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Assessment and morphometric analysis for prioritizing erosion-prone area in RS and GIS environment

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Abstract
The land and water, limited in nature are decreasing continuously. Planning and management of these natural resources requires enormous data. Geo-morphological characteristics of a watershed are commonly used parameters for developing the regional scale hydrological models for resolving various hydrological issues of the ungauged watersheds. Applications of geographical information system (GIS) techniques are much time saving, efficient, and appropriate for geospatial planning. GIS can handle complex issues and huge databases for manipulation and retrieval. An accurate understanding of the hydrological behaviour of watershed is important for effective management. In India most of the watersheds are ungauged. So, the morphometric characterisation of watershed can play an important role in inadequate data collection. The morphometric characteristics of a watershed represent its attributes and can be helpful in synthesizing its hydrological behaviour. The present study was focused on prioritization of 18 subwatersheds of the Panam catchment based on GIS environment through morphometric analysis. Morphometric analysis and prioritization of watersheds are very important for water resource modelling and flood management practices. Priority of watershed was allotted on the basis of compound parameter value, which means that the level of soil erosion increased with decreased in values of compound parameters or the priority increases with decrease in their values. The ascending order of priority of watersheds according to compound parameter was MHL43nf10II, MHL43nf10, MHL43nf3, MHL43nf16, MHL43nf13, MHL43nf9, MHL43nf2, MHL43nf15, MHL43nf1, MHL43nf10I, MHL43nf14, MHL43nf7, MHL43nf4, MHL43nf11, MHL43nf12, MHL43nf8, MHL43nf6 and MHL43nf5. The watershed MHL43nf10II possessed highest priority 1 which indicated greater degree of erosion and hence, it becomes potential candidate for applying soil and water conservation, vegetation, and forestation etc. measures. While, the other watersheds with lower priorities were subjected to lower degree of erosion. Thus the morphometric and runoff potential properties determined for this basin as whole and for each watershed would be useful for the sound planning of water harvesting and groundwater recharge projects.

Keywords: Assessment, morphometric analysis, RS, GIS environment

1. Introduction
The natural resources, i.e., land and water are very limited and its availability is decreasing continuously due to growing population pressure. Therefore, planning and management of these natural resources is the dire need for the sustainable and judicious use. Ever increasing population pressure, urbanization and imperviousness of land surface has been resulting the scarcity of availability of land and water resources. In India, 172 m ha about 53 % of the total area suffers from serious soil erosion and other forms of degradation. In India that supports 16 % of the world's population on 2 % of the global land area, the problem is too serious (Sebestain *et al.* 1995). Therefore, planning and management of land and water resources on a sustainable basis without deterioration and with constant increase in productivity is the mainstay for mankind. For efficient and sustainable management of natural resources, watersheds or hydrological units are considered efficient and appropriate for the necessary survey and investigation/assessment and subsequent planning and implementation of various development programs such as soil and water conservation, catchment area development, erosion control in catchment, command area development, dry land or rain-fed farming and reclamation of ravine lands etc. The hydrologic units are equally important for the development of water resources through major, medium and minor storage projects as well as farm level water harvesting structures.

So, the watershed approach is more rational, because land and water resources have optimum interaction and synergetic effect when developed on the watershed basis. An accurate understanding of the hydrological behaviour of watershed is important for effective management. In India most of the watersheds are ungauged. So, the morphometric analysis of watershed can play an important role in inadequate data collection. The morphometric characteristics of a watershed represent its attributes and can be helpful in synthesizing its hydrological behavior (Pandey *et al.* 2004) [2]. Studies conducted by Sanware *et al.* (1988) [7], Prasad *et al.* (1992) and Sharda *et al.* (1993) [31] concluded that remote sensing and GIS techniques have a great use in characterization and prioritization of watershed areas. It is very difficult to develop a large area in one stretch, due to some geo-hydrological, geo-environmental and economic conditions. So, there is a need to identify and prioritize the area while executing the developmental activities.

The present study is focused on prioritization of 18 subwatersheds of the Panam catchment based on GIS environment through morphometric analysis. Morphometric analysis and prioritization of watersheds are very important for water resource modelling and flood management (Youssef *et al.*2011; Miller and Craig 2010; Bali *et al.* 2012). It includes identification and evaluation of watershed which contributes to excessive erosion losses using faster and indirect methods and established relationships. Prioritizing erosion-prone areas in the catchment is essential when financial resources for executing a conservation plan are limited. The area most likely to contribute to a large volume of sediment, and which are susceptible to a high degree of erosion, get higher priority in treatment.

2. Description of study area

The area selected for present study was Panam reservoir catchment, the sub basin of Mahi Lower basin. The Mahi basin extends over an area of 34,842 Sq. km. and lies between 72° 21' E to 75° 19' E and 21° 46' N to 24° 30' N. The basin is comprised of two sub-basins *viz.*, Mahi upper sub basin (65.11% of total basin area) consisting of 41 watersheds and Mahi lower sub basin (34.89% of total basin area) consisting of 22 watersheds. The principal tributaries of the river are the Som, which rises on eastern slopes of Aravalli in Udaipur district of Rajasthan and Anas which rises from Jhabua district of Madhya Pradesh joining Mahi in Dungarpur district of Rajasthan. The Panam rises near Bhabra in Jhabua district of Madhya Pradesh joining Mahi from left in Panch Mahals district of Gujarat. The river flows about 538 km through Dhar, Jhabua and Ratlam districts of Madhya Pradesh, Banswara in Rajasthan and Panch Mahal districts of Gujarat before falling into the Arabian Sea through the Gulf of Khambhat in Kheda district of Gujarat. The Panam has a total length of about 136 km and drainage area of about 2349.04 Sq km. having an average annual rainfall is 940 mm. The Panam catchment is part of Mahi Lower sub basin as shown in Fig.1.

