Granulometric Studies of the Surface Sediments of Kulfo River, Southern Nations, Nationalities and People's Region (SNNPR), Ethiopia, East Africa

Jai Ram Ojha, Subodh Kumar Chaturvedi and Anirudh Bhowmick

Abstract: The Kulfo River, flowing in the 'Main Ethiopian Rift Valley', is one of the important river of SNNPR. The river profile, volume of river water flow, rainfall, topography, geology, climate and land use are the controlling agents for the erosion, transportation and deposition of sediments in this area. A total of seven sediment samples collected at water-land interface along the Kulfo River have been utilized for their granulometric analysis. The study reveals unimodal, moderately to well sorted fine sands in upstream indicating a single source of sediment supply in the river. Farther away from upstream, the textural properties of sediments indicate bimodal to polymodal, poorly to moderately as well as well sorted medium to fine sands reflecting more than one source of sediment supply.

Index Terms: Granulometric studies, Kulfo River, Main Ethiopian Rift Valley, Paleoclimate, Paleoenvironment.

1. INTRODUCTION

Kulfo River is one of the important river of SNNPR, which flows in Main Ethiopian Rift Valley. The river water is an important source for irrigation of agricultural lands in this region. Agriculture is the main source of income for the people in Ethiopia which largely depends on the rainfall. The region has witnessed frequent changes in rainfall pattern resulting in floods and droughts. The occurrences of drought have caused fall in food grain production that have lead to the wide spread famine in Ethiopia. The loss of life during famine could be avoided if such natural calamities are predicted in advance so that planners could take suitable measures to face such challenges effectively with minimum loss of life. However, in order to model the long term occurrences of such natural calamities, it is necessary to infer the occurrences of such events in recent geological past. It is well known that the sediments and fauna contained within are sensitive to climatic changes and have proved to be the best proxies to infer paleoenvironmental and paleoclimatic conditions [1], [2], [3], [4], [5], [6], [7], [8]. Though, lake sediments of African regions have been utilized for paleoclimatic studies [9], [10], [11], [12], [13],[14]., the river sediments have not been given due attention by the previous researchers.

River banks are the important sites for ancient human civilizations throughout the globe due to the readily available water and food. Furthermore, rivers also provide various living and nonliving resources such as placer deposits of economically important minerals, building materials, fertile lands and hence, source of livelihood, employment, recreation for the people living in the vicinity of rivers. River water carries various types of rock materials along its course and deposits it at suitable locations. Such erosion, transportation and deposition of rock materials by river depend on topography, lithology, climate, rainfall, velocity and volume of water, distance and duration of transport, shape of channels, etc. Among various natural agencies, rainfall is one of the important natural agents that govern the sediment transport and depositional framework in the river basin. In accordance with the 'James Hutton Principle' it is necessary to investigate the distribution pattern of recent sediments together with other sedimentary signatures to infer the past climatic changes in this region. In the present endeavor, an attempt has been made to understand the various sedimentary processes utilizing the textural analysis of surface sediments collected from the land-water interface along the Kulfo River around Arba Minch town, Ethiopia.

2. AN OVERVIEW OF THE STUDY AREA

The study area is situated in the southwestern part of 'Main Ethiopian Rift Valley' near Arba Minch town, Ethiopia. Kulfo River originates from the Genta Mountains. It starts from the junction of Titka and Gwado rivers at 60 07'latitude and 370 27' longitudes and flowing through the rift along its course. Finally, it discharges its water into the Lake Chamo and alternatively to the Lake Abaya during peak rainy season.

The geological and geomorpholgical characteristics of this river are related to the gradient of the terrain from steep mountainous to gently sloping areas of the region. According to the static and dynamic characteristics, alluvial river patterns are categorized as 'straight', 'meandering' and 'braided' in general. Thus, the sequence of straight, meandering and braided rivers corresponds to an increase in valley slope or stream power magnitude [15]. Beneath the main channel, several minor and ephemeral channels occur, characterized by bifurcations and a major flow direction in to the Lake Abaya. Most of the ephemeral channels are ceasing in the lower flood plains. The catchment area of the Kulfo River is characterized by steep topography in the upper part and almost flat at the lower part bounded by high mountains and ridges with gorges and steeply undulating lands at places (Figure 1).

