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Development of a Geomorphological Erosion Index for Shakkar Watershed

Sarita Gajbhiye[1*], S. K. Sharma[2] and S. Tignath[3]
[1]Department of Water Resource Development & Management, IIT, Roorkee - 247 667, India
[2]Department of Soil and Water Engineering, JNKVV, Jabalpur - 482 004, India
[3]Department of Geology, Govt Model Science College, Jabalpur - 482 004, India
***Email:** gajbhiyesarita@gmail.com

Abstract: Geomorphological parameters directly or indirectly reflect almost entire watershed based causative factors affecting runoff and sediment loss/soil erosion. So, in the absence of sufficient hydrological data morphometric parameters along with satellite based land use/ land cover information of watershed may be helpful in prioritizing the sub-watersheds. Keeping these aspects in view, it was planned to develop a geomorphological index in the Shakkar river catchment of Upper Narmada Basin, India, The objective of the present study is to develop the Geomorphological Index using Principal Component Analysis on the morphometric parameters derived from the Geographic Information System (GIS) environment, which can be used by the field investigators and modeler's in assessing the soil erosion. As an outcome of the analysis, the geomorphological index synthesizes the status of the three morphometric parameters i.e. drainage frequency (F_s), form factor (R_f) and bifurcation ratio (R_b) into a single indicator of geomorphological index. The Geomorphological Index (GI) for the study area found to vary from 3.64 to 21.63. The implementation of geomorphological index may provide the guiding data for sustainable water-resources management in Shakkar river watershed.

Keywords: Soil erosion, Morphometric Parameter, Geomorphological Index, Principal Component Analysis.

INTRODUCTION

The watershed management planning highlights the management techniques to control erosion in the catchment/ watershed area (Gajbhiye et al, 2015a). Soil erosion is one of the most serious environmental problems in the world today, as it threatens agricultural and natural environment. As it makes very miserable situation that at a time when agricultural efforts are focussed on increasing food production, soil degradation is increasing worldwide. The major factor responsible for soil erosion include rainfall, soil type, vegetation, topographic and morphological characteristics of the basin (Kothyari and Jain, 1997; Sharma et al., 2015).Serious soil erosion is occurring in most of the world's major agricultural regions and the problem is growing as more marginal land is brought into production. Study on global soil loss has indicated that soil loss rate in the U.S. is 16 t/ha/yr; in Europe it ranges between 10 – 20 t/ ha/yr, while in Asia, Africa and South America between 20 and 40 t/ha/yr (Pimentel, 1986). Majority of the developing countries suffer from varying degree of soil erosion and degradation mainly due to rapid rates of deforestation, poor irrigation and drainage practices, inadequate soil conservation, steep slopes and overgrazing. According to the Global Assessment of Human-Induced Soil Degradation there are 1.9 billion hectares affected by soil degradation world-wide, 850 million hectares of which are within the Asia-Pacific region, accounting for about 24% of the total regional land area (United Nations, 1997). Thirteen per cent of arable land in the region is severely degraded, 41 percents moderately degraded and 46 per cent is slightly degraded (Anon, 1996).

The geomorphological parameter directly or indirectly reflects almost entire watershed based causative factor affecting runoff and sediment loss. Geomorphological analysis provides quantitative description of the basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964). Wherever, non availability of hydrological data is a serious limitation, morphometric parameter of watershed to a considerable extent may be helpful in characterizing a watershed's hydrological response. For assessing erosion, several empirical models based on geomorphological parameters were developed in the past for quantifying sediment yield (Mishra et al., 1984; Garde and Kothari, 1987; Jos and Das, 1982). The geomorphological parameters that are important from the hydrological point of view include the linear, aerial and relief aspects of the watersheds i.e. catchment area, basin length, mean basin elevation, drainage density, stream frequency bifurcation ratio, length of overland flow, form factor, elongation ratio, circulatory ratio, texture ratio and compactness coefficient (Nautiyal, 1994; Gajbhiye et al., 2014b; Gajbhiye 2015a). Jain and Goel (2002) investigated vulnerability of catchments to erosion of basin for planning soil conservation of 16 sub-watersheds of Ukai dam catchment using index based approach incorporating morphometric parameters and identified the two sub- watersheds which are most susceptible to erosion among the studied sub-watersheds. Rao and Srinivas (2008) also stressed the role of morphological parameters. Sharma (2010) in his study in Gusuru river watershed of Tons river basin, Madhya Pradesh, India for prioritizing micro-watershed for conservation measures termed the morphometric parameters i.e. stream frequency, length of overland flow, form factor, texture ratio, relative relief, drainage density, ruggedness number, elongation ratio, circulatory ratio and compactness coefficient as erosion risk assessment parameters. Nautiyal, 1994; Srivastava and Mitra, 1995; Srivastava,1997; Nag, 1998; Agarwal,1998; Biswas et al.,1999; Singh and Singh, 1997; Sreedevi et al., 2001; Vittala et al., 2004; Reddy et al., 2004; Sharma et al, 2013; Gajbhiye et al., 2013 and all have concluded that remote sensing and GIS are powerful tools for studying basin morphometry and continuous monitoring.