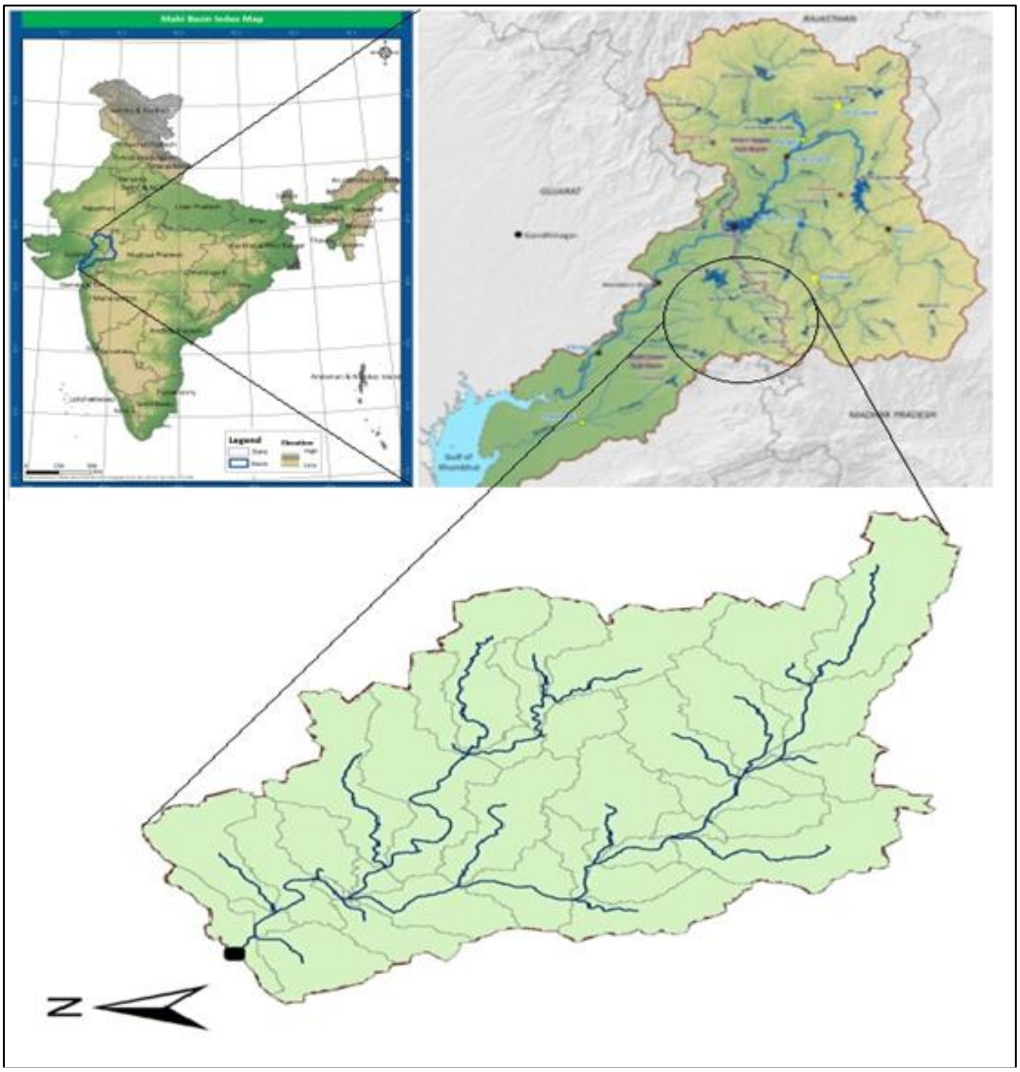

Fig 1: Location map of study area (Panam catchment)

3. Methodology

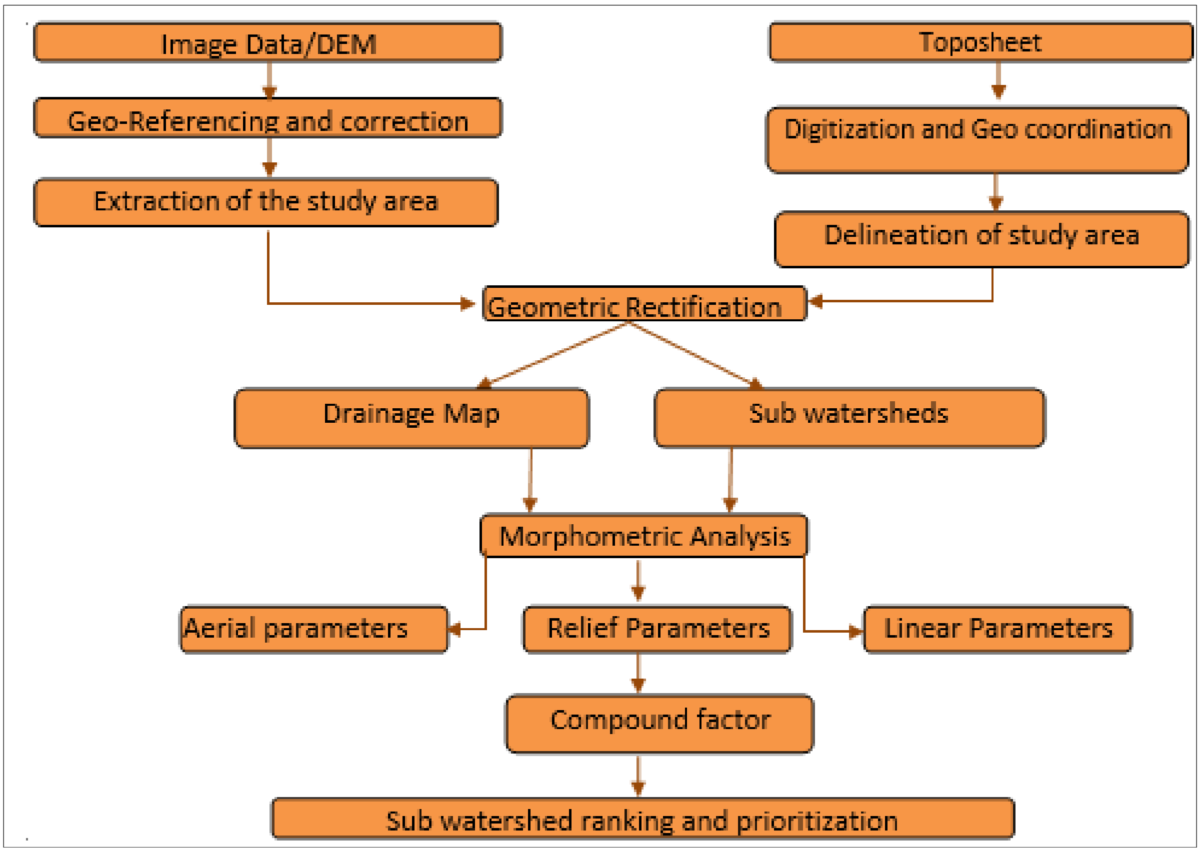

Fig 2: Flow chart for the calculation of morphometric characters

The response of a particular watershed to different hydrological processes and its behaviour depends upon various physiographic, hydrological and geomorophological parameters. Though, these are watershed specific and thereby unique, the characterization of a watershed provides an idea about its behaviour. Hydrologists attempted to relate the hydrologic response of watersheds to watershed morphologic characteristics. The overall methodology adopted for the characterisation of watershed parameters is depicted in Fig.2.

