

## Grouping of Geomorphic Parameters in Selected Watershed using Principal Component Analysis for Hydrological Modelling

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### Abstract

*The hydrologic behaviour of any basin/watershed is studied by the hydrologic modelling. Principal component analysis (PCA) is a statistically method which uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values the of linearly uncorrelated variables called principal components. The PCA has been applied for 13 dimensionless geomorphic parameters of 11 selected watershed in upper and middle Godavari sub basin, Maharashtra (India) in order to group the parameters in different components on the basis of their significant correlations. Results of the PCA shows that first two PC are strongly correlated with some geomorphic parameters. However, the third PC is not found strongly correlated with any of the parameters but is moderately correlated with length width ratio ( $L_b/L_w$ ). The result clearly shows that due to poor correlation with other, the hypsometric integral and main stream channel slope could not be grouped with any of the component. The principal component loadings matrix obtained using correlation matrix of finally selected eleven parameters reveals that first three components together account for 94.283 % of the total explained variance. The results shows that the PCA is good tool for screening out the insignificant parameters in the study of watersheds hydrologic behaviour like runoff and sediment yield modelling. Therefore, principal component lading matrix is applied in order to get better correlations and clearly grouped the parameters into physically significant components.*

**Keywords:** Principal Component Analysis, Multivariate, Watershed, Geomorphic Parameters, Godavari, Maharashtra.

### Introduction

The soil and water are the important the natural resources for the survival of all living beings on the earth. The soil and water conservation measures are planned on the basis of the watershed. Watershed is considered as an ideal unit for land and water resources planning and management purposes<sup>1</sup>. India many watersheds are ungauged in such cases for the study of such modelling of the watershed essential. Hydrologic modelling is basically a tool for prediction of hydrologic behaviour of a basin<sup>2</sup>. Geomorphological characterization of the watershed is also done for the development of the regional hydrological models for solving the various hydrological problems of the ungauged watersheds or in the case of inadequate data situations.

The management activities are planned on the basis of prioritization of the watershed. Runoff and sediment yield from a catchment are the main criteria for the prioritization of the watershed. But it requires continuous monitoring of the watershed. In the absence of sediment yield data the morphometric parameters are helpful in assessing most critical sub-watershed<sup>1</sup>. Remote Sensing (RS) and Geographical Information System (GIS) techniques are new techniques and very useful for assessment of morphometric analysis of the watershed.

The collection and analysis of geomorphological characteristics are often time-consuming, hence its need to reduce the number of parameters which can simulate the behavior of the drainage basin on the basis of morphological characteristics. The screening of large number of interrelated variables for their under-lying dimensions is best achieved by multivariate statistical techniques of principal component analysis(PCA)<sup>2</sup>. The PCA reduces the number of inter-correlations among variables into a set of uncorrelated factors, these together summarize the data into the original matrix and explain relations and its influences among the variables. The PCA is dimensional reduction technique which gives more information from the less dimensions in the original space. Therefore, the present study was undertaken to study the inter-correlationship among the variables in order to screen out the less significant variables out of the analysis and to arrange the remaining into physically significant groups by applying PCA for better interpretability.

**Study Area:** The present study was carried for 11 selected watershed in upper and middle Godavari sub basin in Maharashtra state (India). The Godavari river one of the largest river in Peninsular India and third largest in India. The Godavari river is also known as “Vridha Ganga” or “Dakshin Ganga”<sup>4</sup>. The Godavari river rises from Brahmagiri, Trimbakeshwar in Nashik district (Maharashtra) at an elevation of 1,067 m<sup>5</sup>. The Godavari river basin extends over the state like Maharashtra,

A.P., Chhattisgarh, Telangana and Odisha in addition to smaller parts in M.P., Karnataka and Union territory of Puducherry. The basin lies between latitudes 16°16'0" North and 23°43' longitudes 73°26' to 83°07' East. The basin is roughly triangular in shape having an area of 3,12,813 km<sup>2</sup> (approx. 10% of the total geographical area of the country)<sup>4</sup>.

