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Texture and major element geochemistry of channel sediments in the Orsang and Hiren River Basins, Gujarat, India: Implications for provenance and weathering

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ABSTRACT

Size, shape, degree of sorting, and composition of sediments in the river channels are controlled by climate, lithology, weathering, sorting, and medium of transportation. The present investigation is focused on the grain-size and geochemical analysis of the channel sediments of the Orsang and Hiren river basins. Major outcrops in the study area are Archaean granites, granitic gneisses, Upper Cretaceous to lower Eocene Deccan Volcanic Basalts (DVB), Quaternary sediments and minor proportion of Proterozoic low grade metamorphic rocks. The sediments are poorly to moderately sorted, very finely skewed, suggesting its derivation from heterogenous sources, while the kurtosis value indicates a high-energy depositional environment. The sediments are with gravelly sand texture and the mean grain size is varying from 581.9µm to 1284.2µm. The DVB provenance of the Hiren river basin and granitic provenance of the Orsang river basin is clearly reflected in the texture and geochemical composition of sediments. The TiO_2 and Fe_2O_3 contents of sediments from the Hiren river basin are distinctly higher and are comparable to the basalts of the Saurashtra region of the Deccan Province. Sediments collected after Orsang and Hiren rivers confluence and from Narmada river show higher concentration of felsic sources, indicating that Orsang river's sediment supply significantly outweighs Hiren rivers. The arkosic-litharenite nature points towards less transportation and moderate chemical weathering for the Orsang river sediments. The low Chemical Index of Alteration (CIA) values (Avg. 48.45 and 56.99 for Orsang and Hiren rivers, respectively) and A-CN-K plot also suggest the supply of sediments from minimally weathered detritus under a semi-arid condition.

Keywords: Sediments, Grain Size, Orsang River, Provenance, Transportation, Weathering

INTRODUCTION

River sediments are unconsolidated fragments of pre-existing rocks that have undergone both mechanical and chemical weathering. Both weathering and erosion contribute to the degradation of the rocks, but this degradation has different impact on different types of rocks (Joshua and Oyebanjo, 2010). The size and shape of sand grains in the river provide ideal information about transportation media (Bui et al., 1989); they also provide clues on sediment discharge rates and the environment during deposition of sediments (Gray and Simões, 2008; Williams, 2012). The distribution of sand grains is largely influenced by three key processes: sediment movement, sediment aggregation, and depositional mechanism (Wai et al., 2004). Sediment textures and geochemistry have been extensively used to extract information on provenance, weathering conditions, tectonics, fluvial processes, and paleoclimate conditions (Nesbitt and Young, 1982; Bhatia, 1983; McLennan et al., 1983; Taylor and McLennan, 1985; Wronkiewicz and Condie, 1987; Cullers et al., 1988; Fedo et al., 1995; Sharma et al., 2013). In this context, grain-size data provide clues to sediment provenance, transport history, depositional conditions, and classifying sedimentary facies and environments, which are largely controlled by the nature of the source rock and the transport agent (e.g., Folk and Ward, 1957; Friedman, 1979; Singh and Rajamani, 2001; Bernabeu et al., 2002; Guti errez-Mas et al., 2003; Benavente et al., 2005; Garzanti et al., 2011) while geochemical characteristics reveal the provenance, nature and degree of weathering at the source region of sediments, which is controlled by lithology, climate, and tectonics (Taylor and McLennan, 1985; Singh, 2009; Mondal et al., 2012; Hernández-Hinojosa et al., 2018). In addition, reworking also affects the chemical composition of sediments (McLennan, 1982; Cox and Lowe, 1995). Several authors have investigated the fluvial sediments of Indian rivers to understand the source and process controls on the geochemistry of sediments (Jain and Tandon, 2003; Juyal et al., 2006; Sanyal and Sinha, 2010; Garçon and Chauvel, 2014; Maharana et al., 2018). However, textural and geochemical studies on the fluvial sediments from Orsang and Hiren river basins, which are part of west-flowing river system, are yet to be studied. Additionally, distinctly different spatio-temporal geologic domains are traversed by Orsang and Hiren rivers, making them strongly suitable for understanding provenance control. The data generated in the present study will help to unravel the effect of weathering, provenance and variations in the textural and geochemical characteristics of sediments.

