Journal of Nepal Geological Society, 2023, Vol. 65 (Sp. Issue), pp. 41–48
https://doi.org/10.3126/jngs.v65i01.57744

Analysis of size, shape and textural maturity of sands from the Kaligandaki River

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ABSTRACT

The Gandaki River System is one of the major river basin of the Himalaya originating from China and flows through Nepal and eventually mixes with the Ganga River in India. The study aims at analyzing the textural properties (size and shape) and maturity of the Kaligandaki River sands, and their downstream variation. Sand samples were collected along the river from the Tethys Himalayan region up to the Indo-Gangetic Plain of Nepal. The sands are classified as slightly muddy sand, in which mean and median sizes and sorting increase with respect to the distance downstream from the provenance. The results indicate that coarsely skewed and platy to mesokurtic sands become nearly symmetrical to finely skewed and leptokurtic suggesting increase in fine-grained sands and enhancement of sorting downstream. The percent of fines (mud) ranges from 0 to 5% and shows no distinct downstream variation trend. Mean roundness of quartz is generally sub-angular (2 to 3ρ), and downstream variation does not reflect change in roundness category. However, there occurs slight diminish of roundness with distance downstream. Inclusive graphic standard deviation (σ_1) varies from 0.30 to 1.38φ. After 100 km downstream, σ_1 decreases reflecting improvement of sorting. Sediments are immature to mature, and are sub-mature in upstream and midstream segments except for few sites where they are immature not due to flux, but probably due to local contribution of fines. Due to increased downstream distance, sediments tend to be more mature owing to enhancement of sorting

Keywords: Kaligandaki River, roundness, sorting, textural maturity, sands

Received: 31 December 2022 **Accepted:** 30 May 2023

INTRODUCTION

River transport sediments in a continuous manner as it descends down from higher elevation region to lower elevation region. The sources of sediment come through different geo-morphological processes in the upland area. The active glaciological processes high seismicity, steep valleys with frequent avalanching, intense monsoonal rainfall, and glacial activities support high erosion rates in the Himalayan catchments (Hasnain and Thayyen, 1999; Singh et al., 1999). These transported sediments are derived from various source of rocks depending upon the geology of the source area. Along the Himalayan river courses downstream variation of constituents and texture (size, sorting and shape), and maturity of sands is important to understand rate of modification of detritus by high- to low-gradient transition of rivers (McBride and Piccard, 1987; Lewis and McConchie, 1994), and to recognize presence or absence of textural inversion (Folk, 1980).

The Gandaki River System covers an area of 46300 km^2 of and lies in central Nepal. It extends from China in the north and flows through Nepal and to India (Fig. 1). The Kaligandaki River flows through various geological units of the Nepal Himalaya and mixes with other major tributaries of the Gandaki River System at southern area.

Altogether 33 samples have been collected from the main stream and 10 samples from its tributaries (Fig. 2). The sample number for the main stream begins as KG-1, it is the upstream sample located near Lomanthang of Mustang district. The numbering increases as moving downstream accordingly up to KG-33 at the Tribeni Dham.

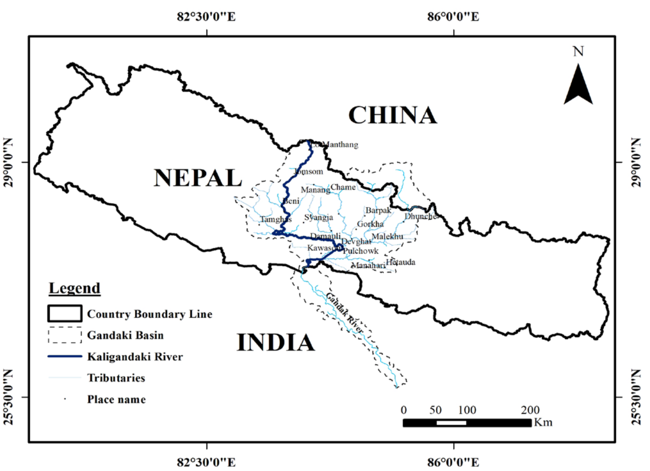

Fig. 1: Gandaki Basin map within the territory of Nepal.