One way to describe geological characteristics of a watershed, e.g, permeability, requires listing of all relevant primary and derived geomorphological watershed parameters. However, such list would normally be quite long and entails the comparison of several geomorphological characteristics of different watersheds which is quite cumbersome process (Desmukh et al., 2011). Also Desmukh et al. (2011) in their study developed a Geomorphological Permeability Index in southern sub-basin of the great Narmada basin, MP, India. Another Texture-Slope index has been proposed by Desmukh et al. (2010) for Sher river of Narmada basin to prepare erosion risk map and the erosional scale of the area using same index. An index related to erosion status of an area and based on indirectly measurable quantities shall prove to be handy and cost effective and therefore, much needed for larger areas of any country which lie unmonitored in the world. A Geomorphological Index is one such fundamentally related index to state erosion status of any watershed that allows the analyst to combine information from different morphological parameters into a single value for a better interpretation.

The variations in the geomorphological parameters in the basin across an area are the eventual outcome of the systematic or abrupt variations in the said environments. Thus, the parameters based index is a superior technique to classify and prioritize sub-watersheds than the descriptive distribution of geological rock type or geomorphological features in general. Two watersheds having common geomorphological rock type and identical geomorphic features may be very different in their behaviour and development due to variations in structural conditions, structural lineaments, degree of weathering of rock types and positioning of rock types with respect to the local base level of erosion. These factors with their continuous impact on the behaviour of an area of the size of watershed lead to significantly different development of characteristic parameters from those of the adjoining watersheds, falling in the same hydro-metrological unit.The main objective of this index is to evaluate the general state of soil erosion, depending on a group of established morphometric parameters. This objective was pursued in the Shakker river watershed of upper Narmada basin, Madhya Pradesh, India.

MATERIALS AND METHOD

Study Area

The Shakkar river rises in the Satpura range, east of the Chhindi village, Chhindwara district, Madhya Pradesh at an elevation of about 600 m and at latitude of 22°232 N and of longitude 78°522 E (Fig.1). The watershed covers 2220 km^2 area. The climate of the basin is generally dry except the southwest monsoon season. The southwest monsoon starts from it middle of June and lasts till the end of September. October and the first half of November constitute the post monsoon or retreating monsoon season. The normal annual rainfall is 1192.1mm. The normal maximum temperature recorded during the month of May is 42.5° C and minimum during the month of January is 8.2° C. Soils are mainly clayey to loamy in texture with calcareous concretions invariably present They are sticky in summer, due to shrinkage, develop deep cracks. They are generally having higher percentage of montmorillonite and bedellite type of clay. Along the banks of the rivers and at the confluence of the river, light yellow to yellowish brown soils are noticed which were deposited during the recent past. These soils are clayey to silty nature Mishra et al., 2013; Gajbhiye et al., 2013b; Gajbhiye et al., 2014a,d).

GIS Map Generations

The present study has been carried out in GIS environment (ARC GIS 9.1, 2006) using SRTM DEM,

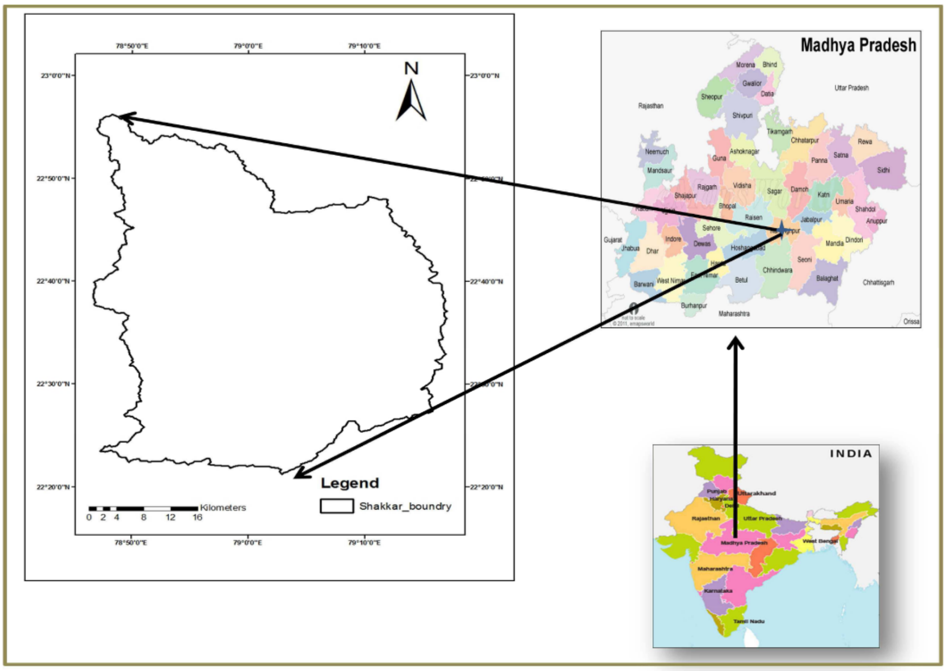

Fig.1. Location map of the study area.

