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Impact of morphometric and land cover parameters on bed sediments of stream watersheds in the Bhagirathi valley, Uttarakhand, India

Zabiullah Ansari* and Sarfaraz Ahmad
Department of Geology, Aligarh Muslim University, Aligarh, UP, India
geology.zabi@gmail.com

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Abstract

A study has been attempted to recognizing grain size characteristics and its relation with morphometric and land cover parameters on bed sediment of watersheds located in Bhagirathi basin, Garhwal Himalaya. To achieve the objective, twenty one bed sediment samples was collected from stream joining to the river Bhagirathi. Grain size analyzed and Folk and Ward's units were calculated. Morphometric and land cover parameters of the watersheds were determined using SRTM DEM, LANDSAT ETM+. The result suggests that the stream bed sediments in high altitude watersheds are characterized by moderate grain size, poorly sorted and extremely leptokurtic in nature. At a lower altitude, the bed sediments show large grain size, poorly sorted and very leptokurtic. The impact of the morphometric parameters has a significant relationship with sediment asymmetrical dispersion. Agriculture and glacier cover have more impact on sediment characters than any other land cover. The principle component analysis explains the 89% of the variance in the data. Dominant factors controlling the sediment nature are associated with agriculture practices and maximum elevation, minimum elevation and area of the watersheds.

Keywords: Watersheds, bed-sediment, morphometric, Bhagirathi valley, Garhwal Himalaya.

Introduction

Himalaya provides a unique natural laboratory to analyze the impact of geology, climate, erosion and tectonic forces which impact on geomorphometric properties of the landscape. Hence, numerous field-based work have done on the basis of geomorphology and tectonic processes in the Himalayan watersheds[1-4]. The sediments, from the watersheds in the Himalaya act as an important role in world sedimentological forecast and effect of large human population of the world[5]. In recent years, due to large quantity of human settlement and hydropower projects activity in the Bhagirathi valleys, denudation of sediments have become a focus of current scenarios for better construction activity and reservoirs management in the region.

Studying Himalayan sediment size is significant to understand the river related activity for instance geomorphology, land use/ land cover pattern and hydrological processes. Due to natural processes like climatic condition, river discharge, basin relief, lithology and some anthropogenic activities bounded for grain size variation[6-15]. In the Himalayan terrains, rivers are major constituting to controlling the sediments grain size and this sediments vary both spatially and temporally depending on natural processes like rainfall, gradient and water discharge and vice-versa.

These complex interactions cannot be identified in the main composite stream in Ganga plains. Therefore, the high altitude pristine environment provides unique opportunity to reveal the processes of sedimentation activity. However, little information is available for the sedimentological processes in sub-alpine and forested watersheds in the Himalayan region. The understanding of the evolution of the sedimentological characteristics of watershed in headwater is crucial to predicting the fate of sediments interaction with pollutant in downstream. This integrated study dealing with sediments characteristics of a particular watershed to analyse the impact of any future change in land cover and consequent to sedimentological characters in watershed and downstream. Along with landcover the diverse morphometric parameters relationship with sediment can be used for sedimentological modeling purposes in the mountainous region.

Area of study: A research has been carried out in the watersheds joining the Bhagirathi River, which is a major stream of the Ganga river. The Gomukh is the main source of Bhagirathi river which situated at Gangotri glacier eastern slope of Chaukhamba Mountain in the Garhwal eastern Himalayas (Figure-1). The Bhagirathi River traverses around 225 km across the Himalayas and meet Alaknanda river at Devprayag, and this points have called the Ganga river. Geographically the catchment is bounded by $30^0 10'$ to $30^0 30'$N latitudes and $78^0 10'$ to $79^0 15'$E longitudes. Most of the streams of the river Bhagirathi evacuate largely from the rocks of the lesser and Central crystalline rocks primarily consisting of schists, micaceous quartzites, calc-silicates, amphibolites, gneisses, granites, slates, and phyllites.

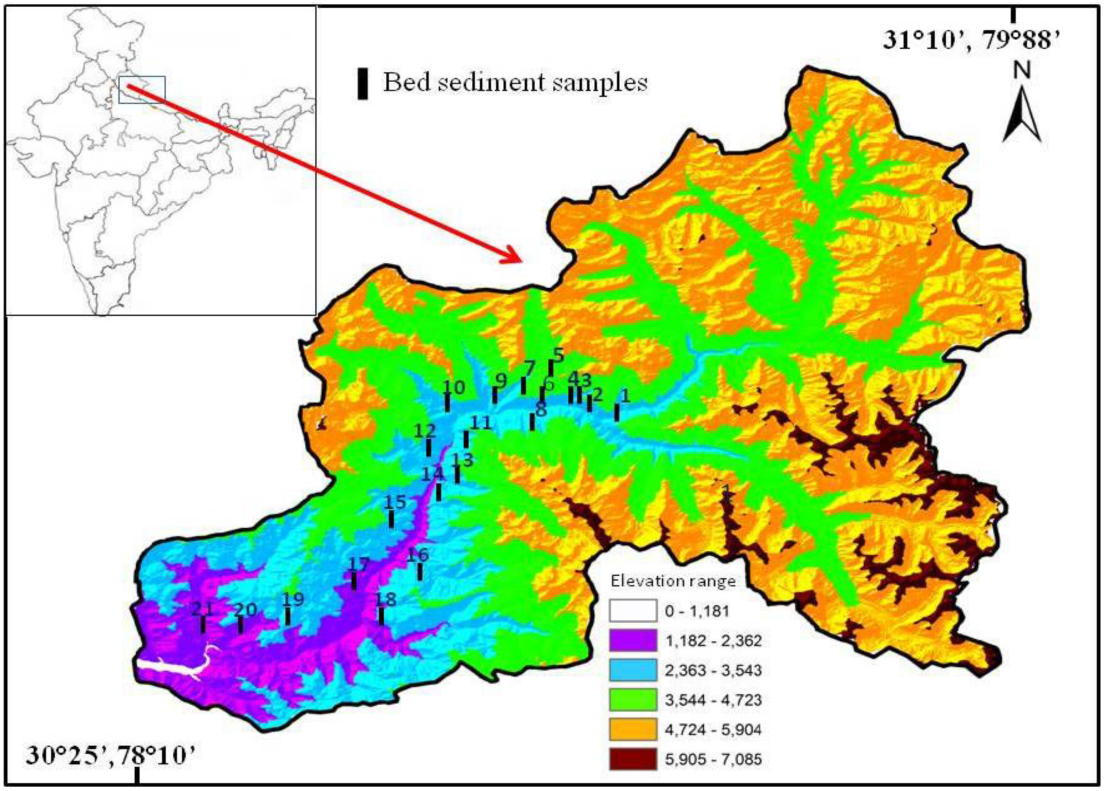

Figure-1: Location sites of stream bed sediments sample in the Bhagirathi valleys.

