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Estimation of Hypsometric Integral and Groundwater Potential Zones of Amarja Reservoir Catchment, Karnataka, India using SRTM Data and Geospatial Tools

Syed Shams Rizvi,* Mohammed Aslam M. A.

*Department of Geology, Central University of Karnataka, Kalburagi, Pin- 585367, Karnataka, India

*****Email: shamsrizviamu@gmail.com

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Abstract: Hypsometric integral always play a significant role in watershed health condition. It is nothing but the total time taken in reduction of land area to its vile. Drainage network and studies of various landform features always help in the search of groundwater resources. Morphometric parameter of a drainage basin always helps to understand water use and land use of the basin. The present study aims to find out the geological stages through hypsometric integral values and groundwater potential zones using morphometric parameters to classify it into very good, good, moderate and poor zones using GIS tools. The total area of catchment is 544.76 km^2, which is surrounded by Deccan traps. The catchment is further separated into 5 sub-basins on the basis of 4th order stream to get the more specific result. The SRTM (Shuttle Radar Topography Mission) data have been generated from USGS website and further analysed to identify the drainage pattern, slope, contours etc. using *ArcGIS 10.0 software*. The most important parameters like linear, areal and relief for groundwater investigation have been analysed. The analysis revealed that the hypsometric integral value of sub-basin IV of Amarja reservoir catchment is 0.30 which is showing the late mature stage of the basin. Apart from that, the values of sub-basins II, III and V are 0.54, 0.50 and 0.43 respectively, represent the mature stage while sub-basin I has an integral value of 0.67 which represents the young stage of the basin and it is more susceptible for erosion. Drainage pattern of the catchment could be mainly described as sub dendritic to dendritic. Drainage texture was found to vary from 0.41 to 1.16 which is an indicative of massive coarse to granular texture. An average bifurcation ratio of basin is estimated 3.51 which is an indicator of structural control over the basin. Slope values were found to be in a range from 0.71 to 5.73 degree which indicates very gentle to moderate slope.

Keywords: Hypsometric integral, morphometry, DEM, GIS tools, Amarja reservoir catchment.

Introduction

Hypsometry is the term, which explains the overall slope and forms of a drainage basin and was proposed by Langbein. Hypsometric integral always play a key role in watershed condition. It has been further categorized into 3 stages in which first stage is called monadnock stage which is also known as old stage, where the value of hypsometric integral ($H_{si} \leq 0.3$). In this case watershed is fully developed. The second stage is known as equilibrium stage which is also called mature stage, where the values range from 0.3 to 0.6. Last stage is called in-equilibrium stage which is also called young stage, where the value of hypsometric integral will be greater than or equal to 0.6. In this situation, watershed would be more susceptible to erosion. Typically, different value of hypsometric integral reveals the different stages during evolution. Apart from that, hypsometric integral is inversely proportional to the steepness of slope, channel gradients, total relief and also to drainage density. These parameters are helpful in the positive correlation with rates of erosion. Mainly water resources were used for agriculture, domestic and industrial purposes. The continuous increase in demand and supply of water resource for these activities became threat to groundwater reservoir. It has been very difficult to manage the groundwater resources and their management. Providing fresh and safe drinking water to the society has become a critical issue to the civil authorities. Morphometric analysis is a surface indicator, which provides characteristics and nature of groundwater resources to be managed in an effective and sustainable manner. Keeping this aspect, a study has been done about morphometric characterization of Amarja reservoir catchment. Morphometry is also helpful to understand the landform feature of the earth. The parameters always play a key role to identify groundwater resources through the detailed studies of landform features and drainage network of the basin. The parameters frequently depend upon precipitation, infiltration, soil characterization, evaporation, transpiration and lithology of area. Remote sensing techniques provide precise information within stipulated period and are very important in morphometric analysis by integrating them with GIS tools. Several important morphometric parameters such as stream order, stream length, mean stream length, stream length ratio, basin length, basin perimeter, bifurcation ratio, mean bifurcation ratio, drainage density, stream frequency, drainage texture, form factor, circulatory ratio, elongation ratio and length of the overland flow have been considered for analysis. Geospatial tools have applications in the water resources potential analysis.

Physiography and Geology of the Study Area

The Amarja reservoir catchment bounded by 544.76 km^2 which lies in latitudes 17^0 50' 9" N to 17^0 72' 20" N and longitudes 76^0 45' 8" E to 76^0 55' 20" E (Figure 1). The catchment consists rock of Mesozoic to Lower Tertiary age. Amarja reservoir catchment comes under Aland taluk, Kalburagi district. Kalburagi district is a dry area having low annual rainfall. Most of the population lives in poverty in Aland taluk. A major part of population has migrated to cities due to lack of water, education, unemployment and agricultural development. The area also has a record of the maximum incidents of farmer suicides due to the dry seasons. Aland comes under unproductive tehsils of India in terms of employment, malnutrition and lack of industrial and agricultural development.