STUDY AREA

The Orsang river is one of the major tributaries of the Narmada river, which covers 4000 km^2 and has a total channel length of 135 km. It spreads over a geographical area extending from approximately 73°26'24" E to 74°20'24" E longitudes and 21°57'36" N to 22°35'24" N latitudes (Fig. 1). The Orsang river originates in the Aravalli Mountain ranges of Madhya Pradesh's Jhabua district and travels for about 20 kilometres in a south-westerly direction over the wide alluvial plain before joining the Narmada river in Chandod, Gujarat. The south-flowing Bharaj river enters the Orsang river near Jetpur Pavi, and the southwest-flowing Hiren river joins further downstream at Chhota Udepur. The Kevdi-Kundal mountainous topography serves as the main water divide, separating the two distinct drainage zones. The general climatic condition of the study area is a moderate subtropical monsoonal climate very similar to other north-western peninsular river basins (Maharana et al. 2018). The Orsang river flows through deformed metamorphic and igneous rocks including granite, gneiss, quartzite, schist, limestone, phyllite, meta-subgreywacke and slate; while Hiren flows through predominantly basaltic terrain with few carbonatite patches (Merh, 1995; Chamyal et al., 2011; Shah et al., 2021). The stratigraphy of the study area ranges from the Archean to the Recent, with a gap of Palaeozoic rocks as in most of India. The northern and north-eastern regions of the basins expose the granitic and gneissic rocks of the Archean basement and the Proterozoic rocks (Champaner group). In the southeast region, the basement is covered by post-Cretaceous sediments and significant volcanic rocks (Fig. 2). The post-Cretaceous Intratrappean and Infratrappean sediments are exposed as scattered inliers, whereas younger volcanic rocks from the Deccan Traps and few Tertiary and Quaternary lithologies are well represented (Merh, 1995; Chamyal et al., 2011).

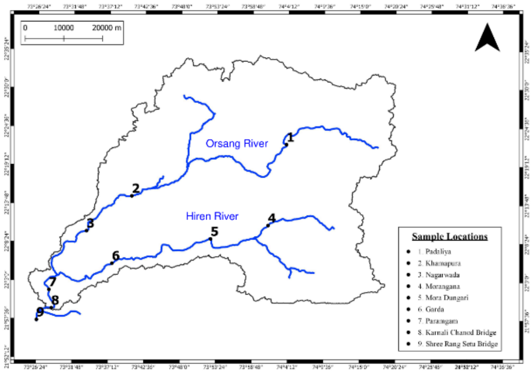

Figure 1. Basin Map of the Orsang and Hiren rivers.

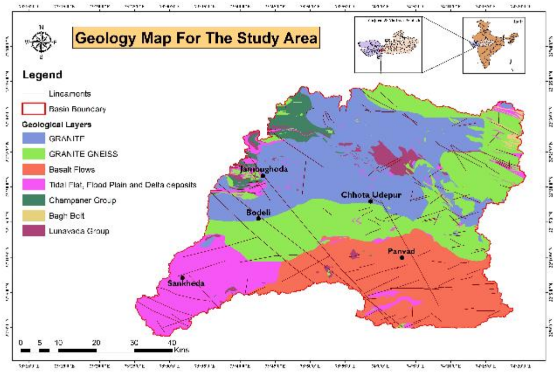

Figure 2. Geological map of the Orsang and Hiren river basins showing various lithological units. This map is extracted from Geological Society of India base map.

