JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.86, October 2015, pp.445-458

Textural Characteristics of Sediments and Weathering in the Jhelum River Basin Located in Kashmir Valley, Western Himalaya

Riyaz Ahmad Mir[1]* and Gh Jeelani[2]
[1]Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee – 247 667, India
[2]Department of Earth Sciences, University of Kashmir, Srinagar – 190 006, India
***Email:** riyazgsi@gmail.com

Abstract: This study presents a detailed textural and geochemical study of sediments of river Jhelum and its tributaries of Kashmir valley. The textural studies clearly established that the sediments were dominantly of medium grain size, moderately sorted and very positively skewed. The kurtosis suggested dominantly leptokurtic nature of sediments. The sediments were deposited under moderate to low energy conditions with dominant rolling processes. The statistical parameters showed little spatial as well as temporal variations. The observations are supported by the frequency curves and bivariate plots between various textural parameters, confirming the polymodal nature of sediments with dominant to moderate sand fraction. The bimodal and unimodal nature of the sediments was also present at certain locations. The major oxide elemental chemistry of the sediments indicated that the dominant elemental oxide was SiO_2 followed by Al_2O_3 in all the sediments. The Chemical Index Alteration (CIA) and Resistant Index of Maturity (R_M) reflected moderate weathering and immaturity of the sediments in the basin.

Keywords: Grain size, Weathering, Jhelum, Kashmir valley, Himalaya.

INTRODUCTION

The grain size is the most fundamental property of sediments affecting their entrainment, transport and deposition. Grain size studies provide important clues to the sediment provenance, transport history and depositional conditions (Folk and Ward, 1957; Friedman, 1979; Bui et al. 1990, Ganesh et al. 2012). Thus, the knowledge of sediment size and textural parameters is one of the better tools to differentiate various depositional environments of recent as well as ancient sediments (Mason and Folk, 1958; Friedman, 1961; Nordstorn, 1977, Kumar et al. 2010). Different agents such as wind, water commonly separate particles by their size (Friedman and Sanders, 1978). The sediment texture has also a close relationship to the topography, wave and current pattern and depositional conditions (Rao et al., 1997; Singh et al., 1998). The rivers worldwide tansport about 15-16 × 10^9 tonnes per year of sediments to the oceans (Milliman and Meade, 1983; Walling and Webb, 1983). Subramanian et al. (1987) has reported that the Indian rivers transport about 1.2 × 10^9 tonnes of sediments per year. Geochemical studies of the bottom sediments of water bodies such as rivers, estuaries and basins are very helpful in understanding the different sediments sources, element distribution pattern and evaluating the existing environmental conditions in an area (Paul, 2001).

In the past few decades, textural and geochemical studies of sediments have been a subject of intense research. Here an attempt is made to determine the texture, grain size distribution and geochemical nature of sediments of the Jhelum river basin.

STUDY AREA

The Jhelum river basin is located in the north-west of India, stretches between 34° 17' N to 37° 6' N latitude and 73°6' E to 80° 30' E longitudes and is about 140 km long and 50 kilometres wide. The river flows across the main valley of Kashmir up to Bounyari in Bandipora district where it joins the Wular lake. It then emerges from the lake near Sopore in Baramulla district and flows in south-western direction leaving the valley near Gantamulla through a narrow gorge across the Pir-Panjal and turns towards the south along a synaxial bend (Wadia, 1934). The river drains the whole of Kashmir valley. The basin covers an area of 33670 km^2 and the length of the river course is about 129 kms. From the upstream to 30 km downstream of the Wular lake the gradient is 0.2% and after crossing the Pir-Panjal the gradient becomes steeper (Paul et al. 1999). The river is fed by a number of tributaries on both sides at different reaches. The tributaries of river Jhelum are divided into two

0016-7622/2015-86-4-445/$ 1.00 © GEOL. SOC. INDIA

categories as the right bank and left bank streams. The significant tributaries joining the Jhelum on its right bank include Sandrin, Bringi, Arapath (Kuthar), Liddar, Arapal, Sindh and the Pohru. The Vishav, Doodganga, Sukhnag, Rambiara, Romshi and Ningal join with the river on its left bank (Fig. 1).

CLIMATE AND GEOLOGY OF THE AREA

The Jhelum river basin is characterized by temperate climate with January being the coldest month and July the warmest. In the main Kashmir valley the temperature goes below -5ºC during winter season and reaches above 30ºC during summer season. The mean annual precipitation is about 1100 mm. However, the precipitation has a peculiar distribution pattern throughout the year. March receives maximum precipitation and October least. September to November months are usually the driest, whereas from December to April much of the precipitation occurring as snow accumulates at higher reaches. The maximum discharge in the Jhelum river occurs in May and June, despite moderate precipitation, due to the melting of the snow. The lowest discharges occurs during the months of October to Febuary (Mir and Jeelani, 2015).

Kashmir valley has varied topography and geology. The high structural hills, small mounds of Karewas, colluvial fans below the hill slopes and the alluvial filled valley are the main geomorphic features. The intermontane Kashmir valley has a stratigraphic succession from Precambrian to Recent, with a complete stratigraphic sequence of marine Paleozoics, Mesozoics and Cenozoics (Ganju and Khar, 1984).

MATERIALS AND METHODS

Fifteen composite bed sediment samples were collected during two periods i.e. high flow period (June-2008) and low flow (January-2009) period along the river Jhelum and its tributaries. Four samples were collected and made to a single composite sample to represent each station (i.e. 15 sites). Sampling of sediments was carried out using a scoop from the shallower depth (<1 m) and by an Ekman dredge from deeper depths (<5m). The sediment samples were collected in polythene bags prior to analysis. Four samples were collected from within the main stream of river Jhelum and the remaining from the tributaries prior to their confluence with the main stream. The details of the sampling sites are given in the (Table 1). Figure 1 shows the location map of the study area. The S-1 to S-15 represents the sample IDs.

The particle size analysis of the sediments was carried out by sieving method (Lindholm, 1987). Before analysis, an amount of 100gm of sediments from each sample was weighed by digital balance for the separation of various size fractions. Then the powder was poured onto the upper sieve of the set and stacked with a sieve-shaker at about 20 strokes per minute for more than 10 minutes. In order to avoid the error in the percentage of the weight, a pan was kept at the bottom of stacked sieves to retain the finest particles and

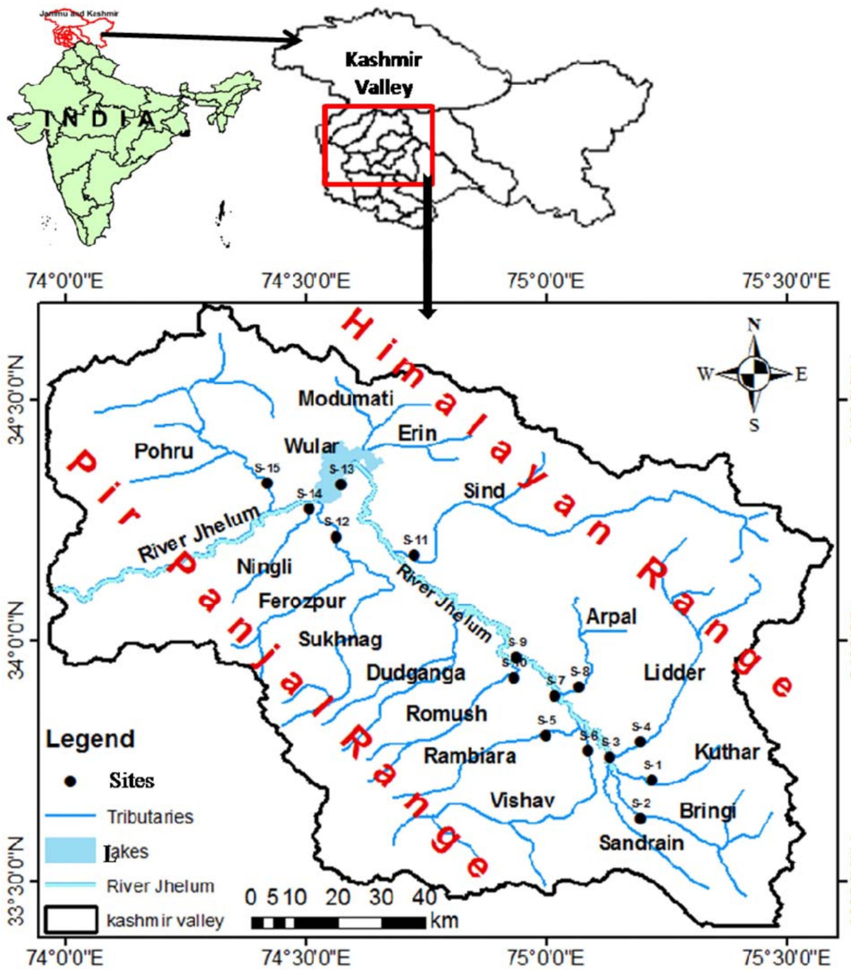

Fig.1. Location map of the study area.

