IJRSG
EXPLORING INNOVATIVE TECHNICAL RESEARCH

International Journal of Remote Sensing & Geoscience (IJRSG)
www.ijrsg.com

APPLICATION OF PRINCIPAL COMPONENT ANALYSIS IN GROUPING GEOMORPHIC PARAMETERS OF UTTELA WATERSHED FOR HYDROLOGICAL MODELING

Shailesh Kumar Sharma. 1; Sanjay Tignath 2; Sarita Gajbhiye 3; Rupesh Patil 4,
Department of Soil and Water Engineering, College of Agricultural Engineering, JNKVV, Jabalpur (M.P.) 1, 4,
Department of Geology, Government Science College, Jabalpur (M.P.) 2,
Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee 3

Abstract

Geomorphological characteristics of a watershed are very commonly used for developing the regional hydrological models for solving the various hydrological problems of the ungauged watersheds or inadequate data situations. So, in the present study GIS technique has been used to determine the geomorphological parameters of Uttala nala watershed which is tributary of Son river, located in Sahadol district of Madhya Pradesh. Many of the geomorphic parameters are known to be strongly correlated. There is considerable amount of redundancy in the array of geomorphic parameters currently in use. The screening of such large number of interrelated variables for their underlying dimensions is best achieved by multivariate statistical techniques of the principal component analysis. Results of principal analysis of eleven geomorphometric parameters clearly reveals that some of the parameters are strongly correlated with the components but stream frequency does not show correlation with any of the component. So it has been screened out of analysis. The principal component loading matrix obtained using correlation matrix of ten parameters reveals that first three components together account for 93.71 per cent of the total explained variance. Therefore, principal component loading is applied in order to get better correlation and clearly group the parameters in physically significant components. Based on the properties of geomorphic parameters, three components were defined as slope or steepness, drainage and shape component. One parameter each from the significant component may form a set of independent parameter at a time in modeling the hydrological responses such as runoff and sediment yield from small watersheds.

Keywords: Geomorphic Parameters, Principal Component Analysis, GIS

Introduction

The development of land and water resources on a sustainable basis without deterioration and with constant increase in productivity is the mainstay of mankind. Ironically, adequate emphasis has not been paid to conserve, develop and judiciously utilize these resources in many parts of country. This is evident from the fact that 175 million ha of land in India constituting 53% of its total geographical area, suffers from such deleterious effects. It has been estimated that about 16.4 tones/ha of soil is detached annually in our country because of destruction (Singh, 2000).Apart from serious losses of production, the immediate action of the problem is seen through excessive and premature siltation of multipurpose reservoirs constructed with huge investments. Hence, it becomes necessary to protect their lives as they are considered one of the important resources for national economy. To overcome aforesaid conditions at the national level, an integrated watershed management considering crop production, soil and water conservation and management, reclamation of waste land and degraded lands is essential to increase overall efficiency of the watershed.

Soil and water conservation measures on watershed basis can play an important role in formulating long term comprehensive land and water management strategies. There may be various considerations for the implementation of management programmes in the few sub-watersheds only. It is always better to start management measures from the most critical sub-watershed. Sediment yield from a catchment is one of the criterions to find most critical sub-watershed to soil erosion. However, this criterion requires for assessing continuous monitoring of sediment samples at the catchment outlet. Such data are hardly available in India for small watersheds. Although the sediment yield from large basins can be obtained from such observation, it is not possible to ascertain the vulnerability to soil erosion of small watersheds within a basin. In the absence of sediment yield data morphometric parameters may be helpful in assessing most critical sub-watershed. Morphometry is the measurement and mathematical analysis of the configuration of the earth’s surface, shape and dimensions of its landforms (Clarke, 1966). This analysis can be achieved through measurement of linear, aerial and relief aspects of basin and slope contributions.

Morphometric analysis of a basin can be better achieved through a latest technology like GIS as conventional measurement of these parameters is laborious and cumbersome. Many researchers have demonstrated the potential of GIS technique for morphometric analysis of watershed (Shrimali et al., 2001; Thakker et al., 2007; Sharma et.al, 2010).