SAMPLING AND ANALYTICAL METHODS

For the study of the textural analysis and geochemistry, nine unconsolidated sediment samples were collected, i.e. three samples were collected from the Orsang and the Hiren river channels, two samples were collected after the confluence of the Orsang and Hiren rivers, and one sample was collected from the Narmada river. The sample locations were considered by i) the length of the river, ii) equal spacing of sampling site and iii) the geology of the basin. The location details are given in Table 1. One sample was taken from the Narmada river after the confluence of the Orsang river into the Narmada river. Such sites have been very important for the sample collection, especially for the geochemical study. The samples were collected after few inches of sediments in the surface layer was removed to prevent any contamination. Nearly 2 kg of sample was collected in a polythene bag and was dried under sunlight. After the removal of moisture from the samples, they were processed for sieve analysis and geochemistry. Before grain size analysis, the samples were treated with cold HCl and H_2O_2 to remove carbonates and organics, and then the grain size fractions were measured by dry sieving. The British Standard Sieve Analysis Method was adapted for the present work. For sieve analysis, a representative size of 300 gm from the collected samples was obtained by the coning and quartering method. Sieve analysis is carried out using the eight ASTM sieves, including 4750, 2000, 1000, 600, 300, 212, 150, 75 microns, and a pan. Sediments finer than 75 microns are collected into the pan, and 43 microns are assigned to them for processing the data through GRADISTAT program. The grain size data generated after sieving is listed in Table 2. The obtained data is processed in the GRADISTAT programme developed by Blott and Pye (2001). To measure the Mean, Sorting, Skewness and Kurtosis the Arithmetic method is

Table 1. Location details, sample type, textural group and sediment name for channel sediments from study area

Sample number	River name	Locations	Latitude (N)	Longitude (E)	Sample Type	Textural Group	Sediment Name
1	Orsang River	Padaliya	22°22'15"	74°3'56"	Unimodal, Poorly Sorted	Gravelly Sand	Very Fine Gravelly Coarse Sand
2		Khammapura	22°14'53.0"	73°40'38.0"	Bimodal, Poorly Sorted	Gravelly Sand	Very Fine Gravelly Coarse Sand
3		Nagarwada	22°09'57"	73°33'54"	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Fine Gravelly Coarse Sand
4	Hiren River	Morangana	22°10'59"	74°1'18"	Bimodal, Poorly Sorted	Gravelly Sand	Fine Gravelly Coarse Sand
5		Moradungari	22°8'54"	73°52'30"	Unimodal, Moderately Sorted	Gravelly Sand	Very Fine Gravelly Coarse Sand
6		Garda	22°5'55"	73°37'41"	Unimodal, Poorly Sorted	Gravelly Sand	Fine Gravelly Coarse Sand
7	Orsang River (after confluence of above two basins)	Paramgam	22°01'42"	73°28'23"	Unimodal, Poorly Sorted	Gravelly Sand	Very Fine Gravelly Coarse Sand
8		Karnal Chanod Bridge	21°59'10"	73°28'40"	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Coarse Sand
9	Narmada River	Seturam Bridge	21°57'27"	73°26'17"	Unimodal, Moderately Well Sorted	Gravelly Sand	Fine Gravelly Coarse Sand

Table 2: Basin wise grain size data generated after sieving of 300 gm sediment sample.

	Orsang River basin			Hiren River basin			Orsang River (After confluence)		Narmada River
Sample No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Location	Padaliya	Khammapura	Nagarwada	Morangana	Moradungari	Garda	Paramgam	Karnali Chanod Bridge	Seturam Bridge
Aperture (microns)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)	Sediments Retained (g)
4750	7.9	14.1	4.35	35.0	14.6	13.8	28.2	-	8.38
2000	16.1	23.7	6.29	44.3	25.4	17.04	50.8	0.61	10.9
1000	72.9	75.3	27.03	55.5	83.5	38.5	86.2	8.31	32.3
600	131.6	112.2	125.8	63.6	141.5	114.2	84.1	116.9	215.3
300	42.6	37.18	102.5	44.3	21.3	79.8	22.9	118.7	28.8
212	18.8	20.51	26.2	37.5	6.16	26.6	10.2	42.4	1.17
150	4.11	7.7	1.8	8.6	1.47	4.72	4.61	5.87	0.1
75	4.11	5.34	3.03	7.16	3.36	3.16	8.15	4.5	0.84
43 (Pan)	0.71	3.14	2.13	3.11	2.35	1.65	3.02	1.63	0.63

adopted. Major elements were determined from bulk sediment samples by using an ElvaX Plus X-Ray Fluorescence (EDXRF) Spectrometer using pressed pellets. Pressed pellets were prepared by using collapsible aluminium cups. These cups were filled with boric acid and a few grams of the finely powdered sample and then pressed under a hydraulic press. For all elements, laboratory precision is better than 5%.