Table 1. Summary of sampling sites.

S. No.	Sample ID	River/ Tributary	Location	Latitude	Longitude	Altitude
1	S-1	Kuthar(Arapat)	Bangidar (Khanabal)	N.33º442 037"	E.75º082 257"	1582m
2	S-2	Bringi	Bangidar	N.33º442 042"	E.75º082 574"	1586m
3	S-3	Jhelum(i)	Gur (Khanabal)	N.33º442 564"	E.75º072 937"	1606m
4	S-4	Liddar	Gur	N.33º452 018"	E.75º072 859"	1613m
5	S-5	Rambiara	Naiyan (Sangam)	N.33º492 069"	E.75º072 778"	1611m
6	S-6	Vishav	Naiyan	N.33º492 060"	E.75º032 998"	1611m
7	S-7	Jhelum(ii)	Chursu (Awantipora)	N.33º572 099"	E.75º552 806"	1616m
8	S-8	Arapal	Chursu	N.33º572 099"	E.75º552 806"	1616m
9	S-9	Jhelum(iii)	Kakapora	N.33º572 108"	E.75º552 806"	1583m
10	S-10	Romshi	Kakapora	N.33º572 074"	E.75º552 077"	1573m
11	S-11	Sindh	Shadipora	N.33º592 375"	E.74º552 498"	1523m
12	S-12	Haritar	Haritar (Sopore)	N.34º192 275"	E.74º332 528"	1579m
13	S-13	Jhelum(iv)	Ningal (Sopore)	N.34º172 253"	E.74º302 499"	1584m
14	S-14	Ningal	Ningal	N.34º172 253"	E.74º302 499"	1584m
15	S-15	Pohru	Daubgam	N.34º152 935"	E.74º252 935"	1575m

weighted. The United States based – American Society for Testing Material (ASTM) with the grades was used as

Mesh No	5	10	18	35	60	120	230
Opening mm	4	2	1	0.5	0.25	0.125	0.62

The Went-Worth scale 16mm, 8mm, 4mm, 2mm, 1mm, 1/2mm, 1/4mm, 1/8mm etc. was used for the analysis of grain size. It is based on a systematic base 2 logarithmic scales. The phi – mm ASTM Mesh Sieve in this material was related as shown in Table 2.

The major element analysis of sediments was done at Khyber Cement Industry Ltd, Khonmoh, Srinagar. The collected bottom sediments were pulverized in a mortar with a rubber tipped pestle. The geochemical analysis was carried out by decomposition of each sample by HNO_3, HCl, H_2SO_4 and HF mixture from a solution A and B. Solution was prepared by decomposition of 0.5 gm of each sediment sample by fusion with NaOH for five minutes in nickel crucible. The mixture was cooled to room temperature, bleached with distilled water, covered with lid and kept overnight. Then, the solution was taken into a beaker and acidified with, 20ml of 1:1 HCl and boiled for 10 minutes on a hot plate to get clear solution. After cooling, solution is taken into 1000ml volumetric flask and the volume of it was made up to the mark and was stored in polythene bottles. The CaO was determined by EDTA titration using Pattens and Readers reagents as indicator. The MgO by EDTA titration using thymolpthylene as indicator, whereas the Fe_2O_3 by titrating the samples against EDTA using sulphosalsalic acid as an indicator. Al_2O_3 by the EDTA titration using xylenolene orange as indicator. SiO_2 was estimated by baking method and the Na_2O and K_2O by Flame Photometry (Ghosh and Mathur, 1996).

RESULTS

Sediment Distribution and Texture

The detailed representation of the textural parameters in terms of frequency curves, grain size analysis, and bivariate plots have been constructed. The textural analysis of the sediments from the study area was carried out and the results are presented in (Tables 3). Most of the sediment samples collected from the Jhelum river and its tributaries are concentrated towards the sand corner of the Sand-Gravel-Mud ternary plot (Lindholm, 1987) (see Fig. 2a, b). The percentage composition budget of sediments is dominated by sand (very coarse to very fine sand) at all sites as shown in (Fig. 3). On an average more than 95% of sediments are composed of sand. The mud contributed on an average about 2%. However, the gravels are recorded only at few sites contributing about more than 3% to the composition budget of sediments. In general, a higher proportion of sand was recorded varying in size from very coarse to very fine size with little percentage of mud and gravels. Spatially, the sites S-1, S-11, S-14, and S-15 of tributaries recorded higher proportion of gravels than the

Table 2

(ϕ)	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5
Mm	4	2.828	2	1.414	1	0.707	0.5	0.351	0.25	1.177	1.123	0.088	0.062	0.044
ASTM mesh	5	7	10	14	18	25	35	45	60	80	120	170	230	325

Table 3. Statistical overview of textural parameters of the sediments of river Jhelum and its tributaries. (Index: Mz-mean size, σI-standard deviation, SkI-skewness, KG-kurtosis)

S. No.	Sampling station	Sam. ID	High Flow								Low Flow							
			Mz	σI	SkI	KG	Mz	σI	SkI	KG	Mz	σI	SkI	KG	Mz	σI	SkI	KG
1	Kuthar	S-1	1.03	1.47	-0.16	1.42	Coarse sand	Poorly sorted	Near symmetrical	Leptokurtic	0.47	1.28	0.12	0.92	Very coarse sand	Poorly sorted	Fine skewed	Mesokurtic
2	Jhelum	S-2	1.93	1.09	-0.25	1.56	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic	1.9	1.08	-0.03	0.92	Medium sand	Moderately sorted	Near symmetrical	Mesokurtic
3	Jhelum	S-3	0.92	0.7	-0.02	1.2	Coarse sand	Moderately well sorted	Near symmetrical	Leptokurtic	1.03	0.78	0.01	1.01	Coarse sand	Moderately sorted	Near symmetrical	Mesokurtic
4	Lidder	S-4	2.35	0.66	0.26	1.47	Fine sand	Moderately well sorted	Fine skewed	Leptokurtic	2.7	0.98	-0.01	0.99	Very fine sand	Moderately sorted	Near symmetrical	Mesokurtic
5	Rambiara	S-5	1.77	0.66	0.12	2	Medium sand	Moderately well sorted	Fine skewed	Very leptokurtic	1.88	0.74	-0.06	1.15	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic
6	Vishav	S-6	1.43	0.8	0.07	1.56	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic	1.47	1.04	0.12	1.07	Medium sand	Moderately sorted	Fine skewed	Mesokurtic
7	Jhelum	S-7	1.67	0.65	-0.21	1.57	Medium sand	Moderately well sorted	Near symmetrical	Very leptokurtic	1.8	0.92	0.06	1.07	Medium sand	Moderately sorted	Near symmetrical	Mesokurtic
8	Arapal	S-8	0.7	1	0.25	1.9	Coarse sand	Moderately sorted	Fine skewed	Very leptokurtic	0.8	1.08	0.31	0.92	Coarse sand	Moderately sorted	Very fine skewed	Mesokurtic
9	Jhelum	S-9	1.5	0.83	-0.22	1.23	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic	1.43	1.03	0.03	0.85	Medium sand	Moderately sorted	Near symmetrical	Platykurtic
10	Romshi	S-10	1	0.9	0.03	1.25	Coarse sand	Moderately sorted	Near symmetrical	Leptokurtic	1.23	1.05	0.08	0.97	Medium sand	Moderately sorted	Fine skewed	Mesokurtic
11	Sindh	S-11	0.57	1.07	-0.08	1.13	Very coarse sand	Moderately sorted	Near symmetrical	Leptokurtic	0.53	1.15	0.02	0.78	Very coarse sand	Poorly sorted	Near symmetrical	Platykurtic
12	Haritar	S-12	1.35	0.58	-0.13	1.39	Medium sand	Moderately well sorted	Near symmetrical	Leptokurtic	1.37	0.81	0.06	0.9	Medium sand	Moderately sorted	Near symmetrical	Mesokurtic
13	Jhelum	S-13	1.42	0.81	-0.09	1.55	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic	1.43	1.05	0.03	0.89	Medium sand	Moderately sorted	Near symmetrical	Leptokurtic
14	Ningli	S-14	0.25	0.88	-0.05	1.36	Very coarse sand	Moderately sorted	Near symmetrical	Leptokurtic	0.4	1.09	0.09	0.89	Very coarse sand	Moderately sorted	Fine skewed	Leptokurtic
15	Pohru	S-15	0.2	1.16	0.12	1.38	Very coarse sand	Poorly sorted	Fine skewed	Leptokurtic	0.37	1.27	0.11	1	Very coarse sand	Poorly sorted	Fine skewed	Mesokurtic