Methodology

For revealing the sediment characteristics, twenty one stream bed sediment samples have been collected in zip-lock polythene bags using a plastic scoop from at different streams in numbers of watersheds along the main Bhagirathi river during post monsoon (Figure-1). The grain size distributions were determined by sieve shaker (Fritsch Analysette 03.502) and textural characteristics of grain size were analysed by Folk and Ward[16] method.

For morphometric parameters, uses Raster format of void filled SRTM DEM-90 meter resolution data set for the evaluation of the terrain characteristics of watersheds in Bhagirathi basin. Data sets are freely available from NASA's website. The PCI – Geomatica V.9.1.0 was used to generate the automatic watershed boundaries using Hydrological Modeling. Terrain attributes of the watersheds were extracted e.g., form factor, circulatory ratio, maximum basin length, perimeter, relief, mean elevation; gradient, maximum elevation, and the Angle of azimuth were determined using terrain characteristics parameters and manual digitization shown in (Table-1).

For land cover parameters analysis, the locations of bed sediments are overlain on FCC (False Color Composition) image prepared by 432 (RGB) bands of LANDSAT ETM + (spot Path 147, 146 and Row 38, 39) data acquired in October 2003. This data was downloaded from Global Land cover Facility, Maryland University, USA. The elevation, longitude, latitude information of the samples was documented from GPS Garmin Etrex-10 and slope information of streams has been extracted from SRTM DEM (Shuttle Radar Topographic Mission) using PCI Geomatica 9.1.1. The land covers in particular watershed is mapped using standard remote sensing to identify the land cover characteristics e.g., textural, color and hue technique etc., Major land covers were digitized under GIS technique and percentages are presented in Table-2a and b.

Table-1: Morphometric parameters and their formulas.

Morphometric parameter	Formulas
Form factor	$R_f = A/Lb^2$
Circulatory ratios	$Re = 4\pi A/P^2$
Maximum basin length	Meter
Perimeter	P= 2(length + width)
Relief	$H_{max} - H_{min}$
Mean elevation	$\sum H_{max} - H_{min}/2$
Gradient	Relief/Maximum basin length
Maximum elevation	Meters

Table-2a: Landuse/Landcover and morphometric parameters of streambed sediment of Bhagirathi river basin based SRTM DEM

Latitude	Longitude	Elevation (m)	GC %	BLC %	FC %	ALC %	GLC %	Area (km^2)
31.0015	78.8989	2980	5	65	35	0	0	0.15
31.0115	78.8837	2879	0	50	50	0	0	0.19
31.0427	78.8412	2610	0	20	80	0	0	0.53
31.0435	78.8335	2617	0	35	60	0	0	1.7
31.0444	78.8142	2561	0	15	75	10	0	1.2
31.0402	78.7811	2527	40	30	30	0	0	19
31.0393	78.7663	2520	0	20	80	0	0	2.8
31.0333	78.7562	2526	40	30	30	0	0	9.7
31.0349	78.7467	2506	2	8	70	20	0	90
30.9725	78.6964	2654	70	15	10	0	5	3.9
30.9213	78.6823	2180	10	10	40	0	40	18
30.8430	78.6271	1696	40	5	40	15	0	36
30.8238	78.6178	1594	10	20	40	25	5	11
30.7663	78.5911	1445	0	20	40	40	0	9
30.7422	78.5435	1335	0	25	70	4	0	13
30.7526	78.4733	1202	2	40	40	18	0	29
30.7389	78.4081	1122	0	5	60	35	0	43
30.7429	78.3591	1060	0	5	75	20	0	39
30.7364	78.3491	1041	0	5	75	20	0	27
30.6123	78.3146	828	0	10	30	60	0	179
30.5519	78.3197	878	0	5	70	25	0	105

Table-2b: Landuse/Landcover and morphometric parameters of streambed sediment of Bhagirathi river basin based SRTM DEM

FF	CR	MBL (m)	PR (Km)	Relief (m)	MIE (m)	Gradient (m)	MXE (m)
0.06	0.74	1	2	1697	3515	2020	4363
0.06	0.74	1	2	1364	3302	1378	3984
0.05	0.61	2	3	1051	3144	587	3669
0.05	0.57	3	6	1440	3269	465	3989
0.04	0.54	3	5	3308	4213	1225	5867
0.04	0.45	10	23	3512	4313	344	6069
0.06	0.81	3	7	984	3045	359	3537
0.04	0.54	6	15	2620	3888	405	5198
0.03	0.40	19	53	3482	4296	184	6037
0.06	0.77	3	8	1584	3468	508	4260
0.05	0.57	9	20	2992	3629	338	5125
0.04	0.47	9	31	2533	3016	283	4282
0.06	0.70	6	14	1776	2534	318	3422
0.05	0.67	5	13	1769	2389	347	3273
0.04	0.56	7	17	2036	2362	293	3380
0.05	0.58	10	25	2526	2481	243	3744
0.04	0.53	13	32	2177	2270	174	3358
0.05	0.62	10	28	1967	2070	193	3053
0.06	0.70	7	22	1648	1889	222	2713
0.04	0.55	19	64	2003	1919	106	2920
0.04	0.49	18	52	1965	1974	107	2956

GC= Glacier cover, BLC = Barren land cover, FC = Forest cover, ALC = Agriculture land cover, GLC = Grass land cover, FF = Form Factor, CR = Circulatory ratio, MBL = Maximum basin length, PR = Perimeter, MIE = Minimum elevation, MXE = Maximum elevation.

