Original Research Article

Categorization of Morphometric Surface through Morphometric Diversity Analysis in Kushkarani River Basin of Eastern India

ABSTRACT

The present work attempts to build up and categorize morphometric surface of distinct identities and potentialities considering 16 morphometric parameters as spatial data layers in GIS environment. For constructing the morphometric diversity model relative importance of the selected parameters is assessed and weighted compositing is being made. Separately, relief and drainage diversity models have been prepared and finally entire surface is categorized into some distinct morphometric sub units having their own terrain characteristics and associated cultural features. Out of total river basin only 11% area comes under highly diversified surface and maximum part of the area comes under quite monotonous surface with least variation. Highly diversified surface is prone to rilling, gullying and consequently soil erosion. It is also tried to identify whether relief and drainage model exert significant impact on morphometric diversity model. It is identified that relief diversity model carries significant impact on morphometric diversity model as indicated by high correlation coefficient (r=0.94).

Keywords: Mophometric surface, Weighting of parameters, Weighted linear combination (WLC), Drainage diversity model (DDM), Relief diversity model (RDM) and Morphometric diversity model (MDM).

1. INTRODUCTION

Landscape is an essentially visual phenomenon or as a particular constitution of topography, land use, vegetation cover and settlement pattern [1,2] and morphometric surface is one of the fundamental terrain base on which cultural and ecological conditions can be draped. Morphometric analysis includes a good number of quantitative indicators based on which terrain units can be recognized and each such terrain units **(unit)** provides a strong base of (**for**) analyzing terrain processes and associated cultural fabrics [3,4] . Previous studies focused on morphometric characteristics of various drainage basins using GIS and remote sensing technique for terrain analysis [5-11]. The Morphometric parameter (**parameters**) calculated in the study are flow directions, flow accumulation, upstream and downstream, stream link, stream network, stream order, and digital elevation models (DEMs) etc.[12,13]. Generally in this studies emphasize segregated statistical analysis or mapping of the individual morphometric parameters. Among then some studies correlate morphometric parameters and potential ground water investigation [14-20], recharge estimation[21-23] and surface water availability[24-26] etc. Some works (**studies**) laid importance on sub basin priority for promising planning unit [27-30]. The present work pursues how to indentify morphometric surface units using different morphometric parameters as spatial data layers. Primarily, drainage and relief morphometric surface(**s**) are tried to (delete) recognized and finally morphometric surface is also being identified. Here attempt is also being taken (**made**) regarding prioritizing incorporated parameters considering their importance towards bringing morphometric diversity.

Morphometric diversity analysis actually helps to find out some nearly homogenous landscape units which are uniform in morphometric characteristics. Each unit can be considered as a homogenous hydro-geomorphic spatial unit with unique nature and potential viability of land use. Landscape unit with highly diversified morphometric characteristics is healthy in geomorphic processes and forms and active in term(**s**) of ongoing terrain processes. On the contrary, lowly diversified landscape unit is characterized by relatively monotonous processes and forms. Each landscape unit is uniquely potential for resources and economic activities. This fact becomes highly vivid when range of morphometric differences is very high and size scale is very large. In case of small basin over homogenous physiographic unit, it is not so clear and therefore, not so effective for dictating the LULC characteristics [31, 32] . But some indirect influences can be streamlined. For example, morphometric diversity unit has its potentiality to characterize soil loss processes, runoff processes, recharge activities etc. These are often responsible for controlling LULC and livelihood opportunities. Hypsometric surface is well explained in relation to geology of the present study area using hypsometric integral (HI) of different sub basins by Khatun and Pal [33]. This surface envisages the erosion processes, soil loss, sediment deposition pattern etc.

2. STUDY AREA

Kushkarani river (length: 35 km) basin, covering an 172 sq km area (see fig-1), is a sub basin of Mayurakshi river system located mainly over the western part of Chottonagpur plateau fringe **in** Birbhum district of West Bengal and Jamtara district of Jharkhand with 23°54' 36'' N to 24°00' N latitudes and 87°14'24'' E to 87°30' E longitudes. The total basin area comes under **rarh** tract topography [34] with lateritic soil formation [35] which is mainly received by flowing rivers from Chottonagpur plateau. This river pours into Tilpara barrage which is located over master stream Mayurakshi river [36] . The elevation of this catchment varies **from** 155 m. (at the source region) to 62 m. (at the confluence region). Maximum area of the basin **shows** rugged topography with an average elevation of 108 m. Average slope of the basin is 1–4 degree whereas it is <1 degree in the confluence part of the basin measured as per Wentworth's method [37]. The basin falls under the hot and sub-humid monsoonal climatic region. The average annual rainfall is 1444 mm. Maximum (82%) rainfall **occurs from** June to September. There is a short rainy season in spring, March to May due to **nor'wester** (**NW**) disturbance. The estimated runoff of this basin area in monsoon time is 693.34 mm. which is also a significant factor for controlling soil erosion potentiality.

