Environmental impact assessment of the Kolar River catchment, Central India using RS and GIS based on morphological parameters

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Abstract

The benefit of using both technique of Remote Sensing (RS) and GIS for morphometric analysis is very helpful in assessing environmental impact on water resources which is not only time saving but also enhances accuracy in analysis for those inert areas which are difficult to access physically like that of Kolar river watershed, a semi-arid zone. The performed morphometric analysis includes linear, areal and relief aspects. Catchment having dendritic patterns of stream and drainage texture of value 2.72 shows coarse nature. The slopes are mostly ranging from flat terrain (<5%) to low steepness slope (10-15%). Aspect map shows eastward inclination of slope which receives more light and high moisture retention which is apt for vegetation growth.

Based on the analysis, it is concluded that the characteristics of catchment are no structural disturbances in basin, course natured, poor drainage basin with low hydrological response. Finally, it is anticipated that this study will add to further research in this region.

Keywords: Morphological survey, watershed management, aspect ratio, river basin, Kolar Dam.

Introduction

Morphometric analysis is pre-requisite for watershed management decisions for its development. The use of Remote sensing and GIS makes it even much better for the remote location which is difficult to access[13]. In India about 54 percent of land area comes under arid and semi-arid zones. Due to global warming, earth surface temperature is rising with an unprecedented rate[3]. Rainfall pattern is also affected by rise of local temperature in rainfall intensity, spatial and temporal variation over the years which also affect the hydrograph analysis. Available water resources are becoming scarce for daily water consumption, agricultural needs and industrial needs which can hinder the economic growth of the region[20].

Geomorphological characteristics of watershed which include geological features such as geological structures, cross-section, river profile and other hydraulic features directly or indirectly indicate water storage potential of watershed[2]. These morpho-logical features are crucial pre-conditions for accessing the water storage capacity of rock strata and drainage networks[11]. Drainage patterns have their own nature and types which are function of rock types and geological features[18]. So, there is need for quantitative morphometric analysis which will reflect hydrological response and will be helpful in establishing hydrological response units, hydrological models which predict nature of watershed and water balance equations.

For watershed management, planning and distribution of water resources, a quantitative morphometric analysis is applied to drainage basins[7]. Morphometric analysis gives dynamic balance between matter and energy, helps in critically observing interrelation between drainage pattern attributes and affecting factors and also helps in evaluating and comparing other basins developed in different geological and spatial-temporal systems.

Manual morphometric analysis is time consuming involving a lot of calculations and is impractical in present scenario. In such cases, GIS with Remote sensing data which contains high resolution satellite imagery is an excellent tool for monitoring geological changes pertaining to LULC for assessing soil erosion and feature extraction works. Surface hydraulic parameters are capable tools for management, planning and distribution of water related resources and infrastructure.

Morphometric analysis of drainage patterns is essential for rainfall-runoff modelling[9], delineation and modelling of watershed[13], underground water recharge points[10], determination of locations of dam and weirs, water storage capacity and geological interrogations such as lithology, soil texture mapping for soil nutrients and identification of faults and folds in river channel bed[16], watershed prioritization[5], ground water resources identification[8], critical watershed identification[12] and regional hydrologic simulation[4].

This hydro-morphological study is aimed to explore various geological features related to Kolar River terrain for the management of water resources which is not only sustainable but life changing also.

Material and Methods

Study Area: Kolar catchment is situated in Sehore district of State of M.P. in India between longitude of 77 to77.25-degree East and latitude of 22.75 to 23.20-degree North. Shehore, Ichhawar and Bhopal (capital of Madhya Pradesh located at a distance of 32 Km) are the main cities located nearby. Kolar reservoir is main source for drinking water supply and irrigation water supply. Main villages in the catchment are Brijesh Nagar, Bhura Kheda, Lotiya, Sali Kheda and Bordi Kalan. Kolar Dam is located in Birpur Village (Figure 1).