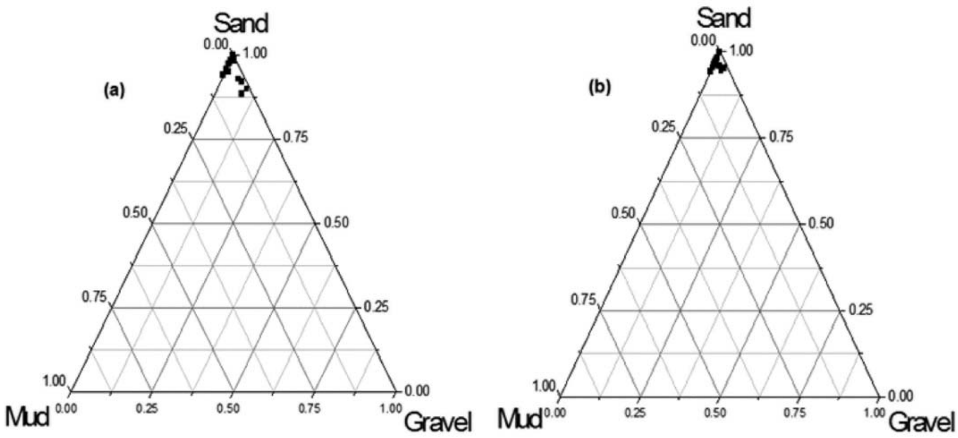

Fig.2. Ternary plot showing the dominance of sand component of sediments of river Jhelum and its tributaries during (**a**) high flow and (**b**) low flow, periods.

other sites, thereby reflecting higher flow velocity in these channels. The site (S-4) recorded a high proportion of mud as compared to the other sites, which is ascribed to the low current velocity. Grain size studies revealed coarse, medium and fine sands are progressively abundant down the stream. Allen (1970) stated that the downstream decrease in phi mean and the progressive enrichment of finer spectral classes would be due to abrasion and progressive sorting. Temporally, the proportion of sand was recorded high d uring low flow period except in the sites S-3, S-6, S-7, S-9 and S-10. The site S-9 shows no variation in the proportion of sand between these two periods. The percentage of mud was observed to be high during the high flow period. However, the sites S-6, S-9, S-10, S-11, S-13, S-14 and S-15 showed low proportion of mud. On the other hand, the gravels were recorded to be lowest during low flow period as compared to high flow period.

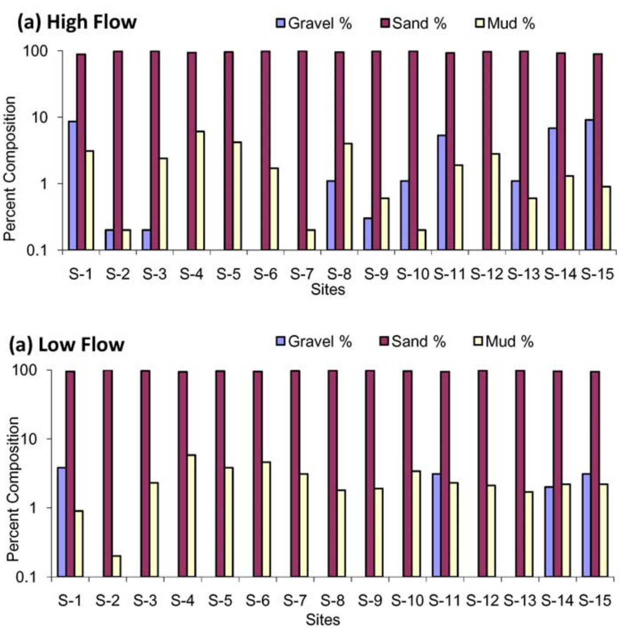

Fig.3. Spatial variation of percent composition of sediments down the stream of river Jhelum and its tributaries during two periods of flow.

DISCUSSION

Statistical Measures of Grain Size Distribution and their Interpretation

The various parameters namely, mean size; sorting, skewness and kurtosis are used to evaluate cumulative frequency distribution (Trask, 1932; Otto, 1938; Inman, 1952; Mc common, 1962). The values of the textural parameters and grain size distribution of the samples (Table 3) were computed by the formulae suggested by Folk and Ward (1957).

Graphic Mean Size: It indicates the average size of the sediments or the central tendency which in turn indicates the average kinetic energy of the depositing agent. However, the mean size depends upon the nature of the parent material. The graphic mean size of the sediments of river Jhelum and its tributaries varied from 0.22µ (S-15) to 2.35µ (S-4) with an average of 1.23µ, indicating that the sand size varies from coarse sand to fine sand. 60% of the samples were medium grained sand while 27% was medium sand and 13% was fine grained sand. The mean size indicated that the fine sands were deposited at a moderately low energy conditions. The sites with coarse sand were (S-3, S-8, S-11, S-14, and S-15). This mean size is attributed to the high flow and little distance of transportation. However, the site (S-4) recorded fine sand size due to long transportation and hard rock present in the catchment area. Temporally, there is no variation in the mean size of the sand with the exception of (S-1) and (S-3). The mean size of the sediments showed decreasing trend down the stream initially and then reversal due to the joining of the tributaries with the main stream of river Jhelum. The reversal in the mean size indicated fluctuations in the hydrodynamic conditions as shown in (Fig. 4a). When the competency of the river water declines, the coarser sediments will be deposited where as the finer will be transported further downstream. However, from (Fig. 4a), it is evident that the competency of the river water fluctuates at many locations due to confluence of the tributaries from right and left banks. The abrupt decrease in phi mean (increase in grain size) downstream as shown in (Fig. 4a) might be resulted from the turbulence induced by tributaries during confluence. The variations in phi mean size indicates that differential energy conditions led to the deposition of these sediments at different locations. Mean size of the sediments are influenced by the source of supply, transporting medium and the energy conditions of the depositing environment (Kumar et al., 2008).

Inclusive Graphic Standard Deviation (Sorting): It measures the sorting or uniformity of the particle size distribution and indicates the fluctuation in the velocity conditions of the depositing agent and about its average velocity. Cadigan, (1961) states that the function of sorting is inversely proportional to the standard deviation. The sorting of sediments is controlled to a certain extent by the size distribution of the source material. The graphic standard deviation of sediments varied from 0.58µ to 1.47µ with average of 0.95µ, indicating moderately well sorted to poorly sorted sand. About 33% of the samples were poorly sorted followed by 33% of the samples moderately sorted and the remaining were moderately well sorted. The poorly sorted sediments belong to sites S-1, S-2, S-8, S-11, and S-15 which are from the tributaries with high fluctuations in the flow velocity. Temporally, there is little variation in the standard deviation of the sediments. The poorly sorted nature of sediments is apparently due to the mixing of the recent sediments with the old sediments in this complex flow of the river. Like in the mean size, there are also reversals in the trends of standard deviation values, thereby indicating the energy variations in the hydrodynamic system were responsible for the deposition of these sediments as shown in (Fig.4b). The variation in the particle dispersion is due to the riverine and creeks sediments. Down the stream, as the particle size increases, the sorting alters and thus becomes poor (see Fig.4b). The observed decrease in sorting is presumably due to the transport of mixed sediments downstream. The variations in the sorting values is likely due to continuous addition of finer/coarser materials in varying proportions from the tributaries.