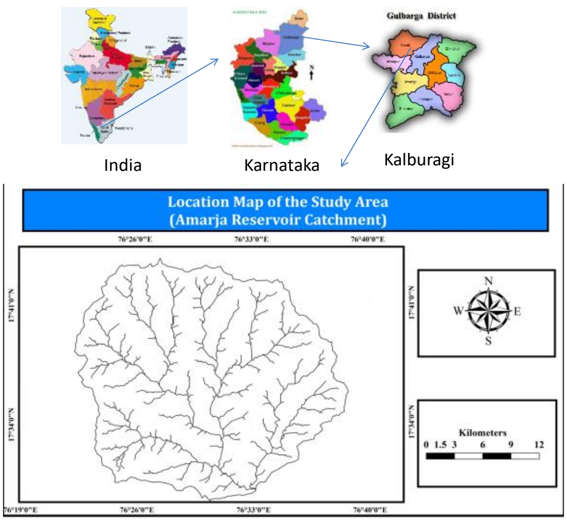

Fig. 1 Location map of the study area.

The region is also called Deccan plateau. It consists of rocks of Deccan trap (mainly basalts) and also sedimentary rocks in some places. These rocks are composed of soft and hard lava flows, whose weathering has produced flat-toped hills and terrace like features. Ridges, pediments, flat and undulating landscape and lineaments are the main structures in the area (Reddy, 2007). The highest contour of 600 m elevation is marked in the northern part while the lowest contour of 475m is marked in the southern part of the catchment.

Slope is also an important indicator and it always affects the contribution of rainfall in the drainage basin, groundwater and is helpful in selecting a suitable site for artificial recharge structure. Very gentle to moderate slope has been marked with inclination towards southern part of the catchment. The area contains deep black soil generally derived from Deccan traps. Moreover, the climate behavior of district is normally dry and seasons follow the general pattern of that of other Deccan regions. The summer period begins during February and endures up to June.

The month of December comes under the coldest month having a temperature variation 29.5^0C to and 10^0C. In the peak of summer, temperature rises up to 45^0C. The relative humidity contrast is 26% in summer season and increases up to 62% in the winter period. Figure 2 elucidates the drainage network setting of the catchment. The different color indicates different stream order in the catchment. The average annual rainfall received by the area is 777 mm while the annual minimum rainfall is 342 mm and the annual maximum rainfall is 1270 mm (CGWB, 2012).

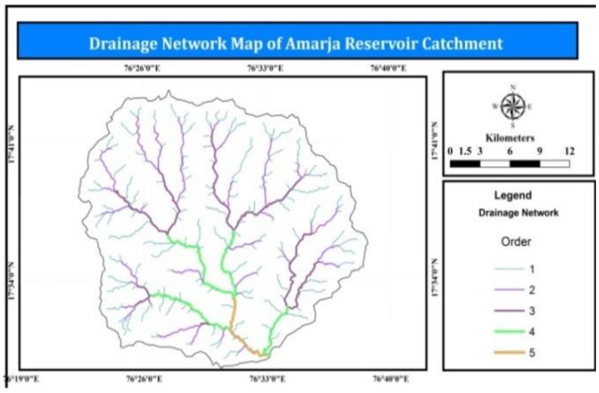

Fig. 2 Drainage network map of Amarja reservoir catchment.

Materials and Methods

An attempt was carried out to analyse geological stages and groundwater potential zones using RST (remote sensing technique) and GIS (geographic information system tools). Digital Elevation Model data have been procured from Shuttle Radar Topographic Mission (SRTM), USGS website. The digital elevation model is processed in *ArcGIS 10.0 software*. Spatial analysis tools were used to analyse the DEM data for the drainage catchment. First digital elevation data have been processed using fill tool to remove discontinuity and sink errors and then stream order, stream feature, flow direction, flow accumulation and drainage network of the catchment are developed by applying the necessary tools.

Strahler's (1964) concept has been used in stream ordering. The entire catchment is further separated into 5 sub-basins (Fig. 3) on the basis of 4^{th} order stream. Figure 4 elucidates the digital elevation model (DEM) of the catchment. The boundaries of the sub-basins were delineated using the watershed tool in *ArcGIS 10.0* software. Slope map was created by using the downloaded DEM as input file. Basin length, basin area, bifurcation ratio and basin perimeter were calculated for the entire catchment and also for sub-basins. Linear, aerial and relief parameters have been calculated by using the morphometric equations (Table 1). Contour values have been plotted using DEM data in spatial analyst tools of *ArcGIS 10.0 software*. Hypsometric integral values of different sub-basins have been governed by using elevation data.

Hypsometric integral is a good watershed health indicator. It is a very important parameter in assessing the nature of active tectonic deformation. The parameter is also helpful in finding out the tectonic and erosional processes, which are responsible in the shaping of watershed.

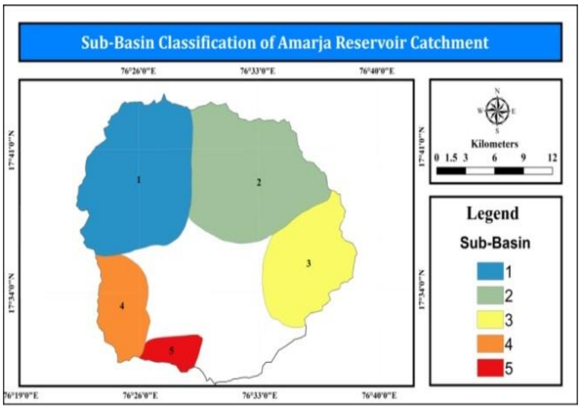

Fig. 3 Sub-basin classification map of Amarja reservoir catchment.

The elevation relief ratio (E) is indistinguishable to the hypsometric integral ($E \approx H_{si}$). (Pike and Wilson, 1971)

Hypsometric integral (H_{si}) = Mean elevation – Minimum elevation / Maximum elevation – Minimum elevation (Equation-1).