There are many small river and rivulets that contributes their sediments to the main stream of river, among them the major ones are the Modi Khola, Myagdi Khola, Raghuganga River, Rapati River, Jemir Khola, Badigad Khola, Nisti Khola, Ramdi, Jyagdi Khola, and Trishuli River. The sample number for these tributaries is assigned as TKG-1, TKG-2, TKG-3, TKG-4, TKG-5, TKG-6, TKG-7, TKG-8, TKG-9, and TKG-10, respectively.

METHODS

Sieve set were selected following the Krumbein's 1 ϕ interval (Krumbein, 1934) and the grain size grade of

Fig. 2: Sampling location map of the Gandaki Basin.

Udden-Wentworth. The roundness and sphericity of 100 quartz grains from each size grade were analyzed. Powers (1953) roundness chart was used to compare the outliners of quartz to determine roundness values (Rho scale). Likewise, in order to determining the sphericity of the quartz grains it was matched with the chart developed by Rittenhouse (1943).

RESULTS

The river flows through Lomanthang, Kagbeni, Marpha, Tatopani, Beni, Baglung, Kushma, Syangja, Tanahun, and eventually mixes with the Trishuli River at Devghat and is termed as the Narayani River. The river then flows through Narayanghat, Meghauli and enters India in the south where it is known as the Gandak River. The elevation after entering the territory of Nepal is above 3300 m at Lomanthang and the lowest is about 120 m before entering into India (Fig. 3).

Texture of sands

Grain size

The percent of fines value ranged between 0 and 7, the minimum value is 0.24 which is at KG-11 and the maximum value is 6.30 at KG-12. Although it showed sudden abnormality at KG-12 than from KG-11, the difference in value of fines does not indicate major change in the textural maturity status.

The sorting value shows decreasing trend as the downstream distance increases. The maximum sorting value is 1.38 at KG-5 and minimum at KG-32 which is 0.35. This decrease in sorting value with increase in downstream distance indicates the sorting of sediments are getting improved as poorly sorted at the upstream section to moderately well sorted at mid-section and finally well sorted at the downstream section.

Grain shape

The grain shape analysis is a major analysis method to determine the texture that eventually helps in analyzing maturity status of the sediments. To determine the mean roundness and sphericity of sand grain the individual size fraction from very coarse to fine from all samples collected from the river basin were analyzed. It was again summed to calculate the average value and the class range were assigned accordingly. It resulted that most of the samples fall under sub-angular class except one which is in angular class (KG-28).

The sphericity is of low to medium class, the sphericity at the upstream section is mostly medium. The mid-section and the downstream section are mostly low and are medium in few samples (Table 1).

The average roundness of the tributary samples collected from various distances along the main stream is mostly sub-angular except TKG-3 which is angular. The sphericity is low of samples TKG-1, TKG-2, TKG-3, and TKG-10 and medium of samples TKG-4, TKG-5, TKG-6, TKG-7, TKG-8, and TKG-9 are shown in Table 2.