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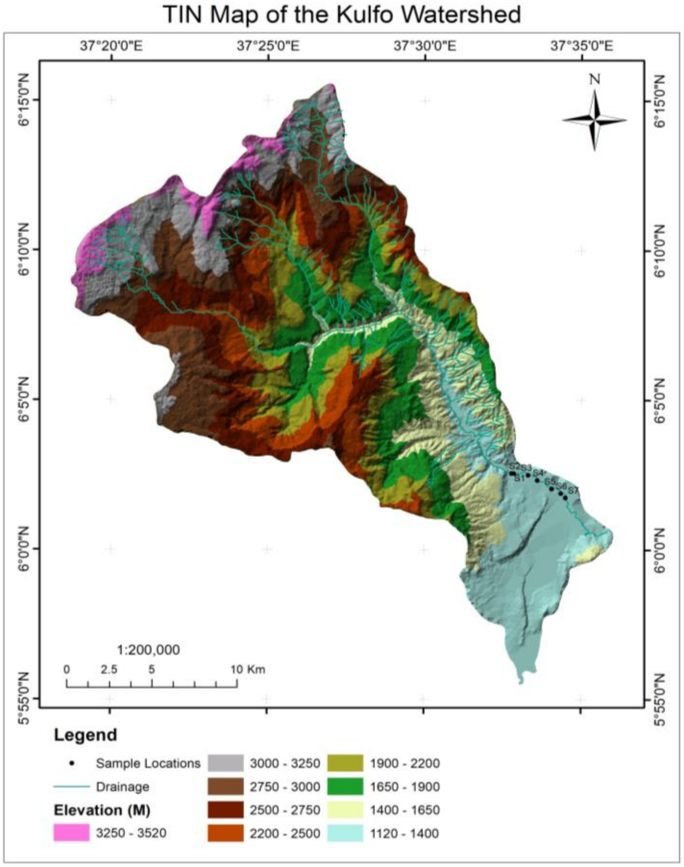

***FIG.1**: Triangulated Irregular Network (TIN) of Kulfo River Basin*

The upper part is the source of sediment from where it is transported to the lower part of the river basin. The lower part is serving as depositional site for the sediments since the area is almost flat lands. The middle part of the river is the most mature where the vigorous meandering capacity of river is diminished. However, the river erodes its channel rocks only selectively changing its course where it finds obstruction too hard to remove. Meandering indicates a typical feature of a mature type of river regime [16]. High sediment load of the river during flood events is caused by soil erosion in the catchment area [17]. The Kulfo River deposits its bed load at inflexion zone between graben flank and graben floor. The suspended load of the river, on the other hand, is deposited in the alluvial plains forming distinct natural levees parallel to its lower course [18], [19]. The origin of suspended load is characterized by the presence of clay minerals; goethite and hematite all pointing out river bank deposit correspond to soil sediments [20]. Some sedimentary structures such as 'mud cracks' and 'ripple marks' are also found associated with the sediments (Figures 2a & b). The study area is covered by volcanic igneous rocks such as aphanetic and vesicular basalts. Both rocks are composed of fine grained, dark coloured mafic minerals. The rocks are well exposed and highly weathered in the up-stream. But in the lower stream, these rocks are covered under the sediments deposited by the river and hence, not found exposed. The climate in the region is arid to semi-arid. The mean annual temperature and rainfall is about 25°C and 750mm respectively. Climatic condition of the area is described by bimodal rain fall pattern. The main rainy season, ranges from April to June in which the maximum rain fall reaches up to 129.7 mm/month. This bimodal rainfall badly affects the flow direction, nature and capacity of erosion of the Kulfo River. It also controls the production, transportation and depositional pattern of the sediment in the distal part of the river basin.