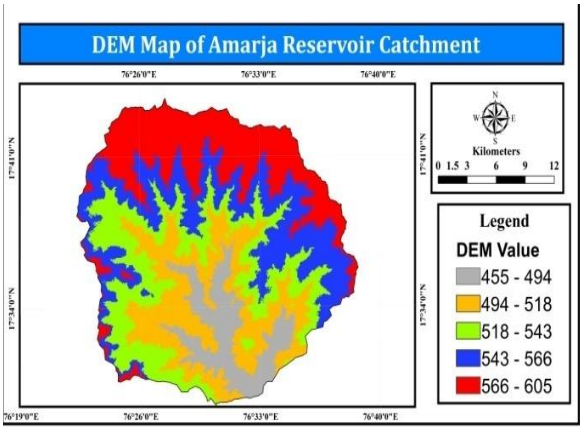

Fig. 4 DEM map of Amarja reservoir catchment.

By using this formula, estimation of hypsometric integral became much easier with accurate results. The mean elevation is expressed as weighted mean elevation of watershed, which is derived from perceptible contours of delineated sub-watersheds. It is understood that elevation (max.) is the highest value, while minimum elevation is the elevation within the generated sub-watersheds. The analysis of hypsometric integral is always helpful in differentiating the stages of erosional landforms during their evolution; the difference in the values is directly related to the degree of disequilibria in the poise of erosive and tectonic forces. According to Strahler (1952),

Table 1. Methods for calculating morphometric parameters.

S. No.	Morphometric parameters	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm = Lu/Nu Lu= Total stream length of order ‘u’ Nu= Total no. of stream segments of order ‘u’	Strahler (1964)
4	Stream length ratio (RL)	RL=Lu/Lu-1 Lu=Total stream length	Horton (1945)
5	Bifurcation ratio (Rb)	Rb=Nu/Nu+1 Nu=Total no. of stream segments	Schumn (1956)
6	Drainage density (D)	D=Lu/A Lu=Total stream length of all orders, A= Area of the basin (km^2)	Horton (1932)
7	Mean Bifurcation ratio (Rbm)	Average of bifurcation ratio of all orders	Horton (1945)
8	Stream frequency (Fs)	Fs=Nu/A Nu=Total no. of stream of all orders	Horton (1932)
9	Drainage Texture (Rt)	Rt=Nu/P Nu=Total no. of stream of all orders P=Perimeter (km)	Horton (1945)
10	Constant of channel maintenance (C)	C=1/D D= Drainage density	Schumm (1956)
11	Form factor (Rf)	$Rf=A/Lb^2$ Lb^2 = square of the basin length	Horton (1932)
12	Circulatory ratio (Rc)	$Rc=4 \times \pi \times A/P^2$ Pi (π) = 3.14 P^2 = Square of the perimeter	Miller (1953)
13	Elongation ratio (Re)	$Re=2\sqrt{(A/\pi)} / Lb$ Lb= Basin length	Schumm (1956)
14	Length of overland flow (Lg)	Lg=1/D X 2 D= Drainage density	Horton (1945)

hypsometric integral is inversely proportional to channel

Table 2. Linear parameters of Amarja reservoir catchment.

Sub-basins	Stream order (U)					Total stream number	Basin Length (L) in kms	Stream Length (Lu)					Mean Stream Length
	1	2	3	4	5			1	2	3	4	5	
I	47	6	2			56	15.28	49.56	30.59	15.31			31.82
II	42	9	2			53	14.63	51.95	17.79	20.81			30.18
III	22	5	2			29	14.56	27.20	11.99	15.90			18.36
IV	15	5	2			22	6.65	20.28	7.55	3.82			10.55
V	4	2	1			7	6.66	1.81	6.88	0.97			3.22
Total at Amarja Reservoir Catchment	176	35	9	4	1	225	34.84	150.8	74.80	56.81	35.98	8.55	65.38

gradient, steepness of the slope, total relief and the drainage density.

Results and Discussion

Linear Parameters of Amarja Reservoir Catchment

The linear aspects of Amarja reservoir catchment deal with order of the stream, stream length, basin length, mean stream length and bifurcation ratio and shown in Table (2) and (3) respectively.

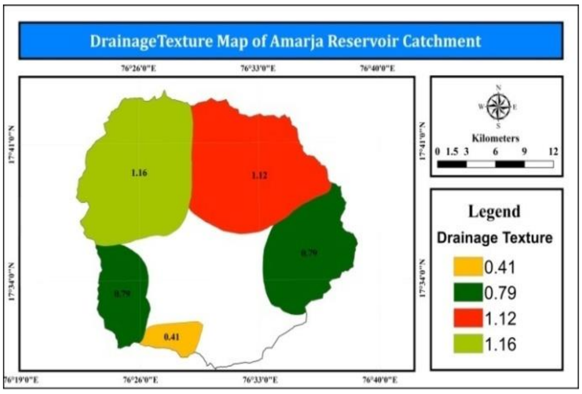

Fig. 5 Drainage texture map of Amarja reservoir catchment.

Stream order

Stream ordering has been done according to Strahler's rule. The smallest tributaries of the watershed are called 1st order stream, when two 1st order streams merged at a confluence, then 2nd order stream is formed and so on. There are 225 streams that were recognized, in which 176 are first order, 35 are second order, 9 are third order, 4 are fourth order and 1 of fifth order where all the streams have been merged. It has been noticed that the number of stream order is increasing as the stream segment is decreasing. Streams which are formed have dendritic to sub-dendritic drainage pattern.