The method of quantitative analysis of watershed was developed by Horton (1945) and was further modified by Strahler (1964). Sufficient works on the quantitative analysis of geomorphological parameters of watersheds have been done in India and abroad (Ghose et al., 1969). However, a very little work on the interrelationship of morphological parameters has been carried out. To determine interrelationship of these geomorphological parameters is very important to develop sediment yield regression models (Hydrological modeling). Statistical methods are applied in a variety of fields in hydrological research. Factor analysis is useful for interpreting morphometric parameters and relating the same to specific hydrological processes. Multivariate analysis is simply a collection of procedures for analyzing the associations between two or more sets of data that have been collected on each object in one or more samples of object. Synder (1962) introduced some solutions, possibilities of multivariate statistics in hydrological modeling. Wong (1979) utilized a multivariate statistical technique component analysis in analyzing the effects of twelve basins and climatological parameters. Wallis (1965) in discussion of multivariate statistical methods in hydrology recommends, for multifactor hydrological problems, the use of principle component analysis with varimax rotation of the factor weight matrix. Hann and Allen (1972), Decoursey and Deal (1974) and have also demonstrated the use of multiple regression analysis for development of hydrological predictions equations involving geomorphic parameters. Mishra and Satyanarayana (1988) carried out principal component analysis with varimax rotation on ten geomorphic parameters at Damoder valley catchment of India and concluded that nine parameters could be significantly grouped into three components. Singh et.al (2009) carried out principal component analysis to thirteen geomorphic parameters collected for sixteen watersheds of Chambal catchment of Rajasthan. The parameters are grouped into three components. Therefore, in this study an attempt has been made to determine geomorphological parameters and to study the intercoorelationship (multicollinearity) among 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 principal component analysis for better interpretability.

Materials and methods

Uttala Nala watershed, a tributary of Son river falling in Sahadol district of Madhya Pradesh lying between 23˚8´21.6″ to 23˚13´19.2″ N latitude and 89˚19´54.7″ to 81˚28´48.76″ E longitude has been selected as the study area. The elevation of the watershed range from 460 to 800 m above mean sea level. The location map of the study watershed is shown in Fig. 1. The total area of the watershed is 4763 ha. The watershed receives an average annual rainfall of 1099.9 mm and more than 80 % of rainfall is received during the monsoon season (June to October). The minimum and maximum temperature varies in the range of 2.6˚C to 46˚C.

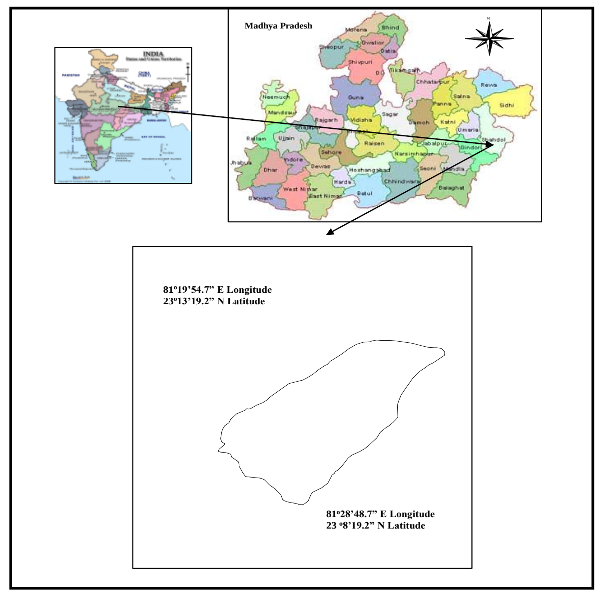

Figure 1. Location map of Uttala nala watershed

A. Geomorphometric Parameters The watershed boundary of the study area was delineated using Survey of India Toposheet (64 E/8) on 1:50000 scale. The delineated watershed boundary was further sub divided into sub-watersheds. The input parameters for present study such as area, perimeter, stream order, number of streams, stream length, elevation and basin length were derived from digitized stream network and contour map in GIS environment. The morphometric parameters for the delineated watershed area were calculated using formula suggested by Horton (1945), Strahler (1964), Schumm (1956) and Miller (1953) given in Table 1.