The basin having mostly fertile soil and tropical climate<sup>4</sup>. The major soils types in the Godavari basin and adjoining areas are black (Regur), red, laterites and lateritic, alluvium, mixed red & black soils, mixed red & yellow and saline and alkaline soils. The Pravara, the Manjra, the Maner, the Purna, the Penganga, the Pranhita, the Wardha, the Indravati and the Sabari are the major tributaries of the Godavari. The Godavari basin is sub divided in to 8 sub basins viz. Upper, Middle, Lower, Indravati, Manjara, Wainganga, Wardha and Pranhita and other (Anonymous, 2012). The major Land Use Land Cover (LULC) in Godavari basin are agricultural land 1,86,347.17 km<sup>2</sup> (59.57%), built up land 5,187.26 km<sup>2</sup> (1.66%), Forest 93142.06 km<sup>2</sup> (29.78%), Grassland 85.84 km<sup>2</sup> (0.03%), Wasteland 16785.92 km<sup>2</sup> (5.36%), Water bodies 11,263.75 km<sup>2</sup> (3.60%)<sup>5</sup>.

The Central Water Commission (CWC) assessed water resources potential in Godavari basin is about 110.54 km<sup>3</sup> out of

that the utilizable surface water is approx. 76.3 km<sup>3</sup> and replenishable ground water is approx. 45 km<sup>3</sup>. There is a vast potential for irrigation development and hydropower generation in the basin. The present utilization is of the order of only 40 km<sup>3</sup> in the case of surface water and 6 km<sup>3</sup> in the case of ground water. Considering the potential of the basin the hydrologic modelling purposes, the present study was selecting 11 sub watershed located in Nashik, Ahmednagar, Beed, Jalna, Parbhani, Aurangabad and Nanded district as shown in Figure-1.

## Methodology

Geomorphological characteristics plays very important role in the study hydrologic behaviour of the watersheds and therefore, number of parameters which signify the watershed characteristics are evaluated from the Survey of India (1:50,000 scale) toposheets. The 13 dimensionless geomorphic parameters for the 11 selected watersheds in the upper and middle Godavari basin, Maharashtra (India) were extracted in the Geographic Information System (GIS) environment using Arc GIS 10.2 software. The various formula used to extract the geomorphic parameters are give in the Table-1.