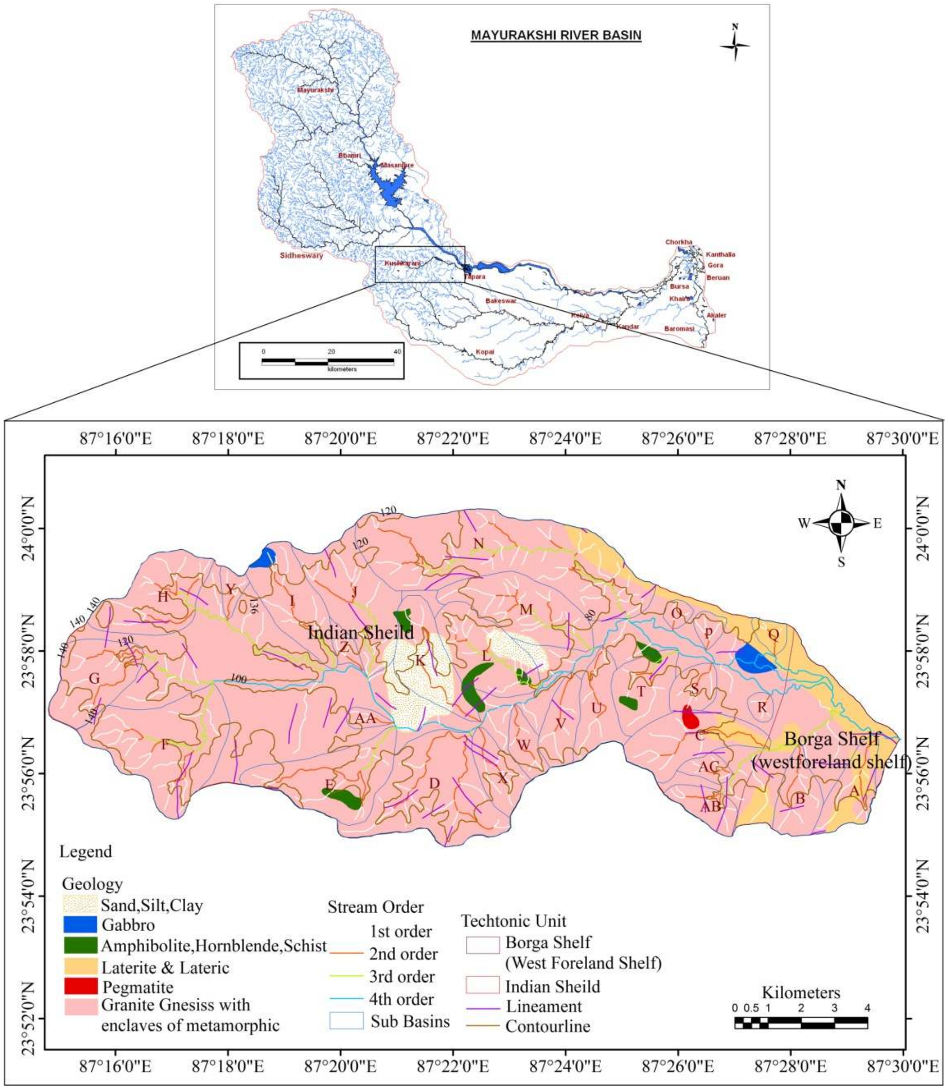


Fig: 1 Study Area map

3. MATERIALS AND METHODS

For constructing morphoetric surface and its categorization, 18 associated parameters have been taken into consideration. All the parameters have been described in table 1. All these data layers have been developed from Toposheets (SOI), satellite imageries and SRTM DEM of United States Gelogical Survey (USGS).

Table 1: Parameters and formulae of parameters

Parameters	Formulae
Bifurcation ratio(Rb)	Ratio of number of stream segments of one order to the number of the next higher order [38]
Stream frequency (Sf)	Total number of streams/Basin area [39]
Drainage density (Dd)	Total stream length/Basin area [40]
Drainage Texture (Dt)	Total number of stream in all segments /Basin perimeter [39]

Drainage Intensity (Di)	Drainage frequency/drainage density; Di=Sf/ Dd [40]
Infiltration Number (In)	In=Sf * Dd [40]
Areal symmetry (Aa)	Area of the low area of the stream/ Area of the more area of the stream [40]
Constant of Channel Maintenance(CCM)	1/Drainage density [38]
Length of overland flow (Lof)	1/Dd*0.5 [39]
Form factor (Ff)	Basin area/Basin length^2 [39]
Elevation (H)	Height at MSL.
Relief ratio(Rh)	Basin relief/Basin length [38]
Relative relief (Rhp)	Basin relief/(Perimeter × 100)[42]
Hypsometric Integral(Hi)	Ratio between Elevation and area
Average slope (s)	$\tan\theta = N \times \frac{I}{636.6}$ N=number of contour cuttings per miles or km.,I=contour interval, 636.6=constant[37]
Ruggedness number (Rn)	Basin relief * Drainage density [43]
Dissection index (DI)	DI= Dd * (H /1000) [44]
Hydraulic Gradient (HG)	HG=(hc-hf)/D*100 [45] hc=Height at source, hf=height at confluence D= Distance between source and confluence

3.1 Methodology for Constructing Morphometric Models:

For identifying morphoetric surface and its categorization, three models have been constructed, namely relief diversity model (RDM), drainage diversity model (DDM), morphometric diversity model (MDM). Separately these have been made for illustrating distinct characters of the drainage scape, relief scape and as a whole Morphometric surface. While selecting parameters some of the parameters are common because these can directly or indirectly represent both relief and drainage diversity. For example, birfurcation ratio is basically a drainage parameter but high bifurcation ratio indicates sudden change of the break of slope and thereby represents relief character also. **Similarly**, Ruggedness number is basically a relief parameter but it is highly associated with **terrain** ruggedness and can determine the arrangement of drainage network. Another motto behind such approach is to understand the role of drainage and relief parameters for bringing morphometric diversity over the basin area. Fractal analysis, discriminant analysis etc. were previously used by different scholars [46,47]for landscape identification, but present spatial approach can also be used for making such differences over surface. Two methods are mainly used for developing all the models, first one is simple Linear Combination (LC) method, where selected parameters are combined using raster calculator tool of Arc GIS 9.3 and another is Weighted Linear Combination (WLC) method of Carver [48] and Eastman [49] where combination of the parameters are made by emphasizing their relative importance. For calculating the weight of each parameter, PCA based correlation matrix is used and data standardization for the same is done using equation 1 and 2. All the layers adopted here have been converted into raster form because execution of compositing of layers is raster based. Two tier weighting has been done for each layer. One is intra parameter ranking based on 10 point scale. Selection of scale point should be based on level of accuracy required for work. Greater number of classes will provide precision in final output. Here 10 classes have been done for describing the entire spectrum of variable into manageable form. Maximum rank (e.g. 10) is provided to that class having maximum diversity. Secondly, weight is assigned to each parameter based on their relative importance to the aim. Weightage of each attribute has been defined objectively (see table 4 and5) considering the degree of correlation of each driving factor with each other. The logic behind this consideration is that highly correlated parameter maximally explains the spatial dissimilarity. Normalization of respective weight (values of r for respective parameters) based on dimension index has been done for considering it in a scientific scale. The result of each normalized value is called attribute weight.

Expression of weight calculation is as follows:

$$w_j = \frac{a_{j_r}}{\sum_{j=1}^{n} j_r} \text{ --- (Eq. 1)}$$

wj=weight of jth parameter; ajr= correlation coefficient of jth attribute; Σ jr = summation of correlation of all jth variable.

Rank of all sub classes under each attribute is then multiplied by the defined weight of each individual attribute. This function can be presented using the following formula.

$$\text{WLC}= \sum_{j=1}^{n} a_{ij} w_j \text{ ----------------------------------- (Eq. 2)}$$

Where, aij= ith rank of jth attribute; wj= weightage of jth attribute.

This weighted linear combination has been done using raster calculator tool in Arc GIS environment. Table 2 shows selected spatial data layers of different models. Table 3 depicts the selected 10 parameters for relief diversity model i.e. Ruggedness number, dissection index, elevation, relative relief, relief ratio, slope, hydraulic gradient, regional sinuosity, asymmetry factor and bifurcation ratio, their subclasses, sub classes ranges, subclass ranking and weight of the parameters following the 10 points scale and PCA based WLC. For drainage and overall morphometric diversity model, same type of process has been adopted but not described here separately. Table 4 shows logic behind 10 point scale distribution among the intra classes and normalization process for final weight generation. For example, slope is one of the parameters for this work. Here, 10 weights are assigned to highest degree of slope class because it causes maximum diversity over surface. Table 5 and 6 describe the same for drainage and morphometric diversity models.