Stream Length

Another important factor is stream length, which makes us understand topography and its variations. Stream length is calculated by the concept of Horton (1945) method using suitable tools in *ArcGIS 10.0 software.* It generally indicates surface runoff characteristics of the stream. Streams having shorter length, which indicates the steeper slope while the streams having longer length will indicate the flatter gradients. It has been retrieved that the stream length of the first order stream is 150.8 kilometre while 2nd order is 74.80 kilometre, 3rd order stream is 56.81 kilometre, but 4th order stream show 35.98 kilometre in length and the final and important stream i.e., 5th order is 8.55 km. It has been found that the 1st order streams have maximum length and it decreases as the stream order increases.

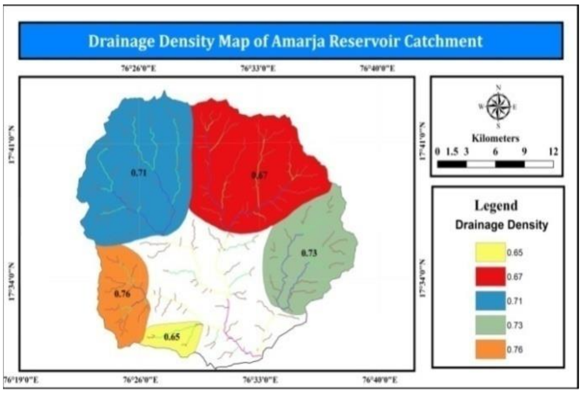

Fig. 6 Drainage density map of Amarja reservoir catchment.

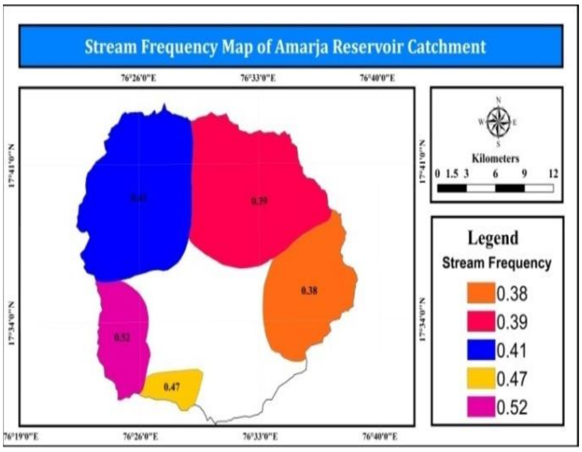

Fig. 7 Stream frequency map of Amarja reservoir catchment.

Mean Stream Length

Mean stream length is the concept which deals with size of drainage network and can be appraised as dividing the total stream length by the available number of stream segments. The first and second order stream is almost similar as 31.82 and 30.18 respectively, while the next higher order stream values are suddenly changed as 18.36 kilometre for third order, 10.55 kilometres for fourth order and 3.22 kilometres for the 5th order. The average value of entire basin has been calculated to be 65.38.

Table 3 Linear parameters of Amarja Reservoir Catchment.

Sub-Basin	Total Stream Length	Stream Length Ratio (RL)	Bifurcation Ratio (Rb)				Mean (Rb)
			Rb1	Rb2	Rb3	Rb4	
I	95.46	1.01	7.83	3.00			5.41
II	90.56	1.01	4.66	4.50			4.58
III	55.09	1.02	4.4 0	2.50			3.45
IV	31.67	1.03	3.0 0	2.50			2.75
V	9.67	1.11	2.0 0	2.00			2.00
Total at Amarja Reservoir Catchment	282.45	1.00	4.81	3.00	2.25	4.00	3.51

Table 4 Aerial parameters of Amarja Reservoir Catchment.

Sub-basin	Basin Area (Sq Km)	Perimeter (Km)	Drainage Texture	Drainage Density	Stream frequency	Texture Ratio
I	133.95	48.23	1.16	0.71	0.41	0.97
II	133.22	47.28	1.12	0.67	0.39	0.88
III	75.24	36.47	0.79	0.73	0.38	0.60
IV	41.64	27.63	0.79	0.76	0.52	0.54
V	14.68	16.72	0.41	0.65	0.47	0.24
Total at Amarja Reservoir Catchment	544.76	101.54	2.21	0.52	0.41	1.73

Table 5 Aerial parameters of Amarja Reservoir Catchment.

Sub-Basin	Form factor	Elongation Ratio	Circulatory Ratio	Length of Overland Flow	Constant of channel maintenance
I	0.57	0.85	0.72	0.70	1.41
II	0.62	0.87	0.75	0.74	1.49
III	0.35	0.66	0.71	0.68	1.36
IV	0.72	1.09	0.68	0.66	1.31
V	0.22	0.64	0.65	0.76	1.54
Total at Amarja Reservoir Catchment	0.45	0.75	0.66	0.96	1.92

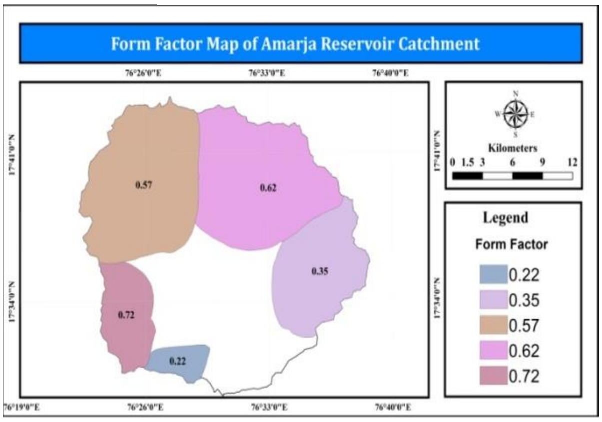

Fig. 8 Form factor map of Amarja Reservoir Catchment.