geological map and geomorphology map of the study area. The study area is classified into sub-watersheds on the basis of stream ordering as suggested by Strahler (1964). The fourth order watershed is taken to be an appropriate unit as it reflects the complete spectrum of drainage processes from valley deepening to lateral widening, from valley erosion to deposition, from cascading to concaving of profiles. Therefore, basins of fourth order are the smallest complete fractal units repeated over larger and higher basins and hence preferred. By selecting the lower order sub-watershed as a unit, the number of sub-watersheds (sample data) has increased but the corresponding area of analysis decreased. On the other hand, by selecting higher order sub-watershed as a unit, the number of sub-watersheds (sample data) would decrease but the corresponding area of analysis would increase. The classified sub-watersheds are fourth order watersheds and the remaining sub-watersheds represent areas formed around fifth, sixth, seventh and eighth order of stream, wherein fourth order is absent while first, second and third order is associated with fifth or sixth or seventh order. Drainage map and sub-watersheds of the study area is presented in Fig.2. The input parameters for the present study are area, perimeter, elevation, stream length etc. and obtained from the coverage of drainage network map in GIS environment.

Formulation of Geomorphological Index for Soil Erosion (GI)

An index is formulated based on the morphometric parameters, which takes into account the mathematical formulation by using Principal Component Analysis (PCA). The following three steps are most often associated with the development of any index.

Parameter Selection

Parameter selection is based on three steps. Step 1 is

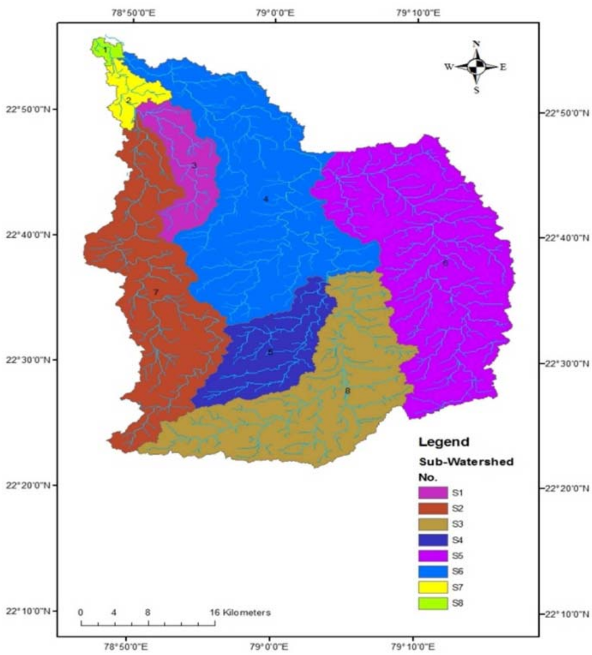

Fig.2. Drainage and Sub-watersheds of Shakkar river watershed

Principle Component Analysis which provides information on the most meaningful parameters, which describe whole data set affording data reduction with minimum loss of original information (Helena et al., 2000). The geomorphic parameters are usually many times correlated. The correlation indicates that some of the information contained in one variable/geomorphic parameter is also contained in some of the other remaining variables geomorphic parameters. The principal component analysis breaks down the battery of intercorrelations among variables into a set of uncorrelated factors; these together summarize the data in the original matrix and explain the underlying relations and influences among the variables. Principal component analysis is applied for all geomorphic parameters to calculate the correlation matrix and also to derive principal components (Sharma et al., 2015a; Gajbhiye et al., 2015b). The first factor loading matrix and rotated factor loading matrix are used in this analysis.

Step 2: screening of parameters after subjecting the first factor loading matrix to varimax rotation, an effort is made to regroup the parameters into the factors and to screen out the parameters which do not have any significant correlations with rotated factors or components. After screening out such parameters, the correlation matrix of a new set of parameters is further subjected to the principle component analysis to obtain a new unrotated factor loading matrix. The procedure is repeated till the interpretation of 'physical significance' is simplified.

Step 3: order of importance the amount of covariance explained by each component and its percentage with respect to the total covariance of the components for rotated factor loading matrices were calculated. Then, in order to rank the parameters according to their importance, the coefficient of determination, which is the square of the rotated factor loadings, is multiplied by the percentage of total rotated covariance of that component to obtain the order of importance of each parameter. The Principal Component (PC) can be expressed as:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots\ldots + a_{im}x_{mj} \quad (1)$$

where z = component score; a = component loading; x = measured value of variable; i = component number; j = sample number; and m = total number of variables.