Table 1. Formula for Computation of Morphometric Parameters

Morphometric Parameters	Formula	Refrence
Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, R_b = Bifurcation Ratio N_u = Total number of stream of segment of order u N_{u+1} = Total number of stream of segment of next higher order	Schumn (1956)

Drainage density (D_d)	$D_d = L_u / A$ Where, D_d = Drainage density L_u = Total stream length of order u A = Area of basin	Horton (1945)
Texture ratio (T)	$T = N_1 / P$ Where, T = Texture ratio N_1 = Total number of streams of first order P = Perimeter	Horton (1945)
Stream Frequency (F_u)	$F_u = N_u / A$ Where, N_u = Total number of streams of all order A = Area of basin	Horton (1945)
Circulatory ratio (R_c)	$R_c = 4 \Pi A / P^2$ Where, R_c = Circulatory ratio A = Area of basin P = Perimeter	Miller (1953)
Form factor (R_f)	$R_f = A / L_b^2$ Where, R_f = Form factor A = Area of basin L_b = Length of basin	Horton (1945)
Elongation ratio (R_e)	$R_e = (2/L_b) * (A/\Pi)^{0.5}$ Where, R_e = Form factor A = Area of basin L_b = Length of basin	Schumn (1956)
Length of over land flow (L_o)	$L_o = ½ D_d$ Where, L_o = Length of over land flow D_d = Drainage density	
Relative relief (R_r)	$R_r = H/P$ Where, R_r = Relative relief H = Maximum watershed relief P = Perimeter of basin	
Relief ratio (R_h)	$R_h = H / L_b$ Where, R_h = Relief ratio H = Maximum watershed relief L_b = Length of basin	
Ruggedness number (R_N)	$R_N = H * D_d$ Where, R_N = Ruggedness number H = Maximum watershed relief D_d = Drainage density	

B. Principal Component Analysis The method of principal components or component analysis is based upon the early work of Pearson with specific adaption to principal component analysis suggested by the Hotelling (1933). The geomorphometric parameters are usually many times correlated. The correlation indicates that some of the information contained in one variable is also contained in some of the other remaining variables. More specifically, the first principal component is that linear combination of the original variables which contributes a maximum to their total variance; the second principal component, uncorrelated with the first, contributes a maximum to the residual variance, and so on until the total variance is analyzed. Since the method is so dependent on the total variance of the original variables, it is most suitable when all the variables are measured in the same units. Hence, it is customary to express the variables in standard form, i.e., to select the unit of measurement for each variables so that its sample variance is one. Then, the analysis is made on the correlation matrix, with the total variance equal to n. The objectives are achieved in three steps:

Step 1 Calculate the correlation matrix, R

Step 2 Calculate the principal component loading matrix by principal component analysis.

Step 3 In the principal component (PC) Loading matrix, Eigen values greater than one indicates significant PC loading.

Eigen value indicated how well each of the identified factors fit the data from all the geomorphic parameters on all the principal components.

C. Correlation Matrix The inter-correlation matrix of the geomorphic parameters is obtained by using the following procedure:

1. The parameters are standardized

$$X = (x_{ij} - x_j) / S_j \quad (1)$$

Where,

X denotes the matrix of standardized parameters

x_{ij} ith observation on jth parameters

i 1………, N (Number of observation)

j 1……….,, P (Number of observation)

x_j mean of the jth parameters

S_j standered deviation of the jth parameters

2. The correlation matrix of parameters is the minor product moment of the standardized predictor measures divided by N and is given by

$$R = (x' \times x) / N \quad (2)$$

where, x' denotes the transpose of the standardized matrix of predictor parameters

D. Principal Component Loading Matrix The principal component loading matrix which reflects how much a particular parameter is correlated with different factors, is obtained by premultiplying the characteristics vector with square root of the characteristics values of the correlation matrix.

$$\text{Thus, } A = Q \times D^{0.5} \quad (3)$$

where

A principal component loading matrix,

Q characteristics vector of the correlation matrix

D characteristics value of the correlation matrix

Results and discussion

The drainage and sub-watershed map of Uttala Nala watershed is presented in Fig 2.

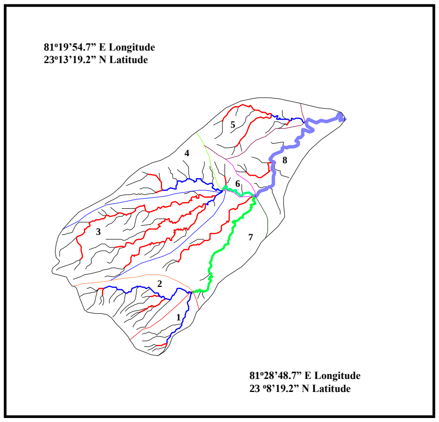

Figure 2. Stream network with sub watershed boundaries

Morphometric parameters of sub watersheds were calculated in GIS environment and are presented in Table 2 and computed geomorphometric parameters are presented in Table 3.