3.1 Computation of morphological characteristics

Computation of watershed morphological characteristics is a prerequisite to further detailed hydrological analysis of the watershed. Morphological characteristics like stream order, drainage density, aerial extent, watershed length and width, channel length, channel slope and relief aspects of watershed are important in understanding the hydrology of the watershed. Runoff response of the watershed is different for various slopes, shapes, lengths, widths and areas of watershed. Response is also affected by the factors like drainage density, length of overland flow, stream frequency, relative relief and relief ratios. A detailed analysis of the drainage network in a watershed can provide valuable information about watershed behaviour which will be useful for further hydrological analysis. The order, pattern and density of drainage have a profound influence on watershed as to influence runoff, infiltration, land management etc. It determines the flow characteristics and thus erosional behaviour. The Geographic Information System (GIS) has unique features to relate to the point, linear and area features in terms of the topology as well as connectivity (Murali, 2006). Increased interest is being directed to the mapping of hydro-geomorophological characteristics using GIS and Remote Sensing techniques. Walsh (1998) described the applications of remote sensing and GIS for geomorphic research. Watershed boundary map, drainage network map and contour map were prepared and utilized for computation of the morphological characteristics of the watershed using Arc GIS 9.1. Important watershed characteristics included in the study are discussed in terms of linear, aerial and relief aspects.

A common task in hydrology is to delineate the watershed from a topographic map. The Survey of India topographic maps on a scale of 1:50,000 were collected. The collected topographic sheets were scanned and registered with tic points and rectified in Arc map of Arc GIS 9.1. Further, the rectified maps were projected and merged together as a single layer. The present study area of Panam catchment was delineated in GIS environment. Stream network of the study area is digitized from SOI toposheets of 1:50000 scale which are geocoded in ERDAS Imagine 9.1. One of the first attributes to be quantified was the hierarchy of stream segments according to an ordering classification system based on ranking of streams proposed by Strahler (1964) [36]. In this system, channel segments were ordered numerically from a stream's Headwaters to a point somewhere down stream. Numerical ordering begins with the tributaries at the stream's headwaters being assigned the value 1.A stream segment that resulted from the joining of two 1st order segments was given an order of 2nd. Two 2nd order streams formed a 3rd order stream, and so on. The trunk stream through which all discharge of water passes is therefore the stream segment of the highest order. The number of stream segments present in each order along with their lengths is recorded in the topology built by GIS. Formulae and relationships for the computation of the morphometric parameters are listed in Table 1.

Table 1: Formulae and relationships for the computation of the morphometric parameters

Morphometric parameter	Formula/Relationship	Reference
Stream order	Hierarchical rank	Strahler,1964
Stream length	Length of stream	Horton,1945
Mean Stream length	Lsm=Lu/Nu, where, Lu=Total stream length of order u, Nu=Total no of stream segments of order u	Strahler,1964
Stream length ratio	RL= Lu/Lu-1, Where, Lu=Total stream length of order, u", Lu-1=the total stream length of its next lower order.	Horton,1945
Bifurcation ratio	R_b= Nu/Nu+1, Nu= total number of stream segments of order u, Nu+1= number of stream segments of the next higher order.	Schumn,1956
Mean Bifurcation ratio	Rbm= average of the bifurcation ratio of all order	Strahler,1957
Relief ratio	Rh= H/L_b, where H= total relief (relative relief) of the basin, L_b= basin length.	Schumn,1956
Drainage density	D= Lu/A, where A is the total area of the basin (km)^2, Lu is the total stream length of all orders.	Horton,1932
Stream frequency	Fs= Nu/A, Where Nu is the total number of streams of all order, A is basin area in km^2	Horton,1932
Drainage Texture	Rt= Nu/P, where Nu is the total number of streams of all order, P is the perimeter of the basin in km^2	Horton,1945
Form factor	Rf= A/Lb^2 is the square of the basin length (km), A is the basin area in km^2	Horton,1932
Circularity ratio	Re= 4π A/P^2, where A is the area (km)^2 and p is the perimeter (km) of the watershed	Miller,1953
Elongation ratio	Re= 2sqrt (A/π)/Lb, where A is the area (km)^2 and P is the perimeter (km) of the watershed	Schumn,1956
Length of overland flow	Lg= 1/(D*2), where D is the drainage density	Horton,1945

An integrated and comprehensive watershed management, which envisages optimal utilization of land, water and vegetation of a watershed, is achieved through multiple objectives such as controlling damaging runoff thereby controlling erosion and effect reduction in the sediment production as well as enhancing ground water storage and appropriate use of the land resources in the watershed. Formulation of proper management programs requires reliable and up-to-date information about various factors such as size and shape of the watershed, topography, soil, land use/ land cover, drainage parameters etc. Therefore, prioritization of the watershed is suggested for systematic planning to make the best use of the land and water resources and their management.

The morphometric parameters i.e Bifurcation ratio (Rb), Stream Frequency (Fs), Length of overland flow (Lg), Texture Ratio(T), Drainage Density (Dd), Elongation Ratio (Re), Form Factor (Rf), Circulatory Ratio (Rc) and Compactness Coefficient (Cc) are also termed as erosion risk assessment parameters or linear parameters and have been used for prioritizing watersheds (Biswas *et al.*, 1999) [4]. These linear parameters such as Bifurcation ratio (Rb), Stream Frequency (Fs), Length of overland flow (Lg), Texture Ratio (T) Drainage Density (Dd), and relief parameters like relief, relative relief and relief ratio have a direct relationship with erodibility, higher the value, more is the erodibility. Hence, for prioritization of watershed, the highest value of linear parameter is rated as rank 1, second highest value is rated as rank 2 and so on, and the least value is rated last in rank. Shape parameters such as Elongation Ratio (Re), Form Factor (Rf), Circulatory Ratio (Rc) and Compactness Coefficient (Cc) have an inverse relationship with erodibility (Ratnam *et al*. 2005), lower the value, more is the erodibility. Thus, the lowest value of shape parameters is rated as rank 1, next lower value was rated as rank 2 and so on and the highest value is rated last in rank. Hence, the ranking of the watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters.