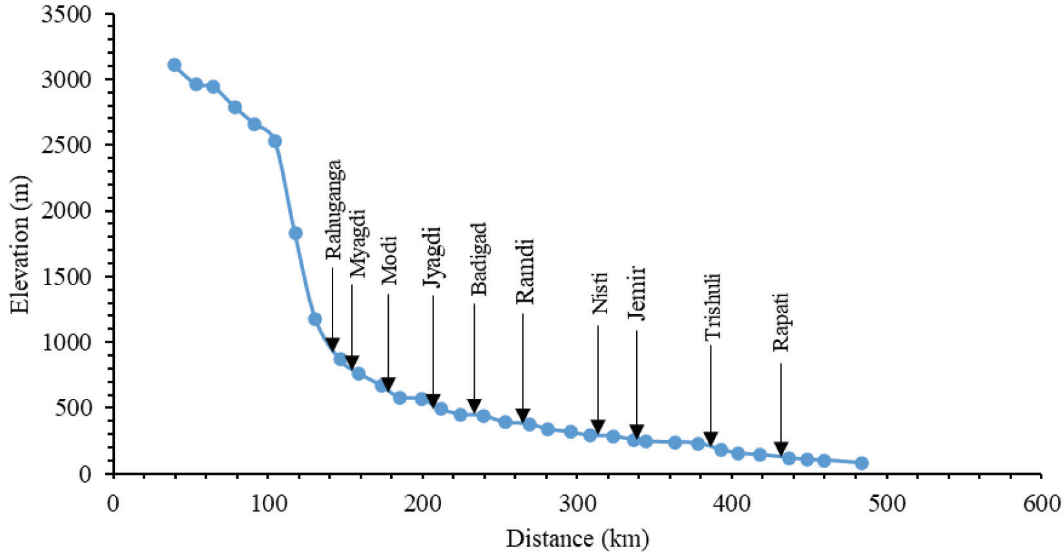

Fig. 3: Longitudinal profile of the Kaligandaki River.

Table 1: Calculation of mean roundness and sphericity of various grain sizes and there average to determine class range.

Sample No.	Mean roundness							Sphericity						
	vf	f	m	c	vc	R avg.	Class	vf	f	m	c	vc	S avg.	Class
KG-1	2.11	2.45	2.49	2.87		2.48	SA	0.77	0.78	0.78	0.80	0.00	0.62	Low
KG-2	2.43	2.60	2.66	2.81	2.49	2.60	SA	0.77	0.79	0.79	0.79	0.78	0.78	Medium
KG-3	1.86	2.22	2.12	2.59	2.63	2.28	SA	0.78	0.80	0.78	0.80	0.81	0.79	Medium
KG-4	2.19	1.98	2.26	2.08	2.14	2.13	SA	0.79	0.78	0.76	0.76	0.74	0.77	Medium
KG-5	2.29	2.39	2.38	2.66	2.58	2.46	SA	0.78	0.79	0.80	0.78	0.80	0.79	Medium
KG-6	2.50	2.53	2.47	2.76	2.72	2.60	SA	0.77	0.80	0.81	0.79	0.81	0.79	Medium
KG-7	2.60	2.74	2.78	3.03	3.03	2.84	SA	0.79	0.79	0.78	0.78	0.79	0.78	Medium
KG-8	2.95	2.77	2.85	2.74	2.69	2.80	SA	0.78	0.77	0.79	0.77	0.78	0.78	Medium
KG-9	2.64	2.49	2.65	2.56	2.47	2.56	SA	0.78	0.78	0.81	0.80	0.79	0.79	Medium
KG-10	2.60	2.43	2.52	2.61		2.54	SA	0.79	0.78	0.80	0.81		0.63	Low
KG-11	2.56	2.46	2.42	2.53		2.49	SA	0.79	0.80	0.77	0.79		0.63	Low
KG-12	2.37	2.48	2.49	2.46	2.25	2.41	SA	0.77	0.79	0.80	0.79	0.77	0.78	Medium
KG-13	2.41	2.33	2.57	2.59	2.52	2.48	SA	0.78	0.80	0.78	0.79	0.77	0.78	Medium
KG-14	2.55	2.71	2.28	2.57		2.53	SA	0.78	0.77	0.78	0.81		0.63	Low
KG-15	2.62	2.60	2.66	2.36		2.56	SA	0.77	0.81	0.81	0.79		0.64	Low
KG-16	2.39	2.68	2.70	2.74	2.45	2.59	SA	0.78	0.78	0.77	0.78	0.77	0.78	Medium
KG-17	2.55	2.21	2.58	2.19		2.38	SA	0.78	0.78	0.80	0.78		0.63	Low
KG-18	2.58	2.68	2.50			2.59	SA	0.77	0.79	0.78			0.47	Low
KG-19	2.19	2.64	2.32	2.59		2.44	SA	0.76	0.79	0.79	0.80		0.63	Low
KG-20	2.62	2.64	2.80			2.69	SA	0.78	0.77	0.79			0.47	Low
KG-21	2.62	2.64	2.17			2.48	SA	0.79	0.78	0.77			0.47	Low
KG-22	2.36	2.20	2.17			2.24	SA	0.75	0.77	0.80			0.46	Low
KG-23	2.26	2.21	2.25			2.24	SA	0.78	0.78	0.79			0.47	Low
KG-24	2.20	2.08	2.14	2.48	2.21	2.22	SA	0.76	0.77	0.79	0.78	0.79	0.78	Medium
KG-25	2.30	2.25	2.29			2.28	SA	0.78	0.77	0.81			0.47	Low
KG-26	2.22	2.23	2.18			2.21	SA	0.76	0.78	0.80			0.47	Low
KG-27	2.21	2.07	2.13	2.22		2.16	SA	0.77	0.78	0.79	0.79		0.63	Low
KG-28	2.06	1.78	2.13			1.99	A	0.80	0.75	0.75			0.46	Low
KG-29	2.22	2.08	2.17	2.24	2.50	2.24	SA	0.78	0.78	0.79	0.76	0.78	0.78	Medium
KG-30	2.21	2.15	2.13	2.22	2.53	2.25	SA	0.77	0.78	0.79	0.80	0.80	0.79	Medium
KG-31	2.09	2.07	2.19	2.23		2.15	SA	0.77	0.78	0.80	0.81		0.63	Low
KG-32	2.31	2.31	2.29			2.30	SA	0.77	0.79	0.79			0.47	Low
KG-33	2.33	2.31	2.18	2.69		2.38	SA	0.79	0.78	0.79	0.81		0.63	Low