Inclusive Graphic Skewness:- It measures the asymmetry of the frequency distribution and marks the deposition of the mean with reference to the median. If there is more material of the sample in the coarse tail of the graph, the sample is coarsely skewed; the skewness is referred as negative skewness if the mean is towards the coarser side of the median. On the other hand, if the more material of

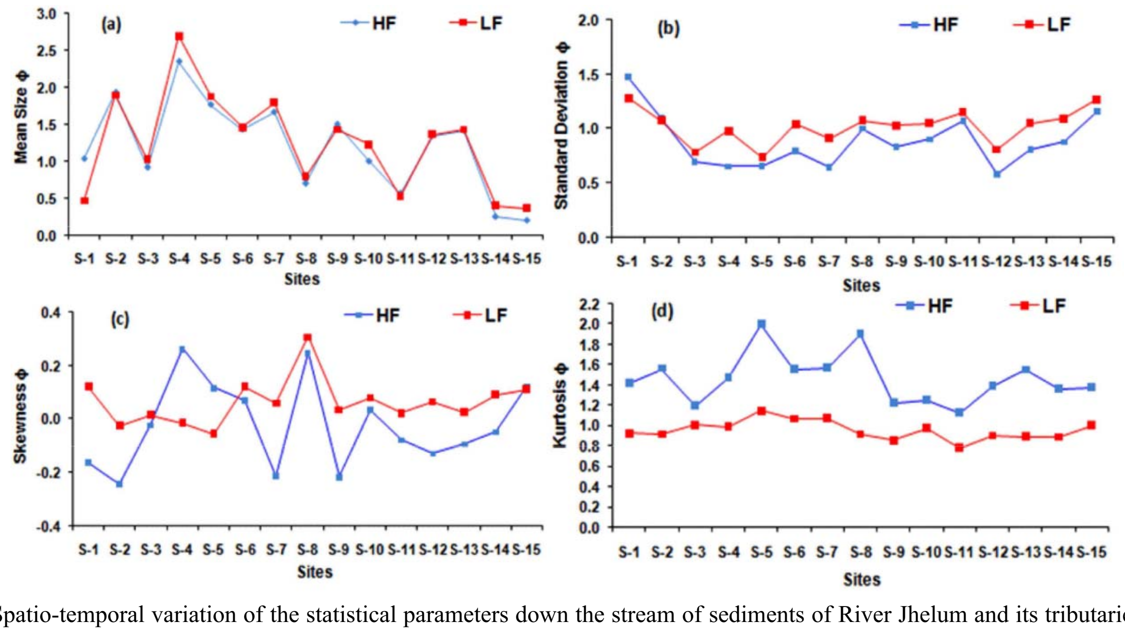

Fig.4. Spatio-temporal variation of the statistical parameters down the stream of sediments of River Jhelum and its tributaries during high flow (HF) and low flow (LF) periods.

the sample is in the fine tail of the graph, the sample is finely skewed and the skewness is referred to as positive skewness. Mathematically, skewness is function of standard deviation and is inversely proportional to it (Cadigan, 1961). The inclusive graphic skewness ranged from -0.25ϕ to 0.26ϕ with a mean of 0.019ϕ, reflecting that the sands are coarse to fine skewed. In a fine skewed sediment population, the distribution of grains will be from coarse to fine and the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of sediments which are coarse skewed . Martins (1965) has suggested that coarse skewness in sediments could be due to two possible reasons. Addition of material to the coarser terminal or selective removal of fine particles from a normal population by winnowing action. However, the sediments are dominantly very positively skewed. The positive skewness indicated unidirectional transport or the deposition of sediments in sheltered low energy environment (Brambati et al. 1969) whereas negative skewed sediments indicate deposition at high energy environments (Rajasekhara et al. 2008). 33% of the sediments were coarse skewed followed by 27% of sediments fine skewed and 20% of sediments of very fine skewed nature. Another 20% of sediments were near symmetrical. In the upstream, particularly tributaries, which consists of abundance of coarse fraction with less amounts of fine modes yield coarse skewness. In the downstream the fine mode generally increases and the skewness of sediments shifts to fine entities. The presence of nearly symmetrical skewed samples indicated an equal proportion of different modes. The very fine skewed nature of the sediments indicate excessive riverine input. Strongly fine skewed and fine skewed sediments generally imply the introduction of the fine material. The coarsely skewed sediments have developed relatively under high energic condition areas near the mouths of inflow streams while near symmetrical sediments have developed under relatively low energic conditions. Temporally, the skewness showed much variation as compared to other statistical parameters. The variations in the values of skewness downstream reflect the change in the flow of the river and its tributaries (Fig. 4c).

Inclusive Graphic Kurtosis:- It measures the ratio between sorting in the tails of the frequency distribution and the sorting in the central portion of distribution or it is a ratio of sorting within the central 90% of the distribution to the central 50% of the distribution. Cadigan (1961) defines kurtosis as, the measure of peakedness or broadness of the curve, would be affected by deviations near the centre of the distribution. The kurtosis values are similarly a function of standard deviation and are inversely proportional to it. For normal distribution the kurtosis is unity and if a value of kurtosis is greater than unity, it then indicates that the velocity of fluctuations were restricted within the central 50% of the average velocity. Kurtosis of the sediments of river Jhelum and its tributaries varied from 1.13ϕ to 2ϕ with an average of 1.205ϕ, suggesting leptokurtic to very leptokurtic sediments. In natural environments, the kurtosis values reflect the fluctuations in the velocity of the depositing medium. A value greater than unity suggests greater fluctuations (Verma and Prasad, 1981). 67% of the sediments were leptokurtic in nature and 27% very leptokurtic sediments. Temporally, the values of kurtosis showed high variation. The leptokurtic nature indicate high deposition of fine particles of sediments. The kurtosis does not show any specific trend downstream (Fig. 4d). Extreme high or low values of the kurtosis implied that a part of the sediment achieved its sorting elsewhere in a high energy environment (Friedman 1962). However, slight variation in the kurtosis values downstream is a reflection of the flow characteristic of the depositing medium. The variation in the kurtosis values is a reflection of the flow characteristics of the depositing medium (Seralathan and Padmalal, 1994; Baruah et al. 1997). The dominance of the fine size of very leptokurtic nature of the sediments reflect the immaturity of the sand. This may be due to the variation in the sorting values due to continuous addition of finer/ coarses materials in varying proportions by tributaries.

Frequency Curves

Frequency Distribution Curves (FDC) are pictorial representation of weight percentage of different fractions of sediments. FDC are used to describe the nature of sediments. The FDC from different sites of the river Jhelum are shown in (Fig. 5). Frequency distribution curves illustrate that the majority of sites have polymodal sediments with the exception of the sites S-1, S-4, S-6, and S-12 which are bimodal. Figure 6 shows the cumulative curves of the sediments drawn on phi probability paper.