Results and discussion

In this study, an assessment of relationships was determined between watershed characteristics and bed sediment characteristics to enhance the knowledge of natural as well as anthropogenic processes shown in (Table- 2a&b and 3a&b). Based on these relationships, the sediment characteristics can be predicted for better sediment management in the region. The understanding of these interactions in rough terrain like Himalaya is a big challenge because of intense tectonic activity and many more interactions. Impact of these processes at the local scale in rough terrain can be explained by the easily derived morphometric parameters of watersheds in the area 21 Bed sediments characteristics are the product of complex interaction with bedrock erosion, tectonic, hydrological, and hydraulic processes[8,9,17,18,19]. Therefore, characterization of sediments envisaged the processes of operating in the watershed and this information are essentials for sediment management design of Dams and other utilities.

The statistical analysis of grain size of bed sediments showing a systematic variation and mean size varies from 0.239(ϕ) to 2.261(ϕ) (Figure-2). It is observed that watersheds in high altitude zone show medium sand size, at moderate altitude watersheds, show coarse sand and lower altitude watersheds steams are associated with very coarse sand size. The watersheds size is big in lower altitude and smaller in high altitude, therefore more runoff generation at a lower altitude and vice verse. High concavity along with high monsoonal precipitation at lower altitude results in the swift mobilization of sediments in lower altitude. However, low concavity due to high tectonic uplift along with snow precipitation at high altitude results in fine to medium sized bed sediments[21,22].

The distribution of bed sediments revealed that 64% of bed sediments are moderately well sorted, while 27% of bed sediment fall in poorly sorted class and only 10% of the sample shows well sorted in nature (Figure-3). A relationship between skewness and mean size indicate that most of the sample fall in very fine skewed and some of very coarse skewed (Figure-4). The kurtosis of bed sediments show that most of the samples have high kurtosis values and scattered diagram between mean size and kurtosis indicate that, most of the samples fall in extremely leptokurtic class while few samples fall under very leptokurtic class (Figure-5).

High gradient, slope, and relief along with tectonic activity in secluded Himalayan watersheds lead to moderate sorting and very leptokurtic nature of bed sediment. High leptokurtic nature of bed sediment suggests the influence of only few sources and limited mixing from the glacier watersheds[23]. While the moderate sorting and less leptokurtic nature of bed sediments are related to high energy in big watershed and combine to sediments from other factors at lower altitude zone.

Table-3a: Textural analysis of streambed sediment of Bhagirathi river basin based on graphics mean method.

Lat	Long	Elev.(m)	Mean(Φ)	Sort(Φ)	Skew(Φ)	Kurt(Φ)
31.0015	78.8989	2980	0.7	1.27	1.01	2.67
31.0115	78.8837	2879	0.24	0.65	1.21	4.78
31.0427	78.8412	2610	1.61	0.9	0.04	2.69
31.0435	78.8335	2617	2.16	0.96	-0.73	3.11
31.0444	78.8142	2561	2.17	0.91	-0.95	3.86
31.0402	78.7811	2527	1.45	0.85	-0.13	2.99
31.0393	78.7663	2520	2.26	0.7	-0.54	3.31
31.0333	78.7562	2526	2.01	0.97	-0.52	2.71
31.0349	78.7467	2506	0.77	1.17	0.87	2.53
30.9725	78.6964	2654	0.99	1.11	0.47	2.07
30.9213	78.6823	2180	2.2	0.63	-0.89	5.34
30.8430	78.6271	1696	0.36	0.96	1.5	4.95
30.8238	78.6178	1594	0	0.47	2.42	18.02
30.7663	78.5911	1445	0.75	1.19	0.66	2.52
30.7422	78.5435	1335	0.09	0.55	2.18	11.06
30.7526	78.4733	1202	0.7	1.11	1.09	2.95
30.7389	78.4081	1122	0.51	0.92	1.03	3.88
30.7429	78.3591	1060	0.19	0.73	1.61	6.27
30.7364	78.3491	1041	-0.05	0.48	3.69	29.55
30.6123	78.3146	828	0.18	0.68	2.1	8.56
30.5519	78.3197	878	0.86	1.12	0.58	2.25

Table-3b: Textural analysis of streambed sediment of Bhagirathi river basin based on graphics mean method.

D10(Φ)	Med(Φ)	D90(Φ)	(D90 / D10) (Φ)	(D90 - D10) (Φ)	(D75 / D25) (Φ)	(D75 - D25) (Φ)
-4.71	-0.94	3.01	-0.64	7.73	-2.87	2.02
-4.62	-0.87	1.35	-0.29	5.97	-0.69	0.73
0.39	1.62	2.83	7.21	2.43	2.74	1.49
0.67	2.29	3.42	5.14	2.75	1.82	1.32
0.71	2.28	3.36	4.72	2.65	1.54	0.98
0.32	1.48	2.59	8.15	2.27	2.89	1.42
1.19	2.29	3.29	2.76	2.1	1.42	0.8
0.5	2.14	3.32	6.56	2.82	2.04	1.39
-4.09	-0.82	2.69	-0.66	6.78	-3.2	2.26
-2.53	0.65	2.61	-1.03	5.14	-2.71	2.72
1.34	2.24	3.03	2.25	1.69	1.36	0.69
-3.74	-0.99	1.87	-0.5	5.62	-1.08	1.05
-6.24	-0.65	-0.22	0.03	6.03	3	-0.65
-1.79	0.28	2.66	-1.49	4.44	-1.63	2.58
-6.2	-0.69	0.6	-0.1	6.8	2.68	-0.58
-5.32	-0.93	2.59	-0.49	7.91	-3.11	1.9
-2.69	-0.37	1.92	-0.71	4.61	-1.73	1.71
-5.48	-0.81	1.35	-0.25	6.83	0.77	0.09
-4.69	-0.59	-0.87	0.19	3.82	3	-0.59
-7.55	-0.72	1.15	-0.15	8.7	2.19	-0.43
-2.27	0.35	2.57	-1.13	4.84	-2.3	2.65