Bifurcation Ratio

It has been expressed as number of stream segments divided by the number of segments of next higher order. Bifurcation ratio of the entire catchment show ranges from 2.25 to 4.79. Whereas the value is low for the 3rd order, but, it is high for the first order stream, which indicates structural disturbances but these structures generally do not distort the drainage network. The average value of bifurcation ratio of entire catchment is 3.702 which suggest that there is structural control in the development of catchment.

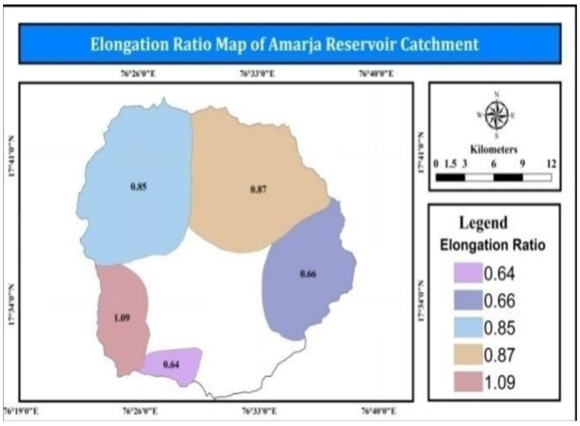

Fig. 9 Elongation ratio map of Amarja reservoir catchment.

Basin Length

The largest length of basin and one end being the mouth of the stream is termed as basin length. The basin length of the catchment has been calculated as 35.19 km.

Aerial Parameters of Amarja Reservoir Catchment

The aerial parameters of the catchment are as follows and they are shown in Tables 4 and 5 respectively.

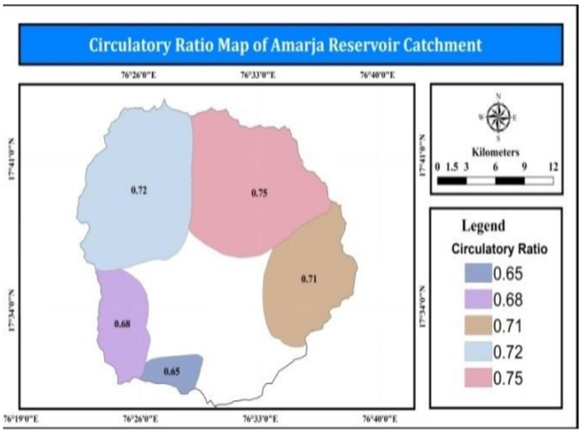

Fig. 10 Circulatory ratio map of Amarja reservoir catchment.

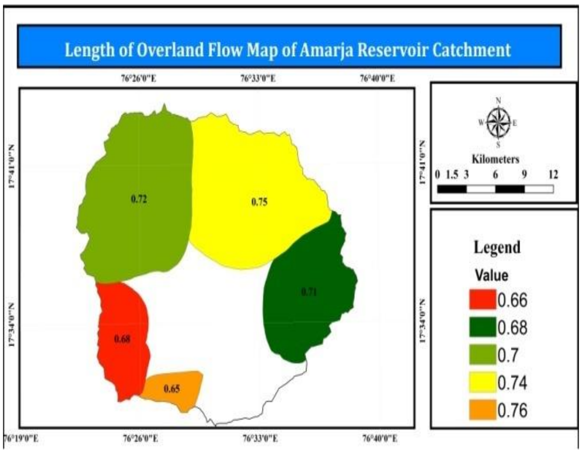

Fig. 11 Length of overland flow map of Amarja reservoir catchment.

Drainage Texture

The total number of stream segments divided by perimeter of that area is known as drainage texture. Hard rock terrain represents the coarse texture while the soft and weak rock terrain with sparse vegetation represents fine texture. In 1950, Smith classified drainage texture into five categories on the basis of drainage density. Drainage density < 2.0 reveals very coarse drainage texture, whereas 2.0 to 4.0 show coarse in nature and 4.0 to 6.0 shows moderate.

The values recovered from the study for fine texture ranges from 6.0 to 8.0, and the value which shows > 8.0 represents very fine texture. Figure 5 depicts the drainage texture for the entire catchment and the value shows 2.21, which represents coarse texture while the sub-basin texture of the catchment ranges from 0.41 to 1.16, which is less than 2.0, indicating very coarse grain drainage texture.

Drainage Density

It represents the distance and coverage of the channels and expresses the ratio of total length of all streams by total area. It always depends upon lithological character, climate, soil permeability and also on infiltration capacity. The region associated with low drainage density is very good for water potential while the region linked with high density is generally not good because it gives more runoff and low infiltration capacity. Drainage density of the catchment (Fig. 6) varies from 0.52 to 0.76 km/km^2 which indicate very coarse drainage texture and the characteristics of hard rock. Therefore, the higher density regions are not good for groundwater development and it indicates sparse vegetation.