Mode: Mode is a peak of an incremental frequency curve. It represents most frequently occurring particle size or its maximum concentration in a sample. A sample having one particular size of sediments dominating over others is called 'unimodal' and is represented on the size-frequency curve by a more or less conspicuous peak. Curves with two conspicuous peaks are termed as 'bimodal' and with more than two peaks as 'polymodal' . The nature of the sediments of the present river for the two periods of flow is given in (Table 3). The frequency distribution curves illustrated that majority of sites showed polymodal sediments with the exception of the sites S-1, S-4, S-6, and S-12 which were bimodal (Table 4). The mode of the sediments showed little temporal variation at almost all the sites with the exception of the sites S-3, S-5, S-9, S11, S13, S-14, and S-15 as shown in (Fig.5). The site (S-1) showed bimodal nature in the high flow period and polymodal nature in the low flow period. On the other hand, the site (S-2) showed polymodal nature in high flow period and bimodal nature in low flow period. The site (S-4) showed bimodality during the high flow period and unimodality during low flow period whereas the site (S-6) exhibited bimodality during high flow period and polymodality during low flow period. The (S-7) showed polymodality in high flow and unimodality during low flow period. The site (S-8) showed polymodality during high flow period and bimodality during low flow period while the site (S-10) changed from polymodal nature in

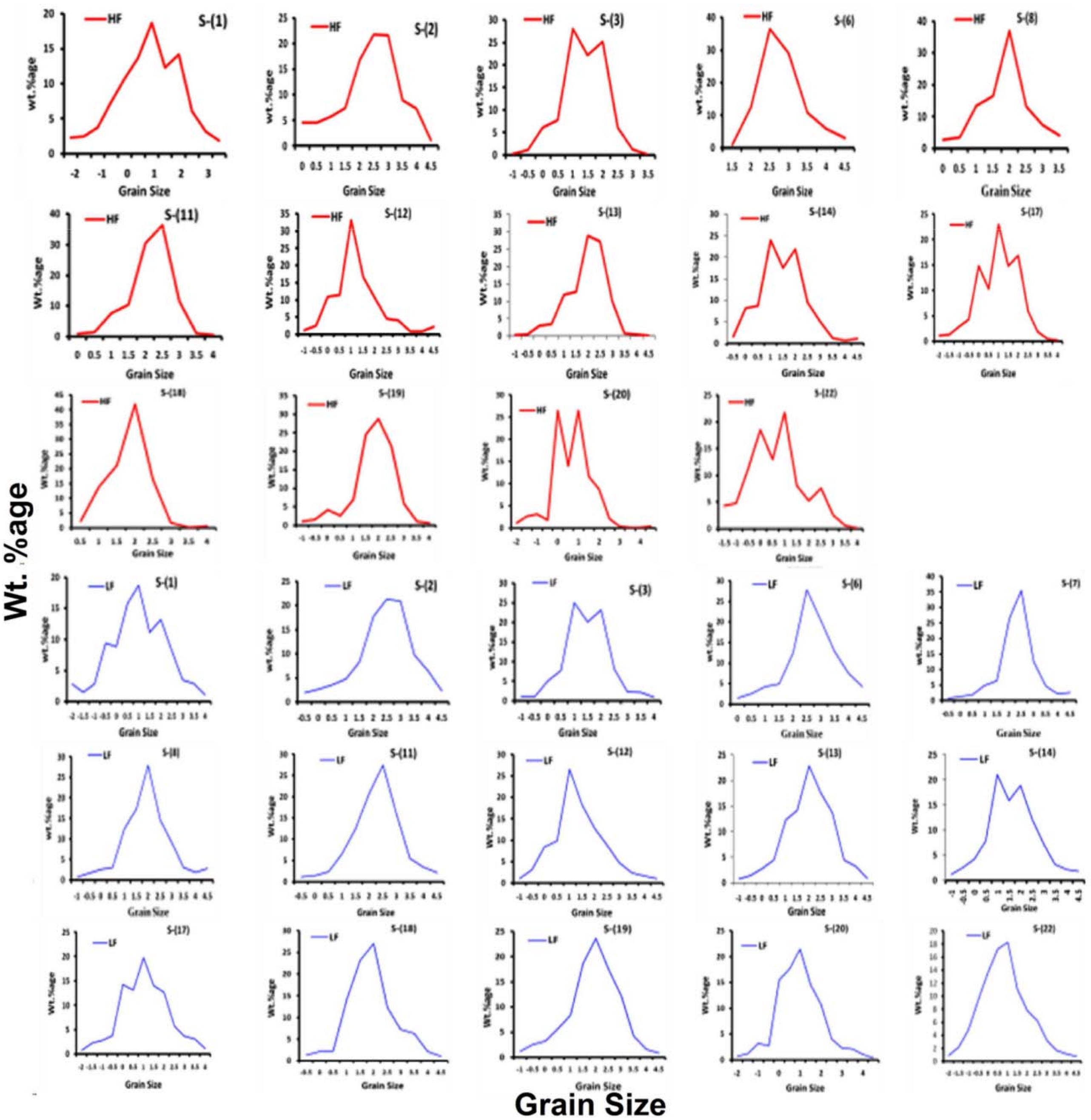

Fig.5. Frequency Distribution Curves showing the behaviour of sediments of River Jhelum and its tributaries. (Note: Red coloured graphs represent high flow period and blue coloured graph represents low flow period).

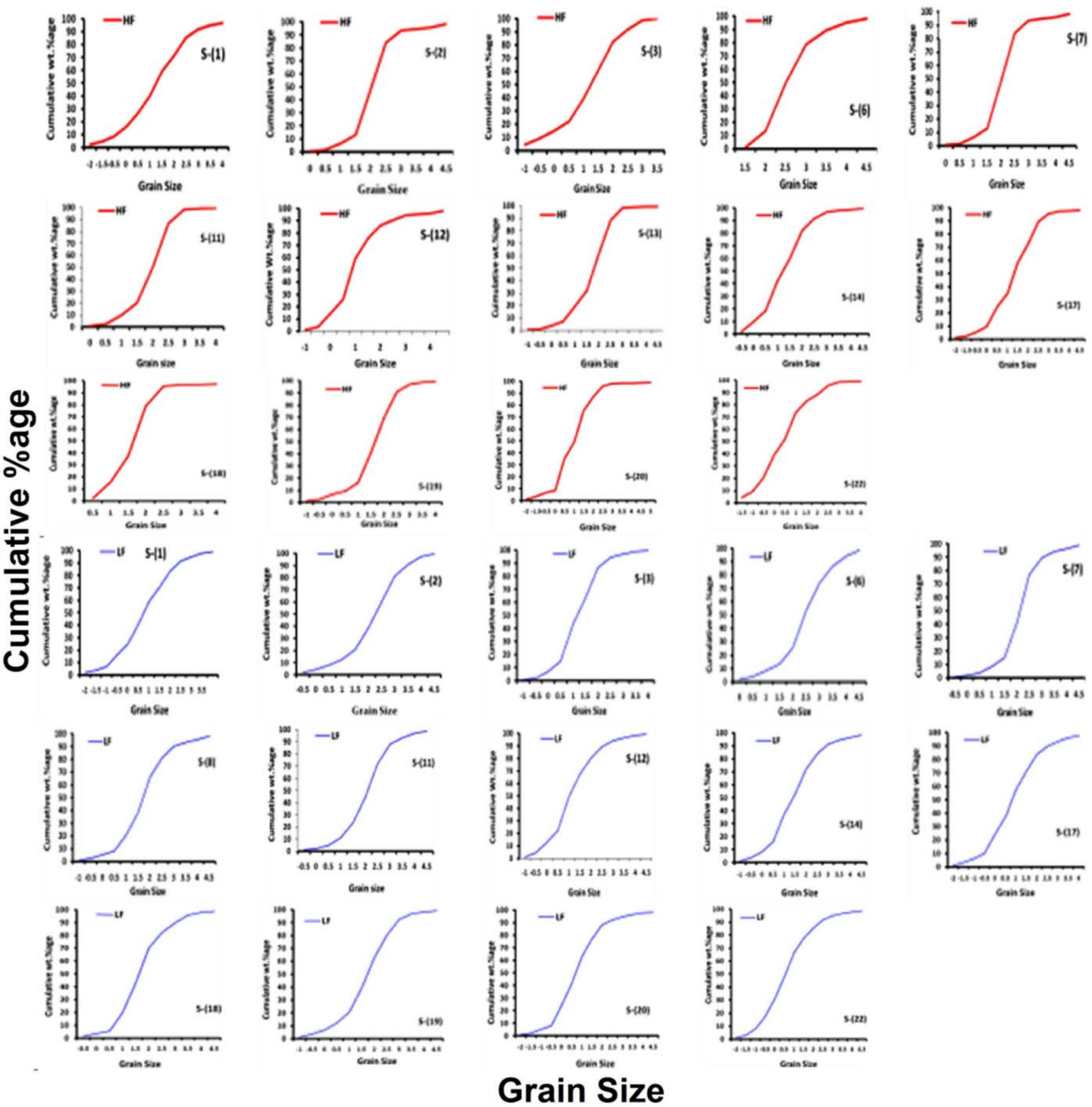

Fig.6. Cumulative Frequency Curves of the sediments of River Jhelum and its tributaries. (Note: Red coloured graphs represent high flow period and blue coloured graph represents low flow period).

high flow period to bimodal nature in low flow period. The site (S-12) exhibited bimodal nature during high flow period and polymodal nature during low flow period. In general, the sediments of river Jhelum and its tributaries showed little variation in the nature of the sediments. The polymodal nature of the sediments indicated that the particles were derived from several sources. In addition to it, fluctuations were also indicated by the polymodal nature, in the current velocity during the deposition of these particles.