Area and perimeter of sub watersheds varies from 1.33 to 12.39 km^2 and 5.75 to 15.94 km respectively. After analysis of drainage map it was found that Uttala Nala watershed is of 5th order type and drainage pattern is dendritic. The bifurcation ratio (R_b) reflects geological and tectonic characteristics of watershed area were calculated for all eight sub-watersheds and are given in Table 3. These values are more or less normal in the sub watersheds 1, 4, 5, 6, and 7 as they range between 1 and 3 (Horton, 1945).

The important parameters that describe the shape of the basin form factor, circulatory ratio and elongation ratio were computed for all eight sub watersheds (Table 3). In the present case sub watersheds have lower R_f value (0.14 to 0.36) indicating them to be elongated in shape and suggesting flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than those of circular basin. In the present case circulatory ratios for sub watersheds are 0.31 to 0.65, indicating that the area is characterized by high relief and the drainage system is structurally controlled. The value of elongation ratio (Re) for sub watersheds varies between 0.42 and 0.67 indicates sub watersheds to be elongated with high relief and steep slopes.

Relief ratio (R_h), and Ruggedness number (R_N) values for all the sub watersheds are given in Table 3. Sub watersheds with high R_h are considered critical from erosion point of view and should be provided with suitable soil and water conservation measures. The Ruggedness number ranges from 0.82 to 2.64 for different sub watersheds. The sub watershed 2 has an overall roughness or unevenness.

Drainage density (D_d), Stream frequency (F_u) and Texture ratio (T) values are computed for all the sub watersheds and are given in Table 3. Drainage frequency values of all the sub watersheds have close correlation with Drainage density indicating the increase in stream population with respect to increase in Drainage density. In the present study low value of D_d for sub watershed 7 indicates that it has highly resistant, impermeable sub soil material with dense vegetation cover and low relief. Texture ratio values for sub watersheds ranges from 0.91 to 3.86.

Length of over land flow values are between 0.30 and 1.33 for all the sub-watersheds. However, compactness coefficient values vary from 1.53 to 3.25 for sub-watershed 7 and sub-watershed 1 respectively.

The correlation matrix (Table 4) of eleven geomorphometric parameters reveals that strong correlations (correlation coefficient more than 0.9) exists between drainage density and length of over land flow, between stream frequency and form factor, between circulatory ratio and elongation ratio, between relief ratio and ruggedness number and relative relief. Also, good correlation (correlation coefficient more than 0.75) exists bifurcation ratio and texture ratio, length of over land flow, ruggedness number, between drainage density and stream frequency, ruggedness number between form factor and elongation ratio. Some more moderately correlated parameters (correlation coefficient more than 0.60) are bifurcation ratio with drainage density, relief ratio, ruggedness number, stream frequency with circulatory ratio, elongation ratio, length of over land flow, circulatory ratio with form factor, form factor with length of over land flow and length of over land flow with ruggedness number. It is very difficult at this stage to group the parameters into components and attach any physical significance. Hence, in the next, the principal component analysis has been applied. The correlation matrix is subjected to the principal component analysis.

The principal component loading matrix obtained from correlation matrix (Table 5) reveals that the first three components whose Eigen values are greater than one, together account for about 89.277 per cent of the total explained variance. The first component is strongly correlated (loading of more than 0.80) with circulatory ratio and elongation ratio and good correlation (loading of more than 0.70) with form factor, which may be termed as shape component. The second component is strongly correlated with bifurcation ratio, texture ratio and length of over land flow and moderately correlated with (loading of more than 0.60) drainage density which may be termed as drainage component. Third component is strongly correlated with relief ratio, relative relief and ruggedness number. It is evident from these results that some of the parameters are highly correlated with some of the component but the parameter texture ratio could not be grouped with any of the component because of its poor correlation with them.