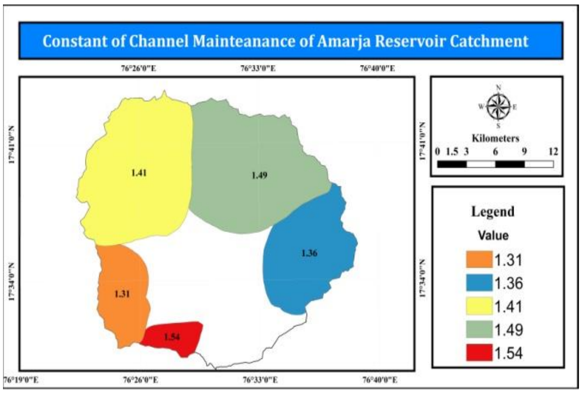

Fig. 12 constant of channel maintenance map of Amarja reservoir catchment.

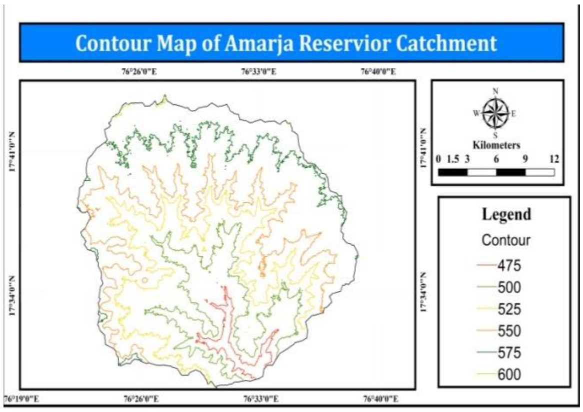

Fig. 13 Contour classification map of Amarja reservoir catchment.

Texture Ratio

This can be expressed as the first order stream basin, which divides its perimeter. It depends upon lithology, relief aspects and infiltration capacity of the sub-basins. The texture ratio varies from 0.24 to 0.97 and overall value of the entire catchment is 1.73.

Stream Frequency

Total number of stream segments to the area of that basin can be termed as stream frequency. It is also called channel frequency. The basin having higher stream frequency represents hard rock formation, scant vegetation and elevated runoff. Figure 7 states that the values of stream frequency are that of the sub-basin range from 0.38 to 0.52 and mainly deals with the lithology of basin and influences the drainage pattern. The estimated average value of entire catchment has found to be 0.41.

Form Factor

This can be expressed as the ratio of area of a basin to its square of length. Horton expressed basin shape on the basis of form factor values. The value of form factor (Fig. 8) for entire basin is calculated to be 0.45 which represents the more elongated nature of catchment. The value of form factor which is greater than 0.78, represents a circular shape. In case of sub-basin IV, form factor is found to be 0.72 which is near to 0.78, strongly suggesting the circular shape of the catchment.

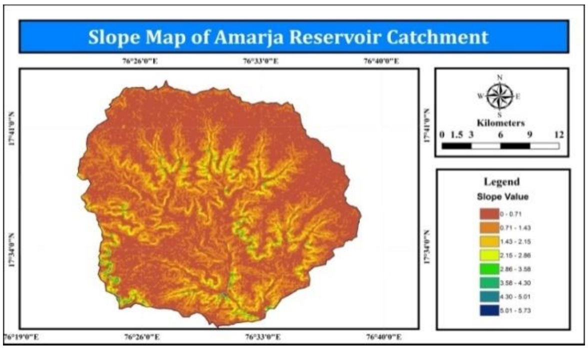

Fig. 14 Slope classification map of Amarja reservoir catchment.

Elongation Ratio

Diameter of the area divided by the drainage basin and the maximum basin length is said to be elongation ratio. The elongation ratio estimated generally ranges from 0.6 to 1.0. Low relief regions normally close to 1.0 whereas the high relief regions generally possess the values from 0.6 to 0.8. The elongation ratio for the entire catchment is estimated to be 0.75 which indicates that the catchment has reasonable to elevated relief and steep ground slopes (Fig. 9).

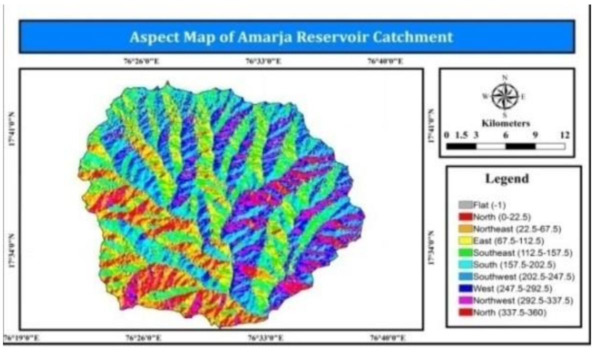

Fig. 15 Aspect classification map of Amarja reservoir catchment.

The sub-basins i.e. I, II and IV of Amarja reservoir catchment, the elongation values are close to 1.0 which shows low relief area and close to high erosion with sedimentation load.

Circulatory Ratio

It can be calculated as the basin area divided by the area of circle having same circumference. Generally, value of circulatory ratio varies 0.6 to 0.7 for stream in homogeneous geological material (Miller, 1953). It is always helpful to predict certain hydrological features of catchment and mainly depends on geological structure, climate condition, slope pattern, geomorphology and the relief of the basin. The circulatory value for the entire catchment is estimated to be 0.66, which suggests that the shape of the catchment is fairly elongated and the area is not prone to high floods (Fig. 10). In case of sub-basins I, II and III, the calculated values of circulatory ratio are greater than 0.7, which suggests that the shape is more or less circular and with low to moderate relief.