After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each watershed were added up for watersheds to arrive at compound value (Cp). Based on average value of these parameters, the watershed having the least rating value is assigned highest priority; next higher value is assigned second priority and so on (Mishra *et al*. 2010). The watershed which got the highest Cp value is assigned last priority.

4 Results and Discussion

4.1 Delineation of sub watershed boundary

The study area, Panam catchment was divided into 18 sub watersheds with codes viz., MHL43nf1, MHL43nf2, MHL43nf3, MHL43nf4, MHL43nf5, MHL43nf6, MHL43nf7, MHL43nf8, MHL43nf9, MHL43nf10, MHL43nf10I, MHL43nf10II, MHL43nf11, MHL43nf12, MHL43nf13, MHL43nf14, MHL43nf15 and MHL43nf16 as shown in Fig. 3.

4.2 Extraction of digitized soil map

The soil map of the Panam catchment is presented in Fig. 5.10 and the soil texture pattern is shown in Table 2. The GIS analysis showed that 5.16, 0.01, 30.68, 22.20 and 41.95 per cent area is having soil type of clayey, course loamy, fine, fine loamy and loamy respectively. It was seen that the loamy soil exist in major part of the catchment area and some part contains the clayey soil.

Table 2: Soil texture pattern of Panam catchment

Sr. no	Area coverage (%)	Texture	Taxonomical description	
1	5.16	Clayey	Clayey, Mixed, Hyperthermic, calcareous, Lithic, Ustochrepts	Inceptisols
2	0.01	Coarse Loamy	Coarse Loamy, Mixed, Hyperthermic, Fluventic Ustochrepts	Inceptisols
3	30.68	Fine	Fine, Mixed, Hyperthermic,Vertic, Ustochrepts	Inceptisols
4	22.20	Fine Loamy	Fine Loamy, Mixed, Hyperthermic, Fluventic, Ustochrepts	Entisols
5	41.95	Loamy	Loamy, Mixed, Hyperthermic, Lithic Ustochrepts	Inceptisols

4.3 Geomorphological analysis of sub watersheds of Panam catchment

The catchment was divided into 18 sub watersheds with codes viz., MHL43nf1, MHL43nf2, MHL43nf3, MHL43nf4, MHL43nf5, MHL43nf6, MHL43nf7, MHL43nf8, MHL43nf9, MHL43nf10, MHL43nf10I, MHL43nf10II, MHL43nf11, MHL43nf12, MHL43nf13, MHL43nf14, MHL43nf15 and MHL43nf16 considering the geo-morphological parameters as shown in Fig.3.

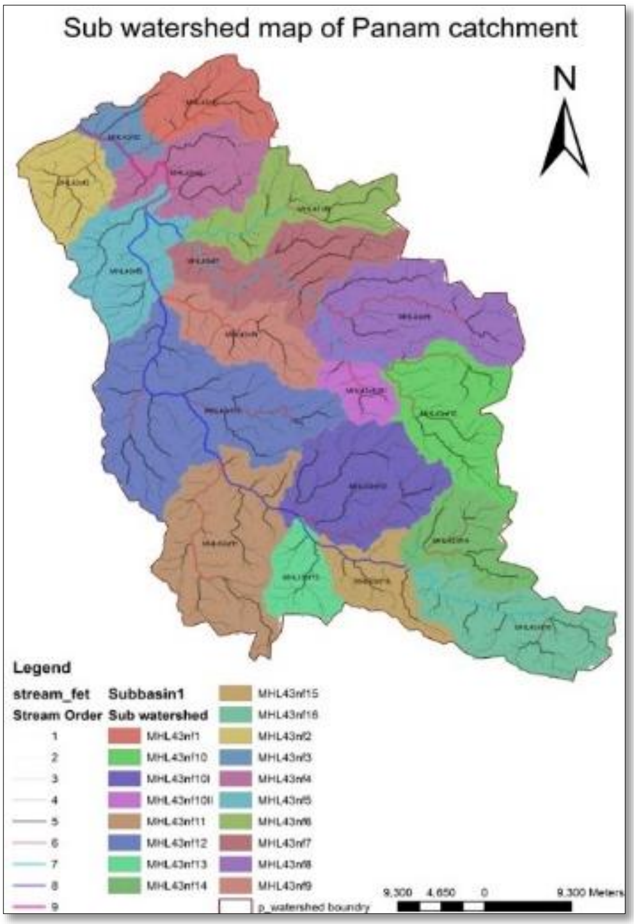

Fig 3: Sub watersheds of Panam catchment

4.3.1 Linear aspects of sub watersheds of Panam catchment

The linear aspects consist of stream order, stream number, bifurcation ratio, stream length ratio and length of overland flow. All the values of all 18 sub watersheds are shown in Table 3

Generally higher the order, longer the length of stream was noticed in the nature. Longer length of stream is advantages over the shorter length, in that the former collects water from wider area and greater option for construction a bund along the length. Lower stream lengths are likely to have lower runoff (Chitra *et al.*, 2011). The higher amount stream order indicates lesser permeability and infiltration in these sub watersheds. The number of streams in each order varied