Table 2: Mean roundness and sphericity of samples from the tributaries of Gandaki River System.

Sample No.	Mean roundness							Sphericity						
	vf	f	m	c	vc	R avg.	Class	vf	f	m	c	vc	S avg.	Class
TKG-1	2.09	2.10	2.02	2.37		2.15	SA	0.78	0.79	0.78	0.81		0.63	Low
TKG-2	2.11	2.15	2.00			2.09	SA	0.78	0.77	0.78			0.47	Low
TKG-3	2.23	1.59	1.93	2.15		1.98	A	0.77	0.78	0.77	0.77		0.62	Low
TKG-4	2.11	2.36	2.26	2.55	2.50	2.36	SA	0.76	0.78	0.79	0.79	0.80	0.78	Medium
TKG-5	2.37	2.46	2.43	2.39	2.41	2.41	SA	0.75	0.78	0.80	0.76	0.76	0.77	Medium
TKG-6	2.51	2.57	2.60	2.58	2.45	2.54	SA	0.76	0.79	0.79	0.77	0.76	0.77	Medium
TKG-7	2.45	2.29	2.66	2.44	2.44	2.46	SA	0.76	0.78	0.80	0.76	0.78	0.78	Medium
TKG-8	2.45	2.51	2.32	2.45	2.45	2.44	SA	0.78	0.79	0.79	0.79	0.78	0.79	Medium
TKG-9	2.42	2.37	2.46	2.62	2.42	2.46	SA	0.80	0.78	0.80	0.79	0.78	0.79	Medium
TKG-10	2.31	2.11	2.14	2.19		2.19	SA	0.77	0.76	0.76	0.76		0.61	Low

Textural maturity

Textural maturity is a measure of maturity status in texture. The analysis of maturity in the texture of sediments is an important measure as it reflects the mode of sediment transport. It is determined by integrating the values of percent fines, sorting and average roundness. Folk (1980) described that the change in textural properties of sediments during its transport passes sequentially through 4 different stages of textural maturity.

The result presented in Table 3 showed that the samples from the upstream section and mid-section are sub-mature in nature, except the samples of KG-20 and KG-12 are immature. The downstream section samples are mostly mature in maturity status.

Similarly, analyzing the maturity of the tributaries (Table 4), it revealed that all of the samples of them are in sub-mature state.

Table 3: Downstream variation in textural maturity assigned using grain size and shape parameters.