Bivariate Plots

Bivariate plots between certain parameters are also helpful to interpret the energy conditions, medium of transportation, mode of deposition etc. Passega, (1957); Visher, (1969) and Folk and Ward, (1957) described that these trends and interrelationship exhibited in the bivariate plots might indicate the mode of deposition and in turn aid in identifying the environments. An attempt has been made here to utilize these bivariate plots to study the

Table 4. Nature and number of modes of sediments of river Jhelum and its tributaries during high flow and low flow period. (Note: Locations with * represent low flow period)

Loca-tions	Values of Modes	Texture	Nature
S-1	0.6, 1.7	Coarse to medium sand	Bimodal
S-1*	-2, 3, -0.3, 0.7, 1.7, 3.3, 3.7	Granule to very fine sand	Polymodal
S-2	1.7, 2.2, 2.8, 3.8	Medium to very fine sand	Polymodal
S-2*	2.4, 3.8	Fine to very fine sand	Bimodal
S-3	-0.25, 0.8, 1.8	Very coarse to medium sand	Polymodal
S-3*	-0.2, 1.4, 2.3, 3.7	Very coarse to very fine sand	Polymodal
S-4	2.2, 2.28	Fine sand	Bimodal
S-4*	2.25	Fine sand	Unimodal
S-5	0.7, 1.6, 2.25	Coarse to fine sand	Polymodal
S-5*	1.25, 2.3, 2.75	Medium to fine sand	Polymodal
S-6	0.7, 1.75	Coarse to medium sand	Bimodal
S-6*	1.25, 2.25, 5	Medium to coarse silt	Polymodal
S-7	1.25, 2.25, 2.75	Medium to fine sand	Polymodal
S-7*	2.25	Fine sand	Unimodal
S-8	-0.3, 0.8, 2.7	Very coarse to fine sand	Polymodal
S-8*	-0.25, 0.8	Very coarse to coarse sand	Bimodal
S-9	-0.25, 0.75, 1.6, 2.1	Coarse to fine sand	Polymodal
S-9*	0.8, 1.8, 2.9, 4	Coarse to very fine sand	Polymodal
S-10	-0.2, 0.6, 1.6	Very coarse to medium sand	Polymodal
S-10*	0.8, 1.9	Coarse to medium sand	Bimodal
S-11	-0.4, 0.7, 1.6	Very coarse to medium sand	Polymodal
S-11*	-1.7, -0.25, 0.9, 1.6, 3.4	Granule to very fine sand	Polymodal
S-12	0.7, 1.6	Coarse to medium sand	Bimodal
S-12*	1.6, 2.3, 3.7	Medium to very fine sand	Polymodal
S-13	-0.25, 1.3, 1.7, 2.2	Very coarse to fine sand	Polymodal
S-13*	-0.4, 1.3, 2.25, 3	Very coarse to fine sand	Polymodal
S-14	-1.3, -0.25, 0.8, 1.7	Granule to medium sand	Polymodal
S-14*	0.4, 1, 2.3	Coarse to fine sand	Polymodal
S-15	-0.4, 0.7, 2.2	Very coarse to fine sand	Polymodal
S-15*	-1.3, -0.4, 0.9, 2, 3.25	Granule to very fine sand	Polymodal

trends and interrelationship of the statistical parameters of the sediments of river Jhelum and its tributaries. The relationship between grain size parameters during two periods of the high flow and low flow is shown in (Fig.7). The binary plot between (Mz) and (ó1) (Fig.7a) exhibited an almost linear relation and showed that the sediments of the river Jhelum and its tributaries were poorly to moderately well sorted during the high flow period and poorly to moderately sorted during the low flow period. The sorting worsens as the phi mean size decreases. This is true in the case of the gravel rich tributary sediments. The plot also showed the dominance of moderately sorted sediments for a wide mean size during both the seasons. The plot between (Mz) and (SK) (Fig.7b) is almost curvilinear facing upwards, reflecting the sediment distributional behaviour as classic (Folk and Ward, 1957; Friedman, 1961). The plot also showed that the sediments were coarse skewed to fine skewed during high and low flow periods. This plot showed the dominance of near symmetrical sediments during both the periods. The plot between the (Mz) and (KG) (Fig.7c) exhibited a slightly rising linear pattern reflecting an admixture of coarser and finer particles and showed that for wide values of mean size (Mz), the sediments were of leptokurtic to very leptokurtic behaviour during high flow period and platykurtic to leptokurtic during the low flow period. The relationship between (óI) and (SK), (KG) and (óI) and (KG) and (SK) didn't show clear trends and thus, do not yield much information. However in the (óI) and (SK) plot (Fig.7d), the sorting of sediments remain mostly moderate with decrease in skewness during both the periods.. The plot between (KG) and (óI) (Fig.7e) showed that the kurtosis of the sediments tends to remain mostly very leptokurtic during high flow period and platykurtic during the low flow period for poor sorting as shown in (Fig.7e). In general, the sediments showed normal kurtosis in the (KG) and (SK) plot (Fig.7 e, f). The plots reflected in general poly modal nature of sediments.

WEATHERING IN THE BASIN

Continental weathering is a major geological process responsible for landscape evolution and exerts a major control on the transport of eroded materials from continents to the oceans and on the cycles of many chemical elements, including carbon, at the earth's surface (Dessert et al. 2001). In this context, the major element oxide analysis of the sediments was carried out to study the intensity of weathering in the present river basin. The statistical values of major element oxides is given in the (Table 5). The results of major chemical oxides of sediments collected revealed that SiO_2 was the dominant oxide constituting >65% of the total oxide elemental composition of the sediments. SiO_2 is followed by Al_2O_3 and CaO contributing 12% and 15% to the total oxide budget of the sediments. Owing to the wide variability in the surficial lithology in Kashmir valley, the major oxide chemistry of the sediments of the study area varied widely.

Chemical Index of Alteration (CIA):- To evaluate the extent of weathering in the provenance, the CIA defined by (Nesbitt and Young, 1982) was calculated as

