservation and construct it across the 2nd or third order streams of both the Anjani and Jhiri river basin.

III. In the alluvial tract of the study area, recharge wells or shafts are suggested, because the groundwater can be tapped through deep tube wells. This type of structure can be constructed in the lower part of the Anjani and Jhiri river catchment, mainly at Ahire Bk, Pashtane Bk and Tarde Bk villages in Anjani river basin and at Vaktuki, Anjan vihire and Jhurkheda village in Jhiri river basin. The most feasible artificial recharge structure in such areas are recharge wells/shafts on the river bed of the tributaries.

IV. Controlling urban expansion in the study area is suggested. The study area is a recharge area for the shallow and deep aquifers, and the urban expansion will reduce the area of recharge.

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