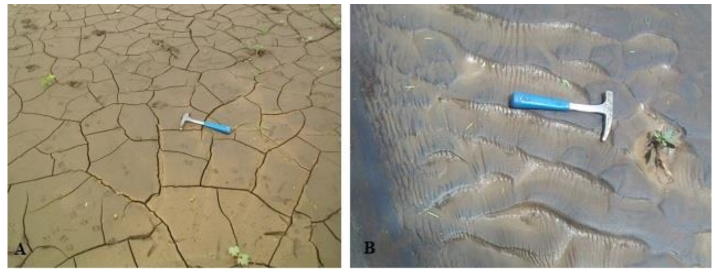

***Fig. 2: (a**) Mud Cracks and (b) Ripple Marks in the Kulfo River Sediments*

3. MATERIALS AND METHODS

Sedimentary samples were collected from different locations at land-water interface along the Kulfo River (Figure 3) during the field work held in the months of April and May, 2018. Field photographs had also been taken to reveal the various channel features together with different sedimentary structures (Figures 2a & b) associated with the river bed. All the samples were properly labeled and transported to the geology department laboratory of the Arba Minch University. A total of seven sediment samples were selected for their textural analysis utilizing 'wet pipette' and 'dry sieve' methods.

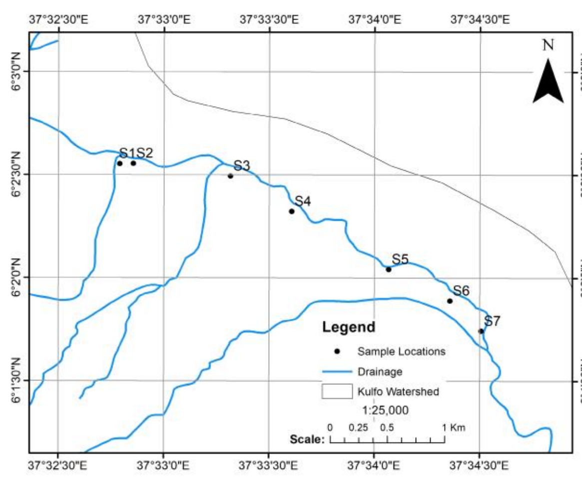

***Fig. 3:** Locations of Surface Sediment Samples Collected at Land Water Interface in Kulfo River*

The representative samples were dried at 75ºC temperature overnight in the hot air oven. For estimation of sand-silt-clay ratio, 50 grams of properly dried and weighed sediment samples had been soaked in water for dispersion in 1000ml beaker. A little amount of water was added in the beaker to dissociate the lumps. Once the lumps were dissociated, the beaker was filled with water and kept overnight for settling without any disturbance. Next day the excess water was removed using a decanting tube. Again, the beaker was filled with water, kept for another night and later the water was decanted the next day. Thereafter, the sediments were washed out through 63µm sieve repeatedly until clear water passes through sieve. Proper care was taken to note that the total volume should not exceed 1000ml. The sediments screened through the sieve were collected in a plastic pan and later transferred to 1000ml measuring cylinder for silt and clay ratio estimation. The residual coarse fraction obtained in the sieve was dried and weighed. This is the amount of sand content in the sediment. The volume of the water in the cylinder as mentioned above was made to 1000ml. Later, the content in the cylinder was stirred vigorously for 45 seconds and the time was noted. As per the room temperature exactly after one hour fifty one minutes, a pipette of 10ml volume capacity connected with a tube was lowered in the cylinder up to 10cm from the water level. Thereafter, 10ml of the aliquot containing clay was pipette out. This aliquot was transferred in a properly washed, dried and weighed 25ml beaker and kept in a hot air oven for drying. The dried clay sediments were weighed using electronic balance and the amount was recorded. Finally, the amount of silt present in the sediment was obtained by subtracting the collective weight of sand and clay from the total weight of sediment. For dry sieve analysis, the known quantity of each dried sediment samples were weighed and soaked with water in a beaker. The soaked sediment samples in beaker were stirred with glass rod and left for 20 seconds for settling the particles. Thereafter, the supernatant turbid solution was siphoned out. The siphon in the beaker was positioned at least 1” above the sediment to save the settled materials from any disturbance. Such decantation was repeated till a clear solution had been obtained. The properly washed sediments were dried in a hot air-oven. Dried and cooled samples were weighed for obtaining the sand content. The losses in the weights were accounted for the weight equivalent to silt and clay in sediment samples. Further, the samples were treated with H_2O_2 to remove the organic matter and then with 10% HCl to remove carbonate content from the samples. Thereafter, it had been dried in the hot air-oven and after weighing the same, it was sieved at 1/2Φ interval. The sieve sets were stacked in order of their respective sizes from coarse (710µm) to fine sized (63µm) sieves. The pan was kept at the bottom and the topmost sieve was covered with the lid. The sieving of the sediments was carried out for 15 minutes using ‘Ro-Tap Mechanical Sieve Shaker’. The samples retained in individual sieve sizes were weighed separately. The weight percentage data of the samples were processed using computer software GRADISTAT version 8.0 [21]. The values of the different sedimentological parameters obtained through the method of moments [22] have been incorporated in the present research paper. These are the most accurate values since it employs the entire sample population [23].