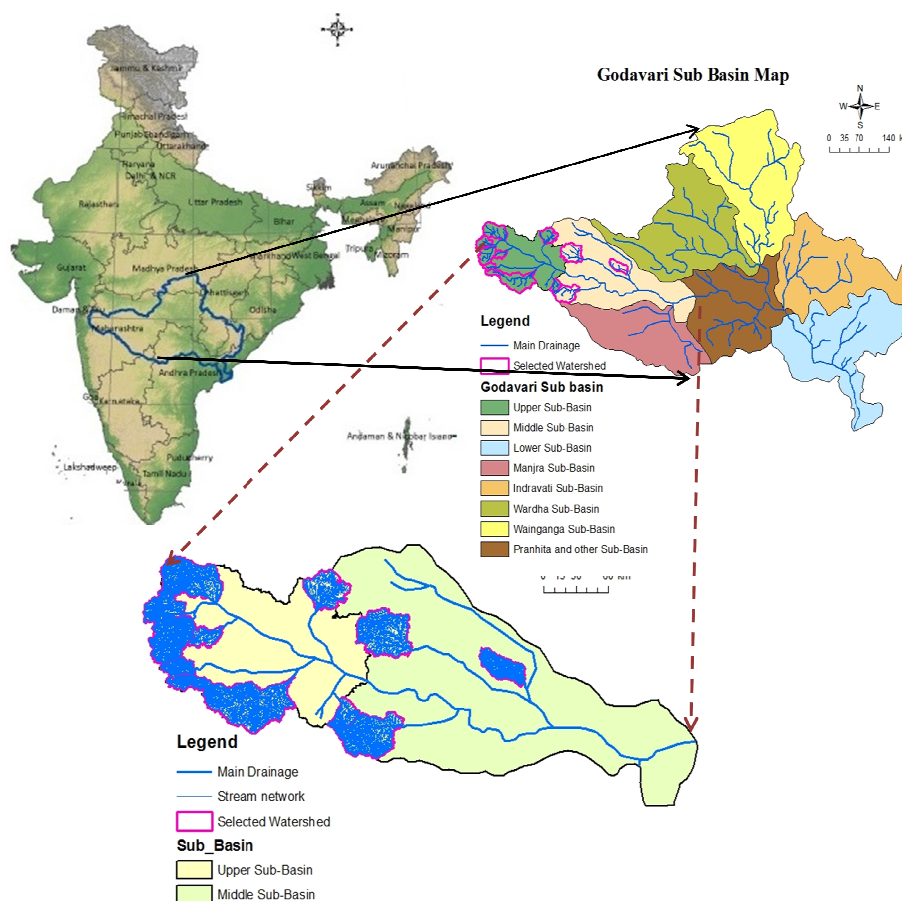


Figure-1  
Location map of the study area

**Table-1**  
**Formulae for computation of geomorphic parameters**

Morphological characteristics	Formula
Average slope of the watershed ( $S_a$ ) <sup>2</sup>	$S_a = H L_{ca}/(10A)$ $H$ =Maximum watershed relief (m) $L_{ca}$ =Average length of the contour (km) $L_{ca} = \sum_{i=1}^n \frac{L_{ci}}{n}$ $L_{ci}$ = Length of individual contour (km) $n$ = Number of identifiable contours, $A$ = Drainage area (km <sup>2</sup> )
Relief ratio ( $R_r$ ) <sup>2</sup>	$R_r = \frac{H}{L}$ $L$ = Main stream length (m)
Relative relief ( $R_R$ ) <sup>2</sup>	$R = \frac{H}{P} \times 100$ $P$ = Perimeter of watershed
Main stream channel slope ( $S_c$ ) <sup>2</sup>	$S_c = \frac{\text{Area Under the curve}}{5L^2}$ $L$ = Main stream length expressed in km
Elongation ratio ( $R_e$ ) <sup>2</sup>	$R_e = \frac{D_c}{L}$ $D_c$ = Diameter of the circle with the same area as that of the basin $L$ = Maximum length of basin (m)
Basin shape factor ( $S_b$ ) <sup>2</sup>	$S_b = \frac{\text{Square of the maximum length of basin}}{\text{area of the basin}}$
Length-width ratio ( $L_b/L_w$ ) <sup>2</sup>	$L_b/L_w = \frac{\text{Maximum length of watershed}}{\text{Width of the watershed}}$
Stream-length ratio ( $R_l$ ) <sup>6</sup>	$R_l = \frac{\bar{L}_u}{\bar{L}_u - 1}$ $L_u$ = Mean length of stream of $u$ order and $L_{u+1}$ = Mean length of stream of the next lower order
Bifurcation ratio ( $R_b$ ) <sup>7,6</sup>	$R_b = \frac{N_u}{N_u + 1}$ $N_u$ = Number of stream of order $u$ and $N_u + 1$ = Number of stream of order $u + 1$ .
Hypsometric analysis of drainage basin <sup>2,8</sup>	The curve is derived by plotting the relative heights ( $h/H$ ) and relative areas ( $a/A$ ).
Circulatory ratio ( $R_c$ ) <sup>9</sup>	$R_c = \frac{A_u}{A_c}$ $A_u$ = Watershed area and $A_c$ = Area of circle having the same length of perimeter as the basin.
Ruggedness number ( $R_N$ ) <sup>2</sup>	$R_N = \frac{H D_d}{1000}$ $H$ = Watershed relief and $D_d$ = Drainage density
Drainage factor ( $D_f$ ) <sup>2</sup>	$D_f = \frac{F_s}{D_d^2}$ Stream frequency ( $F_s$ ), $D_d$ =Drainage density

The 13 geo-morphological parameters from 11 selected watersheds in upper and middle Godavari sub basin are presented in Table-2.