Table 2 : Name and number of parameters used for different diversity models.

Type of model	Number of parameters	Name of the parameters
Relief diversity	10	Ruggedness number, dissection index, elevation, relative relief, relief ratio, slope, hydraulic gradient, regional sinuosity, asymmetry factor and bifurcation ratio
Drainage diversity	13	Drainage density, drainage frequency, Bifurcation ratio, relative relief, drainage intensity, drainage texture, regional sinuosity, junction frequency, constant channel maintenance, length of over land flow, infiltration number, form factor and ruggedness number.

Morphometric Diversity	16	Asymmetry, Stream Density, Stream Frequency, Drainage intensity, Dissection index, Drainage Texture, Form Factor, Hydraulic gradient (HG), Infiltration Number, Junction Frequency, Bifurcation Ratio, Relief Ratio, Relative Relief, Ruggedness Number, Elevation and Slope.

Table 3: Example of Assigning Ranks and weight of the parameters for construction relief diversity model

Parameters	Sub classes	Given rank	Weights of parameters	Parameters	Sub classes	Given rank	Weights of parameters
Dissection index	0.095-0.16	1	0.87	HG	0.26-0.57	1	0.52
	0.16-0.20	2			0.57-0.82	2	
	0.20-0.23	3			0.82-1.02	3	
	0.23-0.26	4			1.02-1.23	4	
	0.26-0.29	5			1.23-1.47	5	
	0.29-0.33	6			1.47-1.74	6	
	0.33-0.37	7			1.74-2.03	7	
	0.37-0.41	8			2.03-2.30	8	
	0.41-0.47	9			2.30-2.74	9	
	0.47-0.58	10			2.74-3.32	10	
Ruggedness number	0.00-0.005	1	0.77	Elevation	62-74	1	0.58
	0.005-0.011	2			74-83	2	
	0.11-0.015	3			83-91	3	
	0.015-0.19	4			91-99	4	
	0.19-0.024	5			99-106	5	
	0.024-0.029	6			106-113	6	
	0.029-0.034	7			113-121	7	
	0.034-0.041	8			121-129	8	
	0.041-0.05	9			129-138	9	
	0.05-0.063	10			138-155	10	
	0	1			0-1.06	10	
	0-15	2			1.06-1.11	9	

Relative relief	15-21	3	1	Sinuosity	1.11-1.18	8	0.32
	21-26	4			1.18-1.27	7	
	26-30	5			1.27-1.37	6	
	30-34	6			1.37-1.48	5	
	34-39	7			1.48-1.6	4	
	39-44	8			1.6-1.72	3	
	44-48	9			1.72-1.86	2	
	48-54	10			1.86-1.99	1	
Slope	0-0.38	1	0.79	Asymmetry Factor	0.29-0.35	1	0.59
	0.38-0.68	2			0.35-0.4	2	
	0.68-0.1	3			0.4-0.44	3	
	0.1-1.39	4			0.44-0.49	4	
	1.39-1.79	5			0.49-0.54	5	
	1.79-2.12	6			0.54-0.59	6	
	2.12-2.49	7			0.59-0.63	7	
	2.49-2.93	8			0.63-0.68	8	
	2.93-3.37	9			0.68-0.72	9	
	3.37-4.05	10			0.72-0.78	10	
Relief ratio	0.003-0.011	1	0.64	Bifurcation ratio	1.94-2.29	1	0.71
	0.011-0.022	2			2.29-2.73	2	
	0.022-0.038	3			2.73-3.18	3	
	0.038-0.055	4			3.18-3.54	4	
	0.055-0.073	5			3.54-3.83	5	
	0.073-0.089	6			3.83-4.22	6	
	0.089-0.11	7			4.22-4.69	7	
	0.11-0.12	8			4.69-5.17	8	
	0.12-0.14	9			5.17-5.62	9	
	0.14-0.15	10			5.62-6.08	10	

Table 4: **Rank distribution, logic behind rank distribution, correlation score and weighted score of Relief Diversity model**.

Parameters	**Rank**	**Logic**	**Total correlation score(Xi)**	**Weighted score Xi/Ximax**
Dissection index	10 rank at highly dissected area	Extreme dissected area is a very good indicator of relief diversity	4.03	0.87
Ruggedness number	10 rank at maximum rugged topography	More value of Ruggedness number enhance the relief diversity	3.57	0.77
Relative relief	10 rank at highest relative relief	Highest value of relative relief increase the relief diversity	4.63	1
Slope	10 rank at steep slope	Greater value of slope promote the relief diversity	3.65	0.79
Relief Ratio	10 rank at maximum relief ratio	More value of relief ratio demarcated more relief diversity	2.95	0.64
HG	10 rank at highest value of Hydraulic gradient	Higher value of hydraulic gradient shows greater relief diversity	2.38	0.52
Elevation	10 rank at maximum relief	Greater value of relief indicate the more relief diversity	2.66	0.58
Sinuosity	10 rank at less sinuous region	Where sinuosity is low, relief diversity is high	1.49	0.32
Asymmetry Factor	10 rank at more value of asymmetry	More asymmetry shows more relief diversity	2.71	0.59
Bifurcation ratio	10 rank at highest value of Bifurcation ratio	Higher value of Bifurcation ratio denotes the greater relief diversity	3.30	0.71

Table 5 : **Rank distribution, logic behind rank distribution, correlation score and weighted score of Drainage Diversity.**

Parameters	**Rank**	**Logic**	**Total correlation score(Xi)**	**Weighted score Xi/Ximax**
Drainage frequency	10 rank at maximum drainage frequency	Where drainage frequency is maximum Drainage diversity also maximum	5.40	0.914
Drainage density	10 rank at highest drainage density	High drainage density indicates higher drainage diversity.	5.91	1
constant channel	10 rank at more CCM value	High CCM value favorable for more	4.27	0.72

maintenance(CCM)		Drainage diversity		
Drainge intensity	10 rank at greater intensity	Maximum Drainage Intensity lead to drainage diversity	3.04	0.52
Length of over land flow(Lof)	10 rank at maximum value of Lof	High Lof indicates higher drainage diversity	5.68	0.96
6.Drainagre texture(Dt)	10 rank at maximum drainage texture	high value of DT maximized drainage diversity	5.57	0.94
7.Junction frequency	10 rank at highest junction frequency	More junction frequency positively effect on drainage diversity	3.18	0.54
Regional sinuosity	10 rank at lowest sinuosity	Drainage diversity is greater at less sinuous river zone	1.60	0.27
Infiltration number(In)	10 rank at more IN	More In value indicates more drainage diversity	4.54	0.77
Bifurcation ratio(Rb)	10 rank at highest Bifurcation ratio	Frequently flood occurrence observed in high drainage diversity area.	3.40	0.58
Form factor(Ff)	10 rank at highest form factor	Higher value of form factor highlights the absolute drainage diversity	2.82	0.48
Relative relief	10 rank at highest relative relief	High elevation represent greater drainage diversity	2.97	0.50
Ruggedness number	10 rank at greater ruggedness number	Drainage diversity is high in rough topography	5.76	0.97

Table 6: Rank distribution, logic behind rank distribution, correlation score and weighted score of Morphometric Diversity.