RESULTS

SEDIMENT TEXTURAL CHARACTERISTICS

In sedimentology, geomorphology, soil sciences, and sediment textural study involves estimation of the cumulative mass percentage of established size fractions of the total mass of sediment. There are different techniques that have been adopted to study the size distribution and textural characteristics of sediments, because of the shape and density variations of sediments, which include sieving, pipette hydrometers, X-ray attenuation, scanning electron microscopy, and laser diffraction. The mean value is the diameter, which represents the central gravity for the normal distribution of the frequency distribution (Inman, 1952). The second statistical property of grain size analysis is the sorting of grains. It has been studied using the dispersion of the sediment size. Skewness is the third statistical parameter, which measures the degree of asymmetry in the distribution. Kurtosis is a parameter that is used to measure the peakedness of the statistical distribution. Both skewness and kurtosis parameters are helpful for identifying the origin of sediments or sedimentary environments (Ruiz-Martínez et al., 2016). For the present study, the arithmetic method has been undertaken, and the obtained results are shown in Table 3.

The channel sediments of the Orsang river basin mainly consist of sand (72.5–99.3 %) and gravel (0.2–26.5 %), with a very low percentage of mud (0.2–1 %). The histograms for sediments peak around 600 microns in size. The Orsang river sediments are coarser than the sediments of the Himalayan rivers, corroborating the observations of Singh et al. (2007). In the Gravel-Sand-Mud diagram (Folk 1954), the sediments from the Orsang river basin mostly demonstrate gravelly sand texture (Fig. 3). Based on arithmetic method, average mean value of nine samples is 946.6 µm, sorting value is 734.5, Skewness measure is 1.98 and Kurtosis is 8.99. The lowest mean value is observed at Karnal Chanod site with 581.9 µm and highest is from Paramgam (1284 µm). The lowest sorting value is 296.6 obtained from the Karnal Chanod and highest is from Morangana (1079.6). The skewness lowest value is from Paramgam (0.953) and highest is from Seturam (3.002). The kurtosis lowest value is 2.84 from Paramgam and highest is from Karnal Chanod (19.15). The mean grain size values for all locations are listed in Table 3.

Table 3. Location wise textural parameters obtained by Arithmetic method

Sample number	River name	Locations	Arithmetic (Mm)			
			Mean (µm)	Sorting	Skewness	Kurtosis
1	Orsang River	Padaliya	984.7	713.9	1.9	7.1
2		Khammapura	1025.6	829.6	1.6	5.4
3		Nagarwada	722.1	515.0	3.0	15.4
4	Hiren River	Morangana	1055	1079.6	1.2	3.4
5		Moradungari	1121.8	808.4	1.6	5.5
6		Garda	836.9	735.9	2.3	8.3
7	Orsang River (after confluence of above two basins)	Paramgam	1284.2	1068.7	0.95	2.8
8		Karnal Chanod Bridge	581.9	296.6	2.32	19.2
9	Narmada River	Seturam Bridge	907.4	562.7	3.00	13.87

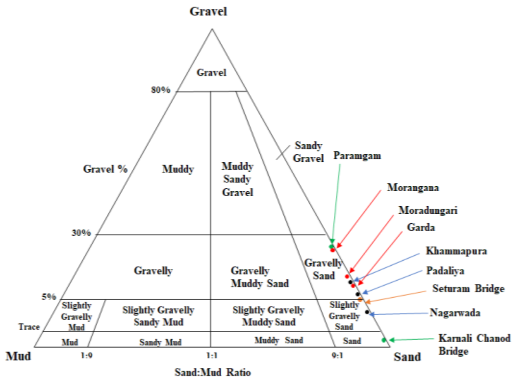

Figure 3. The Gravel-Sand-Mud ternary plot (after Folk, 1954) for Orsang and Hiren river basin sediments. Most of the channel sediments are plotted in the gravelly sand field.