The number of principal components to remain and their component loadings are characterized by eigenvalues, percent of total variance, and cumulative percentage. All of these statistical tests are provided in SPSS 14.0 version for Windows.

Weightage Assignment to All Parameters

A larger weight value implies greater importance of the parameter. In assigning the weight of each parameter, the most challenging factor is that different people may have different opinions. As per the statistical analysis (order of importance) and geological considerations parameter are arranged in their order of merit (Singh, 2006).On the basis of designed proportionally factor weightage was given to different parameters.

Aggregation of Sub-indices (Parameter) to Produce a Final Index

Aggregation is the process of combining and simplifying a group of morphometric parameters. Aggregation is based on the nature of the parameters F_s, L_o, D_d, T, R_r, R_h, S_a, R_b and R_N and these geomorphological parameters generally show positive correlation with soil erosion, and R_f, R_e, C_c and R_c show negative correlation with soil erosion (Biswas et al., 2002; Nooka Ratnam, 2005; Thakker and Dhiman, 2007). The aggregation function of GI is given by following equations:

$$GI(Shakkar) = \frac{(P1*W_{P1})*(P2*W_{P2})*\ldots\ldots(Pn*W_{Pn})}{(Q1*W_{Q1})*(Q2*W_{Q2})*\ldots\ldots(Qn*W_{Qn})} \quad (2)$$

where, P1, P2,.....Pn = Morphometric parameters (which are directly proportional to soil erosion); W_{P1}, W_{P2}........ W_{Pn}= Weightage of the corresponding parameter; Q1, Q2,.....Qn = Morphometric parameters (which are indirectly proportional to soil erosion); W_{Q1}, W_{Q2}........ W_{Qn}= Weightage of the corresponding parameter

The above geomorphological parameters discussed are presented in detail below and results are shown in Table 1.

Relief ratio (R_h): Relief ratio is the total relief of the watershed (H) divided by the maximum length (L_b) of the watershed. High value of watershed slope shows rich drainage pattern which helps quick disposal of runoff. Low-sloped watersheds provide more time to infiltrate the generated runoff and subsequently build ground water storage.

$$R_h = \frac{H}{L_b} \quad (3)$$

Relative relief (R_r): Relative relief is the ratio of the maximum watershed relief (H) to the perimeter of the watershed (L_p).

$$R_r = \frac{H}{L_p} \quad (4)$$

Table 1. Geomorphological parameters of Shakker watershed

Sub-watershed	R_h	R_r	R_N	R_b	D_d	F_s	R_c	R_f	R_e	T	L_o	C_c	S_a	HI
SH 1	0.012	0.002	0.147	3.490	3.673	8.232	0.403	0.794	0.972	4.464	0.136	0.126	6.036	0.471
SH 2	0.007	0.001	0.203	3.553	3.383	7.315	0.283	0.468	0.772	6.739	0.148	0.048	4.099	0.508
SH 3	0.030	0.008	1.682	3.735	2.845	6.614	0.281	0.351	0.669	10.516	0.176	0.021	10.085	0.501
SH 4	0.014	0.003	1.896	4.302	3.101	7.085	0.231	0.291	0.609	22.197	0.161	0.007	9.803	0.497
SH 5	0.023	0.007	1.659	4.177	3.071	7.496	0.356	0.284	0.602	15.815	0.163	0.015	11.670	0.483
SH 6	0.016	0.004	1.865	5.524	3.161	7.177	0.325	0.427	0.738	27.738	0.158	0.006	9.329	0.488
SH 7	0.017	0.005	2.483	4.929	3.100	7.235	0.179	0.174	0.471	16.845	0.161	0.009	14.818	0.491
SH 8	0.023	0.004	1.825	4.753	3.147	7.649	0.290	0.623	0.891	23.088	0.159	0.008	13.071	0.497

Ruggedness number (R_N): Ruggedness number is defined as the product of the maximum watershed relief (H) and its drainage density (D_d). It provides an idea of overall roughness of a watershed.

$$R_N = H^*Dd \tag{5}$$

Bifurcation ratio (R_b): It is the ratio of the number of streams of given order u to the number of streams of next higher order u+1. It reflects the complexity and degree of dissection of a drainage watershed.

$$R_b = N_u / N_{u+1} \tag{6}$$

Drainage density (D_d): It is the ratio of total length of streams of all orders of a watershed to the area of the watershed.

$$D_d = \sum_{u=1}^{n} L_u / A \tag{7}$$

Drainage frequency (F_s): It is the ratio of the total number of streams in a watershed to the watershed area.

$$F_s = \sum_{u=1}^{n} N_u / A \tag{8}$$

Circularity ratio (Rc): Circularity ratio is computed as:

$$Rc = \frac{2}{L_p}\sqrt{\pi * A} \tag{9}$$

Form factor (R_f): Form factor is the ratio of the watershed area (A) to the square of the maximum length of the watershed (L_b).