Because of the physiographic conditions of the particular area. Drainage patterns of stream network from the basin observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. This pattern is characterized by a tree like or fern like pattern with branches that intersect primarily at acute angles. While in some parts of the basin represent parallel pattern type indicating that the topographical features are dipping, folded and highly jointed in the hilly terrains. A parallel drainage pattern consists of tributaries that flow nearly parallel to one another and all the tributaries join the main channel at approximately the same angle. Parallel drainage suggested that the area has a gentle, uniform slopes and with less resistant bed rock (Jensen, 2006). The 1st order streams were found highest in watershed MHL43nf12 (2498 nos.) while, lowest in MHL43nf3 (335 nos.). The 2nd order streams were found highest in watershed MHL43nf12 (589 nos.) while, lowest in MHL43nf3 (79 nos.). In that way, the number of streams usually decreased as the stream order increased. The higher amount stream order indicated lesser permeability and infiltration (Chitra *et al*, 2011). More number of streams in a basin indicated that the topography was youthful and still undergoing erosion. The number of stream segment of different order has been plotted against stream order. Straight line plot indicated that streams of each sub watershed adhere to the Horton principle. However, variation in trend and low value of correlation coefficients may be due to consideration of segments of high order stream. The analysis of bifurcation value showed that the basin and its watersheds possesses well developed drainage network as the bifurcation ratio ranges between 3.1 to 5.0 i.e. low value. The lower bifurcation ratio (3 to5) values are characteristics of the watershed, which has suffered less structural disturbances and the drainage pattern has not been distorted by the structural disturbances (Strahler, 1964) [36]. Horton's law (1945) [14] of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geomorphic series with streams length towards higher order of streams. The stream length ratio of the present study area revealed that there was a variation in stream length ratio in each watershed. Changes of stream length ratio from one order to another order indicated their late youth stage of geomorphic development. Most of the watersheds showed both increasing and decreasing trend in the length ratio from lower order to higher order.

Lower values of length of overland flow reflected low permeability, steep to very steep slopes and high surface runoff. A larger value of length of overland flow indicated longer flow path and thus, gentle slopes. The lower values of length of overland flow indicated that the watersheds were at matured stage and structurally complex in nature (Sethupathi *et al.*, 2011) [30].

Table 3: Linear aspects of sub watersheds of Panam catchment

Sub watershed	Perimeter (km)	Area (Sq.km)	Length of overland flow (km)	Bifurcation ratio (N_u/N_{u+1})	Stream length ratio (L_{u+1}/L_u)
MHL43nf1	59.927	91.21	0.067	3.789	2.342
MHL43nf2	51.068	83.08	0.064	3.746	2.330
MHL43nf3	40.652	40.06	0.056	3.713	2.692
MHL43nf4	81.241	117.28	0.064	3.994	5.467
MHL43nf5	80.336	130.97	0.066	3.100	4.450
MHL43nf6	100.963	123.01	0.062	3.255	2.280
MHL43nf7	101.687	152.42	0.062	3.956	4.364

MHL43nf8	92.640	197.80	0.064	3.599	2.137
MHL43nf9	77.260	102.06	0.065	3.879	2.267
MHL43nf10	84.737	151.48	0.063	3.833	2.263
MHL43nf10I	74.755	177.89	0.06	3.789	2.366
MHL43nf10II	36.898	42.38	0.054	3.303	2.472
MHL43nf11	108.183	225.84	0.066	5.039	2.307
MHL43nf12	135.703	320.50	0.067	4.279	2.409
MHL43nf13	49.034	61.81	0.066	4.023	2.448
MHL43nf14	68.213	96.51	0.067	3.134	2.487
MHL43nf15	70.204	76.84	0.062	3.300	1.942
MHL43nf16	90.288	157.91	0.063	3.903	2.929

4.3.2 Aerial aspects of sub watersheds of Panam catchment

The aerial parameters like drainage density, stream frequency, elongation ratio, form factor, circularity ratio, compactness coefficient and drainage texture were found as presented in Table 4.

Table 4: Aerial aspects of sub watersheds of Panam catchment

Sub watershed	Drainage density (km/km^2)	Stream frequency (1/km^2)	Elongation ratio	Circularity ratio	Form factor	Compactness coefficient	Drainage texture (1/km)
MHL43nf1	7.448	11.194	0.123	0.319	0.352	1.770	17.037
MHL43nf2	7.776	11.182	0.117	0.400	0.360	1.580	18.192
MHL43nf3	8.914	11.183	0.081	0.304	0.308	1.812	11.021
MHL43nf4	7.848	11.170	0.139	0.223	0.257	2.116	16.125
MHL43nf5	7.590	11.186	0.147	0.255	0.248	1.980	18.236
MHL43nf6	8.031	11.145	0.143	0.152	0.154	2.568	13.579
MHL43nf7	8.024	11.009	0.159	0.185	0.119	2.324	16.502
MHL43nf8	7.837	11.178	0.181	0.289	0.387	1.858	23.867
MHL43nf9	7.634	11.179	0.130	0.215	0.218	2.157	14.768
MHL43nf10	7.975	11.150	0.158	0.265	0.281	1.942	19.932
MHL43nf10I	8.287	10.906	0.171	0.400	0.314	1.581	25.951
MHL43nf10II	9.249	11.233	0.084	0.391	0.376	1.599	12.900
MHL43nf11	7.532	10.122	0.193	0.242	0.236	2.031	21.131
MHL43nf12	7.474	10.415	0.230	0.219	0.242	2.138	24.598
MHL43nf13	7.619	10.726	0.101	0.323	0.275	1.759	13.521
MHL43nf14	7.468	11.076	0.126	0.261	0.321	1.959	15.671
MHL43nf15	8.108	11.049	0.113	0.196	0.170	2.259	12.093
MHL43nf16	7.956	11.222	0.161	0.243	0.239	2.027	19.626

The all sub watersheds showed high drainage density (greater than 2 km/km^2) due to the presence of impermeable sub surface material, sparse vegetation and high relief (Nag, 1998, Sethupathi *et al.*, 2011) [30]. High drainage density is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Chow 1964) [7. 36]. The Drainage density of the all sub watersheds revealed that the nature of subsurface strata was impermeable, which is a characteristic feature of very fine drainage as the density values were higher than 5.

The stream frequency for all 18 sub watersheds showed positive correlation with the drainage density which indicated that the stream population increases with the increase of drainage density in all 18 watersheds (Rao *et al.*, 2010) [25, 26, 31].