Kolar is a tributary of Narmada River having cultural command area of 45.10 thousand hectares and ultimate irrigated potential of 60.90 thousand Ha. The maximum and gross storage of reservoir on Kolar Dam which a gravity concrete dam is 270 and 265 MCM and height of 45 m. It has maximum level of 462.20 m. But study site is suffering from adverse effect of erratic nature of rainfall and growing demand of water due to impact of climate change and population explosion. Also due to change in agricultural practices and use of artificial fertilizers water demand of crops increased. Kolar River watershed is surrounded with tropical deciduous forest. Kolar is seasonal river and most of the water it receives is during rainy season from 15 June till 15 September. So, the observation site is selected for the study to understand its water resource capability and also further investigates interlinking possibility of this reservoir.

Data collection: Multispectral band of LISS 3 satellite data set (dated 9 may, 2018), digital elevation model (DEM) (of Cartoset DEM data Version R3) with 10-meter spatial resolution download from BHUVAN Portal of Government of India and Survey of India toposheets are used for the database generation and extraction of area of interest and other drainage parameter. Various softwares such as ARCMAP 10.5 for analysis, ERDAS for georeferencing, Google Earth for identifying land use pattern and AUTO-CAD 3D are used for digitization of streams. Topography sheets numbered 55F1, 55F5, 55E4 and 55E8 were collected from Survey of India office which has scale of 1: 50,000 printed versions. Geological maps were obtained from MPCST, Bhopal.

Morphometric Analysis: Four toposheets were scanned with high resolution printer and georeferenced in ERDAS. Then, sheets were mosaiced with one another and extra area is clipped off. With the mosaiced and georeferenced toposheet, area of interest is prepared with Geometric coordinate system (GCS 84). Drainage network of Kolar catchment was digitized and attributes associated with streams such as order of streams, stream number in each order, stream lengths, watershed area, perimeter, ratio of bifurcation, elongation proportion, relief ratio etc. were calculated using ArcMap 10.5 DEM processed in ArcMap as per the flow chart (table 1 and figure 2).

Detailed morphological parameters along with their formulae and references are given in table and flow diagram involved in morphometric exploration is given in figure 3.