Table 2. Sub watershed wise input Geomorphometric parameters

Sub watershed No.	Area (km^2)	Perimeter (km)	Max. Elevation (m)	Min. Elevation (m)	Total Relief (m)	No. of Streams	Max. Length of Watershed (km)	Total Stream Length (km)
1.	2.33	7.19	780	520	260	9	2.92	7.57
2.	5.64	10.42	800	520	280	22	3.98	4.26
3.	12.39	15.90	760	500	260	28	6.95	4.27
4.	5.25	14.54	560	500	60	13	6.14	11.74
5.	4.96	9.66	520	480	40	14	3.77	10.99
6.	1.33	5.75	520	500	20	6	2.55	4.10
7.	8.76	15.94	540	500	40	8	5.13	13.42
8.	6.96	14.61	500	460	40	10	5.38	13.15

Table 3. Sub-watershed wise computed Geomorphometric parameters

Sub watershed No.	R_b	D_d	T	F_u	R_c	R_f	R_e	L_o	R_r	R_h	R_N
1	3.25	0.83	3.86	0.57	0.27	1.33	0.59	0.60	0.036	0.089	0.846
2	3.31	1.63	3.90	0.65	0.36	1.24	0.67	0.30	0.026	0.070	0.931
3	3.01	1.51	2.26	0.62	0.26	1.27	0.57	0.33	0.016	0.037	0.790
4	2.24	0.69	2.48	0.31	0.14	1.79	0.42	0.72	0.004	0.009	0.134
5	2.22	1.04	2.82	0.67	0.35	1.22	0.67	0.48	0.004	0.010	0.088
6	3.09	0.70	5.26	0.51	0.21	1.41	0.51	0.71	0.003	0.007	0.056
7	1.53	0.38	0.91	0.43	0.33	1.52	0.65	1.33	0.002	0.007	0.061
8	1.89	0.55	1.44	0.41	0.24	1.56	0.55	0.99	0.002	0.007	0.075

Table 4. Intercorrelation matrix of Geomorphometric parameters

	R_b	D_d	T	F_u	R_c	R_f	R_e	L_o	R_h	R_N	R_r
R_b	1.000	0.682	0.820	0.576	0.011	-0.552	0.004	-0.777	0.731	0.760	0.745
D_d	0.682	1.000	0.320	0.754	0.379	-0.684	0.343	-0.900	0.540	0.768	0.543
T	0.820	0.320	1.000	0.395	-0.097	-0.377	-0.110	-0.531	0.392	0.293	0.396
F_u	0.576	0.754	0.395	1.000	0.715	-0.988	0.716	-0.701	0.509	0.577	0.509
R_c	0.011	0.379	-0.097	0.715	1.000	-0.739	0.996	-0.130	0.309	0.300	0.277
R_f	-0.552	-0.684	-0.377	-0.988	-0.739	1.000	-0.750	0.612	-0.501	-0.555	-0.502
R_e	0.004	0.343	-0.110	0.716	0.996	-0.750	1.000	-0.103	0.319	0.297	0.290
L_o	-0.777	-0.900	-0.531	-0.701	-0.130	0.612	-0.103	1.000	-0.520	-0.667	-0.534
R_h	0.731	0.540	0.392	0.509	0.309	-0.501	0.319	-0.520	1.000	0.920	0.998
R_N	0.760	0.768	0.293	0.577	0.300	-0.555	0.297	-0.667	0.920	1.000	0.926
R_r	0.745	0.543	0.396	0.509	0.277	-0.502	0.290	-0.534	0.998	0.926	1.000

Table 5. Principal component loading matrix of eleven geomorphic parameters

Parameters	Components		
	1	2	3
R_b	-0.013	0.806	0.557
D_d	0.419	0.663	0.380
T	-0.130	0.813	0.154
F_u	0.774	0.573	0.225
R_c	0.969	-0.083	0.138
R_f	-0.795	-0.513	-0.225
R_e	0.971	-0.108	0.151
L_o	-0.195	-0.842	-0.317
R_h	0.193	0.252	0.936
R_N	0.237	0.359	0.874
R_r	0.171	0.270	0.937
Eigen Value	5.477	2.407	1.157

In order to screen out parameters having less significance in explaining the component variance, the parameter stream frequency is screened out from analysis. Then correlation matrix and principal component matrix are obtained for ten parameters.

The principal component loading matrix obtained using the correlation matrix of ten parameters (Table 6) reveals that the first three components now together accounts for 93.71 per cent of the total explained variance showing an increase of about 4.43 per cent.