Sort = Sorting, Skew = Skewness, Kurt = Kurtosis, Med = Median

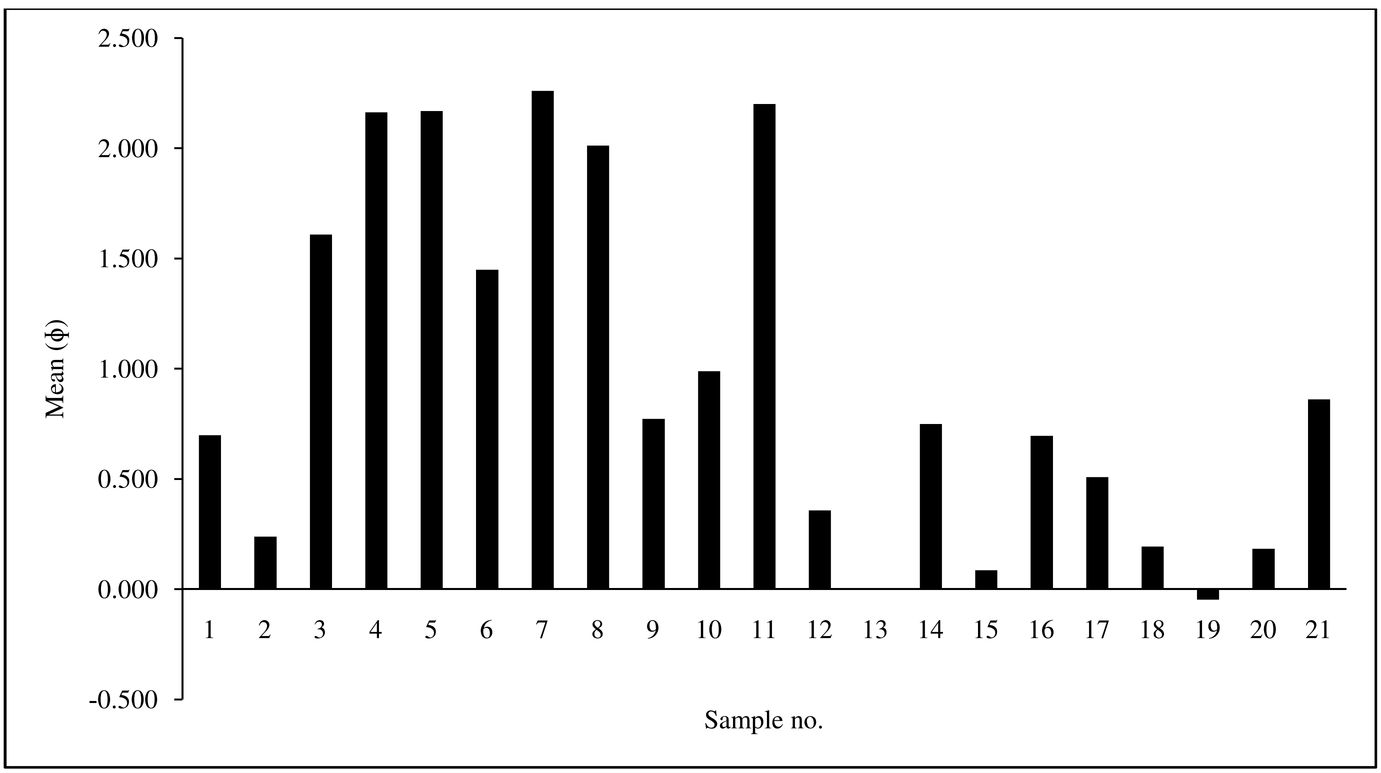

Figure-2: Binary plot showing variation of mean size in Bhagirathi streambed sediments.

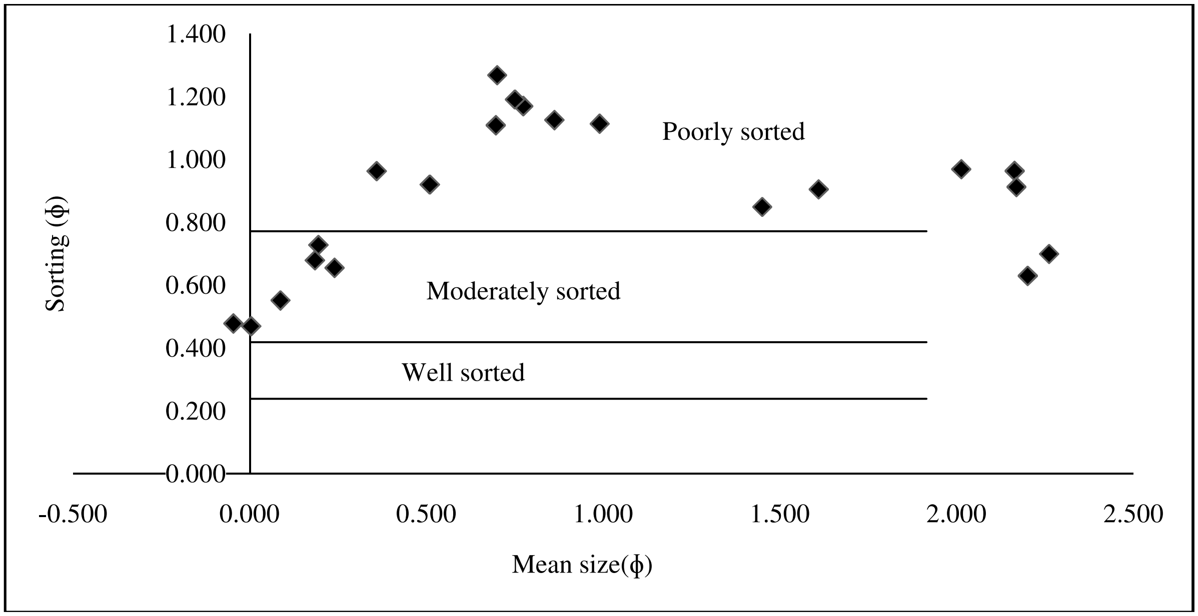

Figure-3: Binary plot showing mean size versus sorting of various streambed sediments.