The value of elongation Ratio (Re) generally varies from 0.6 to 1.0. It is associated with a wide variety of climate and geology and can be grouped into four categories i.e. circular (greater than 0.9), oval (0.9 to 0.8), less elongated (less than 0.7 to 0.8) and elongated(less than 0.7) as per Strahler, 1964. All the 18 sub watersheds can be considered as elongated in nature. The elongated watershed with low value of form factor indicated that the basin has a flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin. The form factor of the all 18 sub watersheds ranged from 0.119 to 0.387. Low form factor value leads to less side flow for shorter duration and high main flow for longer duration (Sethupathi *et al.*, 2011) [30]. The index of form factor showed the inverse relationship with the square of the axial length and a direct relationship with peak discharge. The value of the form factor would always be less than 0.7854 (for a perfectly circular basin) (Chopra *et al.*, 2005) [6]. Smaller the value of form factor, the basin will be more elongated. The basin with high form factors have peak flow of shorter duration, whereas, elongated watershed with low form factors have lower peak flow with longer duration. In present case, all 18 sub watershed were in elongated. Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The texture ratio for all 18 sub watershed varied from 11.021 to 25.951. Texture ratio is classified into five classes i.e. very coarse (greater than 2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (greater than 8). In present study, all 18 sub watersheds have texture ratio of more than 8. Hence, very fine texture i. e higher runoff potential (Smith, 1950) [34].

4.3.3 Relief aspects of sub watersheds of Panam catchment

The parameters of relief aspects of all 18 sub watershed are presented in Table 5. The relief for sub watersheds viz., MHL43nf1, MHL43nf2, MHL43nf3, MHL43nf4, MHL43nf5, MHL43nf6, MHL43nf7, MHL43nf8, MHL43nf9, MHL43nf10, MHL43nf10I, MHL43nf10II, MHL43nf11, MHL43nf12, MHL43nf13, MHL43nf14, MHL43nf15 and MHL43nf16 was 0.342, 0.399, 0.445, 0.327, 0.212, 0.380, 0.567, 0.483, 0.463, 0.619, 0.61, 0.612, 0.551, 0.432, 0.581, 0.615, 0.620 and 0.594 km, respectively. It was suggested that low relief ranges between 0 to 100m, moderately relief between 100 to 300 m and high relief above 300m. The sub watershed MHL43nf5 was of low relief region, rest all 18 sub watersheds were of high relief region. The high relief value indicated low gravity of water flow as well as infiltration into the ground and high runoff conditions (Nongkynri *et al.*, 2011) [23]. Watershed relief is an index of the potential energy available in the drainage watershed. The greater relief, greater the erosional forces acting on the watershed (Patton, 1988) [7]. The watersheds having higher relative relief have higher runoff potential than others. Therefore, the watershed MHL43nf5 and MHL43nf10II had the lowest and highest runoff potential, respectively. The relief ratios of all 18 sub watersheds are presented in Table 5.44. It was noticed that the higher values of relief ratio indicated steep slope and high relief. The higher channel slopes in MHL43nf10II watershed indicated less time of concentration i.e. peak flow occurs in short time while lower slope in MHL43nf5watershed indicated less peaked flow for longer duration. Therefore, while constructing the water harvesting structures on channel of watershed MHL43nf10II, the outlet should be designed of higher discharge capacity and the rest components like headwall, sidewall and wing wall should also be of higher height for the designed storage capacity (Suresh, 2002). The drop structures in series in the channels of this watershed are recommended. The higher ground slope in case of MHL43nf2 and MHL43nf3lying in upper reach of the basin indicated lower time of concentration of overland flow. Also, the possibilities of soil erosion will be higher in this watershed. Therefore, *in-situ* soil and water conservation measures like contour farming, contour vegetative hedge and contour bunding should be given priority in watershed development program.

Table 5: Relief aspects of sub watersheds of Panam catchment

Sub watershed	Relief (km)	Relative relief (km/km)	Relief ratio	Channel slope, (km/km)	Ground slope, (km/km)
MHL43nf1	0.342	0.5707	0.0888	0.0135	0.0888
MHL43nf2	0.399	0.7813	0.1143	0.0167	0.1143
MHL43nf3	0.445	1.0947	0.2747	0.0249	0.2747
MHL43nf4	0.327	0.4025	0.0512	0.0098	0.0512
MHL43nf5	0.212	0.2639	0.0150	0.0059	0.0150
MHL43nf6	0.38	0.3764	0.0163	0.0086	0.0163
MHL43nf7	0.567	0.5576	0.0245	0.0101	0.0245
MHL43nf8	0.483	0.5214	0.0399	0.0136	0.0399
MHL43nf9	0.463	0.5993	0.0585	0.0136	0.0585
MHL43nf10	0.619	0.7305	0.0602	0.0170	0.0602
MHL43nf10I	0.61	0.8160	0.0430	0.0163	0.0430
MHL43nf10II	0.612	1.6586	0.0789	0.0367	0.0789
MHL43nf11	0.551	0.5093	0.0263	0.0114	0.0263
MHL43nf12	0.432	0.3183	0.0245	0.0076	0.0245
MHL43nf13	0.581	1.1849	0.0537	0.0247	0.0537
MHL43nf14	0.615	0.9016	0.0576	0.0226	0.0576
MHL43nf15	0.62	0.8831	0.0292	0.0186	0.0292
MHL43nf16	0.594	0.6579	0.0263	0.0147	0.0263

4.4 Prioritization of sub watersheds

The watershed prioritization was done on the basis of linear parameters consisting of bifurcation ratio, stream frequency, and length of overland flow, drainage density, texture ratio, relief, relative relief and relief ratio. The higher the values of these parameters, higher will be the degree of hazardous. The shape parameters like elongation ratio, circularity ratio, form factor and compactness coefficient varying inversely with the same (Mishra *et al*., 2010). The prioritization ranking was given based on the degree of hazardous and the final prioritization was done on the basis of compound parameter obtained from averaging the values of the rankings of the linear and shape parameters allotted to the watersheds.