Table 6. Principal component loading matrix of ten finally screened out geomorphic parameters

Parameters	Components		
	1	2	3
R_b	0.554	0.807	-0.048
D_d	0.361	0800	0.403
T	0.155	0.802	-0.166
R_c	0.135	-0.038	0.976
R_f	-0.228	-0.538	-0.801
R_e	0.151	-0.065	0.975
L_o	-0.305	-0.856	-0.161
R_h	0.937	0.264	0.181
R_N	0.866	0.381	0.226
R_r	0.938	0.280	0.157
Eigen value	6.475	2.478	1.215

The principal component loading here also improved considerably in almost all significant parameters. The relief ratio and relative relief have strong correlation (loadings of more than 0.90) with the first component. The ruggedness number has good correlation (loadings of more than 0.80) with first component. The bifurcation ratio, drainage density, texture ratio and length of over land flow have the good correlation with the second component. The circulatory ratio and elongation ratio have strong correlation with third component. The form factor has good correlation with third component.

It is observed that the first component is strongly correlated with relief ratio and relative relief and good correlation with ruggedness number which are grouped under slope or steepness component. The second component has good correlation with bifurcation ratio, drainage density, texture ratio and length of over land flow of watershed and is termed as drainage component. The third component has strong correlation with circulatory ratio and elongation ratio and good correlation with form factor hence is called as shape component.

It can be seen how useful the principal component analysis have been in screening out the parameters or variables of least significance and is regrouping the remaining variables into the physically significant factors. Multiple regression technique can then be applied in modeling the hydrologic response such as runoff and sediment yields from the watersheds. One parameter each from significant component may form a set of independent parameters at a time in modeling the said hydrologic response.

Conclusion

The quantitative geomorphometric analysis was carried out in eight sub watersheds of Uttala river watershed, using GIS technique for determining the various areal, relief and linear aspects of the watershed. The conventional methods of morphometric analysis are time consuming, tiresome and error prone, while use of GIS technique allows for more reliable and accurate estimation of similar parameters of watersheds. The morphometric analysis of different sub watersheds shows their relative characteristics with respect to hydrologic response of the watershed. The correlation matrix of eleven geomorphometric parameters revealed that strong correlation exist between drainage density and length of over land flow, between stream frequency and form factor, between circulatory ratio and elongation ratio, between relief ratio and ruggedness number and relative relief. The principal component loading matrix obtained from correlation matrix reveals that the first three components, whose Eigen values are greater than one, together accounts for 89.277 per cent of the total explained variance. Based on the results of the principal component analysis, first component is strongly correlated with circulatory ratio and elongation ratio. The second component is strongly correlated with bifurcation ratio, texture ratio and length of over land flow. However, the third component is strongly correlated with relief ratio, relative relief ratio and ruggedness number. The stream frequency could not be grouped with any of the component because of its poor correlation with them. After screening out the stream frequency the principal component loading matrix of ten parameters indicate that first three component together accounts for 93.71 per cent of the total explained variance. Based on the properties of geomorphometric parameters, three principal components were defined as steepness drainage and shape components. Moreover, it is concluded that in modeling the hydrologic responses such as runoff and sediment yield from small watersheds, the principal component analysis is good tool for screening out the insignificant parameters from the analysis.

References

[1] Clarke, J.I. (1966). Morphometry from maps. Essays in Geomorphology. Elsevier Publ co. New York., 235-274.

[2] Decoursy, D.G. and Deal, R.B. (1974). General aspect of multivariate analysis with application to some problems in hydrology. In: Proceedings of symposium on statistical hydrology, USDA, miscellaneous publication No. 1275. Washington DC, pp 47-68.

[3] Ghose, B., Pandey, S. and Singh, S. (1969). Quantitative Geomorphology of the drainage basin in semi arid environment. Annals of Arid Zone. (1). pp. 37-44.

[4] Hann, C.T. and Allen, D.M (1972). Comparison of multiple regression and principal component regression for predicting water yields in Kentucky. Water Resour Res 8(6):1593-1596.

[5] Horton, R.E. (1945). Erosional development of streams and their drainage basins: A hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull., Vol. 56, pp. 275-370.

[6] Hotelling, H. (1933). Analysis of complex of statistical variables into principal component. J Educ Psychol 24:417-441, 498-520.

[7] Miller, V.C. (1953). A quantitative geomorphic study of drainage basin characteristics in the Clinch mountain area, Virginia and Tennesses. Deptt. of Navy, Office of Naval Res., Technical Report 3, Project NR 389-042, Washington DC.