4. RESULTS

4.1. Wet Sieve Analysis of Surface Sediment Samples

The sand-silt-clay ratio in the above samples obtained through pipette analysis reveals high content of sand and low content of silt and clay at location S1, S3 and S7 (Table 1, Figures 4a and b). The maximum percentage of sand was observed to be 93.4% at location S7 while minimum value of 62.2% of sand observed at location S6. Similarly, the maximum percentage of silt was observed to be 37.74% at location S6 and minimum value of 6.56% of silt content was observed at location S7. The clay content was found to be less than 1.1% at all locations. The surface sediment samples of the river are mostly sand dominated except for a few locations where they are becoming silty-sand in nature (Table 1).

4.2 Dry Sieve Analysis of Surface Sediment Samples

The grain size parameters of the sediments, such as the average grain-size, sorting, skewness and kurtosis are the results of the interplay of various hydrodynamic conditions and processes and hence, they are utilized for classifying the sedimentary environments. The textural analysis of the samples reveals unimodal and moderately well sorted fine sands in the up-stream while farther away from the upstream, the textural properties of sediments indicates bimodal to polymodal, poorly to moderately well sorted medium to fine grained sands. The results of the analyses of different parameters are presented here in Table 2 and discussed as under

4.2.1 Particle Size Distribution of Sand

The particle size distribution reveals the highest occurrence of coarse sand of 34.8% at location S3 but location S7 is devoid of coarse sand. Medium grained sand makes its maximum presence of 35.6% at location S6 while minimum value of 5.1% has been reported at location S1. Further, the highest occurrence of fine sand of 64.6% has been found at location S1 whereas, the lowest occurrence of 24.7% is obtained at location S3. Similarly, very fine sand of 52.1% is found to occur in the highest amount at location S7. The minimum amount of 6.6% of very fine sand has been reported at location S6 (Figures 5a-d).

4.2.2 Mean

Mean grain size of the sediments depends on the grain size range of available material and the amount of energy imparted on it. The grain size studies reveal that the mean value of the sediment grains varies from 3.09Φ at location 2 to 1.78Φ at location 6.

4.2.3 Sorting

Sorting of the sediments is primarily controlled by the size range or material supplied to the place of deposition, current characteristics, rate of supply of sediments and the efficiency of the sorting agent. The maximum sorting value of 1.60Φ in the sediment is observed to be at location 3 while minimum value of 1.78Φ at location 6.

4.2.4 Skewness and Kurtosis

Skewness and Kurtosis are the additional measures of sorting. The values of skewness vary from 2.87 at location 1 to 0.99 at location 6 and of kurtosis from 21.81 at location 1 to 4.55 at location 3 respectively.

5. DISCUSSION

The occurrences of high percentage of coarser materials like sand and low percentages of silt and clay at locations S1, S3 and S7 respectively reflect presence of comparatively high energy environment at these locations. Under high energy environment, heavier materials are settled first on the river bed while finer materials are carried away by the river water in suspension. The ‘Triangulated Irregular Network (TIN) Diagram’ of this region (Figure 1) shows that the above three locations are situated in the close proximity of the different channels that are meeting with the main channel and discharging their water and sediment loads in it.

Table1: *Sediment Sample Coordinates, Percentage of Sand, Silt, Clay and Sedimentary Classification in Surface Sediment Samples*

Sample location	Latitude (°N)	Longitude (°E)	% of sand	% of silt	% of clay	Sediment classification
S1	06° 02' 33.1476″	37° 32' 47.677″	90.8	8.76	0.44	Sand
S2	06° 02' 33.2556″	37° 32' 51.515″	83	16.82	0.18	Sand
S3	06° 02' 29.5872″	37° 33' 19.134″	89	10.4	0.6	Sand
S4	06° 02' 19.3452″	37° 33' 36.594″	80.8	18.1	1.1	Sand
S5	06° 02' 02.4900″	37° 34' 04.282″	63.8	35.8	0.4	Silty sand
S6	06° 01' 53.3532″	37° 34' 21.702″	62.2	37.74	0.06	Silty sand
S7	06° 01' 44.5872″	37° 34' 30.572″	93.4	6.56	0.04	Sand