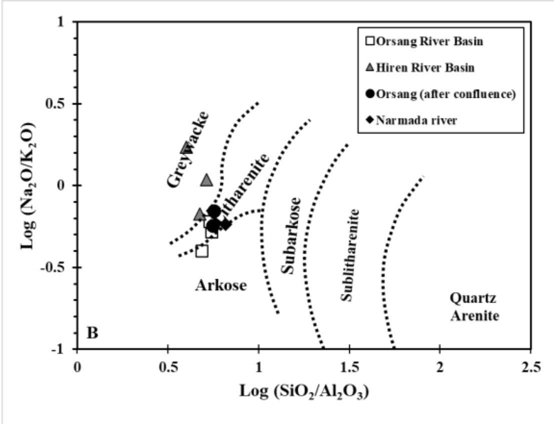

Figure 4. Log (Na_2O/K_2O) vs. log (SiO_2/Al_2O_3) classification plot (Pettijohn et al., 1972).

GEOCHEMISTRY

The geochemical characteristics of river sediments are an essential tool to understand diverse geological processes like the mobility of elements, paleoenvironmental conditions, degree of weathering, and diagenetic changes operating in any particular basin (Taylor and McLennan, 1985; Condie et al., 1992; Singh, 2009; Ramos-Vázquez and Armstrong-Altrin, 2021; Nayak and Singh, 2022). The major-element analyses of sandy channel sediments in the Orsang river basin are listed in Table 4. In the Log (Na_2O/K_2O) vs. Log (SiO_2/Al_2O_3) bivariate plot (Fig. 4; after Pettijohn et al., 1972), the sediments from the Orsang river basin are plotted in the arkose and litharenite fields, while Hiren river samples plotted in the greywacke field. The channel sediments show significant variations in their bulk chemistry, exhibiting the control of diverse sedimentological factors (Fig. 5). SiO_2 content of the samples ranges between 53.16 and 71.28 wt.%, and TiO_2 and Al_2O_3 concentrations vary between 0.2 and 2.2 wt.% and 9.41 and 14.23 wt.%, respectively. The CaO content varies from 3.43 to 18.4 wt.%, while the Fe_2O_3 content ranges from 1.07 to 10.44 wt.%. The TiO_2 and Fe_2O_3 values of sediments from the Hiren river basin are distinctly higher and are comparable to the basalts of the Saurashtra region of DVP (average: 2.23 wt.% and 11.53 wt.%; Laxman et al., 2022).

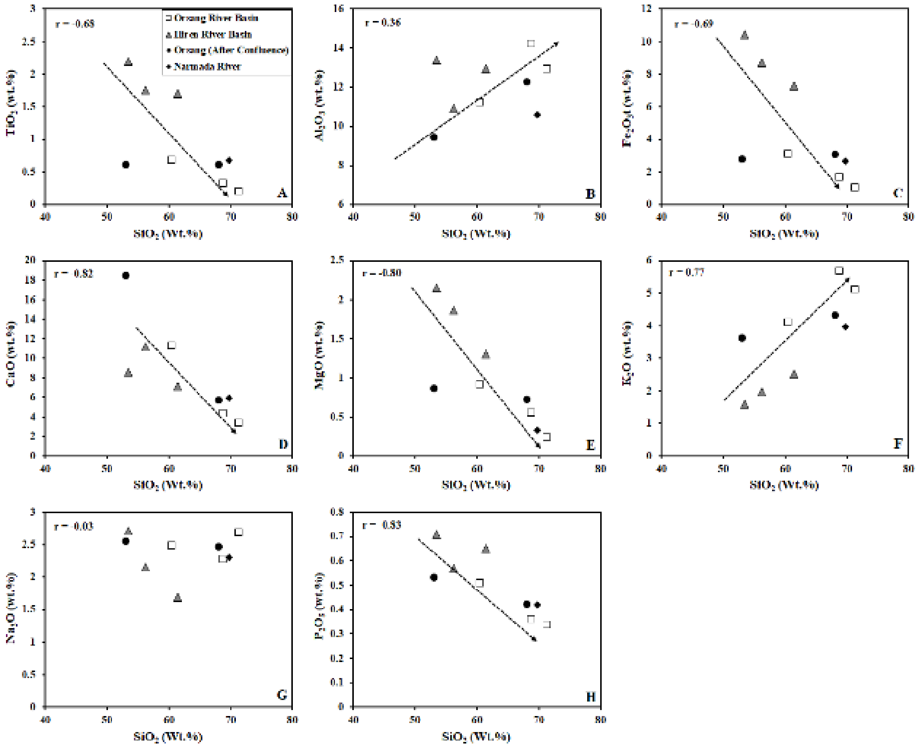

Figure 5. Harker variation plots of major oxides (wt. %) for channel sediments of the Orsang and Hiren river basins