Sample No.	Downstream distance (km)	% fines	Sorting, σ_I		R_{avg}		Textural maturity	
			φ	Class	Value	Class	Class	Value
KG-1	39.43	1.75	0.59	MWS	2.48	SA	SM	1.5
KG-2	53.88	2.57	1.00	MS	2.6	SA	SM	1.5
KG-3	64.86	0.52	0.89	MS	2.2	SA	SM	1.5
KG-4	78.50	0.48	1.07	PS	2.13	SA	SM	1.5
KG-5	91.38	3.25	1.38	PS	2.43	SA	SM	1.5
KG-6	104.54	0.31	1.20	PS	2.57	SA	SM	1.5
KG-7	117.59	1.90	1.23	PS	2.84	SA	SM	1.5
KG-8	130.79	0.47	0.98	MS	2.8	SA	SM	1.5
KG-9	146.60	0.48	0.68	MWS	2.59	SA	SM	1.5
KG-10	158.49	1.09	0.80	MS	2.54	SA	SM	1.5
KG-11	173.46	0.24	0.59	MWS	2.49	SA	SM	1.5
KG-12	184.91	6.30	0.67	MWS	2.45	SA	IM	0.5
KG-13	199.14	1.10	0.76	MS	2.48	SA	SM	1.5
KG-14	212.06	2.46	0.65	MWS	2.53	SA	SM	1.5
KG-15	224.23	2.85	0.60	MWS	2.56	SA	SM	1.5
KG-16	239.12	0.53	0.81	MS	2.59	SA	SM	1.5
KG-17	253.17	0.29	0.50	WS	2.38	SA	SM	1.5
KG-18	269.06	3.39	0.60	MWS	2.58	SA	SM	1.5
KG-19	280.83	3.91	0.68	MWS	2.44	SA	SM	1.5
KG-20	295.70	5.63	0.62	MWS	2.69	SA	IM	0.5
KG-21	308.68	4.03	0.53	MWS	2.48	SA	SM	1.5
KG-22	323.18	2.64	0.40	WS	2.24	SA	M	2.5
KG-23	336.19	0.85	0.37	WS	2.24	SA	M	2.5
KG-24	344.54	1.71	0.58	MWS	2.23	SA	SM	1.5
KG-25	362.92	1.93	0.49	WS	2.28	SA	M	2.5
KG-26	378.00	3.06	0.42	WS	2.2	SA	M	2.5
KG-27	393.06	1.30	0.43	WS	2.16	SA	M	2.5
KG-28	404.07	0.65	0.48	WS	1.99	A	M	2.5
KG-29	418.34	0.95	0.54	MWS	2.18	SA	SM	1.5
KG-30	436.92	0.43	0.51	MWS	2.25	SA	SM	1.5
KG-31	448.52	0.85	0.49	WS	2.15	SA	M	2.5
KG-32	459.74	0.74	0.35	WS	2.3	SA	M	2.5
KG-33	483.86	0.37	0.47	WS	2.38	SA	M	2.5

For textural maturity status; IM = immature (range value between 0-1), SM = sub-mature (range value between 1-2), M = mature (range value between 2-3)

For roundness; A= angular, SA= sub-angular,

For sorting; PS= poorly sorted, MS= moderately sorted, MWS= moderately well sorted, WS= well sorted

Textural inversion

The sudden change in the textural maturity status of sediments caused by factors such as sediment influx by contributing tributaries, change in rock type, hydraulic factors, topographic variations, geology, and climate is termed as textural inversion. There can be a single factor or multiple factors responsible in changing the maturity status of the sediments. In order to determine the responsible factors in changing the maturity status of the sediments Folk (1980) have categorized 6 different type of textural inversions.

Textural inversion type 1, 2, 6: The inversion of type 1 the measure of percent fines or in clay matrix containing rounded grains, type 2 is the measure of roundness in poorly sorted sediments, type 6 is the relation between roundness, sorting in clay matrix. The well sorted sediments with absence in rounded grains in clay matrix are textural inversion falling under type 6 (Fig. 4).

After analyzing the samples from the main stream it resulted that percent fines range from 0 to 5% throughout the river except two samples (KG-12 and KG-20) whose value are slightly above 5%. Since maturity can be determined by the availability of percent fines however, there is no distinct variation throughout the river course, thus it is difficult to define the maturity status of the river.

Mean roundness lies between 2 to 3ρ which means they are mostly sub-angular. The roundness after 100 km distance tends to decrease slightly even though it lies on sub-angular category. Downstream variation does not reflect change in roundness

Table 4: Textural maturity status of the major contributing tributaries of the Gandaki Basin.