**Principal Component Analysis (PCA):** The PCA technique is based upon the early work of Pearson with the specific adaptations of PCA suggested by the Hotellings<sup>10</sup>. The geomorphic parameters are usually correlated with each other. The correlation between these parameters indicates that, the information contained in one variable is also contained in the remaining other variables. The first Principal Component (PC) is that linear combination of the original variables which contributes maximally to their total variance; the second PC, uncorrelated with the first, contributes a maximally to their residual variance, and so on up to the total variance is analyzed. The method is most suitable when all the variables are expressed in the same dimension, as its dependent up on the total variance of the original variables. Hence the expression of variables in standard form essential, i.e. the selection of the unit of measurement for each variable so that its sample variance will be one. The analysis is performed on the basis of the correlation matrix, with the total variance equal to  $n$ . The objectives can be achieved by adopting the following two steps:

Step 1: Calculate the correlation matrix,  $R$   
 Step 2: Calculate the Principal Component loading matrix by PCA.  
 Step 3: In PC loading matrix, Eigen value  $>1$ , indicates significant PC loading.

The identified factors how well fitted in the data within the geomorphic parameters in all PC are expressed based on the Eigen value.

**Correlation Matrix:** The geomorphic parameters inter-correlation matrix is obtained by adopting the following procedure,

The standardization of the parameters:  

$$X = (x_{ij} - x_j) / S_j$$

where:  $x$ = Matrix of standardized parameters,  $x_{ij}$ =  $i$ th observation on  $j$ th parameter,  $i = 1, \dots, N$  ( Number of observations),  $j = 1, \dots, P$  ( Number of parameters),  $x_j$ = mean of the  $j$ th parameter,  $S_j$ = standard deviation of the  $j$ th parameter

The correlation matrix of parameters is the minor product moment of the standardized predictor measures divided by  $N$  and is given by following expression,

$$R = (X' - X)/N$$

where:  $X'$ =Transpose of the standardized matrix of predictor parameters.

**Principal Component Loading Matrix:** The PC loading matrix, reflects how much a particular parameter is correlated with other factors, is obtained by pre-multiplying the characteristic vector with the square root of the characteristic values of the correlation matrix.

$$\text{Thus, } A = Q \times D^{0.5}$$

where:  $A$  = PC loading matrix.  $Q$  = Characteristic vector of the correlation matrix.  $D$  = Characteristic value of the correlation matrix.

## Results and Discussion

Thirteen geomorphic parameter extracted from 11 selected watershed in upper and middle sub basin in Godavari basin are given in Table-2. The PCA is carried out using the SPSS 18.0 software package. Thirteen geomorphic parameters correlation matrix (Table-3) reveals strong correlations (correlation coefficient  $> 0.9$ ) exist between Average slope of watershed ( $S_a$ ) and Elongation ratio ( $R_e$ ), Relief ratio ( $R_r$ ), between Circulatory ratio ( $R_c$ ) and Elongation ratio ( $R_e$ ), Relief ratio ( $R_r$ ) between Relative Relief ( $R_R$ ) and Basin shape factor ( $S_b$ ), Drainage factor ( $D_f$ ). Also, good correlations (correlation coefficient  $> 0.75$ ) exist between  $S_a$ ,  $R_e$  and  $R_c$  and between  $R_e$ ,  $S_b$  and  $R_r$  and  $R_r$  and  $R_n$ ,  $S_c$  and  $R_v$ , between  $S_a$ ,  $R_R$ ,  $R_r$  and