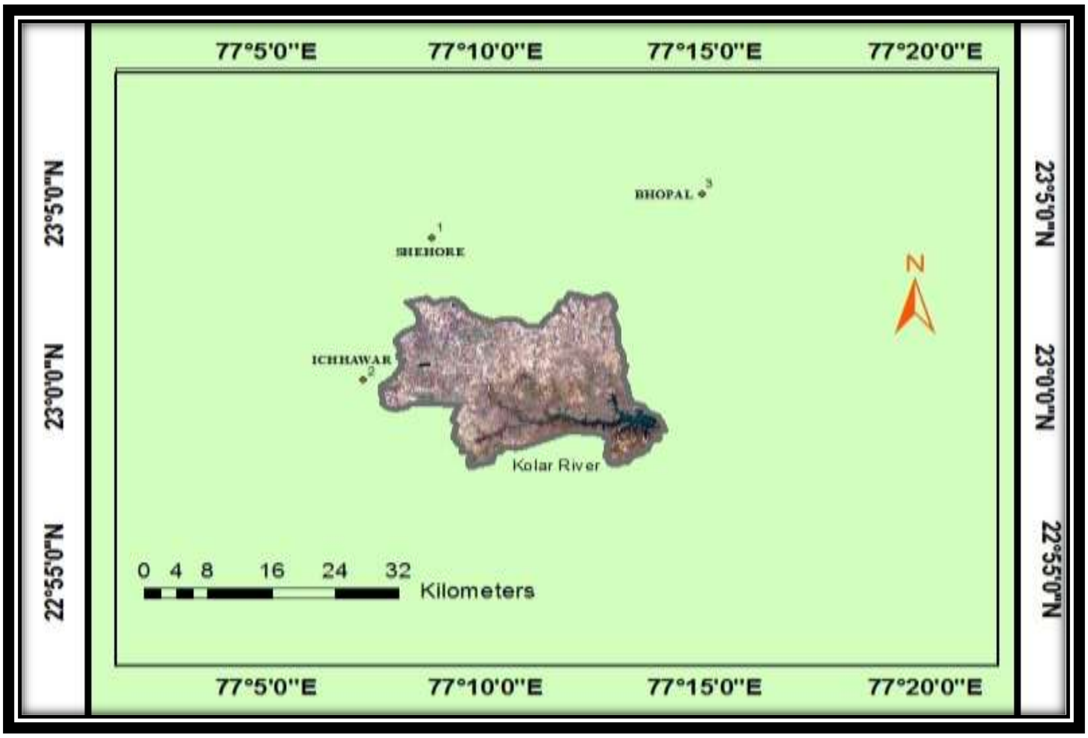

Fig. 1: Location Map of Kolar Reservoir

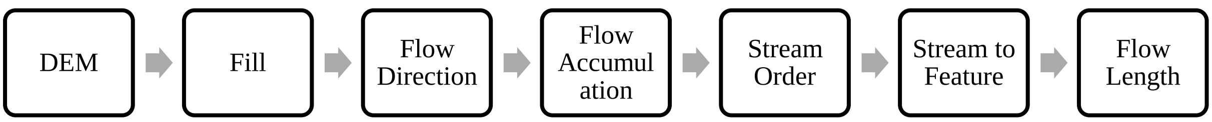

Fig. 2: Flow Diagram of Digital Elevation Model processing

Table 1
Various parameters of morphology of watershed

S.N.	Morphometric Parameters	Formula/Abbreviation
1	Catchment area (Sqkm)	A
2	Watershed boundry (km)	P
3	Length of Basin (Km)	Lb
4	Order of stream[19]	Hierarchical Rank
5	Length of stream channel[6]	Stream Length
6	Mean Stream Length[16]	Lsm=Lu/Nu Where, Lsm= Mean Stream Length.
7	Bifurcation Ratio (Rb)[4]	Rb= N(u)/N(u+1), where Nu= Total no of stream segments of order u.
8	Drainage density (Dd)[6]	Dd9=Lu/A, where Lu= Total Stream length in Km, A= Area in Sq Km
9	Drainage (Stream) frequency (Fs)[6]	Fs=Nu/A, where Nu= Total no of stream segments of order u., A = Area in Sqkm
10	Length of Overland Flow[6]	Lg =1/(Dd)^2
11	Drainage texture[17]	Ft=Nu/P, where P = Peri meter of the watershed
12	Circulatory Ratio (Rc)[17]	Rc = 4XπXA/(P^2)
13	Compactness Coefficient[6]	Cc = 0.2821 (P/A0.5)
14	Elongation Ratio (Re)[14]	Re =(2/Lb)* (A/π)^0.5, where Lb= Basin length
15	Form Factor ratio (Rf)[6]	Rf=A/(Lb^2)