Parameters	**Rank**	**Logic**	**Total correlation score (Xi)**	**Weighted score (Xi/Xi max)**
Asymmetry	10 rank at high asymmetric value	High asymmetric value increase morphometric diversity	3.89	0.62
Drainage Density	10 rank at highest stream density	High stream density indicates higher morphometric diversity.	5.28	0.84
Stream Frequency	10 rank at maximum stream frequency	Where stream frequency is maximum morphometric diversity also maximum	5.17	0.83
Drainage intensity	10 rank at greater intensity	greater Drainage Intensity lead to more diversity	2.80	0.45
Dissection index	10 rank at higher dissected value	More dissected zone indicates more morphometric diversity	5.06	0.81
Drainage Texture	10 rank at maximum drainage texture	high value of drainage texture maximized morphometric diversity	5.05	0.81

Form Factor	10 rank at highest form factor	Higher value of form factor highlights morphometric variety	3.84	0.61
Hydraulic gradient	10 rank at greater HG value	More HG value enhance the differentiation of morphometric diversity	3.07	0.49
Infiltration Number	10 rank at more IN value	More In value indicates more morphometric diversity	4.11	0.65
Junction Frequency	10 rank at highest junction frequency	More junction frequency positively effect on morphometric diversity	4.27	0.68
Bifurcation Ratio	10 rank at highest Bifurcation ratio	Frequently flood occurrence observed in high morphometric diversity area.	5.38	0.86
Relief Ratio	10 rank at highest relief ratio	High relief ratio represent greater morphometric diversity	4.05	0.65
Relative Relief	10 rank at highest relative relief	High relative relief indicates higher morphometric diversity	5.74	0.91
Ruggedness Number	10 rank at greater ruggedness number	morphometric diversity is high in rough topography	6.27	1
Slope	10 rank at steep slope	Steep slope positively control morphometric diversity	4.22	0.67
Elevation	10 rank at high elevation	Morphometric diversity influenced by high elevation	4.41	0.70

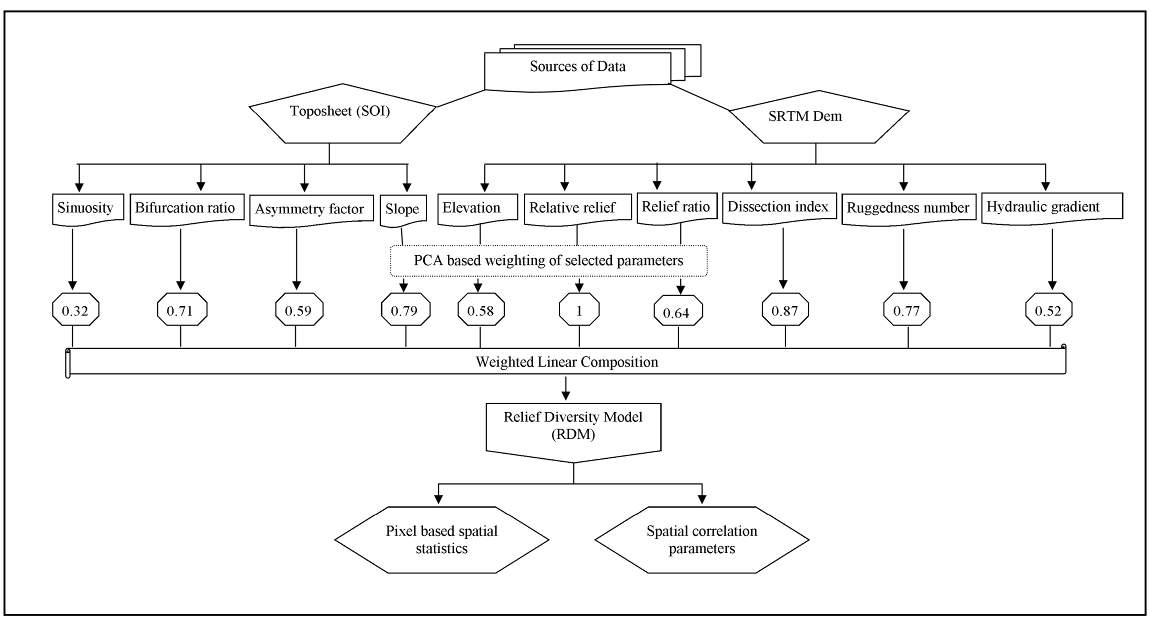


Fig: 2 Work Flow Diagram

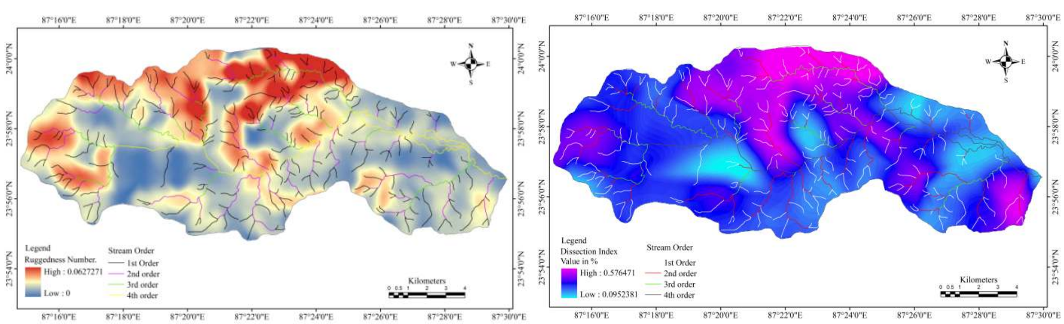
In figure 2 detail methodological flow for constructing relief diversity model has been made. For other cases same approaches have been adopted as shown here but most of the parameters are different.