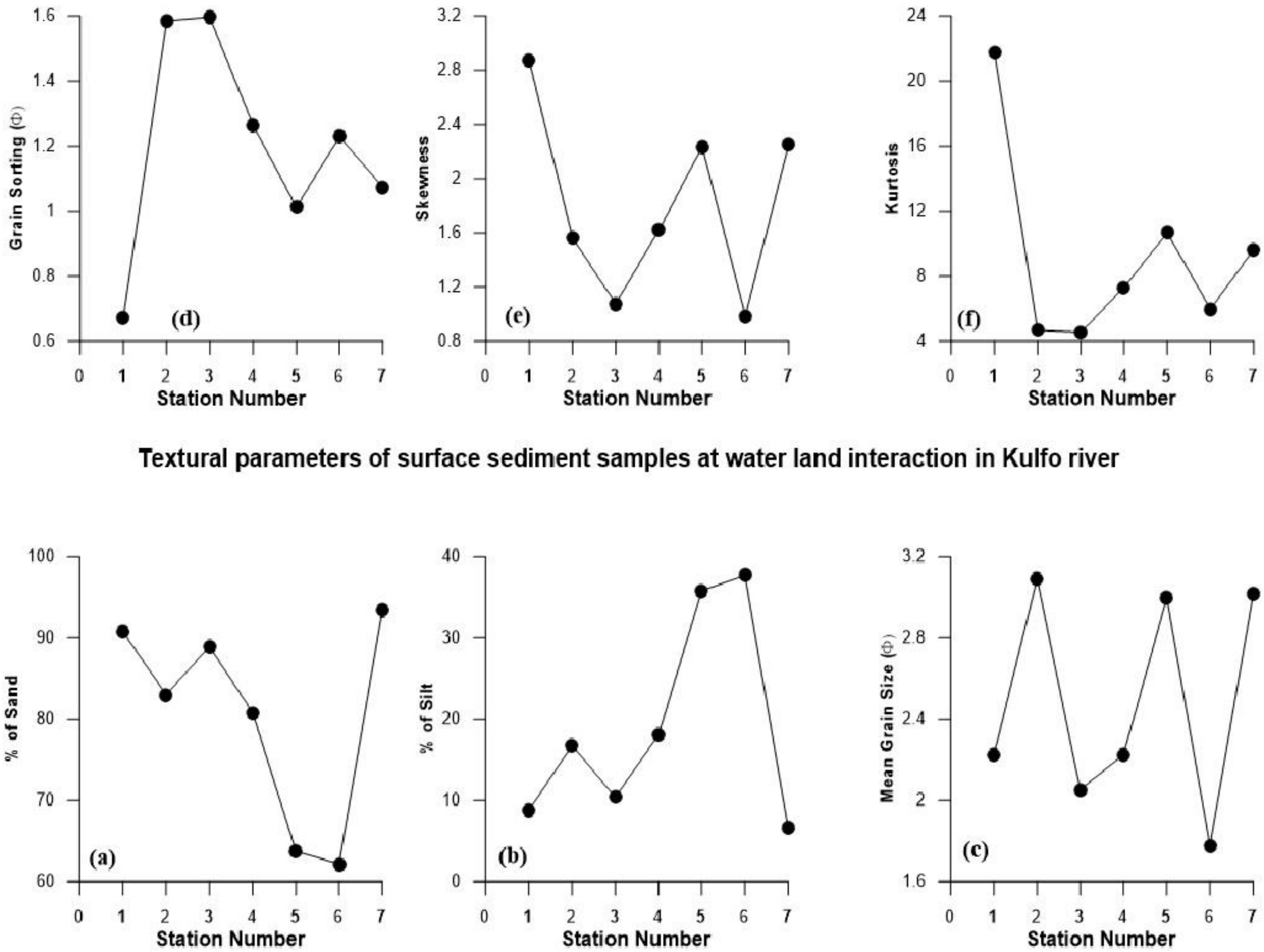

Fig. 4: *Plot of (a) Percentage of Sand, (b) Percentage of Silt, (c) Mean Grain Size (Φ), (d) Sorting (Φ), (e) Skewness and (f) Kurtosis of Surface Sediments Collected at Water Land Interface in Kulfo River*