The MgO values are also higher than the other parts of the Orsang river basin; the high TiO_2, Fe_2O_3, and MgO contents can be attributed to basaltic provenance. The Orsang river basin sediments have lower concentrations of MgO and P_2O_5, ranges from 1.2 to 7.4 wt. % and 0.24 to 0.15 wt. %, respectively. The low concentrations of MgO can be attributed to intermediate to felsic provenance. The K_2O (1.58–5.69 wt. %) of the study area is higher than the Na_2O

Table 4. Major element data (in wt.%) of the Hiren, Orsang and Narmada river channel sediments.

	Orsang River			Hiren River			Orsang River (after confluence)		Narmada River
	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9
Major Oxides	Padaliya	Khamapura	Nagarwada	Morangan	Moradungari	Garda	Paramgam	Karnali Chanod Bridge	Sree Rang Setu Ram Bridge
SiO_2	71.3	68.8	60.4	61.4	53.4	56.2	53.2	68.1	69.7
Al_2O_3	12.9	14.2	11.2	12.9	13.4	10.9	9.4	12.2	10.6
Fe_2O_3	1.1	1.7	3.1	7.3	10.4	8.7	2.7	3.0	2.7
TiO_2	0.2	0.3	0.7	1.7	2.2	1.8	0.6	0.6	0.7
CaO	3.4	4.4	11.3	7.1	8.6	11.2	18.4	5.6	5.9
Na_2O	2.7	2.3	2.5	1.7	2.7	2.2	2.5	2.5	2.3
K_2O	5.1	5.7	4.1	2.5	1.6	2.0	3.6	4.3	4.0
MgO	0.2	0.6	0.9	1.3	2.2	1.9	0.9	0.7	0.3
P_2O_5	0.3	0.4	0.5	0.7	0.7	0.6	0.5	0.4	0.4
LOI	2.1	1.2	4.9	2.8	4.3	4.1	7.4	1.5	2.9
Total	99.4	99.5	99.7	99.4	99.5	99.4	99.2	99.0	99.5

content (1.69–2.71 wt. %). The SiO_2 has a positive correlation with Al_2O_3 and K_2O (r = 0.36 and 0.77 respectively). However, the SiO_2 content of the Orsang river sediments shows negative correlations with TiO_2, Fe_2O_3, CaO, MgO, and P_2O_5 (Fig. 5). The strong negative correlation of SiO_2 with CaO (r = -0.83) suggests the mobility of CaO. The samples taken after the confluence of Orsang and Hiren rivers and sample from Narmada river plot in line with the Orsang river sediments suggesting the higher contribution of sediments from the Orsang river than the Hiren river (Fig. 5).

DISCUSSION

GRAIN SIZE ANALYSIS

The grain size analysis of sediments from the Orsang and Hiren River channels has been carried out by using the GRADISTAT program (Blott and Pye, 2001). The Arithmetic method has been utilized for present work, because it is a most reliable and suitable method for fluvial environment. The results are reported in Table 3. The sorting values show that sediments are poorly to moderately sorted and are very-fine skewed. The moderately well-sorted sediments suggest low and reasonably high energy current (Friedman, 1962; Blott and Pye, 2001). These values show that the sediments derived from the river channel are transported from various sources (Layade et al., 2019). The kurtosis lowest value shows very leptokurtic to extremely leptokurtic nature. These values suggest the high energy depositional environment (Friedman, 1962) and also implies that the central portions are better sorted at the tails and suggests that the samples are located at the water concentrated zone (Layade et al., 2019).