$H_{si}$ ,  $D_f$  and  $R_r$  also between  $R_R$ ,  $R_r$ ,  $S_c$  and  $R_l$ . Also, some more moderately correlated parameters (correlation coefficient  $> 0.60$ ) exist between  $S_b$  and  $S_a$ ,  $R_N$  and  $S_a$ , between  $R_e$ ,  $R_r$  and  $S_c$ , between  $R_e$ ,  $R_c$  and  $H_{si}$  between  $R_e$ ,  $R_c$  and  $D_f$  also  $R_l$  and  $S_a$ . The parameters like  $R_b$  and  $L_b/L_w$  is not showing any significant correlation with any of the parameters hence at this stage it's very difficult to group the parameters into components and attach any physical significance. Hence next step of PCA is applied. The correlation matrix is subjected to the principal component analysis.

The PC loading matrix is obtained from correlation matrix shown in Table-4 shows that the first three components whose Eigen values  $> 1$  which account together about 93.80 % of the total explained variance. The first component is strongly correlated (loadings of  $> 0.8$ ) with  $S_b$ ,  $R_N$ ,  $S_c$ ,  $H_{si}$ ,  $R_l$  and moderately (loadings of  $> 0.6$ ) with  $R_R$  and  $R_r$ , which is termed as steepness or slope component. The second component is strongly correlated with  $S_a$ ,  $R_e$ ,  $R_c$  but moderately with  $R_R$  and can be termed as shape component. The third component is not showing any strong correlation with any geomorphic parameters. The results shows that some parameters are highly correlated with components but due to poor correlation some parameters could not be grouped with any of the components.

**Table-2**  
**Selected dimensionless geomorphic parameters of the selected watershed**

Ws No.	Area (km <sup>2</sup> )	$S_a$	$R_e$	$R_c$	$S_b$	$R_r$	$R_R$	$R_N$	$S_c$	$H_{si}$	$D_f$	$R_l$	$R_b$	$L_b/L_w$
WS1	1445.1	0.7519	0.789	0.8121	0.609	0.5477	0.4974	0.6006	0.8892	0.8296	0.7211	0.6036	5.3457	1.8009
WS2	708.553	0.3364	0.545	0.5661	0.5599	1.0882	0.8116	0.2352	0.365	0.2457	0.7973	0.1601	4.4908	1.4885
WS3	1153.6	0.0112	0.018	0.0212	0.019	0.0241	0.0103	0.0118	0.0125	0.0082	0.0065	0.0037	5.3352	1.5367
WS4	350.239	0.571	0.513	0.642	0.4781	0.5147	0.246	0.5889	0.430	0.5899	0.5682	0.5518	3.0597	1.9138
WS5	429.752	1.2533	1.044	1.9315	3.4346	4.2467	3.1498	3.5313	1.6112	1.851	2.4499	3.4966	3.3433	1.8715
WS6	914.128	0.4321	0.41	0.3542	0.4312	0.4919	0.4867	0.397	0.5947	0.4189	0.4824	0.4498	4.232	0.9432
WS7	1567.43	1.5285	1.854	3.2959	0.7902	2.7392	2.9513	0.8979	0.5611	0.7397	0.905	0.7382	3.2806	1.1441
WS8	684.461	0.0079	0.012	0.0135	0.0142	0.0163	0.0063	0.0116	0.0076	0.0057	0.0043	0.0012	2.4005	2.4442
WS9	357.361	0.0036	0.005	0.0067	0.0069	0.0101	0.0033	0.0048	0.0029	0.0024	0.0022	0.0014	6.5452	1.9967
WS10	2715.68	0.4875	0.456	0.3585	0.3187	0.4745	0.5328	0.5741	0.3075	0.6014	0.5952	0.996	4.0706	2.5720
WS11	1537.51	0.1343	0.164	0.1296	0.1931	0.1559	0.124	0.1012	0.2117	0.0859	0.1339	0.2246	5.8987	1.4584