4.4.1 Priority ranking for linear parameters

The priority of the watersheds on the basis of linear parameters was given on the basis of their magnitudes (Table 6). As the value of linear parameters increases, the priority ranking increases. So, the priority ranking based on bifurcation ratio is given in series to the sub watersheds MHL43nf11, MHL43nf12, MHL43nf13, MHL43nf4, MHL43nf7, MHL43nf16, MHL43nf9, MHL43nf10, MHL43nf1, MHL43nf10I, MHL43nf2, MHL43nf3, MHL43nf8, MHL43nf10II, MHL43nf15, MHL43nf6, MHL43nf14 and MHL43nf5. Similarly, based on stream frequency, priority of watersheds was assigned in the sequence of MHL43nf10II, MHL43nf16, MHL43nf1, MHL43nf5, MHL43nf3, MHL43nf2, MHL43nf9, MHL43nf8, MHL43nf4, MHL43nf10, MHL43nf6, MHL43nf14, MHL43nf15, MHL43nf7, MHL43nf10I, MHL43nf13, MHL43nf12 and MHL43nf11. The priority according to length of overland flow showed that MHL43nf1was the most severe and MHL43nf10IIwas the least severe. Texture ratios revealed that the watershed had the priority in the order of MHL43nf10I, MHL43nf12, MHL43nf8, MHL43nf11, MHL43nf10, MHL43nf16, MHL43nf5, MHL43nf2, MHL43nf1, MHL43nf7, MHL43nf4, MHL43nf14, MHL43nf9, MHL43nf6, MHL43nf13, MHL43nf10II, MHL43nf15 and MHL43nf3. According to drainage density, first priority was given to watershed MHL43nf10II and last to the watershed MHL43nf1, while based on the stream frequency, first to the MHL43nf10II and last to the MHL43nf11. According to the relief, relative relief and relief ratio, the first and last priority was given to the MHL43nf15, MHL43nf10II, MHL43nf3and MHL43nf5, MHL43nf5, MHL43nf5, respectively.

Table 6: Priority ranking for linear parameters

Sub watershed	Bifurcation ratio	Stream frequency	Length of overland flow	Drainage density	Texture ratio	Relief	Relative relief	Relief ratio
MHL43nf1	9	3	1	18	9	16	11	3
MHL43nf2	11	6	8	11	8	14	7	2
MHL43nf3	12	5	17	2	18	12	3	1
MHL43nf4	4	9	9	9	11	17	15	9
MHL43nf5	18	4	4	14	7	18	18	18
MHL43nf6	16	11	13	5	14	15	16	17
MHL43nf7	5	14	14	6	10	8	12	15
MHL43nf8	13	8	10	10	3	10	13	11
MHL43nf9	7	7	7	12	13	11	10	6
MHL43nf10	8	10	11	7	5	2	8	5
MHL43nf10I	10	15	16	3	1	5	6	10
MHL43nf10II	14	1	18	1	16	4	1	4
MHL43nf11	1	18	5	15	4	9	14	13
MHL43nf12	2	17	2	16	2	13	17	16
MHL43nf13	3	16	6	13	16	7	2	8
MHL43nf14	17	12	3	17	12	3	4	7
MHL43nf15	15	13	15	4	17	1	5	12
MHL43nf16	6	2	12	8	6	6	9	14

4.4.2 Priority ranking for shape parameters

The priority of the watershed is inversely proportional to the values of the shape parameters. This means that the level of soil erosion increases with decrease in values of shape parameters or the priority increases with decrease in their values as shown in Table 7. The ascending order of priority order according to elongation ratio is MHL43nf3, MHL43nf10II, MHL43nf13, MHL43nf15, MHL43nf2, MHL43nf1, MHL43nf14, MHL43nf9, MHL43nf4, MHL43nf6, MHL43nf5, MHL43nf10, MHL43nf7, MHL43nf16, MHL43nf10I, MHL43nf8, MHL43nf11 and MHL43nf12. The ascending order of priority order according to circularity ratio was MHL43nf6, MHL43nf7, MHL43nf15, MHL43nf9, MHL43nf12, MHL43nf4, MHL43nf11, MHL43nf16, MHL43nf5, MHL43nf14, MHL43nf10, MHL43nf8, MHL43nf3, MHL43nf1, MHL43nf13, MHL43nf10II, MHL43nf2 and MHL43nf10I. The priority was same according to form factor as that of elongation ratio. According to compactness coefficient the first priority is given to the watershed MHL43nf2and last to the MHL43nf6.

Table 7: Priority ranking for shape parameters

Sub watershed	Elongation ratio	Circularity ratio	Form factor	Compactness coefficient
MHL43nf1	6	14	15	5
MHL43nf2	5	17	16	1
MHL43nf3	1	13	12	6
MHL43nf4	9	6	9	13
MHL43nf5	11	9	8	10
MHL43nf6	10	1	2	18
MHL43nf7	13	2	1	17
MHL43nf8	16	12	18	7
MHL43nf9	8	4	4	15
MHL43nf10	12	11	11	8
MHL43nf10I	15	18	13	2
MHL43nf10II	2	16	17	3
MHL43nf11	17	7	5	12
MHL43nf12	18	5	7	14
MHL43nf13	3	15	10	4
MHL43nf14	7	10	14	9
MHL43nf15	4	3	3	16
MHL43nf16	14	8	6	11

The compound parameter values of all 18sub watersheds of Panam catchment were calculated and given in Table 8. Compound parameter was calculated by averaging the values of the rankings allotted to the watersheds. The value of compound parameters of the all 18 watersheds varied from 8.08 to 11.58. The individual values of compound parameters for the sub watershedsMHL43nf1, MHL43nf2, MHL43nf3, MHL43nf4, MHL43nf5, MHL43nf6, MHL43nf7, MHL43nf8, MHL43nf9, MHL43nf10, MHL43nf10I, MHL43nf10II, MHL43nf11, MHL43nf12, MHL43nf13, MHL43nf14, MHL43nf15 and MHL43nf16 was 9.17, 8.83, 8.50, 10.00, 11.58, 11.50, 9.75, 10.92, 8.67, 8.17, 9.50, 8.08, 10.00, 10.75, 8.58, 9.58, 9.00 and 8.50, respectively. Priority of watershed was allotted on the basis of compound parameter value. That means that the level of soil erosion increased with decreased in values of compound parameters or the priority increases with decrease in their values (Mishra *et al.*, 2010).Therefore the watershed MHL43nf10II should be treated first while MHL43nf5 at last. Highest priority indicated the greater degree of erosion in the particular watershed and it becomes potential candidate for applying soil conservation measures first. The final priority of watershed is shown in Table 8. and Fig. 4.