***Table 2:** Textural Parameters of the Surface Sediment Samples*

Sample No.	S1	S2	S3	S4	S5	S6	S7
Sample type	Unimodal, Moderately well sorted	Bimodal, Poorly sorted	Polymodal, Poorly sorted	Trimodal, Poorly sorted	Bimodal, moderately well sorted	Polymodal, poorly sorted	Bimodal, moderately well sorted
Sediment name	Fine sand	Very coarse silty fine sand	Coarse sand	Medium sand	Very fine sand	Medium sand	Very fine sand
Mean (Φ)	2.22	3.09	2.05	2.23	3.00	1.78	3.02
Sorting (Φ)	0.67	1.58	1.60	1.26	1.01	1.23	1.07
Skewness	2.87	1.56	1.08	1.62	2.24	0.99	2.25
Kurtosis	21.81	4.67	4.55	7.32	10.66	5.97	9.63
% Coarse sand	0.40	0.9	34.8	12.4	0.6	26.6	0
% Medium sand	26.40	14.2	18.7	30.2	5.1	35.6	5.8
% Fine sand	64.60	41.4	24.7	29.5	39.3	29.8	37.1
% Very fine sand	7.70	31.6	17.5	24.6	50.9	6.6	52.1

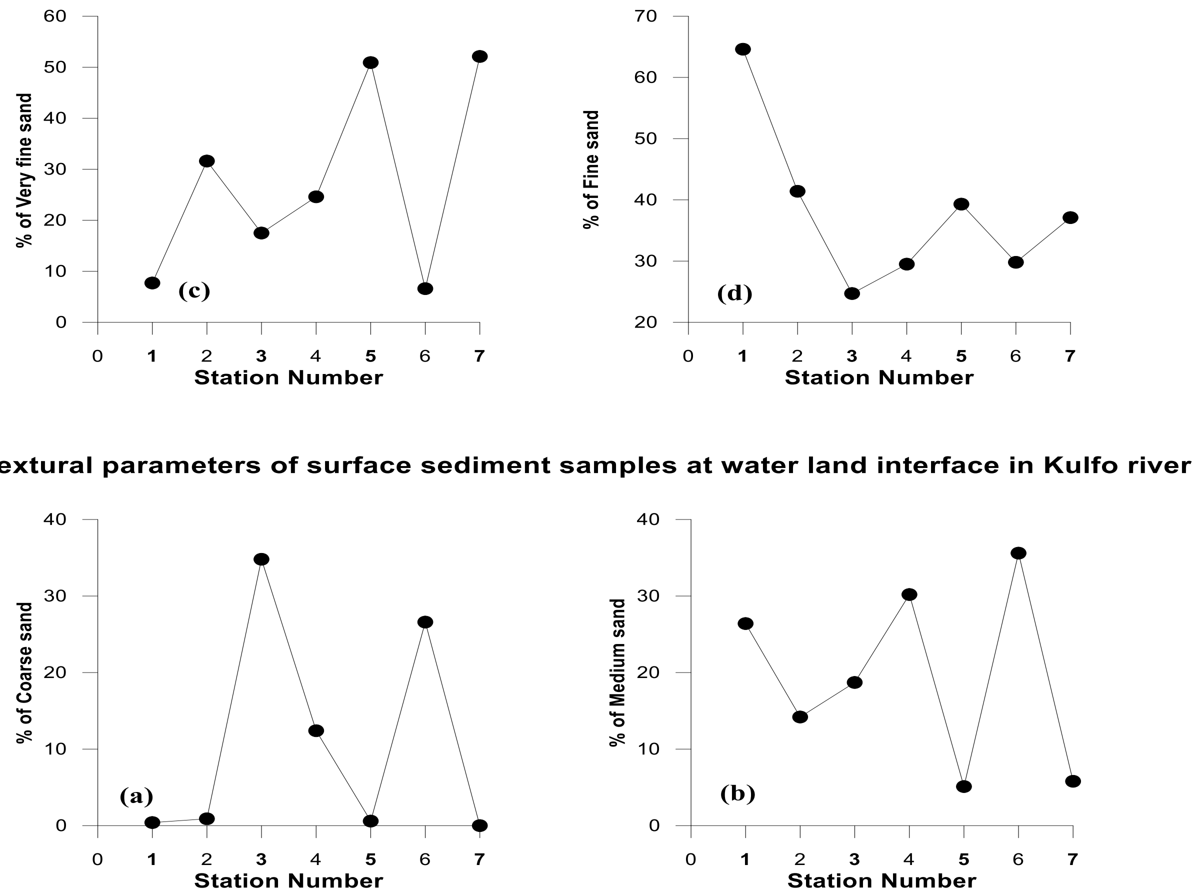

***Fig. 5:** Plot of Percentages of (a) Coarse Sand, (b) Medium Sand, (c) Fine Sand and (d) Very Fine Sand in Surface Sediments Collected at Water Land Interface in Kulfo River*

Conversely, the occurrences of low percentage of sand and high percentage of silt and clay at locations 5 and 6 in the study area could be due to the presence of broad channel profiles resulting the reduction in energy condition of river water, and the soils eroded from the nearby area. The distribution plot of various textural parameters reflects the occurrences of a general decreasing trend of sand percentage and increasing trend of silt percentage from upstream to downstream in the study area (Figures 4a and b). Such distribution pattern of sand and silt on the river floor indicates decreasing energy condition of river water from upstream to downstream. However, the textural parameters like mean grain size, sorting, skewness and kurtosis fluctuate from location to location (Figures 4c-f) reflecting the role of other causative factors like erosion of sediments from nearby cultivated land by rain water and winds, and their deposition in the study area.

While comparing the mean grain size of the sediments, it has been observed that the locations 1,3,4 and 6 are dominated with comparatively larger size sand particles compared to the locations 2, 5 and 7 (Figure 4c). The graphic pattern of sediment sorting reflects better sorting at location 1 in the upstream region and poorly sorted sediments have been observed at locations 2, 3 and 4. The locations 5, 6 and 7 are found to be rich in medium sorting sediments (Figure 4d). Comparatively, better sorting of sediments at location 1 reflects long distance transportation by the river that have winnowed the sediments from source to the final