Sample No.	Tributaries	%fines	Sorting, σ_I		Average roundness		Textural maturity	
			φ	Class	Value	Class	Class	Value
TKG-1	Modi	0.12	0.58	MWS	1.93	SA	SM	1.5
TKG-2	Myagdi	0.06	0.51	MWS	2.09	SA	SM	1.5
TKG-3	Raghuganga	1.43	0.73	MS	1.98	A	SM	1.5
TKG-4	Rapti	0.44	0.87	MS	2.36	SA	SM	1.5
TKG-5	Jemir	1.06	0.71	MS	2.5	SA	SM	1.5
TKG-6	Badigad	0.18	1.06	PS	2.54	SA	SM	1.5
TKG-7	Nisti	0.24	1.36	PS	2.46	SA	SM	1.5
TKG-8	Ramdi	0.15	1.13	PS	2.44	SA	SM	1.5
TKG-9	Jyagdi	0.99	1.27	PS	2.39	SA	SM	1.5
TKG-10	Trishuli	1.89	0.66	MWS	2.19	SA	SM	1.5

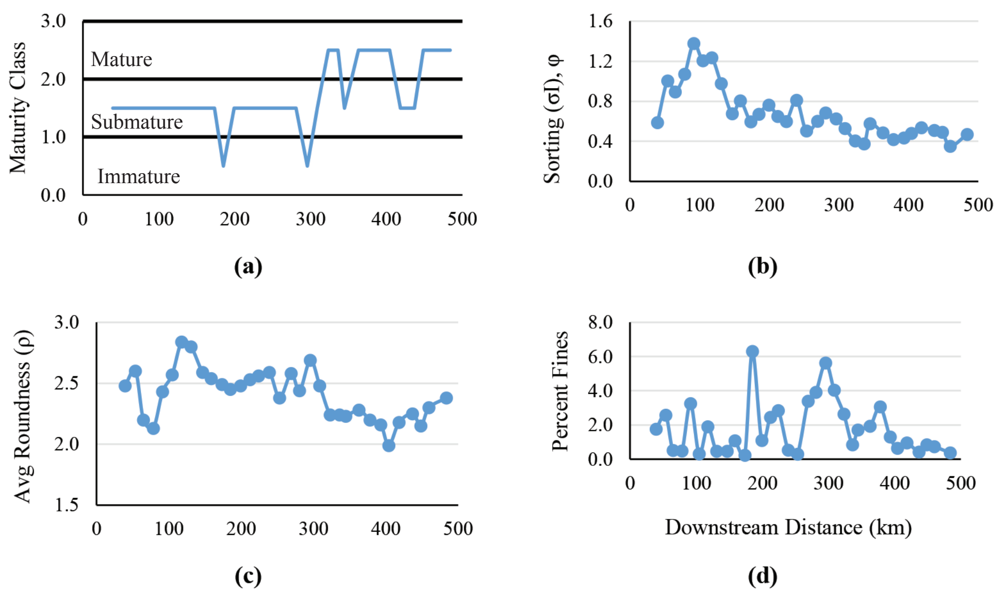

Fig. 4: Graphical plot downstream distance vs (a) maturity class, (b) sorting, (c) average roundness, (d) percent fines.

category. There occurs slight diminish of roundness value with distance downstream.

Inclusive standard deviation (sorting) varies from 0.30φ to 1.38φ. After 100 km downstream the value tends to diminishes showing improvement in sorting trend downstream.

Textural maturity varies between immature to mature. The upstream sediments are sub-mature, the midsection also are sub-mature with some immature at some places. The maturity seems slightly improved at the downstream sections where they are sub-mature to mature in nature. After analyzing the result the improvement in maturity is due to improvement in sorting (Fig. 4). The analysis in the downstream variation of percent fines, roundness and inclusive standard deviation textural inversion of type 1, 2 and 6 could not be seen.

Textural inversion type 3: The relation of grain size with its roundness gives the indication for type 3 textural inversion (Fig. 5). A graphical representation using graph plot between variation of roundness with downstream distance (Fig. 5) and graph between roundness and various size grade from the samples of main stream were plotted to analyze the presence of type 3 inversion.