$$CIA = (Al_2O_3 / Al_2O_3 + CaO^* + Na_2O + K_2O) \times 100)$$

where CaO* is the amount of CaO incorporated in silica

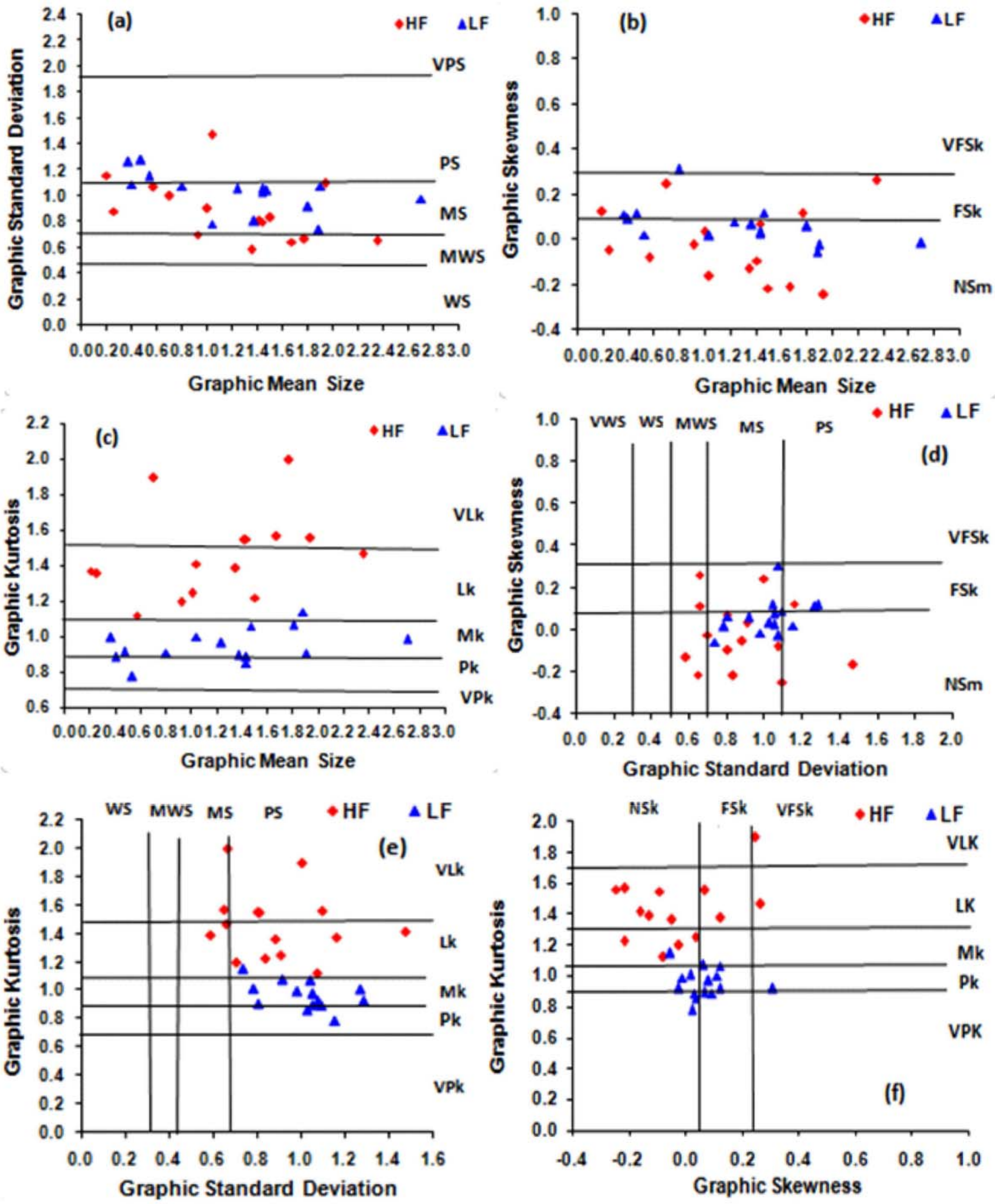

Fig.7. Binary plots between various textural parameters of the sediments of river Jhelum and its tributaries. (Index: VPS-very poorly sorted, PS-poorly sorted, MS, moderately sorted, MWS-moderately well sorted, WS-well sorted, VFSk-very fine skewed, FSk-fine skewed, NSm-near symmetrical, VLk-very leptokurtic, Lk-leptokurtic, Mk-mesokurtic, Pk-platykurtic, VPk-very platykurtic)

fraction of rocks which is corrected following the (McLennan, 1993) method.

The CIA values of the present study were compared with average upper continental crust (UCC: Taylor and McLennan, 1985), post-Archean Shale (PAS) (PAS: Taylor and McLennan, 1985) (see Table 5). The values of CIA of bed sediments of river Jhelum and its tributaries varied from 28 to 78 (Table 6) and were lower than the CIA values of average PAS (69) at most of the sites with the exception of the sites S-7, S-12 and S-15 and higher than UCC (47) with the exception of the sites S-6 and S-11. In general, a moderate weathering was inferred in the provenance of most of the sites with a slightly higher weathering in the provenance of the sites S-7, S-12 and S-15 which was ascribed to the presence of volcani (basalts) rocks and active tectonic upliftment in the area (Singh, 2005).

Resistant Index of Maturity (RM):- The resistant index

Table 5. Statistical overview of the major elemental oxides and comparison CIA (Chemical Index of Alteration) and Rm (Resistant Index of Maturity) values of sediments of river Jhelum and its tributaries with the World averages

S.	Present River (Jhelum)			World averages	
No	Parameters	Range	Mean	Upper Continental Crust (UCC)	Post-Archean Shale (PAS)
1	CaO%	1.7-23.4	8.1	-	-
2	MgO%	0.6-8.4	2.5	-	-
3	Na_2O%	0.7-1.5	1.1	-	-
4	K_2O%	0.6-1.1	0.8	-	-
5	Al_2O_3%	9.2-16.6	12.7	-	-
6	SiO_2%	49.7-78.7	65.2	-	-
7	CIA	28-79	59	47	69
8	R_m	1.9-18	7.9	-	-

of maturity (RM) is used to understand the degree of weathering in the provenance and is calculated by the following

$$RM = SiO_2/(Na_2O+K_2O+CaO+MgO)$$

The RM value for the Jhelum river sediments varied between 1.94 to 17.97 with an average value of 7.85 (Table 5). The low RM values for these sediments indicate their immaturity.

Physical Erosion

The study of sediment transport in the river is significant because of the extensive erosion taking place on the steep mountains due to human activities, filling and changing of river bottoms as well as the water quality. This water is used for drinking, cleaning and hydro-power generation (Wanganeo et al. 1992; Mir and Jeelani, 2015). Thus, an attempt to know the per unit erosion rate in the upper Jhelum basin using sediment discharge, water discharge and area of drainage basin was carried out. Basically, the fine sediments are transported as suspension and the coarser material as bed-load. A regular assessment of sediment discharge of the lower Jhelum basin is made at Uri Hydropower Station. Paul et al. (1999) have reported a discharge of 2.8×10^6 ton/year of sediments with a moderate denudation rate of 0.1 mm/year from the lower Jhelum basin as observed at Uri Hydropower Station. However, such a sediment discharge data is not available for the upper Jhelum basin. Thus, in order to make a rough estimate of the sediment erosion rate per unit area in the upper Jhelum basin, the same sediment discharge dataset has been utilised. The water discharge was measured by velocity area method; drainage basin area was procured from P&D, Flood Control. Department, Srinagar. Thus, the physical erosion rate per unit area of the sediments for the upper Jhelum basin was determined to be 241.362 tons/km^2/year by the following the equation

$$R = E/A$$
$$(\sim E = Qs + Qb)$$
$$\text{Thus}$$
$$R = (Qs + Qb)/A$$

(Derivation of longitudinal river profile, GHR Oct 8th 07):

Where Qs is suspended sediment discharge, Qb is bed load and A is the area of the drainage basin. The Qs was considered to be negligible as compared to bed load. In the same Jhelum basin at Baramullah, the transport corresponds to a yield from the drainage basin of 200-300 ton/km^2/year as reported by Paul et al. (1999).

CONCLUSION

The present work was carried out to study the nature of the grain size distribution along the river Jhelum and its tributaries. Various statistical parameters (i.e. mean size, mode, standard deviation, skewness and kurtosis) are evaluated. The textural parameters indicated that the sediments were coarse to fine grained, moderately well sorted to poorly sorted with dominantly very positively skewed and leptokurtic to very leptokurtic nature. The sediments were deposited under moderate to low energy conditions with dominant rolling processes. The variations in mean size indicated differential energy conditions at different locations whereas, the variation in sorting values indicated continuous addition of finer to coarser material in varying proportions at different locations particularly by tributaries. Frequency Distribution Curves and bivariate plots drawn between different textural parameters clearly established that the sediments were dominantly polymodal in nature. The moderate weathering in the basin was inferred from chemical index of alteration (CIA). The sediments were found to be immature on the basis of resistant index of maturity (R_M).

Acknowledgements: The author would like to thank Mr. Ali Mohammad (Chemist) at Khyber Cement Industry Ltd, Srinagar and P&D, Flood Control Department, Srinagar for their support during the work.

References

Allen, J.R.L. (1965) A review of the origin and characteristics of recent alluvial sediments. Sedimentology, v.5, pp.89-191.

Baruah, J., Kotoky. P. and Sarma, J.N. (1997) Textural and Geochemical study on river sediments: A case study on the Jhanji River, Assam. Jour. Indian Assoc. Sedimentologists, v.16, pp.195-206.