Table 8: Final priority of watersheds based on compound parameter

Sub watershed	Linear parameters								Shape parameters				C_p	Final Priority
	R_b	F_s	L_g	T	D_d	H	R_{hp}	R_h	R_e	R_f	R_c	C_c		
MHL43nf1	9	3	1	18	9	16	11	3	6	14	15	5	9.17	9
MHL43nf2	11	6	8	11	8	14	7	2	5	17	16	1	8.83	7
MHL43nf3	12	5	17	2	18	12	3	1	1	13	12	6	8.50	3
MHL43nf4	4	9	9	9	11	17	15	9	9	6	9	13	10.00	13
MHL43nf5	18	4	4	14	7	18	18	18	11	9	8	10	11.58	18
MHL43nf6	16	11	13	5	14	15	16	17	10	1	2	18	11.50	17
MHL43nf7	5	14	14	6	10	8	12	15	13	2	1	17	9.75	12
MHL43nf8	13	8	10	10	3	10	13	11	16	12	18	7	10.92	16
MHL43nf9	7	7	7	12	13	11	10	6	8	4	4	15	8.67	6
MHL43nf10	8	10	11	7	5	2	8	5	12	11	11	8	8.17	2
MHL43nf10I	10	15	16	3	1	5	6	10	15	18	13	2	9.50	10
MHL43nf10II	14	1	18	1	16	4	1	4	2	16	17	3	8.08	1
MHL43nf11	1	18	5	15	4	9	14	13	17	7	5	12	10.00	14
MHL43nf12	2	17	2	16	2	13	17	16	18	5	7	14	10.75	15
MHL43nf13	3	16	6	13	16	7	2	8	3	15	10	4	8.58	5
MHL43nf14	17	12	3	17	12	3	4	7	7	10	14	9	9.58	11
MHL43nf15	15	13	15	4	17	1	5	12	4	3	3	16	9.00	8
MHL43nf16	6	2	12	8	6	6	9	14	14	8	6	11	8.50	4

R_b: Bifurcation ratio, F_s: Stream frequency, L_g: Length of overland flow, T: Drainage Texture, $D_{d:}$ Drainage Density, H: Relief, R_{hp}: Relief ratio, R_h: Relative relief, R_e: Elongation ratio, R_f: Form factor, R_c: Circularity ratio, C_c: Compactness Coefficient C_p: Compound parameter

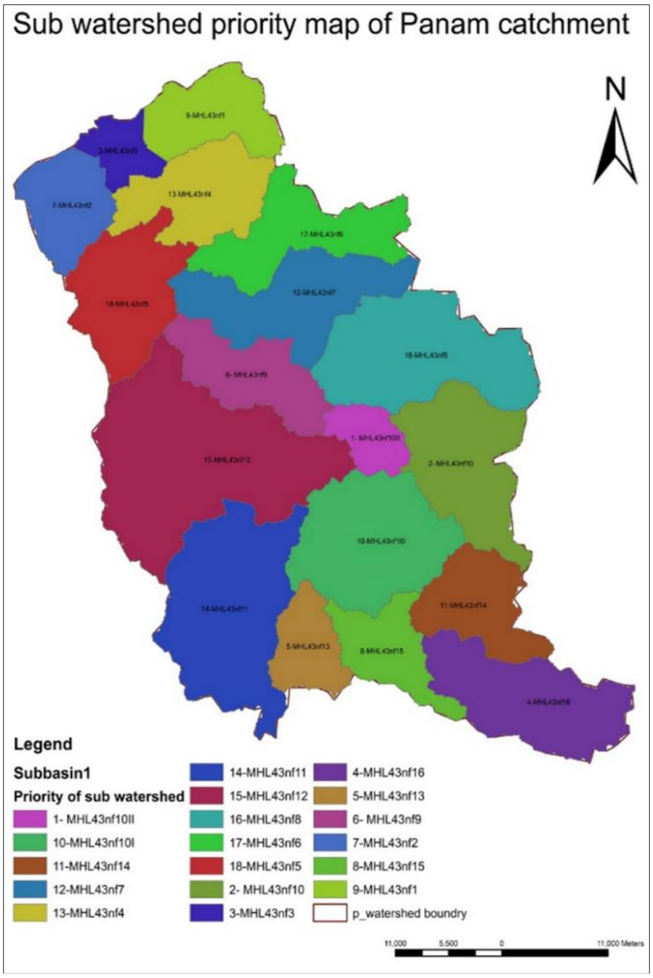

Fig 4: Sub watershed priority map of Panam catchment

5 Conclusions

The specific conclusions drawn from the present study are as follows;

1. The streams in the study area were found to be formed in different drainage patterns due to various landforms. The various drainage patterns observed were dendritic, parallel and trellis. The Panam catchment is a 9^{th} order drainage basin with total number of 26266.00 streams of which 19630, 4651, 1488, 379, 92, 19, 4, 2 and 1 streams were 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th} and 9^{th} order streams, respectively.
2. The mean bifurcation ratio value was 3.623 which indicated that the geological structures are not distorting the drainage pattern. The Bifurcation Ratio (Rb) values of study area indicated that there was a decrease in Rb values from one order to the next order.
3. The length of overland flow for Panam catchment was found as 0.06 km which indicated the low stream frequency in the catchment.
4. The drainage density of the basin was 7.824 km/km^2. As it is very high, more than 2 km/km^2, the study area comes under high drainage density which is sparsely vegetated and shows high relief in the study area.
5. The stream frequency of the study area was 11.182 km^{-2}. High value was observed in this catchment having low permeable geology, high relief and the almost steeper topography.
6. The form factor of the catchment was 0.305 i.e. low form factor value leads to less side flow for shorter duration and high main flow for longer duration.
7. Priority of watershed was allotted on the basis of compound parameter value. That means that the level of soil erosion increases with decrease in values of compound parameters or the priority increases with decrease in their values.
8. The ascending order of priority of watersheds according to compound parameter was MHL43nf10II, MHL43nf10, MHL43nf3, MHL43nf16, MHL43nf13, MHL43nf9, MHL43nf2, MHL43nf15, MHL43nf1, MHL43nf10I, MHL43nf14, MHL43nf7, MHL43nf4, MHL43nf11, MHL43nf12, MHL43nf8, MHL43nf6 and MHL43nf5.

The watershed MHL43nf10II possessed highest priority 1 which indicated greater degree of erosion and it became potential candidate for applying Soil and Water conservation, vegetation, forestation etc. measures, while the other watersheds with lower priorities were subjected to lower degree of erosion.

9. Thus the morphometric and runoff potential properties determined for this basin as whole and for each watershed will be useful for the sound planning of water harvesting and groundwater recharge projects.

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