SOURCE ROCK CONTROL ON GRAIN SIZE

Source lithology, along with weathering and erosion processes, will have a significant impact on the sediment grain size produced in any particular region. For example, weathering of granite characteristically produces sand-sized quartz and feldspar grains, referring to the original mineral size of the source rock granite and clay minerals like kaolinite, smectite and illite (Banfield 1985; Pettijohn et al., 1987). The clays are generally formed due to the weathering of feldspars. In comparison, weathering of basalt produces much of the clay mineral varieties and lithic fragments, and very little sand-sized mineral grains (Pettijohn et al., 1987). To assess the provenance control on the grain size of river sediments, we selected samples that were contributed exclusively from granitic and basaltic sources. The Padaliya location sample from

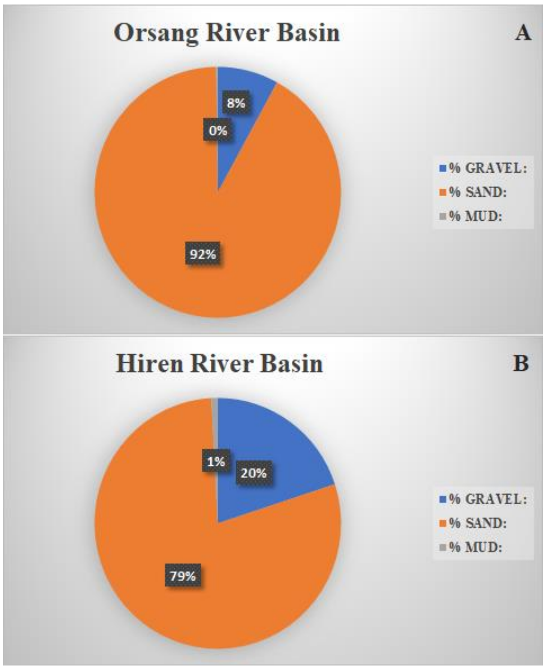

Figure 6. Distribution of Gravel, Sand, and Mud Percentages of Orsang (**A**) and Hiren (**B**) River Basins. The higher proportion of sand in the Orsang river sub-basin compared to the Hiren River sub-basin can be attributed to granitic and basaltic provenances, respectively

the Orsang river represents sediments derived from granitic rocks, while samples collected at Morangana and Moradungari locations from the Hiren river represent sediments derived from basaltic rocks. The granitic sample has 8% gravel and 92% sand while the sediment samples derived from basaltic rocks has 20% gravel, 79% sand, and 1% mud (Fig. 6). A higher proportion of sand in the Orsang river and a higher proportion of gravel and clay in the Hiren river samples can be attributed to granitic and basaltic provenances, respectively.

WEATHERING

The sorting of mineral grains and the degree of both chemical and physical weathering that sediments have undergone can be evaluated by the chemical composition of clastic sediments (McLennan, 1989; Cox and Lowe, 1996; Roddaz et al., 2006; Ramírez-Montoya et al., 2022; Ramos-Vázquez et al., 2022). To determine the impact of weathering and transport, the chemical index of alteration (CIA) values are calculated and are plotted in the Al_2O_3-(CaO+ Na_2O)-K_2O (A-CN-K; Fig. 7A) diagram (CIA: Nesbitt and Young, 1989). The CIA values indicate the intensity of chemical weathering and can be calculated by a formula [Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_2O)×100] in molecular proportions, where CaO is from the silicate fraction only. The CIA values of 50 to 60 suggest low weathering, 60 to 80 suggest moderate weathering, 80 to 100 suggest intense weathering, and un weathered rocks have CIA values of 50 or less than 50 (McLennan, 2001; Teng et al., 2004). The CIA values of Orsang river sediments range between 47.04 and 51.02, with an average of 48.45 suggesting incipient to moderate weathering in the semi-arid Orsang catchment, while Hiren river values are slightly higher than Orsang ranging from 54.23 to 60.97 with an average of 56.99, suggesting moderate weathering. The A-CN-K plot is extensively used to interpret CIA values, possible mineral phases, the weathering trend of the source rocks, and k-metasomatism (Nesbitt and Young, 1984). The un-weathered samples plot close to the Plagioclase-K feldspar join and the less weathered materials plot above the join line. In the A-CN-K plot (Fig. 7a), all the samples from the Orsang river basin plot close to the Plagioclase-k feldspar join, suggesting incipient to moderate chemical weathering under the semi-arid sub-tropical climatic conditions during deposition. The A-CN-K plot alone cannot adequately explain the impact of mafic minerals (olivine, pyroxene, biotite, and hornblende) on sediment chemistry. In order to comprehend how mafic components, impact sediment geochemistry, we also plotted the A-CNK-FM plot, which includes the molar fraction of Al_2O_3, CaO^* + Na_2O + K_2O and FeO + MgO (Nesbitt and Young, 1984). In the A-CNK-FM plot (Fig. 7B), the channel sediments of the Orsang river are plotted near the feldspar-FM join, whereas the Hiren river sub-basin is plotted around the smectite field more towards the FM apex. This implies that the channel sediments of the Hiren river sediments comprise a considerable number of mafic components supplied from Deccan basalts. The samples taken from after the confluence of Orsang and Hiren rivers and from Narmada river are suggesting felsic provenance, which points towards the higher contribution of sediments from Orsang river than the Hiren river (Fig. 7A and 7B).