**Table-3**  
**Interco-relation matrix of the selected geomorphic parameters**

	S <sub>a</sub>	R <sub>e</sub>	R <sub>c</sub>	S <sub>b</sub>	R <sub>R</sub>	R <sub>r</sub>	R <sub>N</sub>	Sc	H <sub>si</sub>	D <sub>f</sub>	R <sub>l</sub>	R <sub>b</sub>	L <sub>b</sub> /L <sub>w</sub>
<b>Sa</b>	1.000	<b>0.969</b>	<b>0.950</b>	0.682	0.858	0.913	0.711	0.765	0.821	0.779	0.673	-0.437	-0.266
<b>Re</b>	<b>0.969</b>	1.000	<b>0.974</b>	0.527	0.781	0.876	0.544	0.621	0.668	0.650	0.495	-0.394	-0.353
<b>Rc</b>	<b>0.950</b>	<b>0.974</b>	1.000	0.569	0.834	0.924	0.588	0.589	0.652	0.650	0.527	-0.414	-0.343
<b>Sb</b>	0.682	0.527	0.569	1.000	0.913	0.807	0.990	0.917	0.926	0.970	0.968	-0.330	-0.038
<b>R<sub>R</sub></b>	0.858	0.781	0.834	<b>0.913</b>	1.000	0.974	0.908	0.827	0.867	0.930	0.865	-0.414	-0.192
<b>R<sub>r</sub></b>	<b>0.913</b>	0.876	<b>0.924</b>	0.807	<b>0.974</b>	1.000	0.812	0.748	0.800	0.848	0.766	-0.415	-0.259
<b>R<sub>N</sub></b>	0.711	0.544	0.588	<b>0.990</b>	<b>0.908</b>	0.812	1.000	0.910	0.950	0.961	0.989	-0.366	0.026
<b>Sc</b>	0.765	0.621	0.589	<b>0.917</b>	0.827	0.748	<b>0.910</b>	1.000	0.961	0.939	0.892	-0.281	-0.158
<b>H<sub>si</sub></b>	0.821	0.668	0.652	<b>0.926</b>	0.867	0.800	<b>0.950</b>	<b>0.961</b>	1.000	0.957	0.946	-0.382	0.009
<b>D<sub>f</sub></b>	0.779	0.650	0.650	<b>0.970</b>	<b>0.930</b>	0.848	<b>0.961</b>	<b>0.939</b>	<b>0.957</b>	1.000	0.944	-0.380	-0.063
<b>R<sub>l</sub></b>	0.673	0.495	0.527	<b>0.968</b>	0.865	0.766	<b>0.989</b>	0.892	<b>0.946</b>	<b>0.944</b>	1.000	-0.345	0.101
<b>R<sub>b</sub></b>	-0.437	-0.394	-0.414	-0.330	-0.414	-0.415	-0.366	-0.281	-0.382	-0.380	-0.345	1.000	-0.197
<b>L<sub>b</sub>/L<sub>w</sub></b>	-0.266	-0.353	-0.343	-0.038	-0.192	-0.259	0.026	-0.158	0.009	-0.063	0.101	-0.197	1.000

a. This matrix is not positive definite. Figures shown in bold indicate strong correlations.