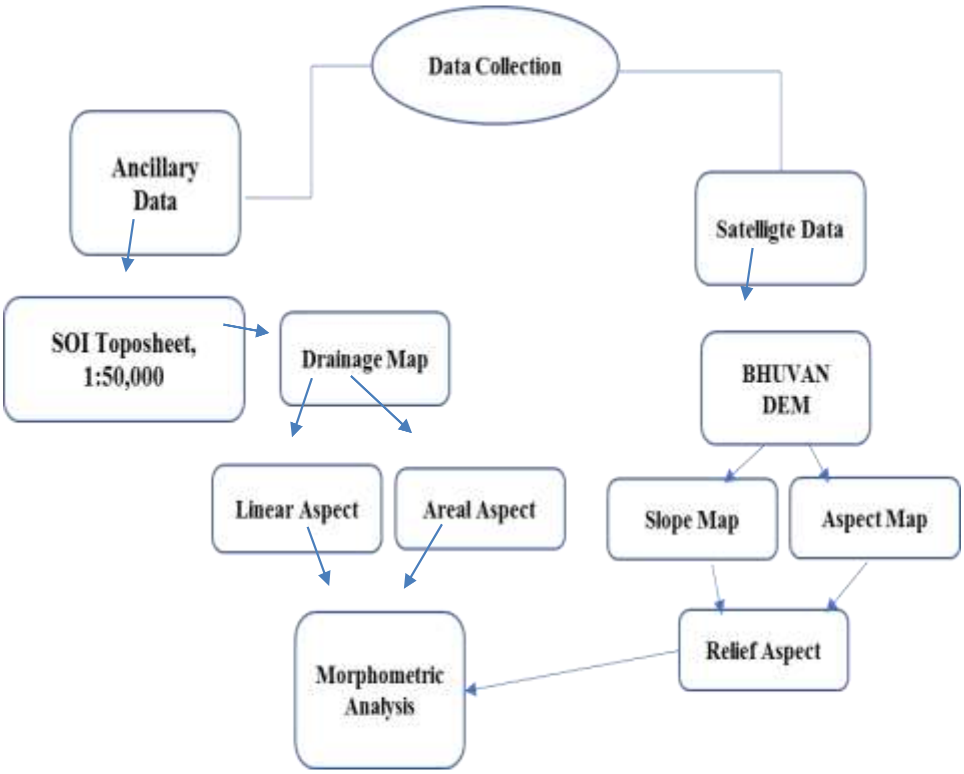

Fig. 3: Flow diagram of Morphometric analysis

Results and Discussion

Kolar river basin catchment is analyzed for linear aspect, areal aspect and relief aspect. Various parameter under these aspects were identified and tabulated. Numerical values of parameters are analyzed and inference is given from standard literature and confirmed by various research works as references.

Linear aspect: Linear aspects include channel networks in relations to uncluttered link as per which topography related properties are analyzed. Kolar river basin catchment has total perimeter length of 122.3 km and area of 521 km^2. The basin length is 41.6 km. The drainage pattern is not in straight path but shows zig-zag pattern and consists of many contributing streams representing dendritic pattern [7]. This pattern is developed when river follows terrain slope. Various linear parameters of watershed are tabulated in table 2.

As given in table 2 which indicates the linear analysis, stream number is decreasing with surge in stream order. Stream order pattern is obtained using ArcMap 10.5 (Figure 6) [6]. Bifurcation ratio of 4.11 is in between 3 to 5 which shows no structural disturbance in watershed and has elongated shape. Also, it is not the same throughout the stream order. Entire stream length is 643.28 km and mean stream length has value of 1.94 kilometers. Kolar River catchment areas have a medium stream frequency of 4.69[19], this indicates that the selected watershed has low relief, medium permeable subsoil material and less vegetation cover.

Table 2
Linear morphometric indicators of Kolar River catchment

S.N.	Parameters	Stream Order					
		1st	2nd	3rd	4th	5th	Total
1	Quantity of Stream	247	66	13	5	1	332
2	Bifurcation ratio	3.74	5.08	2.6	5	-	
3	Mean value of Bifurcation ratio	4.11					
4	Order wise stream length	371.7	143.81	67.30	35.73	24.74	643.28
5	Order wise mean stream length	1.5	2.17	5.176	7.15	24.74	
6	Mean length of watershed	1.94					
7	Drainage Frequency	4.59	5.35	2.83	6	-	
8	Mean Drainage Frequency	4.69					