4. RESULT AND DISCUSSION

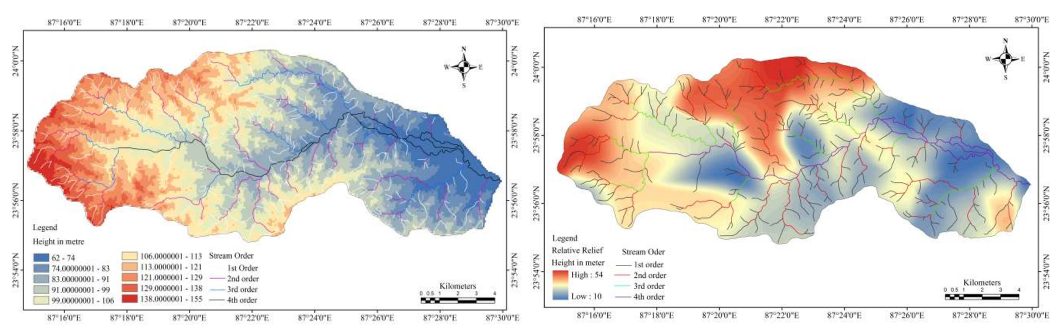
4.1 Spatial data layers used for the models

A brief account of some morphometric characteristics of Kushkarani river basin are as follows: total length of the stream is 33.83 km., bifurcation ration is 4.027, length of over land low is 0.88, constant of channel maintenance is 0.568, sinuosity is 1.33, form factor of the basin is 0.268, drainage density is 1.76 km/sq km. drainage texture is 4.36, drainage intensity is 3.75, hypsometric integral (HI) is 0.48, relative relief is 93m., dissection index (DI) is 0.808, and ruggedness number is 0.062. All these values are representative to the entire basin but spatial variation is very strong.

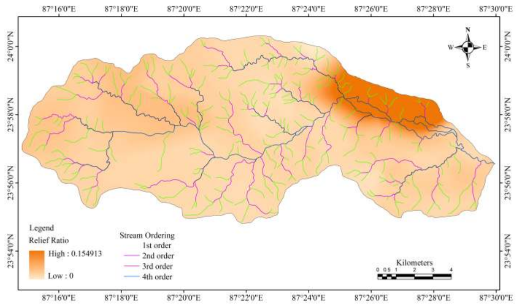
Figure 3 (A-S) represent different spatial data layers used for different diversity model. Different data layers behave differently towards the objective. For example in case of ruggedness number, relative relief, drainage density, intensity, frequency these are high in the upper catchment of the basin whereas it low in the same area i.e. form factor, bifurcation ratio and relief ratio. In the same way differential behavior is also noticeable at the middle and lower catchment of the basin. For example ruggedness number for this basin ranges from 0 to 0.062 (Fig. 3A). Few patches of upper and middle catchments represent high range of value (0.05-0.06) covering an area of 11.6% to total area. Dissection index(DI) ranges from 0.09 to 0.576 and high value is recognized at the upper catchment and left portion of the middle catchment (Fig. 3B). Position of scattered hillock like landform has generated this situation. Relative relief value ranges from 10-54m. (Fig. 3D) and it is high in those part where dissection is high as mentioned earlier. Slope of this basin ranges from 0-4.05° and high degree of slope is noticed at the upper fringe of the upper catchment (Fig. 3F). Figure 3H indicates that sinuosity value ranges from 0-1.98 and no definite trend is identified over the basin as the entire basin lies over the plateau fringe area. Bifurcation ratio (range: 1.93-6.07) is relatively higher in the lower middle and upper part of the lower catchment (Fig. 3J). Since these areas, volume of water and related functions may be energized. Drainage density of this basin ranges from 0-1.4 and it is found in scattered patches over the basin (Fig. 3K).

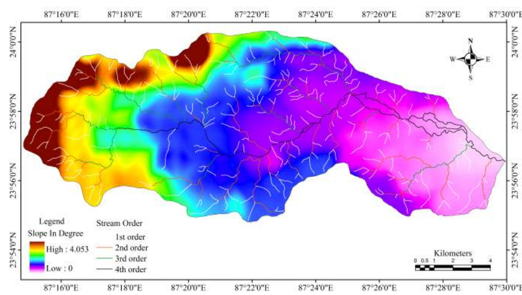


(A) Ruggedness Number (B) Dissection Index

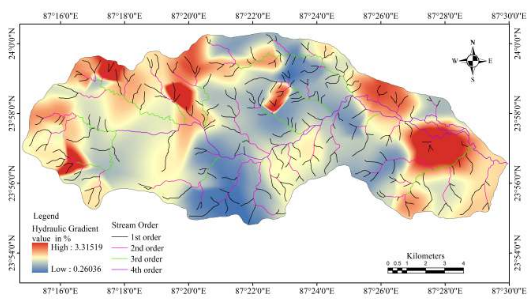


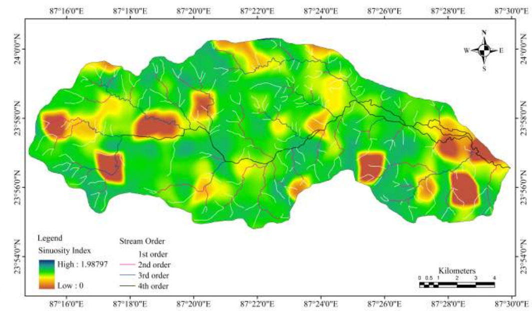
(C) Elevation Map (D) Relative Relief



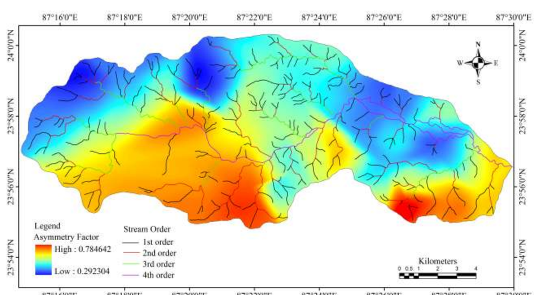


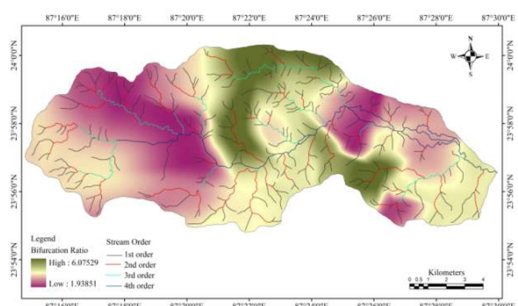
(E) Relief Ratio (F) Slope



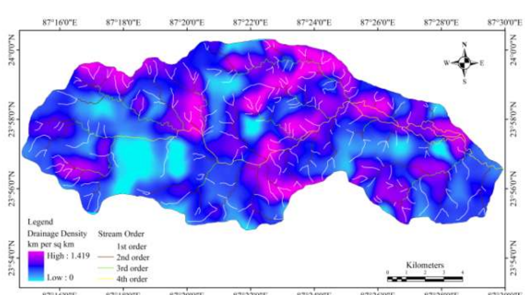


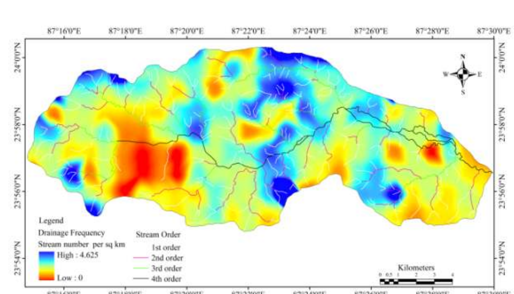
(G) Hydraulic Gradient (H) Sinuosity Index