**Table-4**  
**First (Unrotated) Factor Loading Matrix of Selected Geomorphic Parameters**

Parameters	Principal Components												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Sa	0.907	-0.339	-0.122	0.139	-0.155	-0.051	-0.019	-0.014	0.001	0.012	0.00	0.0	0.00
Re	0.805	-0.530	-0.156	0.174	-0.113	.0048	-0.026	0.005	0.014	-0.007	0.00	0.00	0.00
Rc	0.821	-0.512	-0.169	0.155	0.075	-0.037	0.056	-0.027	0.003	-0.003	0.00	0.00	0.00
Sb	0.924	0.308	0.165	-0.094	0.105	0.029	0.052	-0.026	0.014	-0.003	0.00	0.00	0.00
R <sub>R</sub>	0.973	-0.048	0.020	-0.009	0.221	0.048	0.011	-0.006	-0.002	0.003	0.00	0.00	0.00
R <sub>r</sub>	0.943	-0.232	-0.045	0.062	0.217	0.007	-0.008	0.064	-0.016	0.000	0.00	0.00	0.00
R <sub>N</sub>	0.933	0.324	0.099	-0.039	0.076	-0.074	0.025	-0.026	-0.007	0.003	0.00	0.00	0.00
Sc	0.912	0.177	0.224	-0.081	-0.266	0.046	0.073	0.049	0.003	0.002	0.00	0.00	0.00
H <sub>si</sub>	0.950	0.222	0.049	0.049	-0.201	-0.044	-0.018	-0.021	-0.023	-0.008	0.00	0.00	0.00
D <sub>f</sub>	0.959	0.205	0.098	-0.047	-0.009	0.140	-0.072	-0.025	-0.002	0.002	0.00	0.00	0.00
R <sub>b</sub>	-0.448	-0.038	0.788	0.419	0.035	0.005	0.000	-0.003	0.000	0.000	0.00	0.00	0.00
R <sub>l</sub>	0.903	0.396	0.091	0.003	0.046	-0.112	-0.066	0.029	0.019	-0.002	0.00	0.00	0.00
L <sub>b</sub> /L <sub>w</sub>	-0.151	0.728	-0.523	0.416	0.009	0.036	0.021	0.007	0.001	0.001	0.00	0.00	0.00
Eigen Value	<b>9.397</b>	<b>1.724</b>	<b>1.073</b>	0.447	0.270	0.053	0.023	0.011	0.002	0.000	0.00	0.00	0.00
	<b>93.800</b> per cent												

**Table-5**  
**Principal component loading matrix of 11 finally screened out geomorphic parameters**

Parameters	Principal Components										
	1	2	3	4	5	6	7	8	9	10	11
Sa	1.000	0.969	0.950	0.682	0.858	0.913	0.711	0.779	-0.437	0.673	-0.266
Re	0.969	1.000	0.974	0.527	0.781	0.876	0.544	0.650	-0.394	0.495	-0.353
Rc	0.950	0.974	1.000	0.569	0.834	0.924	0.588	0.650	-0.414	0.527	-0.343
S <sub>b</sub>	0.682	0.527	0.569	1.000	0.913	0.807	0.990	0.970	-0.330	0.968	-0.038
R <sub>R</sub>	0.858	0.781	0.834	0.913	1.000	0.974	0.908	0.930	-0.414	0.865	-0.192
R <sub>r</sub>	0.913	0.876	0.924	0.807	0.974	1.000	0.812	0.848	-0.415	0.766	-0.259
R <sub>N</sub>	0.711	0.544	0.588	0.990	0.908	0.812	1.000	0.961	-0.366	0.989	0.026
D <sub>f</sub>	0.779	0.650	0.650	0.970	0.930	0.848	0.961	1.000	-0.380	0.944	-0.063
R <sub>b</sub>	-0.437	-0.394	-0.414	-0.330	-0.414	-0.415	-0.366	-0.380	1.000	-0.345	-0.197
R <sub>l</sub>	0.673	0.495	0.527	0.968	0.865	0.766	0.989	0.944	-0.345	1.000	0.101
L <sub>b</sub> /L <sub>w</sub>	-0.266	-0.353	-0.343	-0.038	-0.192	-0.259	0.026	-0.063	-0.197	0.101	1.000
<b>Eigen Value</b>	<b>7.720</b>	<b>1.636</b>	<b>1.015</b>	0.439	0.121	0.049	0.017	0.002	.001	.000	.000
	<b>94.284</b> per cent										

In order to screen out parameters having less significance in explaining the component variance from the analysis. Then, the correlation matrix and principal component loading matrix are obtained for screen out parameters. The less correlated parameters such as R<sub>l</sub> and L<sub>b</sub>/L<sub>w</sub> were screen out and finally 11 parameters are selected.