Length of Overland Flow

This is nothing but half of the reciprocal drainage density of the catchment. The average value of the entire catchment was estimated to be 0.96 (Fig. 11). Value varies from 0.66 to 0.76 in concern of sub-basins. According to the estimated values, rain covers a distance before concentrating into different stream channels which indicates coarse grain texture and low to moderate relief.

Constant of Channel Maintenance

According to Schumm, (1956) it is reverse of drainage density. Less value of channel of constant maintenance will indicate less chance of infiltration and higher runoffs while the high value of channel of constant maintenance and vice versa. The value of constant of channel maintenance for all sub-basins varies from 1.31 to1.54 km^2/km, which was relatively higher in range (Fig. 12).

Relief parameters of Amarja Reservoir Catchment: The term relief generally represents the difference in elevation between maximum to minimum contours of a basin. Different relief parameters have been analyzed and shown in Table 6.

Basin Relief

The maximum vertical distance of a sub-basin from highest to the lowest points is called basin relief. The maximum contour is marked as 600m while the minimum contour is marked as 475 m. The basin relief values vary from 50 m to 125 m, which indicate low runoff and moderate infiltration condition.

Basin Relief Ratio

It is defined as the horizontal distance of highest relief along the longest element of basin which is normally parallel to the principal drainage contour. It is inversely proportional to the drainage area. The values of all sub-basins except fifth order range from 5.15 to 7.51. The value of relief ratio of 5^{th} sub-basin is found to be 15.01.

Ruggedness Number

This is nothing but the product drainage density to its basin relief. Higher values of ruggedness number will show higher erosion. The values of ruggedness numbers varies from 0.038 to 0.071 while for the entire catchment, it is estimated to be 0.065.

Table 6 Relief parameters of the Amarja reservoir catchment.

Sub-basin	Relief		Basin Relief	Basin Relief Ratio	Time of Concentration	Ruggedness Number
	Max	Min				
I	600	500	100	6.54	0.030	0.071
II	600	500	100	6.83	0.028	0.067
III	575	500	75	5.15	0.032	0.055
IV	575	525	50	7.51	0.015	0.038
V	575	475	100	15.01	0.011	0.065
Total at Amarja Reservoir Catchment	600	475	125	3.58	0.073	0.065

Table 7 Slope classification (NRSA, 1995).

Number of classes	Description of slope	Class
1	<1	Nearly level
2	1-3	Very gentle
3	3-5	Gentle slope
4	5-10	Moderate slope
5	10-15	Moderately steep
6	15-35	Steep
7	>35	Very steep

Table 8 Criteria to prioritize groundwater potential zones of Amarja reservoir catchment.

S. No.	Groundwater Potential Zones (Amarja Reservoir Catchment)	Very good	Good	Moderate	Poor
1	Drainage texture	0.41 to 0.59	0.60 to 0.78	0.79 to 0.98	0.99 to1.16
2	Drainage density	0.65 to 0.67	0.68 to 0.71	0.72 to 0.74	0.75 to 0.76
3	Stream frequency	0.38 to 0.42	0.43 to 0.45	0.46 to 0.48	0.49 to 0.52
4	Texture ratio	0.24 to 0.42	0.43 to 0.60	0.61 to 0.78	0.79 to 0.97
5	Form factor	0.22 to 0.34	0.35 to 0.47	0.48 to 0.59	0.60 to 0.72
6	Elongation ratio	1.09 to 0.98	0.97 to 0.87	0.86 to 0.76	0.75 to 0.64
7	Circulatory ratio	0.65 to 0.67	0.68 to 0.70	0.71 to 0.73	0.74 to 0.75
8	Length of overland flow	0.66 to 0.68	0.69 to 0.71	0.72 to 0.73	0.74 to 0.76
9	Constant of channel maintenance	1.54 to 1.49	1.48 to 1.43	1.42 to 1.37	1.36 to 1.31
10	Time of concentration	0.011 to 0.016	0.017 to 0.021	0.022 to 0.026	0.027 to 0.032
11	Ruggedness number	0.038 to 0.046	0.047 to 0.054	0.055 to 0.062	0.063 to 0.071

Time of Concentration

This can be expressed as the length of main stream divided by basin relief. In concern of sub-basins, the value varies from 0.011 to 0.032. Maximum value will represent the maximum length in the time span since the movable length of water by the furthermost point to its outlet. Average value of time of concentration of entire catchment is found to be 0.073.

Estimation of Hypsometric Integral (Hsi) Hypsometric values have been calculated on the basis of elevation-relief ratio methods. Maximum, minimum and mean elevations are marked in the study area by contour values (Fig. 13) using different tools in the *ArcGIS 10.0 software*. The analysis revealed that the hypsometric integral value for sub-basin IV of Amarja river basin is 0.30, which shows the late mature stage of the basin. In case of sub-basins II, III and V, the value of hypsometric integrals are 0.54, 0.50 and 0.43 consequently, which indicates the mature stage of the river. Moreover, the sub-basin I having an integral value of 0.67 shows the young stage of the basin and that it is more susceptible for erosion.