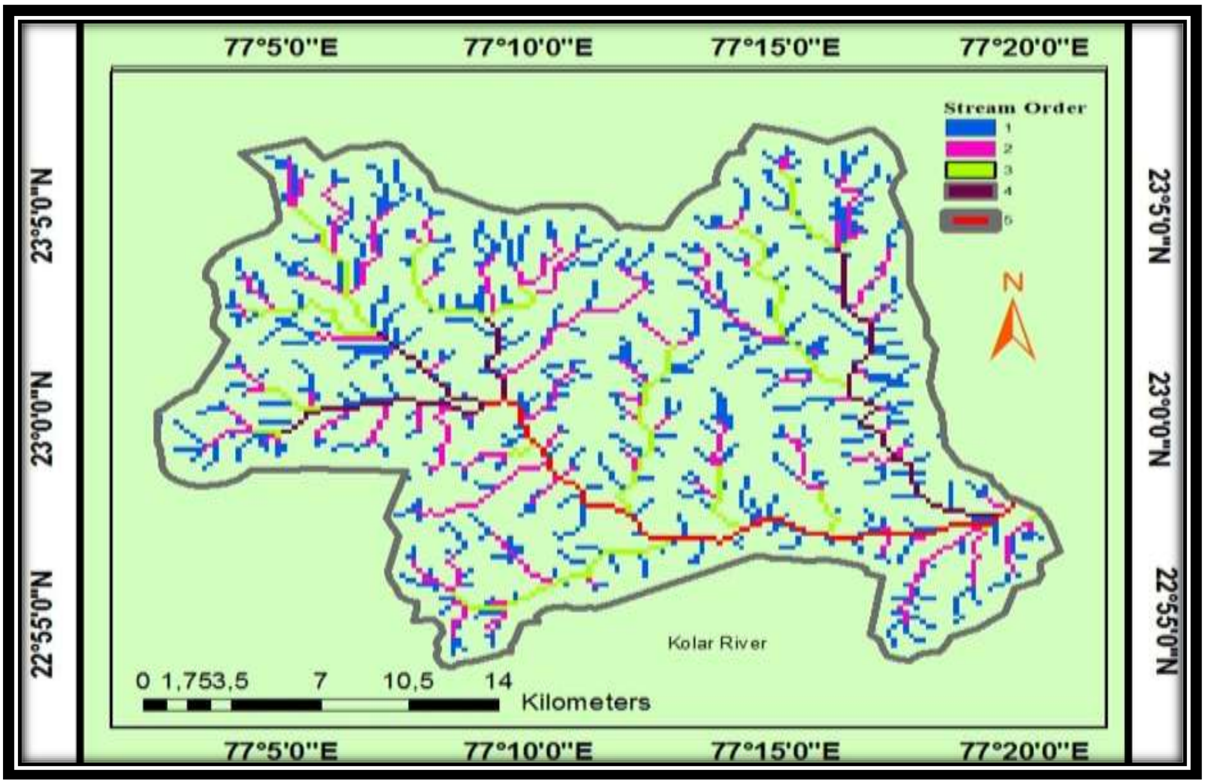

Fig. 4: Linear parameters of Kolar River basin catchment

Areal Aspect: The basin area is significant morphometric parameter which affects areal distribution of morphometric attributes including but not limited to density of drainage (Dd), texture of drainage (Ft), circulatory ratio (Rc), frequency of stream, slope etc. The study indicates Dd to be one of the important areal aspects associated with drainage basin. Here, total stream length is 643.28 km and area is 521.06 km^2. So, as per formula of drainage density given in table 1, it is 1.24 which shows the course nature of watershed. Dd is also strongly correlated with channel maintenance. It specifies moderate drainage conditions in the watershed which is associated with soil transmissibility and restrained susceptibility to erosion.

The basin is poorly drained with slow hydrologic response. There is no rapid movement in surface runoff which makes it even more likely to flooding conditions, gully erosion etc. Drainage texture has the value of 2.72 which shows course type drainage texture. This shows lower watershed recharge capacity, sparse vegetation and closely spaced channels. The stream frequency shows increasing trend from first order to send order and then decreased for third order stream and finally increased for fourth order. Kolar catchment has stream frequency of 4.69 which indicates high sub-soil permeability, rock structure porosity, low rainfall region and high maturity stage of basin. Elongation ratio (RL) used for analyzing catchment alignment helps in indicating hydrological character of river catchment. Calculated value as per table 1 of RL is 0.619 which shows elongate shape of the basin as clearly observed from the AOI.

Maximum value of RL is 1 which shows that the catchment has low relief value and in range 0.6 to 0.8 shows somewhat higher relief value and slope is steep. The circulatory ratio (RC) of Kolar watershed is 0.44. RC value of 1 shows that outer boundary of river basin is perfectly circular which indicates that discharge from all area will reach by same time. The value of 0.44 shows elongate shape of area, low runoff with high base-soil permeability. Value of form factor for Kolar catchment is 0.3 indicating elongate shape and narrow passage with high recharge capacity of watershed ground water.

Relief Aspect: Relief aspect deals with arises due to elevation difference between two extreme points separated by maximum height. Total relief of any river catchment is difference between highest elevation and lowest level of the basin. In the study of Kolar river watershed, relief ratio obtained is 3.82. Lower ratio indicates that basement rocks are present in the form of ridges. This factor is important in studying sediment yielding, conservation of fertile top soil and soil erosion and indicates that most of the basin area has flat to gentle slopes.

Aspect ratio shows the behavior of watershed under the impact of sun's infrared rays for that study area. Slope having west orientation will be much warmer than east facing ones (Figure 5). Vegetation variety and cycle of growth are also affected by aspect ratio. The aspect map of the Kolar River watershed was derived from BHUVAN DEM data used for deriving Kolar basin aspect map in which GIS generated raster files indicating zero degree as true north, ninety degree as east, one hundred and eighty as south and two hundred and seventy as west (Figure 5).