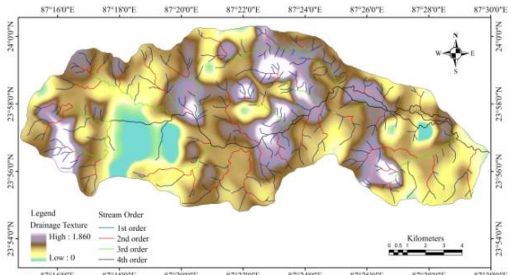


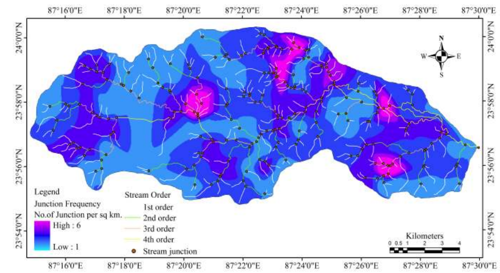
(I) Asymmetry Factor (J) Bifurcation Ratio





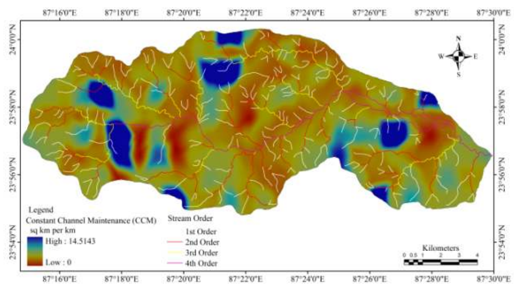
(K) Drainage Density (L) Drainage Frequency

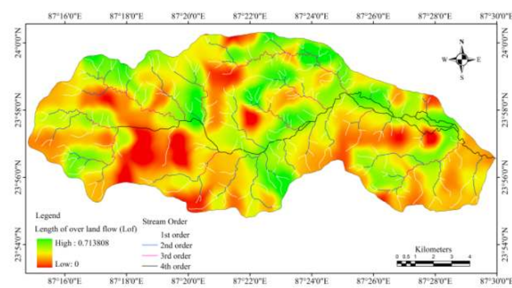




(M) Drainage Texture

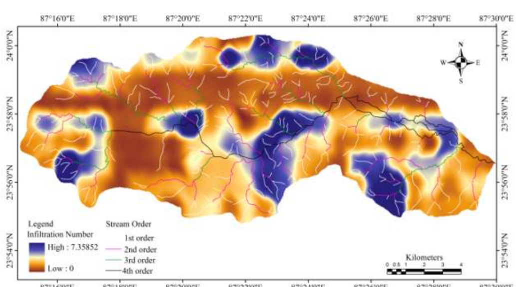
(N) Junction Frequency

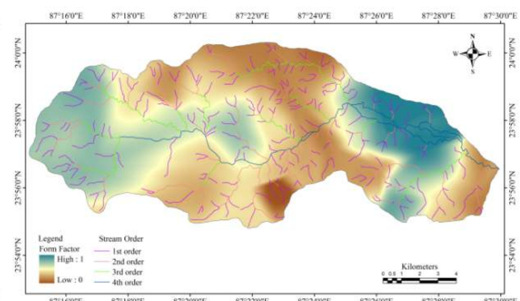




(O) Constant of Channel Maintenance

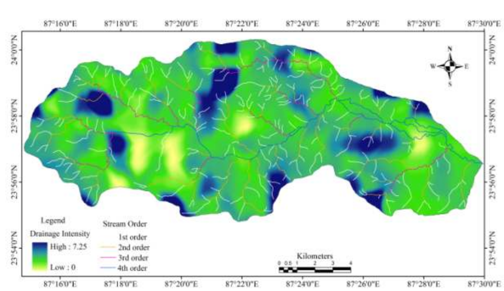
(P) Length of Over Land Flow





(Q) Infiltration Number

(R) Form Factor



(S) Drainage Intensity

Fig 3 (A –S) shows the spatial data layers for constructing the models. The parameters which are used for constructing the three models are described separately in table 2 -4.

4.2 Relief diversity model (RDM)

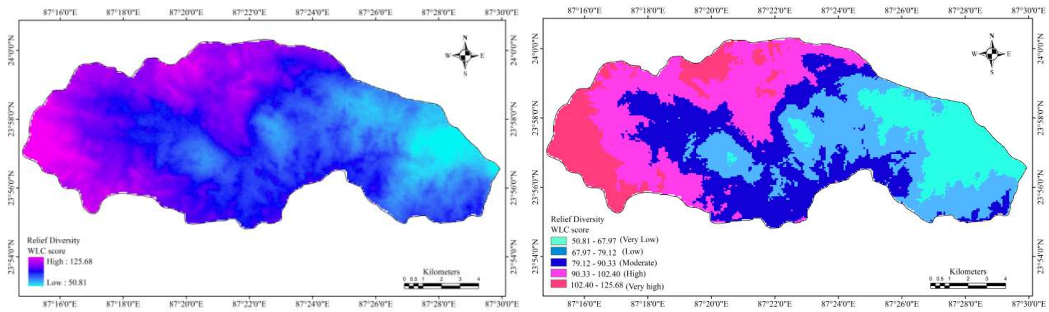


Fig 4 (a) Weighted Relief Diversity (b) Weighted Classified Relief Diversity

PCA based weights composite equation for Relief Diversity

RDM= (Rn*0.87)+(DI*0.77)+(Rhp*1)+(S*0.79)+(Rh*0.64)+(HG*0.52)+(H*0.58)+(Si*0.32)+(Aa*0.59)+(Rb*0.71) ……………………………………………(Eq.3)

Table 7: Area and percentage of area under different weighted Relief Diversity classes.