The analysis showed that although there is small variation in roundness it fluctuates only within the sub-angular category. There is no significant variation in the roundness in any size grades of the samples throughout the river course. Thus it does not indicate there is presence of type 3 inversion throughout the river course.

Textural inversion type 4: Grain size grade vs percentage roundness categories distribution of samples were analyzed for type 4 inversion using bar diagram. While analyzing 9 samples showed type 4 inversion. Those samples are KG-1, KG-2, KG-5, KG-9, KG-12, KG-13, KG-14, KG-16 and KG-20. In those samples textural inversion is observed in size grade very fine in 5 samples, medium in 3 samples and fine in 2 samples.

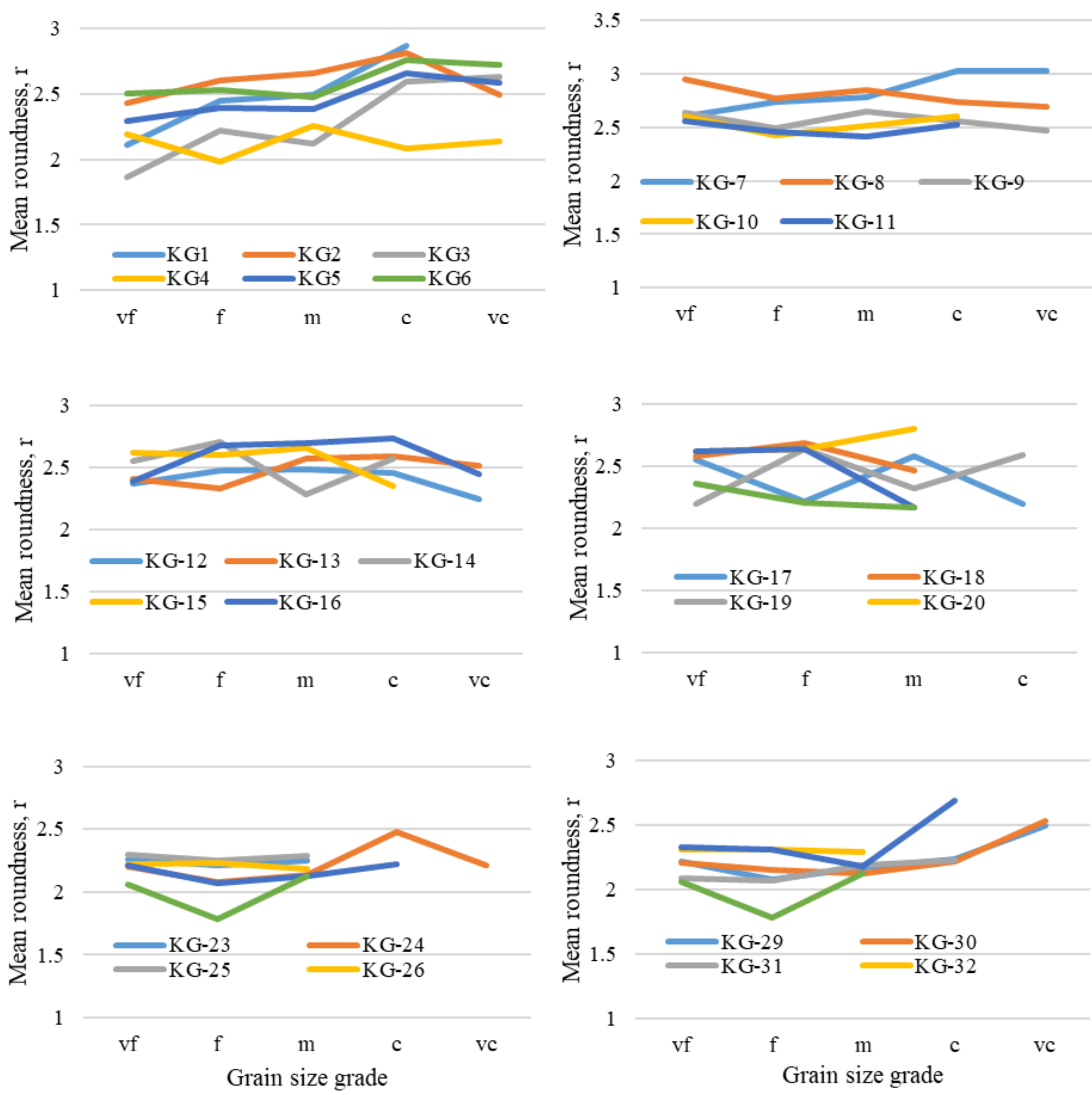

Fig. 5: Graph plot of mean roundness vs grain size grade.

Hence textural inversion is dominant in VF size grade of sand samples. In all those size grades textural inversion is caused by bimodal distribution of size grade with SR and A modes.

Textural inversion type 5: This type of inversion can be processed graphically by histogram plot between weight percentages of various size grades. The presence of bimodal nature in weight percentage of different size grade exhibits type 5 of textural inversion.

The graphical plot for analyzing type 5 inversion resulted there is no any bimodal nature in any samples of the main stream indicating absence of type 5 inversion.

DISCUSSION

Size parameters

The percent fines (mud) ranges from 0.24 to 6.30% and shows no distinct downstream variation trend. The result indicated that coarsely skewed and platy to mesokurtic sands become nearly symmetrical to finely skewed and leptokurtic suggesting increase in fine-grained sands and enhancement of sorting with distance downstream (Table 3). Although there is increase in fines in downstream distance along the Kaligandaki River, there is small increment in mean and median grain size.

The study of sands from the Budhi Gandaki River (Maharjan and Tamrakar, 2019) showed the size of sands ranged from gravelly sand in the upstream to fine sand in the downstream regions. Likewise, Tamrakar and Gurmaita (2001) studied textural and compositional variation of sand along the Manahara-Bagmati River Basin and found that the mean and median grain sizes of sand decrease with improvement in sorting.

Shape parameters

The shape of various size grade were analyzed to calculate the average shape of the samples (Table 1). The roundness of sub-angular class and low to medium sphericity is dominant in the river basin suggesting uniform mode of sediment transport with less influence of the major tributaries.