$$R_F = A / L_b^2 \tag{10}$$

Elongation ratio (R_e): Elongation ratio is the ratio between the diameters of a circle with the same area as that of the watershed to the maximum length of watershed.

$$\text{Re} = \frac{2}{L_b}\sqrt{\frac{A}{\pi}} \tag{11}$$

Drainage texture (T): Drainage texture is defined as the ratio of number of streams of first order to the perimeter of the watershed.

$$T = \frac{N_1}{P} \tag{12}$$

Length of overland flow (L_o): Length of overland flow is equal to one-half of the reciprocal of the drainage density.

$$L_o = \frac{1}{2D_d} \tag{13}$$

Compactness Constant (C_c): Compactness Constant is computed as:

$$Cc = 0.2821 \frac{L_p^{0.5}}{A} \tag{14}$$

Average slope of watershed (S_a): Average slope of the watershed, S_a, has direct influence on the erodibility of a watershed. The higher the percentage of slopes, the higher is the erosion, if other factors remain unchanged, and vice versa. The average slope of the watershed is calculated by using following formula:

$$S_a = \frac{HL_{ca}}{10A} \tag{15}$$

Hypsometric integral (HI): Hypsometric analysis was carried out or the relation of horizontal cross-sectional drainage basin area to elevation was developed in its modern dimensionless form by Langbein (1947). Pike and Wilson (1971) method (or elevation-relief ratio method) is the less cumbersome and faster method and it is used in the study for estimating hypsometric integral. The relationship is expressed as:

$$E \approx H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}} \tag{16}$$

RESULTS AND DISCUSSION

The resulted intercorrelation matrix includes fourteen morphometric parameters/variables of (Table 2). In order to see parameters intercorrelation first Pearson correlation is made if it does not make the groups of physical

Table 2. Intercorrelation matrix of the geomorphological parameter of Shakkar watershed

	R_h	R_r	R_N	R_b	D_d	F_s	R_c	R_f	R_e	T	L_o	C_c	S_a	HI
R_h	1.000	.920	.552	.133	-.757	-.417	-.027	-.244	-.227	.215	.795	-.431	.616	.046
R_r	.920	1.000	.606	.154	-.801	-.514	-.088	-.510	-.500	.169	.833	-.475	.621	-.016
R_N	.552	.606	1.000	.745	-.787	-.523	-.619	-.698	-.706	.753	.748	-.839	.906	.134
R_b	.133	.154	.745	1.000	-.352	-.185	-.330	-.332	-.329	.900	.286	-.658	.619	-.037
D_d	-.757	-.801	-.787	-.352	1.000	.844	.523	.737	.694	-.474	-.995	.852	-.631	-.483
F_s	-.417	-.514	-.523	-.185	.844	1.000	.603	.727	.670	-.276	-.845	.698	-.222	-.689
R_c	-.027	-.088	-.619	-.330	.523	.603	1.000	.696	.710	-.309	-.482	.628	-.489	-.619
R_f	-.244	-.510	-.698	-.332	.737	.727	.696	1.000	.993	-.330	-.703	.740	-.512	-.364
R_e	-.227	-.500	-.706	-.329	.694	.670	.710	.993	1.000	-.299	-.661	.693	-.548	-.297
T	.215	.169	.753	.900	-.474	-.276	-.309	-.330	-.299	1.000	.408	-.765	.573	.098
L_o	.795	.833	.748	.286	-.995	-.845	-.482	-.703	-.661	.408	1.000	-.798	.602	.464
C_c	-.431	-.475	-.839	-.658	.852	.698	.628	.740	.693	-.765	-.798	1.000	-.652	-.537
S_a	.616	.621	.906	.619	-.631	-.222	-.489	-.512	-.548	.573	.602	-.652	1.000	-.047
HI	.046	-.016	.134	-.037	-.483	-.689	-.619	-.364	-.297	.098	.464	-.537	-.047	1.000

Table 3. Total Variance Explained of Shakkar watershed

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.166	58.325	58.325	8.166	58.325	58.325	4.457	31.835	31.835
2	2.098	14.987	73.312	2.098	14.987	73.312	3.979	28.424	60.259
3	1.966	14.045	87.358	1.966	14.045	87.358	3.794	27.099	87.358
4	.987	7.053	94.411						
5	.516	3.685	98.096						
6	.177	1.268	99.364						
7	.089	.636	100.000						
8	4.104E-16	2.931E-15	100.000						
9	1.512E-16	1.080E-15	100.000						
10	1.334E-16	9.529E-16	100.000						
11	2.624E-17	1.875E-16	100.000						
12	-9.650E-17	-6.893E-16	100.000						
13	-3.095E-16	-2.211E-15	100.000						
14	-4.655E-16	-3.325E-15	100.000						