[8] Mishra, N. and Satyanarayana, T. (1988). Parameter grouping- a prelude to hydrologic modeling. Indian J Power River Val Dev 256-260, September.

[9] Schumm, S.A. (1956). Evaluation of drainage system and slopes in bed lands at Perth Ambry, New Jersy. Geolo. Soc. Am. Bull. 67:597-646.

[10] Sharma, S.K., Rajput, G,S, Tignath. S. and Pandey, R.P. (2010). Morphometric Analysis of a Watershed using GIS. J Indian Wat Res Soc. Vol 30, No. (2) : 33-39.

[11] Shrimali, S.S., Aggarwal, S.P. and Samra, J.S. (2001). Prioritizing erosion-prone areas in hills using remote sensing and GIS- a case study of the Sukhna Lake catchment, Northren India. 3(1):54-60.

[12] Singh, R.V.(2000). Watershed planning and management . Yash Publishing House, Bikaner, p 470.

[13] Singh, P.K., Kumar, V., Purohit, R.C., Kothari, M. and Dashora, P.K. (2009). Application of principal component analysis in grouping geomorphic parameters for hydrologic modeling. Water Resour Manage, 23:325-339.

[14] Strahler, A.N. (1964). Quantitative geomorphology of drainage basins and channel networks. Section 4-II. In: Handbook of Applied Hydrology, edited by V.T. Chow. McGraw-Hill, 4-39.

[15] Synder, W.M., (1962). Some possibilities for multivariates analysis in hydrologic studies. J. Geophysical Research. Vol. 62, No. 2, pp. 721-729.

[16] Thakker, A.K. and Dhiman, S.P. (2007). Morphometric analysis and prioritization of miniwatersheds in Mohr watershed, Gujrat using Remote sensing and GIS techniques Journal of Indian Society of Remote Sensing ,35(4):313-321.

[17] Wallis, R. J. (1965). Multivariate statistical methods in hydrology - A comparison using data of known functional relationship. Water Resour. Res. 1: 447-467.

[18] Wong, S.T. (1979). A multivariate statistical model for predicting mean annual flood in New England. Annals Assoc Am Geographers 53:293-311.

Acknowledgment

The writers are grateful to Dean College of Agricultural Engineering, J.N.K.V.V., Jabalpur (M.P.) and Principal Investigator Madhya Pradesh Water Sector Restructuring Project for extending the facilities during the course of study.

Biographies

Dr. S.K.Sharma received M.Tech, Ph.D. in Soil and Water Engineering from J.N.K.V.V., Jabalpur (M.P.). Currently he is an Assistant Professor (Senior Scale) in Department of Soil and Water Engineering, College of Agricultural Engineering, Jabalpur. He has experience of teaching, research and extension for more than 15 years. His area of research includes hydrogeomorphology, Remote Sensing and GIS. He has more than 30 publications in National, International journals, Conferences, 5 Technical Bulletins and one Book Chapter. He is also a Co-Principal Investigator of World Bank funded project on “Agricultural Thematic Mapping on GIS Platform”.

Recently he has presented a paper in International Conference at Kanyakumari and received Best Paper award.

Dr. S.Tignath M.Tech, Ph.D. Professor in Department of Geology, Govt. Autonomous Science College, Jabalpur. He has 30 years teaching experience and Post Doctoral Fellow of Indian Institute of Technology, Roorkee. He has more than 50 publications in International and National Journals and Conferences. His major contribution is in the hydrogeomorphology field.

S.Gajbhiye Sarita Gajbhiye received her B.Tech degree in Agricultural engineering in 2007 and her M.Tech degree (gold medal) in Soil and water engineering in 2009, both from College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur (M.P.). She is currently a PhD student in the Department of Water Resource Development and Management, IIT, Roorkee (U.K.) India. Her current research interests Include Geographical Information Systems, Rainfall-Runoff sediment yield modelling, SCS-CN. She has published around 10 research papers in refereed journals, conference and workshop proceedings.

Patil R.J. received his B. Tech. (Agril. Engg.) degree from College of Agricultural Engineering and Technology, DBSKKV, Dapoli, Dist – Ratnagiri (M.S.) in 2011. He is currently pursuing M. Tech. degree programme in the Department of Soil and Water Engineering, College of Agricultural Engineering, JNKVV, Jabalpur (M.P.).