Relief diversity status	WLC score	Area extent (sq.km)	% of total area
Very low	50.81 - 67.97	24.88	14.47
Low	67.97 - 79.12	38.37	22.30
Moderate	79.13 - 90.34	46.65	27.12
High	90.34- 102.40	41.80	24.30
Very High	102.40- 125.68	20.30	11.81

Relief diversity model mainly is constructed for identifying the unique geomorphological surface based on relief characteristics in the river basin. Equation 3 represents the concise weighted linear combination model of relief diversity. Figure 4(a) shows that very high relief diversity is found at the upper catchment of the basin where ruggedness number, dissection index, elevation, relative relief and slope are high. In this area, average slope is 2.02%, DI is 3.625, ruggedness number is 0.031. Such conditions indicate that the landscape unit is characterized by greater soil erosion potentiality, less chance of ground water recharge etc. Due to having greater potentiality of top soil loss, **there will be paucity of soil nutrients** and therefore, agriculturally this region will not be potential enough. Tree feeling incidents will be more frequent in this area. Out of the total area 11.81% area is found under very high relief diversity zone (table 7). In case of very low relief diversity, it is found at the lower catchment of the basin where ruggedness number, dissection index, elevation, relative relief, and slope are low. Out of the total area 14.47% area **are** come under very low relief diversity zone. This region usually will be highly potential for agricultural activities due to greater potentiality of soil moisture and less susceptibility to soil erosion. Surface and sub surface water potentiality will also support such economic activities.

4.3 Drainage diversity model (DDM)

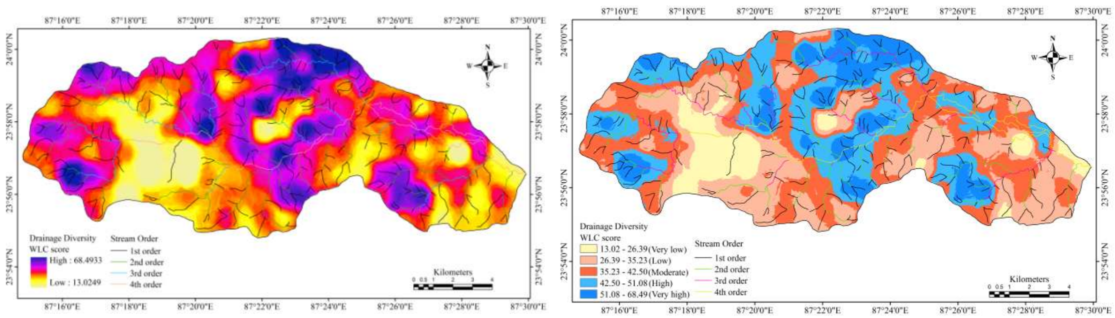


Fig 5 (a) Weighted Composite Drainage Diversity (b) Weighted Composite Classified Drainage Diversity

PCA based weights composite equation for Drainage Diversity.

DDM=(Sf*0.91)+(Dd*1)+(CCM*0.72)+(Di*0.52)+(Lof*0.96)+(Dt*0.94)+(Jf*0.54)+(Si*0.27)+(In*0.77)+(Rb*0.58)+(Ff*0.48)+(Rhp*0.50)+(Rn*0.97)……………………………………………(Eq. 4)

Table 8: Area and percentage of area under different Weighted Drainage Diversity classes.

Drainage Diversity	WLC score	Area extent (sq.km)	% of total area
Very low	13.02 - 26.40	14.85	8.63
Low	26.40 - 35.23	45.72	26.58
Moderate	35.23 - 42.50	50.18	29.18
High	42.50- 51.09	40.14	23.34
Very High	51.09 - 68.49	21.11	12.27

Drainage diversity model has been prepared for identifying unique drainage landscape unit. Equation 4 depicts weighted linear composite model for drainage diversity model. Figure 5(a) and 5(b) respectively illustrated the drainage diversity model in continuous and classified form. Very high drainage diversity is observed at middle and upper catchment of the basin where drainage density (1-1.49 km/sq.km), drainage frequency (3.20-4.625 stream/sq.km), drainage texture (0.732-1.860/sq.km.), length of over land flow (0.340-0.713) and ruggedness number (0.048-0.0627) is high. Table 8 shows that out of the total area of the basin 12.27% area falls under very high drainage diversity zone. This zone is characterized by large number of 1st and 2nd order streams and therefore highly prone to soil loss. Constant erosion activities in this region are not **also** suitable for agriculture activities and construction of settlement. It causes frequent felling of trees. Very low drainage diversity is observed at the lower catchment of the basin where drainage diversity, drainage texture, drainage frequency and ruggedness number are very low. Out of the total area 8.63% area (Table 8) comes under very low drainage diversity zone. Dominance of rills and gullies accelerate the erosion process and natural deforestation.

4.4 Morphometric Diversity models (MDM)

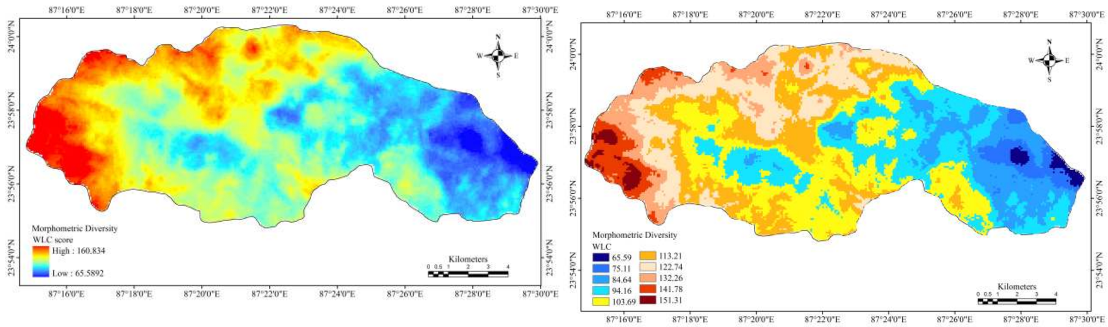


Fig 6 (a) Weighted Morphometric Diversity (b) Weighted classified Morphometric Diversity

PCA based weights composite equation for Morphometric Diversity.

MDM=(Aa*0.62)+(Dd*0.84)+(Sf*0.83)+(Di*0.45)+(Dl*0.81)+(Dt*0.81)+(Ff*0.61)+(HG*0.49)+(In*0.68)+(Rb*0.86)+(Rh*0.65)+(Rhp*0.91)+(Rn*1)+(S*0.67)+(H*0.70)………………………………..(Eq. 5)

Table 9 : Area and percentage of area under different Morphometric diversity classes.