Kolar River catchment consists of slopes east direction oriented mainly. Eastward slopes have nature of low-water percentage retention and higher variety and quantity of green vegetation as compared to its opposite direction i.e. westward slopes. It shows a high percentage of east-facing slopes. Evaporation losses are also high for these types of slopes.

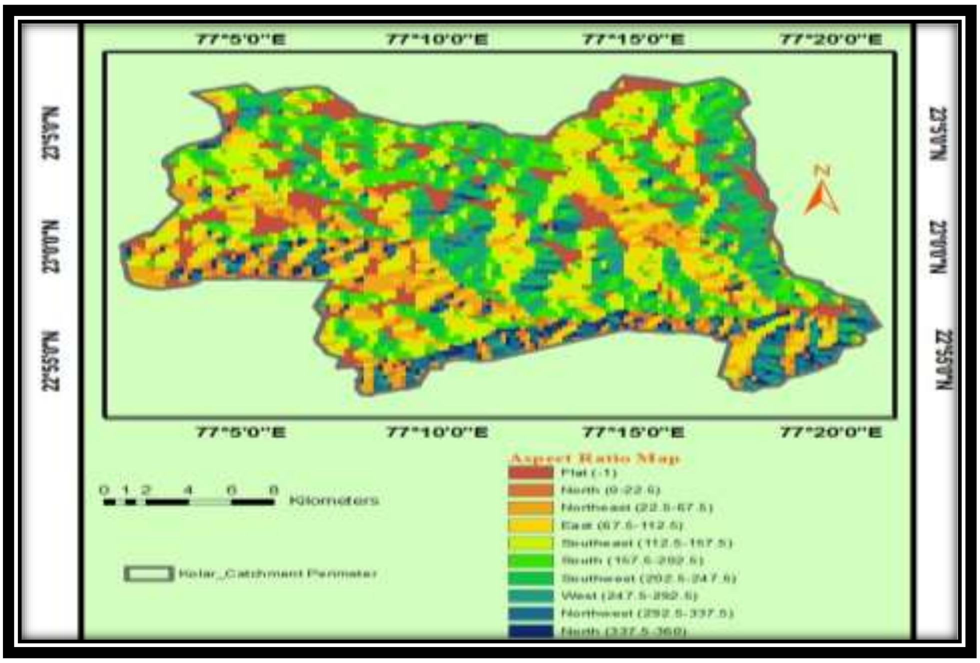

Fig. 5: Aspect Ratio Map of Kolar watershed

Slope Map: Slope of a watershed is prime parameter in deciding the rainfall-runoff characteristics of the catchment and span of time of concentration. It is the tangent of angle formed between the surface profile with horizontal. Soils having lesser infiltration have higher slopes. Slopes are also responsible for aquifer recharge and certain amount of underground flow to it. Table 3 gives the basin relief as 158.85 m present in western and north-west part of the basin. Table 4 gives details of slope.

85 percent of the area of river basin is under 5-degree slope (Figure 6). It indicates that high time of concertation of runoff is expected with lower pick in hydrograph. Remaining 15 percent of area has slopes from gentle to moderate value. Here time of concentration will be less but contribution is less. In gentle slopes, more are the chances of filtration process. Ground water level is also high due to flat profile. As most of the area is below 12 % (5.4 degree), simple watershed conservation practices are required.

Conclusion

Study of Kolar watershed with the application of utilizing RS and GIS as innovative technique for watershed attributes analysis helps in exploring various geological features of Kolar River terrain which has undergone changes due to environmental factors for the management of water resources which helps in the determination of recharge potential, infiltration characteristics, terrain profile, surface runoff, storage capacity and interlinking prospects. Following details about the catchment are obtained from this morphological investigation:

Table 3
Relief Ratio of Kolar watershed (in Km).