significance then PCA is to be made. Therefore, in the present study first correlation matrix was developed and it is very difficult at this stage to group the parameters into components and attach physical significance. Hence, in the next step, the principal component analysis has been applied to the correlation matrix.The results of the PCA indicate the existence of three components (eigen value greater than one) for the 14 parameters, together account for about 87.35% of the total explained variance. (Table 3). For better interpretation of the results, the varimax rotation is chosen, which rotates the principal components in four-dimensional space in such a way that maximizes each indicator's loadings on only one of the four directions. Based on the extraction of principal components amounting to a variance maximizing (varimax) rotation of the original variable space, the results of the rotated component loading matrix are shown in Table 4. The PC 1, which explained 58.32% of the total variation, since it was highly correlated with stream frequency (F_s), circulatory ratio (R_c) and hypsometric integral (HI) (Table 3 and 4). The second PC, which accounted for an additional 14.98 % of the variation, was highly correlated with relative relief (R_r) and relief ratio (R_h) while the third PC was highly correlated with bifurcation ratio (R_b) and texture ratio (T).

Table 4. Varimax rotated matrix of Shakkar river watershed

	Component		
	1	2	3
R_h	-.010	.964	.117
R_r	-.132	.970	.127
R_N	-.366	.476	.781
R_b	-.069	.012	.951
D_d	.604	-.721	-.304
F_s	.836	-.412	-.046
R_c	.816	.053	-.355
R_f	.754	-.317	-.334
R_e	.714	-.305	-.350
T	-.144	.075	.900
L_o	-.578	.767	.233
C_c	.634	-.338	-.626
S_a	-.115	.535	.719
HI	-.808	-.057	-.143

Derivation of the Geomorphological Index

In the initial stages of developing the geomorphological index, we included only the first three Principal component, since they together explained 87.35% of the total variability. We select F_s from PC1, R_r from PC2 and R_b from PC3. After that, order of importance associated with a particular PC axis square with the proportion of variation explained by the corresponding eigenvalue (i.e. PC1 * 58.32; PC2 * 14.98; PC3*14.04 see (Table 5). The highest weightage assigned to F_s (1st order of importance), while the lowest weightage assigned to R_b (3rd order of importance). The overall process to form index is illustrated in Fig.3.

$$GI\ (Shakkar) = (F_s * W_{Fs})*(R_r * W_{Rr})*(R_b * W_{Rb})*100 \quad (17)$$

where, F_s, R_r, R_b = Morphometric parameters. W_{Fs}, W_{Rr}, W_{Rb} = Weightage of the corresponding parameter.

Geomorphological Index for Soil Erosion

The study area was subdivided into eight sub-watersheds. Geomorphological Index (GI) has been calculated for each of the sub-watersheds on the basis of a large number of related morphological parameters. GI values are given in Table 6. GI values are in the range of 3.64 to 21.63 (Fig 4). Values of GI of various sub-watersheds provide a basis to compare watersheds having different types of geological formations underneath. GI also helps to predict the soil erosion condition and weathered condition of geological formation. However, this requires a thorough field investigation of geology and geomorphology of sub-watersheds.

Geology and Geomorphology

It is imperative to correlate the results obtained from statistical analysis with the real field settings in order to develop the GI.

Adhering to the area specific geomorphological index (GI) the data of Shakkar river watershed were analysed and synthesized to generate GI applicable to Shakkar river watershed (Fig. 4). Geology and geomorphology maps are presented in Fig. 5 and Fig. 6, respectively.

Shakkar river watershed has eight sub-watersheds, with basaltic terrain upward and a broad alluvial terrain in its middle and lower reaches. Alluvial soil face recession which is one of the prominent processes of badland formation (Fig 7). In this process, on gaining moisture the slope collapses because of no stress perpendicular to the face resisting pore water pressure. In Fig 8 cohesiveness of sand layer can be viewed and in Fig 9 undercutting action of streams can be seen which gives scouring of non-adhesive

Table 5. Order of importance of parameters for Shakkar river watershed

Parameter	Rotated factor	Square rotated	%covariance	% Importance (%)	Order	Weightage
F_s	0.84	0.70	58.32	40.76	1	1.20
R_r	0.97	0.94	14.98	14.09	2	1.00
R_b	0.95	0.90	14.04	12.67	3	0.80

Table 6. Geomorphological erosion index for Shakkar river watershed

Sub-watershed	F_s	R_r	R_b	Index Score*	Priority of sub-watershed
SH5	7.50	0.007	4.18	21.63	1
SH 3	6.61	0.008	3.73	17.86	2
SH 7	7.23	0.005	4.93	16.22	3
SH 8	7.65	0.004	4.75	15.35	4
SH 6	7.18	0.004	5.52	14.67	5
SH 4	7.08	0.003	4.30	10.22	6
SH 1	8.23	0.002	3.49	6.48	7
SH 2	7.31	0.001	3.55	3.64	8