Brambati. A. (1969) Stratigraphy and sedimentation of Siwaliks of North Eastern India. Proc. Inter. Sem. Intermontane Basins: Geology and Resources, Chiang Mai, Thailand, pp.427-439.

Bui, E.N., Loeppert, R.H. and Wilding, L.P. (1990) Carbonate phases in calcareous soils of the Western United States. Soil Sci. Soc. Amer. Jour., v.54, pp.39-45.

Cadigan, R.A. (1961) Geologic interpretation of grain size distribution measurements of the Colorado Plateau sedimentary rocks. Jour. Geol., v.69, pp.121-144.

Dessert, C., Dupré, B., François, L.M., Schott, J., Gaillardet, J., Chakrapani, G. and Bajpai, S. (2001) Erosion of Deccan Traps determined by river geochemistry: impact on the global climate and the $^{87}Sr/^{86}Sr$ ratio of seawater. Earth Planet. Sci. Lett., v.188, pp.459-474.

Folk, R.L. and Ward, W.C. (1957) Brazos River bar: a study in the significance of grain size parameters. Jour. Sed. Petrol., v.27, pp.326.

Folk, R.L. and Ward, W.C. (1957) Brazos River Bar – a study in the significance of grain size parameters. Jour. Sed. Petrol., v.27(1), pp.3-26.

Folk, R.L. (1966) A review of grain size parameters. Sedimentology, v.6. pp.73-93.

Friedman, G.M. (1961) Dynamic processes and statistical parameters compared for size frequency distributions of beach and river sands. Jour. Sed. Petrol., v.32, pp.327-354.

Friedman, G.M. and Sanders, J.E. (1978) Principles of Sedimentology. John Eiley and Sons, New York.

Friedman, G. M. (1979) Differences in size distributions of populations of particles among sands of various origins. Sedimentology, v.26, pp.332.

Ganesh , B., Naidu, A.G.S.S., Jagannadha M., Rao, T. Karuna, K. and Avatharam, P. (2013) Studies on textural characteristics of sediments from Gosthani River Estuary- Bheemunipatnam, A.P., East Coast of India. Jour. Indian Geophys. Union, v.17(2), pp.139-151.

Geological Survey of India (1989) Stratigraphic sequence of rocks exposed in Kashmir. Geology and mineral resources of the states of India part X – J&K. 2nd Ed.

Ganju, J.L. and Khar, B.M. (1984) Tectonics and hydrocarbon prospects of Kashmir valley- possible exploration targets. Petroleum Asia Jour., pp.207-216.

Ghosh, S.N. and Mathur, V.K. (1996) Testing and Quality Control in Cement Industry. ABI Books, v.3, pp.457-466.

Inman, D. L. (1952) Measures for describing the grain size distribution of the sediments. Jour. Sedim. Petrol., v.22, pp.125-145.

Kumar, G., Ramanathan, A.L. and Rajkumar, K. (2010) Textural characteristics of the surface sediments of a Tropical mangrove ecosystem Gulf of Kachchh, Gujarat, India. Indian Jour. Mar. Sci., v39(3), pp.415-422.

Lindholm, R.C. (1987) A practical Approach to Sedimentology. Allen and Unwin, London, pp.276.

Martines, L.R. (1965) Significance of skewness and kurtosis in environmental interpretation. Jour. Sed. Petrol., v.35, pp.768-770.

Mason, C.C. and Folk, R.L. (1958) Differentiation of beach, dune and aeolian flat environments by size analysis, Mustang Island, Texas. Jour. Sed. Petrol., v.28, pp.211-226.

McCammon, R.B. (1962) Efficiencies of percentile measures for describing the mean size and sorting of sedimentary particles. Jour. Geol., v70, pp. 453-465.

McLennan, S. M. (1993) Sediments and soils: chemistry and abundances. *In:* T.J. Ahrens (Ed.), AGU Handbook of physical constants, Vol 3, Amer. Geophys. Union.

Meybeck, M. (1976) Total mineral dissolved transport by world major rivers. Hydro. Sci. Bull., v.21, pp.265-284.

Milliman, J.D. and Meade, R.H. (1983) World Delivery of river sedimentd to the oceans. Jour. Geol., v.1, pp.1-21.

Milliman, J.D. and Meade, R.H., (1983) World-wide delivery of river sediment to the oceans: Jour. Geol., v.91, pp.1-21.

Nesbitt, H.W. and Young, G.M. (1984) Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamics and kinetic considerations. Geochim. Cosmochim. Acta., v.54, pp.1523-1534.

Nordstrom, K.F. (1977) The use of grain size statistics to distinguish between high- and moderate energy beach environments. Jour. Sed. Petrol., v.47(3), pp.1287-1294.

Otto, G.H. (1938) The sedimentation unit and its uses in field sampling. Jour. Geol., v.46, pp.569-582.

Paul, A. (1999) Description of the river Jhelum drainage in the Kashmir valley. *In:* Lennart Nyman (Ed.), River Jhelum, Kashmir Valley impacts on the aquatic environment. pp. 9-23.

Rajasekhara, R.D., Karuna, K.T. and Deva V.D. (2008) Textural characteristics of south western part of Mahanadi Delta, east coast of India. Jour. Indian Assoc. Sed., v.27, no.1, pp.111-121.

Roi, K.L. (1997) Indias Water Wealth. Orient Longman, New Delhi, pp 267.

Sahu, B.K. (1964) Depositional mechanisms from the size analysis of classic sediments. Jour. Sed. Petrol., v.34, pp.73-83.

Seralathan, P. and Padmalal, D., (1994) Textural studies of surficial sediments of Muvattupvzha river and central vembanad estuary, Kerala. Jour. Geol. Soc. India, v.43, pp.179-190.

Shajan, K.P. (2001) Geochemistry of bottom sediments from a river-estuary-shelf mixing zone on the tropical southwest coast of India. Bull. Geol. Surv. Japan, v.52(8), pp.371-382.

Singh, A.K. and Hasnain, S.L. (1998) Major ion chemistry and weathering control in a hisih altitude basin: Alaknanda river, Garhvval Himalaya, India. Hydro. Sci. Jour., v.43(6), pp.825-843.

Singh, S.K., Sarin, M.M. and Frank, Lenord, C. (2005) Chemical erosion in the eastern Himalayas, major ion composition of the Brahmaputra and $\delta^{13}C$ of inorganic carbon. Geochim. Cosmochin. Acta., v69, pp.3573-3588.

Subrahmanyam, V., Bisham, G. and Ramesh, R. (1987) Environmental geology of the peninsular river basins of India. Jour. Geol. Soc. India, v.30, pp.393-401.

Taylor, S.R. and McLennan, S.M. (1985) The continental crust: its composition and evolution: Oxford, Blackwells, pp.312.

Trask, P.D. (1932) Origin and environment of source beds of petroleum, Houston, Gulf Publ. Co., Huston, pp.323.

Visher, G.S. (1969) Grain size distribution and depositional processes. Jour. Sed. Petrol., v.39, pp.1074-1106.

Wadia, D.N. (1934) The Cambrian-Triassic sequence of NW Kashmir. Rec. Geol. Surv. India, v.68(2), pp.121-176.

Wakatusuki, T., FurUrkawa, H. and Kyuma, K., (1977) Geochemical study of redistribution of elements in soil, 1: Evaluation of degree of weathering of transported soil materials by the distribution of major elements among the particle size fractions and soil extract. Geochim. Cosmochin. Acta., v.41, pp.891-902.

Walling, D.E. and *Webb*, B.W. (1983) Patterns of sediment yield. *In:* K.J. Gregory (Ed.), Background to Palaeohydrology. John Wiley & Sons Ltd, pp.69–100.

Wanganeo, A., Zutshi, D.P. and Wanganeo, R. (1992) Catchment deterioration-fish populations. *In:* A.R. Yousuf, M.K. Raina and M.Y. Qadri (Eds.), Current trends in fish and fishery biology and aquatic ecology. Published by Post-graduate Department of Zoology, University of Kashmir, Srinagar-190006, India, pp.173-178.

(Received: 4 September 2013; Revised form accepted: 20 March 2014)