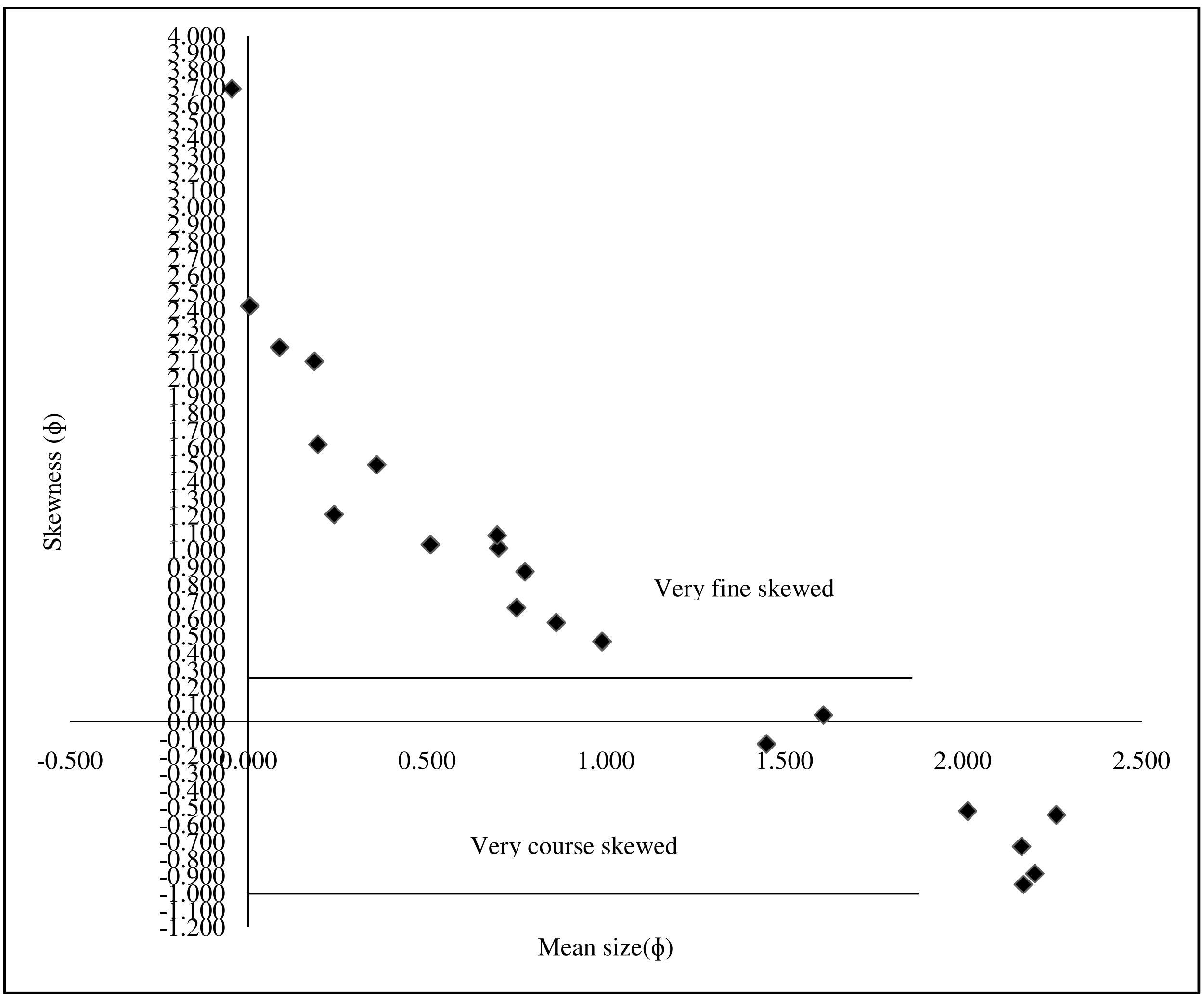

Figure-4: Binary plot showing mean size versus skewness of streambed sediments.