*Index score = $[(F_s*W_{Fs})*(R_r*W_{Rr})*(R_b*W_{Rb})]*100$

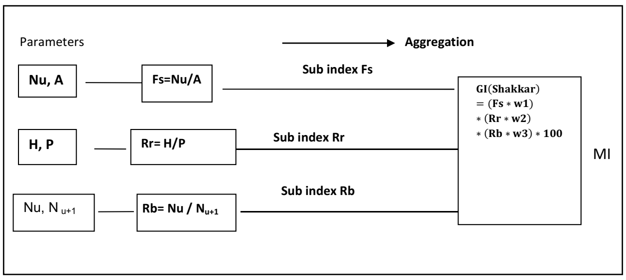

Fig.3. Formulation of a Geomorphological Index for Soil Erosion (GI)

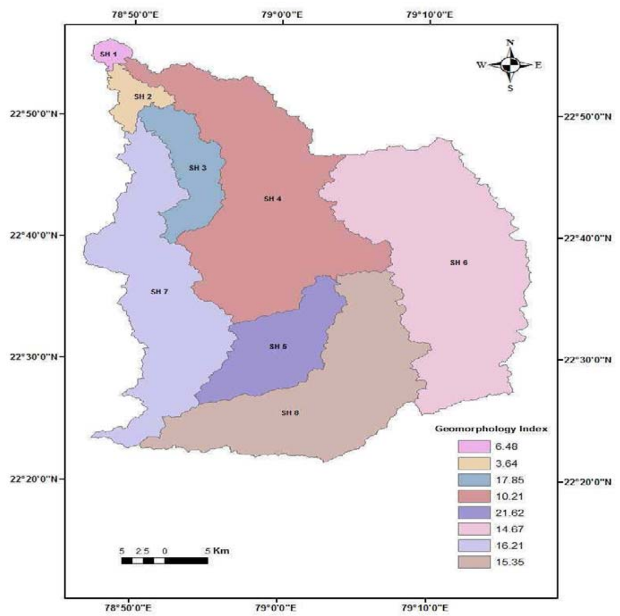

Fig.4. Geomorphological Index of Shakkar river watershed

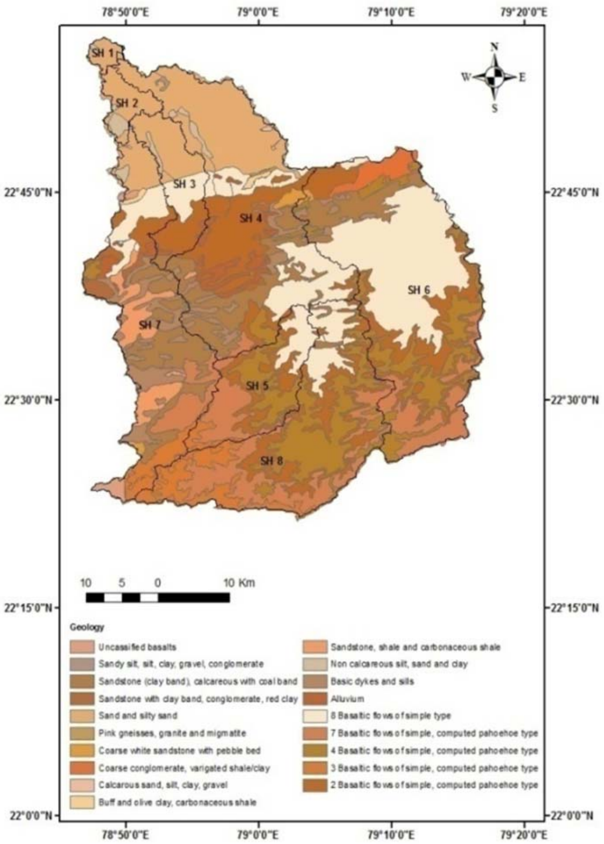

Fig.5. Geology map of Shakkar river watershed

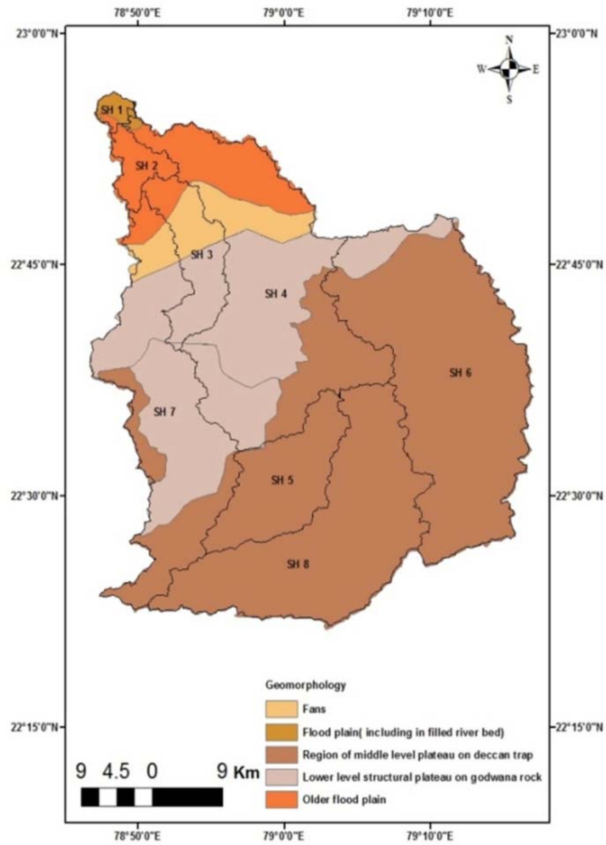

Fig.6. Geomorphology map of Shakkar river watershed

soils in one of the sub-watershed of Shakkar river. The GI values show strong influence of geomorphological status of land form and lithology. The alluvial plain through which it runs after cutting across the Satpura range emerges in openness at Hathanapur. From Hathanapur down to confluence, it is generally, an alluvial plain. It is seen clearly from the GI that alluvial plains are not actually suppliers of sediment as much as the middle level of plateau in the middle and upper reaches. It is because of the fact that the alluvial plain is accretional in nature and it is gathering rather than losing sediments. It is evident in SH 1 and SH 2 belonging to the lower reaches in the alluvial plain ranking at 7th and 8th out of eight sub-watersheds. Further, the GI shows that nearly in identical conditions of areal distribution of middle level plateau with comparable R_f and R_b (the two component of GI). R_r has caused significant variation in soil erosion, as evident in SH 5, SH 7 and SH 8 which rank 1st, 3rd and 4th, respectively, due to relief factor only. It shows the sensitivity of GI. The next two 5th and 6th ranking sub-watersheds are proportional in their ranking with the distribution of middle level plateau, which are 28.92% and 28.43%, respectively. Interesting case emerges here from the GI and it is SH 3 that ranks 2nd and has no middle level plateau. Its high soil loss/soil erosion is due to alluvial fans covering 32% area with greater relief than the adjacent geomorphology and contributing the sediments. The source of sediments in the 2nd ranking sub-watershed (SH 3) is undoubtedly from the fans as its reaming two geomorphic units namely lower level structural plateau on Godwana rocks and older flood plains are comparable in their aerial size with SH 4 which ranks 6th in contrast to SH 3. It is known fact in geomorphology that alluvial fans supply good amount of sediments to the channel system as it is a part of the slope forming processes. The Fig 10 shows the general deteriorating conditions of Shakker river watershed. This is an indication of over grazing along this land also confirmed by the name of Gadarwara (Town of Sheep's). The Shakker river flows in Gadarwara Tahsil of Narsinghpur district of Madhya Pradesh, India. Therefore, from above discussion and the estimated GI values the SH 5 should be given top priority and next to this SH 3 and subsequently others as given in Table 5 for soil and water conservation measures.