Morphometric Diversity	WLC score	Pixel count	Area extent (sq.km)	% of total area
1 (Lowest)	65.59-75.11	225	1.72222	1.00
2	75.11-84.64	724	5.54172	3.22
3	84.64-94.16	2593	19.84763	11.54
4	94.16-103.69	4206	32.19403	18.72
5	103.69-113.21	4983	38.14143	22.17
6	113.21-122.74	3880	29.69872	17.26
7	122.74-132.26	3220	24.64688	14.33
8	132.26-141.78	1509	11.55035	6.71
9	141.78-151.31	858	6.567398	3.82
10 (Highest)	151.31-160.84	273	2.089627	1.21
Total		22471	172	100

Incorporating all the Morphometric parameters finally diversity in Morphometric surface has been constructed (Eq. 5). Figure 6 (a and b) show continuous WLC and classified WLC model for morphometric diversity model respectively. Classified model highlights ten distinct morphometric surfaces with distinct morphometric characters (Fig. 6b). Table 9 represents the area under different morphometric diversity classes, where 1.21% area comes under very high and 1.00% area comes under very low diversity surface. Highly diversified morphometric surface is geomorphological picturesque but accelerated rill and gully action is majorly responsible for high rate soil erosion, fast rate tree felling etc [36] . Soil erosion rate of this area is 6-18 tons/ha/year as per the estimation of Jha and Kapat [50] .Least diversified surface mainly comes under relatively depressed surface at the confluence region where deposition action is more active triggered by back thrust of flow due to rise of water level in Tilpara barrage [51]. This surface is submerged seasonally during monsoon period. Table

10 briefly describes the statistics of different morphometric parameters in different morphometric diversity zones. From this table one can assume the differences of different morphometric surface units. For example, at diversity zone 10 where diversity level is high and it is explained by a number of parameters like high drainage density (0.9-1.40km./sq.km.), high dissection index (0.29-0.50/sq.km.), high stream frequency (2.1-4.5/ sq.km.) etc. This part experiences late youth to mature stage of the cycle of erosion as indicated by hypsometric integral (0.42-0.55). On the other hand lowly diversified area is characterized by low drainage density (0-0.32km./sq.km.), low dissection index (0.09-0.1/sq.km.), low stream frequency (0-0.5/sq.km.) etc. This zone is located at the late mature to old stage of the cycle of erosion (HI=0.35-0.45).

Table 10: Parameter characters in different diversity clusters

Morphometric Diversity	Dd(km/sq.km)	Rhp (in m)	Rn	DI	CCM	Si	Di	In	Dt	L of	S(in degree)	Sf(stream no./sq.km	HG	Hi	Ff	Rb	Rh	H (in m)
1	0-0.32	10-13	0-006	0.09-0.1	0-6	1-1.98	0.05	0-0.5	0-0.5	0-0.2	0	0-0.5	1.5-2	0.35-0.45	0.1-0.52	2-3.5	0-0.001	62-65
2	0.05-0.46	12-16	0.002-0.003	0.09-0.3	0-5.5	1.4-1.9	0.3-1	0-2.5	0.5-0.9	0.1-0.2	0-0.1	0.5-1.2	1.6-2.9	0.39-0.42	0.75-0.89	2-4.2	0.001-0.005	63-69
3	0.2-1	13-20	0.002-0.004	0.1-0.45	3-13	1-1.9	0.8-3.5	1-5.5	0.5-1.1	0.1-0.3	0.2-1	0.2-3.5	1.2-2.1	0.36-0.46	0.12-0.56	1.9-5	0.02-0.05	63-75
4	0.1-1.2	12-22	0.003-0.006	0.02-0.42	0-7	0.4-1.5	0.1-4.5	1.5-5	0.1-1.5	0-0.3	0.5-1.1	0.3-4	0.26-1.56	0.36-0.45	0.12-0.61	2.3-5.2	0.002-0.15	75-83
5	0.6-1.3	15-25	0.005-0.006	0.09-0.3	4-13.5	0.8-1.6	0.5-6.5	2.5-6.5	0.4-1.6	0.1-0.6	0.2-1.3	1-3	0.28-3.1	0.38-0.46	0.15-0.54	2.5-5.5	0.02-0.06	80-100
6	0.7-1.35	20-45	0.007-0.06	0.2-0.4	2-8	0-0.8	2-6	1.5-4.5	0.6-1.4	0.2-0.6	0.5-2.5	0.1-4.5	2-3	0.4-0.5	0.45-0.9	3-5.5	0.06-0.07	78-115
7	0.8-1.39	35-54	0.01-	0.3-	3-8.	0.1-	2.5-	3.5-	0.7-	0.5-	2.5-	0.2-	1.5-	0.3-	0.2-	2.5-	0.05-	100-

			0.06	0.56	5	1.6	7.1	7.4	1.7	0.71	3.5	3.5	3	0.51	0.9	6	0.6	121
8	0.65-1.36	40-50	0.02-0.04	0.35-0.46	3-10	0.2-1.1	4-6	4.5-7.2	0.7-1.6	0.4-0.68	3-4	2-4.2	1.0-3.3	0.35-0.49	0.45-1	3.5-5.1	0.04-0.07	115-132
9	0.7-1.39	30-53	0.03-0.52	0.36-0.51	2-7	0.1-0.9	5-7.1	3-7.1	1.2-1.8	0.5-0.7	3.5-4.1	2.1-4.5	2.9-3.33	0.45-0.51	0.65-1.0	5.1-56	0.06-0.08	120-140
10	0.9-1.40	25-54	0.02-0.056	0.29-0.50	2.5-8	0.15-0.5	4.5-7	3.5-7.4	1.3-1.7	0.5-0.71	3.6-4.1	2.6-4.6	3.0-3.3	0.42-0.55	0.63-1.1	5-5.8	0.06-0.08	135-155

4.5 Spatial Association among the RDM, DDM and MDM

Correlation matrix has been carried out among three above mentioned diversity model(**s**) to know the role of drainage and relief parameters for making the surface diversified. Table 11 shows relief diversity and morphometric diversity are strongly correlated as the correlation value is 0.94 and drainage diversity is positively correlated with RDM and MDM as the correlation values are 0.445 and 0.207 respectively. Former two cases represent significant correlation at 0.01 level of significance. In an ideal river basin, relief and drainage is highly associated, elevation, slope control flow form, flow density etc. but at this present case association between relief and drainage is not so strong. Relation is positive (r=o.207) and also significant at 0.1 level of significance between two but not statistically acceptable. Low relief diversity over this plateau fringe river is the major reason behind such low spatial variability. From this correlation structure, it is clear that for bringing morphometric diversity, relief parameters play stronger role than drainage diversity and drainage diversity of the landscape is also controlled by relief diversity.

Table 11: Correlation among three models

	Relief diversity	Drainage diversity	Morphometric diversity
Relief diversity	1	0.207	0.940
Drainage diversity		1	0.445
Morphometric diversity			1

5. CONCLUSION

From the analysis of three models different unique drainage, relief and morphometric surface(**s**) have been recognized. Composite weighted score of the relevant parameters have been classified into equal 10 classes representing 10 morphometric surfaces. Range of value with greater magnitude of values is considered as most diversified surface with relatively dynamic processes and forms and vice versa. Each unit can be treated as unique in terms of terrain processes and forms. These are also distinct in connection with potentiality for developing its own characteristics assemblages cultural landscapes. Distinguished terrain processes, soil catena, soil loss, water retaining capacity, recharge, surface water availability and runoff characters characterizes the economic activities of the study area specially agricultural activities. So, not only for categorizing morphological units but also for devising economic landscaping such units are important.

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