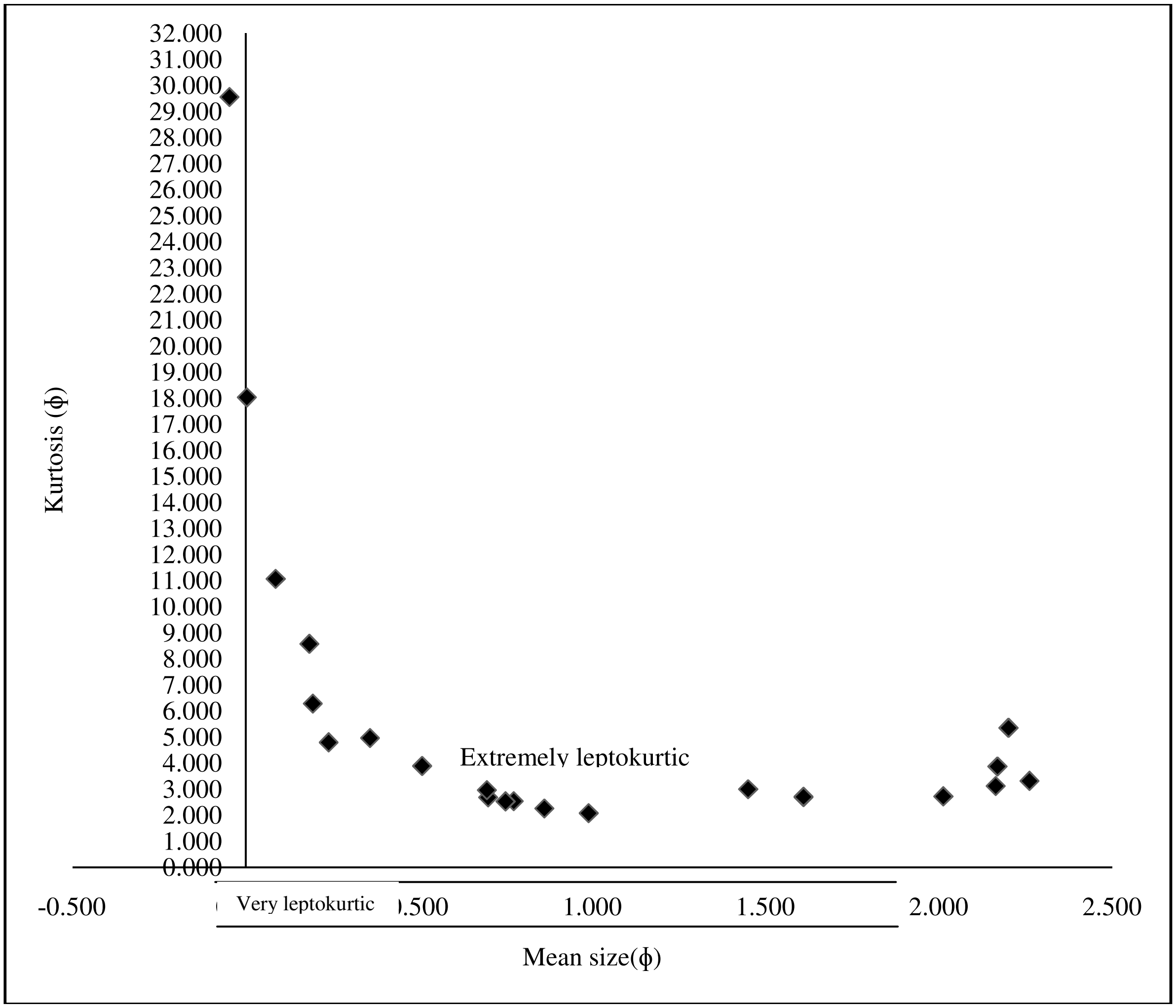

Figure-5: Binary plot showing mean size versus kurtosis of streambed sediments.

Impact of morphometric parameters on stream bed sediments: Morphometric parameters play an important role on watershed of the Bhagirathi basin which determines the bed sediment characteristics. These parameters have a direct impact on the erosion activity and later ability to export sediments. The morphometric parameters consist of a group of clusters that are related to catchment, area, perimeter, shape and terrain characteristics and water network features. In this study, scatter diagrams and correlation matrix have been used to determine the relationship between bed sediments character and morphometric parameters (Table-2). The impact of the morphometric parameter based on aerial aspects does not show any relationship between median grain size, kurtosis etc. However, it has a significant relationship with asymmetrical dispersion (Figure-6a). The median grain (ϕ) of bed sediments shows a negative relationship with the area, perimeter and maximum basin length (Figure-6b and c). However, the mean grain size does not show any relation with aerial parameters and showing moderate bearing with maximum elevation. Asymmetrical dispersion of the sediments in different streams of watershed is showing positive relationship as indicated more diversity in grain size in bigger watersheds. The maximum elevation of the basin has an important bearing on median, skewness and mean size of bed sediments (Figure-6d, e, and f). High altitude has crucial role due to the development of glacier cover, which is the active agent of sediment generation in the mountainous region.

Impact of land cover parameters on stream bed sediments: The land cover characteristics have limited impact on bed sediments and indicated that mean and median size of the bed sediment has no significant relation with different landcovers (Table-2). However, sorting, skewness, asymmetric dispersion, symmetric dispersion and symmetric index are showing the moderate impact of the landcover on them. It is revealed that the glacier cover and agriculture cover have more impact than the barren land cover (Figure-7a, b, c, d, e, f and g). The high impact of cultivated land and sparse forest (situated along the river banks or terraces) yield huge sediment due to low resistivity of agriculture practices. The tillage and overgrazing decrease the resistivity towards erosion and contributes the sediments in intense monsoonal rainfall[24].