CONCLUSION

1 The complexity of linking multidimensional aspects of

Figs.7-10. (7) Alluvial soil face recession one of the prominent processes of badland formation. **(8)** Cohesionless sand layer a view in Shakkar river watershed **(9)** Undercutting action of streams, scouring of non adhesive soils in one of the Shakkar river sub-watershed **(10)** Opening of ravines in Shakkar river watershed. This is an indication of over grazing along this land also confirmed by the name of Gadarwara (Town of Sheeps')

soil water management together has been taken into account in such a way as to construct a holistic soil and water management tool to address the problems of sustainability, and its relation to soil erosion.

2 The methodology based on the principal component analysis was successfully tested in the Shakkar river watershed, and this has shown that there is great potential for the useful application of the index in a variety of locations.

3 The GI values for the Sakkar River basin show strong influence of geomorphological status of land form and lithology. The river, after cutting across the Satpura range, emerges in openness of the alluvial plain and comes down to its confluence with Narmada. It is seen clearly from the GI that alluvial plains are not actually suppliers of sediment as much as the middle level of plateau in the middle and upper reaches. It is because of the fact that the alluvial plain is accretional in nature and it is gaining rather than losing sediments.

4 The composite index proposed herein is presented by an aggregation of three indicators (morphometric parameters). The geomorphological index is seen to be in accordance with field set up relating to geomorphology and geology.

5 This complexity of geological variations and geomorphological processes are fine tuned with the geomorphological parameters. It successfully incorporates the complex proportions of weathered and compact parts of the terrain as confirmed in the field. The Geomorphological Index (GI) developed here through unbiased analysis of the large data set for each watershed has dependable correlation with the soil erosion. The adopted methodology provides reliable and applied way for developing a GI specific to the geomorphological and geological conditions of an area. Thus, the GI proves to be of high significance with the sub-watershed processes in a given condition of structure and lithology.

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