depositional site. The distribution pattern of skewness reveals finely skewed sediments at locations 1, 5 and 7 indicating addition of fine sands whereas, other locations are comparatively coarsely skewed. Similarly, location 1 shows more leptokurtic which indicates better sorting in the central portion of the grain size distribution while remaining locations reflect poor sorting in the central portion and better sorting towards tail ends of the grain size distribution (Figures 4e-f). Sediments at Sample locations S1, S2, S5 and S7 are dominated with fine to very fine sand whereas, S3 is dominated with coarse sand while S4 and S6 are dominated with medium sand (Figures 5a-d). In the vicinity of sample location S2, stones are quarried from the adjacent hills for construction purposes. Washed out fine sediments from the quarry regions are deposited at sample location S2 which is clearly reflected in the textural characteristics. The sediments at sample location S2 is represented by bimodal, poorly sorted very fine sand. Near sediment sample location S3 a tributary of the drainage order of three meets (Figure 1) which brings coarser sediments along with it and deposits in the vicinity of sample location S3 resulting the dominance of coarse sand. The Kulfo river flow is more sensitive to precipitation [24]. Therefore, the sediments washed out by rainfall from catchment area of the river basin additionally contribute the sediment supply to the river floor that have been reflected in the textural analysis of the sediments indicating as more than one source of sediment supply in the sediment samples collected farther away from the upstream region.

6. CONCLUSIONS

The volume of the Kulfo River water flow and the rainfall are the important controlling agents for the transportation of sediments in the study area. The various fluvial processes such as meandering, braided and straight channels together with the various types of sedimentary structures such as mud cracks, ripple marks, point bars and bar deposits have been observed. The grain size distribution patterns of the studied sedimentary samples reveal a general trend of decreasing energy condition from upstream to downstream. The textural analyses indicate unimodal, moderately well sorted fine sands in upstream revealing a single source of sediment supply in the Kulfo River. However, farther away from upstream, the textural properties of sediments reveal bimodal to polymodal, poorly to moderately as also well sorted medium to fine sands reflecting more than one source of sediment supply.

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