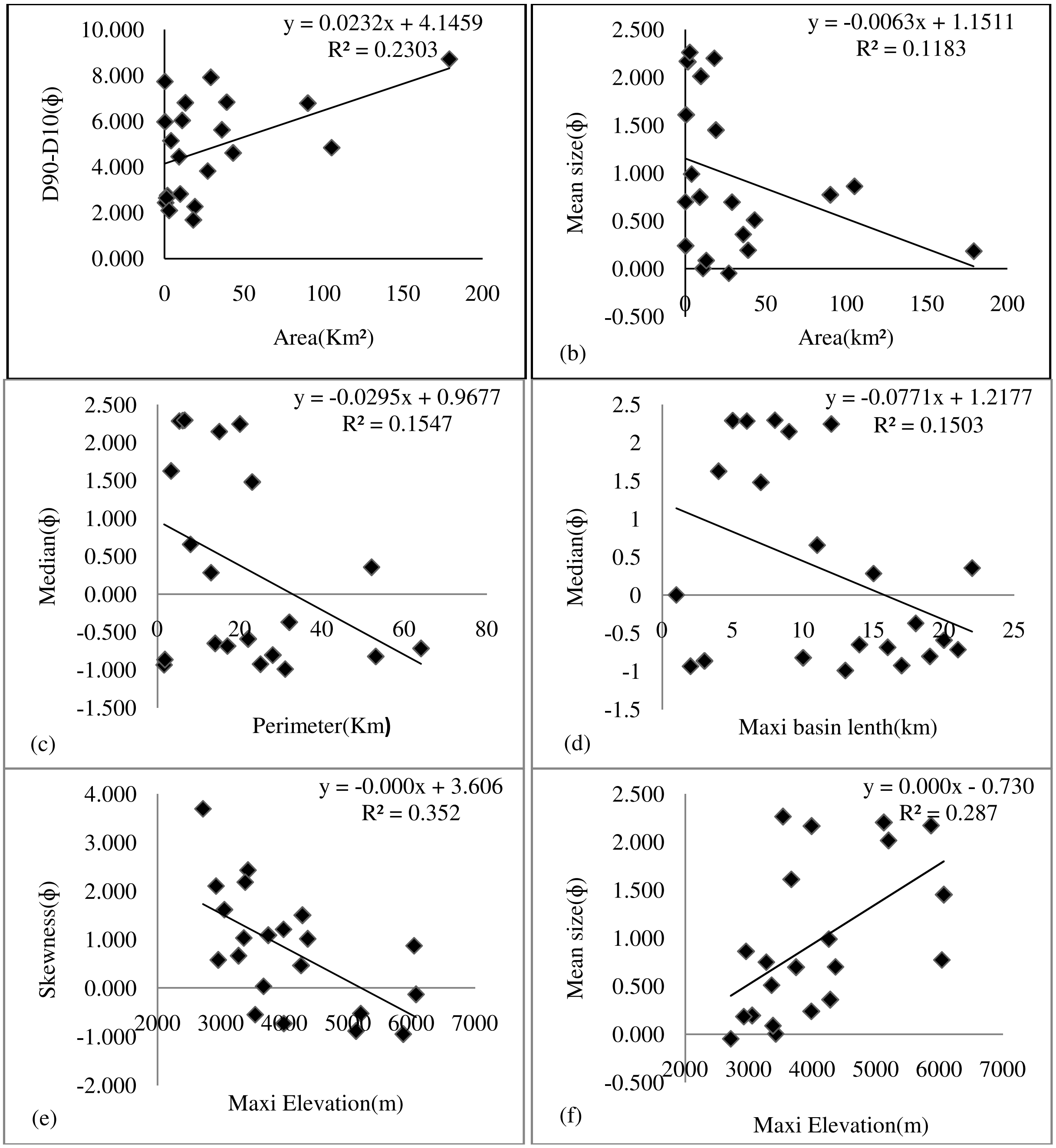

Figure-6: Binary plot showing a relationship between morphometric parameters with bed sediment (a) Asymmetric dispersion vs area, (b) Mean size vs area, (c) Median vs perimeter, (d) Median vs maxi basin length, (e) Skewness vs maxi elevation, (f) Mean size vs maxi elevation.

The glacier cover shows a direct relationship to sorting, skewness, and kurtosis. The best relationship is exhibited by sorting and symmetrical dispersion and relatively less significant relation have been found with kurtosis. While the impact of agriculture cover shows a variable significant relation only with symmetric dispersion and asymmetric index. The barren land cover has an impact only on the asymmetric index of bed sediments (Figure-7h). The high erosion activity from farmland and barren land products in increases fine-grained sediments (i.e. < 2 mm particles of sands, silts and clay) hereafter showed fines sediments also sources in associated stream. Fines components are examined a major non-point source of contamination in rivers and agricultural land include runoff from tilled terrain and bank erosion[25,26]. The fine material could be major components in stream environment by clogging sediment voids[27] and can subsequently change hydrological discharge[28,29] and biological behavior[30-32]. The high proportion of finer particles contribution increases the asymmetrical index of the streams bed sediment.