The downstream reaches also possess sub-angular sediments with low sphericity, it suggests mixing of sediments from small low order feeder tributaries and breaking of individual sediment particles due course of its transportation.

Textural maturity

Textural maturity varies between immature to mature (Table 3). The upstream sediments are sub-mature, the midsection also are sub-mature with some immature at some places.

The sub-mature nature of sediments at the upstream source regions can possibly be due to reworking of sediments deposited in earlier terraces. The maturity seems slightly improved at the downstream sections where they are sub-mature to mature in nature. After analyzing the result the improvement in maturity is due to improvement in sorting. There is no significant role of the tributaries in changing the maturity status, the immature status at the mid-section can be the cause of mixing of fines locally derived by mass wasting. Tamrakar (2009) studied the sediments of the Bishnumati River and found texturally immature sediments. The downstream stretches consisted mostly sedimentary rocks fragments rather than the fragments of source rock comprising of granite and gneiss rock.

As there is no distinct change in maturity status with respect to texture of sediment grain throughout the river profile with some minor changes at few places it suggests that the river is less impacted by other natural and anthropogenic factors. The textural maturity status of the Bishnumati River (Maharjan and Tamrakar, 2020) showed sub-mature characteristics with few textural inversion along the downstream course. Tamrakar and Gurmaita (2001) found that the local influx and reworking of sediments along different section of the Manahara-Bagmati River has contributed greatly for textural inversion.

CONCLUSION

After analyzing the results the improvement in maturity is due to improvement in sorting. There is no any distinct factors that has played an important part in inversing the textural maturity status of the Gandaki Basin within Nepal. There is no significant role of the tributaries in changing the maturity status, the immature status at the mid-section can be the cause of mixing of fines locally derived by mass wasting.

ACKNOWLEDGEMENT

This research is financially supported by Nepal Academy of Science and Technology (NAST). Also, we would like to thank Central Department of Geology for providing necessary services and facilities.

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