Minimum Height	Highest elevation of the basin	Overall river basin relief (H)	Length of the watershed(L)	Relief ratio
437.33	596.176	158.846	41.6	3.82

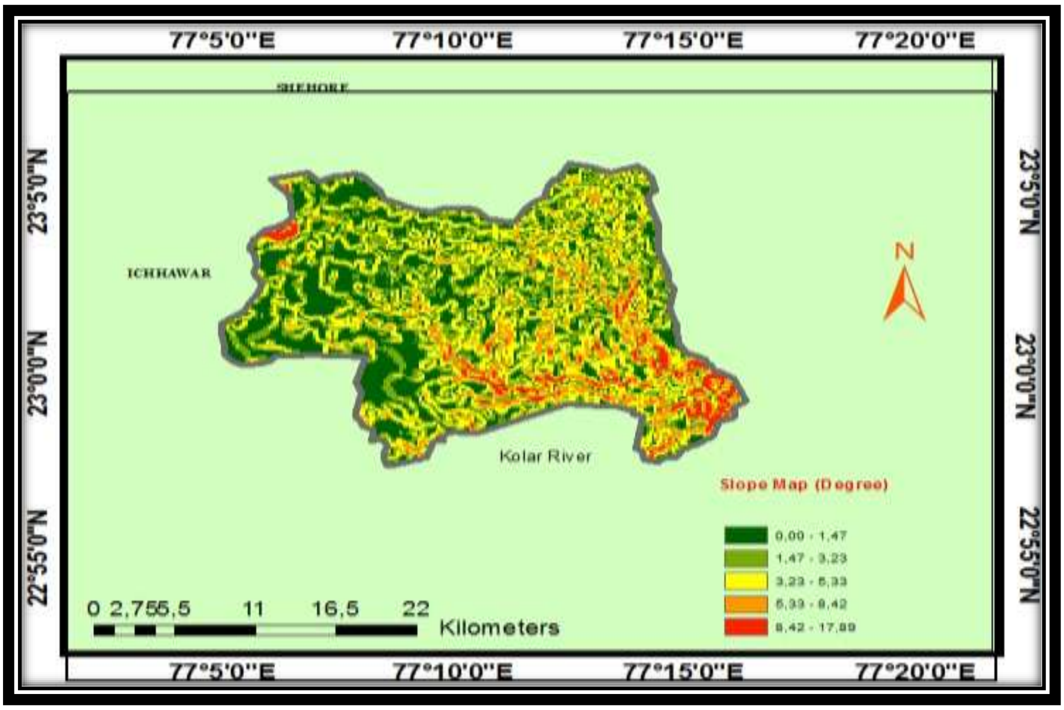

Fig. 6: Slope Percentage Map of Kolar watershed

Table 4
Slope map area distribution of Kolar watershed

S. N.	Slope Map (Degree)	Area (Sq. Km)	Percentage Area (%)
1	0.00-1.47	141.20	27.10
2	1.47-3.23	157.92	30.30
3	3.23-5.33	147.40	28.30
4	5.33-8.42	55.81	10.71
5	8.42-17.89	18.73	3.59
6	Total	521.06	100

1. Soil map and soil texture of Kolar show that it well-drained watershed with the availability of water during cultivation seasons and stream order varying from one to five. Length of streams declines with an increment in stream order and vice-versa for mean stream order.
2. Bifurcation ratio of 4.11 shows no structural disturbances in the watershed.
3. Drainage density is 1.24 and drainage texture of 2.72 shows the course nature of watershed.
4. The low class of Dd shows an inadequately drained watershed beside a sluggish hydrologic response.
5. Stream frequency of 4.69 shows that the selected watershed has low relief, medium permeable subsoil material and less vegetation cover.
6. The circulatory ration of 0.44, form factor like 0.3 and elongation rate of 0.619 mean that the watershed is elongate in shape which is quite evident from the shapefile.
7. Compactness coefficient of the watershed is 1.5 which indicates that low peak flows for a longer duration.
8. Relief ratio of 3.53 shows steep slopes in the watershed. Aspect ratio map shows the eastward nature of the existing slope which ensures good availability of solar radiation and heat throughout the year.
9. Slope map shows more runoff and less filtration of water. LULC shows that most of the areas of watershed are cultivable land followed by forestland and water bodies.

So, the applicability of GIS and RS in watershed attributed analysis has immense help in water conservation practice and management, water budgeting, decision making and further studies for developing the basin for increased water intake via interlinking of nearby rivers. The hypsometric curve also gives the idea about erosion possibility, sub-watershed prioritization and area-elevation relationship.

The overall methodology discussed here combines morphometric and hypsometric studies which are helpful in all phases namely exploration of hidden potential, planning, construction of water resource structure, their operation and maintenance for dam operations, gate opening indicators, drought and streamflow analysis, irrigation operations etc.

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