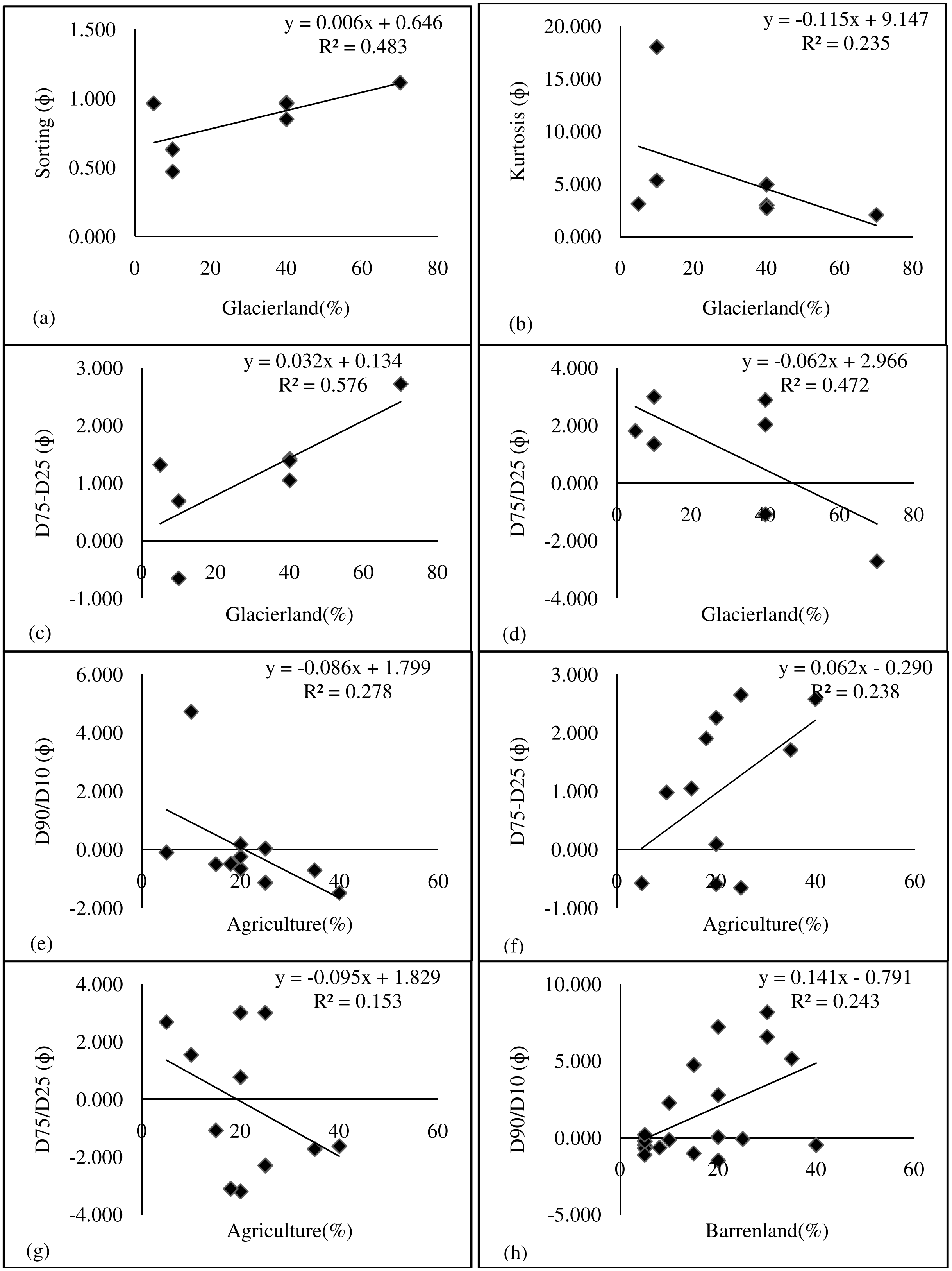

Figure-7: Binary plot showing a relationship between landcover parameters and bed sediment (a) Glacierland vs standard deviation (sorting), (b) Glacierland vs kurtosis, (c) Glacierland vs symmetric dispersion, (d) Glacierland vs symmetric index, (e) Agricultureland vs asymmetric index, (f) Agricultureland vs symmetric dispersion, (g) Agricultureland vs symmetric index, (h) Barrenland vs asymmetric index.

Principal Component Analysis (PCA) of sediments character: The PCA technique has been used to recognize the important parameters that determine the sediment characteristics in many studies[33,34]. On investigating the sediment characteristics by PCA, we try to find out the dominate factors with sediments character by principal components (PCs) that helps us to identify the mechanism as associated with parameters of same behaviour. There are six principal components extracted through PCA which having eigenvalue>1. These components explaining approximately total 89% variations in sediment character on land cover and morphometric parameters (Table-4).

The first principle component accounting for 38.2% of the total variance and it is associated with mean, median, skewness, D10, D90, D90-D10, D90/D10, D75/D25, mean elevation, area, maximum elevation, and agriculture. It can be concluded that the parameters like agriculture covered area, area, maxi elev. and mean elev., bears the high impact on sediment character than others. The cultivation and human activities in sparse forest (situated along the river banks or terraces) resulting in drastic change in bed sediment characters as evident in present study. The second component (19.2%) is associated with longitude, elevation, gradient, latitude, barren land, mean elevation, agriculture, perimeter, maximum basin length, area, and maximum elevation. This factor is mainly associated with morphometric parameters. The 3rd, 4th, 5th and 6th components also do not impact on sediments.

Table-4: Principal component analysis of loading factors for stream bed sediments.

Variables	Component					
	1	2	3	4	5	6
Median	0.957	0.148	0.038	-0.012	0.01	0.103
D10	0.94	0.189	0.203	0.023	0.009	0.086
Ass. Dis	-0.928	-0.099	0.134	0.053	-0.028	-0.071
Mean	0.884	0.264	0.241	0.082	-0.055	0.161
D90/D10	0.776	0.332	-0.214	0.243	0.035	-0.261
Skewness	-0.776	-0.292	-0.464	-0.141	0.017	-0.173
Longitude	0.348	0.883	0.156	0.007	0.065	-0.006
Elevation	0.366	0.851	0.195	0.006	0.137	0.023
Gradient	-0.17	0.825	0.191	-0.203	-0.147	0.057
Latitude	0.467	0.81	0.07	0.081	0.115	-0.04
Barren land	-0.19	0.758	0.198	-0.223	-0.022	-0.093
Mean Elev.	0.397	0.711	0.188	0.447	0.23	0.096
Agriculture	-0.435	-0.702	0.033	0.116	-0.135	-0.045
Perimeter	-0.321	-0.695	0.091	0.567	-0.053	0.019
Max. Basi Lg	-0.258	-0.683	0.115	0.617	-0.062	0.054
Area	-0.345	-0.634	0.095	0.436	-0.123	0.004
Sorting	-0.011	0.101	0.922	0.127	0.111	-0.184
D75 - D25	0.17	0.06	0.914	0.037	0.176	-0.073
D75/D25	0.422	0.01	-0.835	0.008	-0.068	-0.122
Kurtosis	-0.29	-0.19	-0.813	-0.179	-0.022	0.004
D90	0.572	0.272	0.725	0.149	-0.027	0.078
Form factor	-0.102	0.261	-0.113	-0.902	0.047	0.111
Circulatory Rt	-0.102	0.261	-0.113	-0.902	0.047	0.111
Relief	0.048	0.047	0.042	0.884	0.173	0.216
Max.Elev.	0.323	0.564	0.16	0.659	0.238	0.151
Glacier cover	0.157	0.105	0.093	0.071	0.946	-0.061
Forest cover	0.207	-0.103	-0.202	-0.012	-0.818	-0.211
Grassland	0.258	-0.022	-0.124	0.054	0.117	0.921
Total initial Eigen values	10.698	5.402	3.896	2.296	1.65	1.056
% of Variance	38.206	19.293	13.913	8.2	5.892	3.771
Cumulative %	38.206	57.499	71.412	79.612	85.505	89.276

Conclusion

The results show that the grain size characteristic of bed sediments varies with location of the watersheds in different altitude range. High altitude watersheds bed sediments are medium sand size; moderate altitude watersheds are associated with coarse sand and lower altitude watersheds steams are characterised coarse sand size. High gradient, slope, and relief along with tectonic activity in secluded Himalayan watersheds lead to moderate sorting and very leptokurtic nature of bed sediments. The variation in bed sediments are related to size of watersheds, concavity, type of runoff generation and land cover.

The impact of the morphometric and landcover analysis shows a significant relationship with asymmetrical dispersion and median size. Agriculture and glacier cover have more impact than any land cover. The PCA results explain approximately total 89% variations in sediment character; indicate that the agriculture covered area, area of the basin, maxi elev. and mean elev. bears the high impact on sediment character than others loading factors.

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