The principal component loadings matrix obtained from the correlation matrix of finally selected 11 parameters (Table-5) shows that the first three components now accounts 94.284 % of the total explained variance. The principal component loadings is also improved considerably in almost in all significant parameters. The Elongation ratio (Re), Circulatory ratio (Rc) and Relief ratio (Rr) are highly correlated (loadings > 0.9) with the first component. The Relative Relief (R<sub>R</sub>) shows good correlations (loadings of more than 0.8) with the first component. The average slope of watershed (Sa) and Elongation ratio (Re) are highly correlated (loadings > 0.9) with second component whereas Relief ratio (Rr) also shows good correlation. The results found in the study shows that the steepness component is the dominant component followed by shape and drainage components. Therefore, it can be stated that the hydrologic response like runoff yield and soil loss for these watersheds will be high. The peak runoff rate will not achieved

frequently in the watershed only due to the less dominance of shape and drainage components.

The study shows that PCA is very useful tool in the screening out the parameters or variables having least significance and in regrouping the remaining variables into physically significant factors. The hydrologic responses like runoff and sediment yield from watershed can predicted using the multiple regression technique. One parameter each from significant components may form a set of independent parameters at a time in modelling the said hydrologic responses.

## Conclusion

The present study was carried out for 11 sub watersheds in upper and middle Godavari sub basin, Maharashtra (India). The analysis of the geomorphic parameters of the watersheds were performed on the basis 13 parameters of the selected watershed. The correlation matrix of 13 selected geomorphic parameters shows that strong correlation (correlation coefficient > 0.9) exist between Elongation ratio (Re) and Average slope of watershed (Sa), between Average slope of watershed (Sa), Elongation ratio (Re) and Circulatory ratio (Rc), between Relative Relief (R<sub>R</sub>) and Basin shape factor (Sb) between

Average slope of watershed (Sa), Circulatory ratio (Rc), Relative Relief ( $R_R$ ) and Relief ratio (Rr), between Basin shape factor (Sb), Relative Relief ( $R_R$ ) and Ruggedness ratio ( $R_N$ ), between Main stream channel slope (Sc) and Basin shape factor (Sb), Ruggedness ratio ( $R_N$ ), between Hypsometric integral (Hsi) with Basin shape factor (Sb), Ruggedness ratio ( $R_N$ ), Main stream channel slope (Sc) also exist in between Drainage factor (Df) with Basin shape factor (Sb), Relative Relief ( $R_R$ ), Ruggedness ratio ( $R_N$ ), Main stream channel slope (Sc) and Hypsometric integral (Hsi), between stream length ratio ( $R_l$ ) and Basin shape factor (Sb), Ruggedness ratio ( $R_N$ ), Hypsometric integral (Hsi) and Drainage factor (Df). The principal component loading matrix obtained from correlation matrix shows that the first three components, whose Eigen values >1, accounts together about 93.800 % of the total explained variance.

The results of the PCA shows that, first component is strongly correlated with Basin shape factor (Sb), Ruggedness ratio ( $R_N$ ), Drainage factor (Df) and stream length ratio ( $R_l$ ). The second component is strongly correlated with Elongation ratio (Re) and Circulatory ratio (Rc). However, third component is not found strongly correlated with any of the geomorphologic parameters but moderately (> 0.7) correlated with Length width ratio ( $L_b/L_w$ ). After screening out the hypsometric integral (Hsi) and Main stream channel slope (Sc) the PC loadings matrix of 11 geomorphic parameters shows that first three components account approximately 94.283 % of the total explained variance. On the basis of the properties of the geomorphic parameters, three principal components were classified as steepness, shape and drainage components. Finally on the basis of the study results it can be stated the PCA is good tool for screening out the insignificant parameters in the study of watersheds hydrologic behaviour like runoff and sediment yield modelling.

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