Aspect Analysis

Aspect basically deals with the direction of slope faces of a mountain. It always has a great significance. The aspect values vary from -1 degree to 360 degree. The distribution of the aspect values (Fig. 15) are found to be maximum in the western part while it has been recorded minimum in the eastern region.

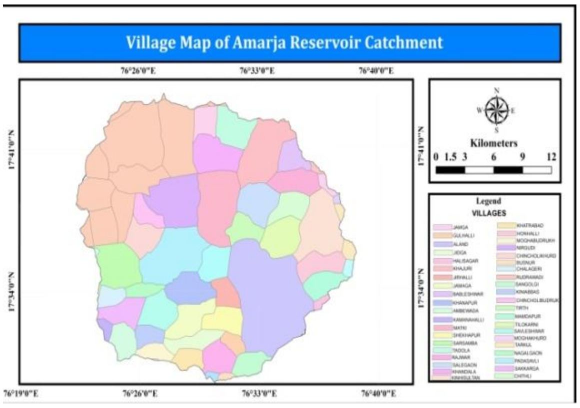

Fig. 16 Village map of Amarja reservoir catchment.

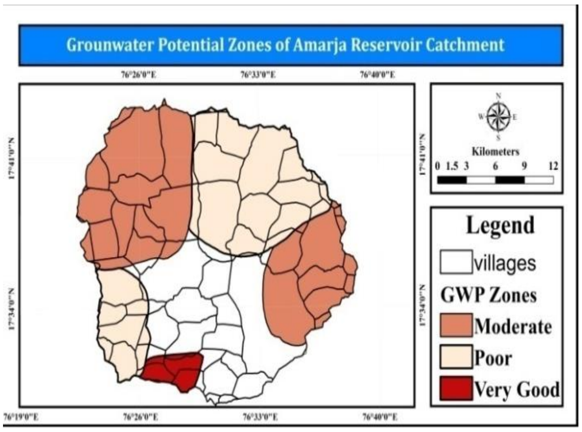

Fig. 17 Groundwater potential zones map of Amarja reservoir catchment.

Slope Analysis

Slope always has a great significance in geomorphological study for watershed development. It plays a key role in rainfall contribution to stream flow and groundwater. It is also important in the estimation of suitable sites for artificial recharge structure. Higher slope values always affect the topography because of higher erosion and rapid runoff. The slope values were analysed on the basis of DEM data and spatial analysis tools in *ArcGIS 10.0 software*. The slope values were estimated to be ranging from 0.71 to 5.73 degree (Fig. 14). The slope values increase from northern to the southern part. Very gentle, gentle and moderate slope has been marked in the study area with the help of slope classification (NRSA, 1995) as shown below Table (7).

Groundwater potential zone map has been generated by the weightage assigned to each responsible parameters of potential zones like drainage texture, texture ratio, circulatory ratio, constant of channel maintenance, ruggedness number, length of overland flow, elongation ratio, stream frequency, form factor, time of concentration and drainage density (Table 8). The analysis revealed that the sub-basin V showed the strong result in the favour of safe zone for groundwater potential prioritization. Sub-basin I and III were found to be in moderate groundwater prospect zones, while result of the sub-basin II is showing very low groundwater prospect zone. In this aspect, it is necessary to take an immediate action for sub-basin II and community participation is also required.

Conclusion

The study has been done to simulate the geological stages of development for all sub-basins on the basis of hypsometric integral values. The analysis revealed that the values of hypsometric integral ranges from 0.30 to 0.67 for all sub-basin. It is confirmed that sub-basins II, III and V have integral values 0.54, 0.50 and 0.43 respectively, which indicates the mature or monadnock stage of the basin. Moreover, sub-basin IV has an integral value of 0.30, suggesting late mature or equilibrium stage of the basin. In this condition, it might need supplementary water harvesting type structure in conservation of water on a suitable place in the catchment area and can be utilized for conjunctive use of water. Sub-basin I is more susceptible to erosion, because it has an integral value of 0.67, indicating young or in-equilibrium stage of the basin. Groundwater potential zones map has been prepared by the analysis of different morphometric parameters (Fig. 17). The analysis elucidates that the villages Hiroli, Nirgudi, Chincholi (B), Chincholi (K) belong to sub-basin I and Kinnisultan, Tarkul, Kanmus, Manhalli, Mamdapur, Honhalli, Hallisagar, Tilokarni belong to sub-basin III respectively and are in moderate zone (Fig. 16). Apart from that the villages Mogha (B), Mogha (K), Khatrabad and Jidga belong to very good groundwater potential zones. But in the case of sub-basin II and IV, the villages Jamga, Tadola, Khajuri, Bableshwar, Battargi, Jamga Khandala, Rudrwadi, Matki, Tirth, Sagelagaon, Chitali, Khandala, Sarasamba, Chalageri, Sakkarga, Kamanahalli, Amberwadi, KInnisultan, Nagelagaon and Allapur belong to very low groundwater prospect zones. In this case immediate action is required to improve the groundwater and sustainable development in the study area. The other villages like Aland, Sangolgi, Busnur Padsawli, Shekhapur, Gulahalli, Jheerahalli, Khanapur, Kawalgi, Tamga and Rajwar are in safe zones. For sustainable development of water resources, agricultural and irrigational purposes, rainwater harvesting structure techniques should be utilized in a proper way. This study would be really helpful to the resident member of the area for exploiting and establishing sustainable development of the catchment.

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