Since the Deccan mafic rocks (tholeiite basalt) have contributed significantly to the Hiren sub-basin, another chemical index termed the Mafic Index of Alteration (MIA) has been used (Babechuk et al., 2014). The MIA is comparable to the A-CNK-FM plot (Nesbitt and Young, 1982, 1989), but the MIA has two forms that apply in oxidizing MIA (O) and reducing MIA (R) environments. Under oxidizing conditions, Fe (particularly Fe^{3+}) remains immobile and acts like Al, while in a reducing environment, Fe becomes mobile as Fe^{2+} moves out of the system. When applying the MIA to the Orsang and Hiren river samples, we inferred that in the A-CNKM-F diagram (Fig. 8A), the samples plot close and parallel to the A-CNKM line. The samples plot

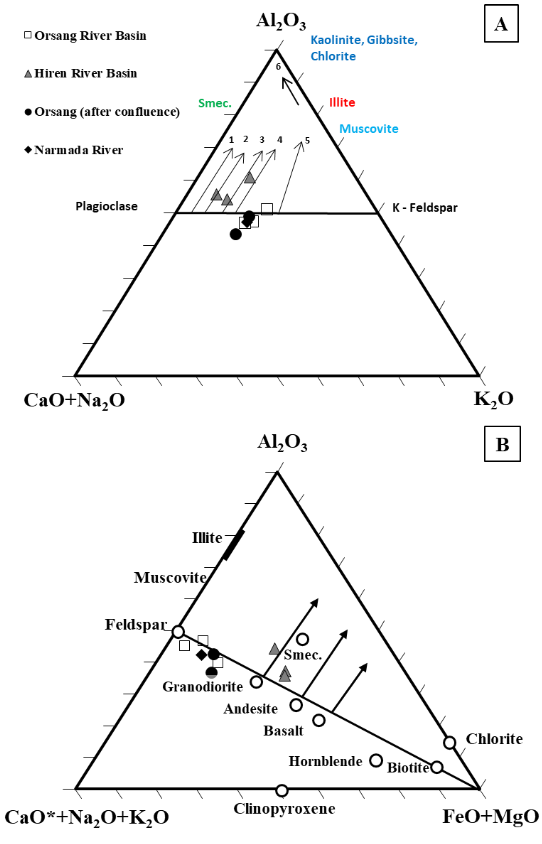

Figure 7. A) A-CN-K plot (Nesbitt and Young, 1984) and **B)** A-FM-CNK plot (Nesbitt and Young, 1989), showing the weathering trend of the Orsang river sediments. In the A-CN-K plot, the trend lines 1 = gabbro, 2 = tonalite, 3 = diorite, 4 = granodiorite, 5 = granite, and 6 = the weathering trend.

close to the CNKM corner, because of the addition of KM components with the CN component, whose concentration is retained during the incipient to moderate degree of weathering. In the Al_2O_3+Fe_2O_3 - MgO - CaO+Na_2O+K_2O diagram (Fig. 8B), where Fe retains with Al due to the immobile nature of Fe^{3+} under an oxidizing environment, the samples plot close to the AF-CNK join and away from the M (MgO) and CNK corners, indicating that Orsang and Hiren river samples have weathered in an oxidizing environment. The arkose-litharenite affinity of Orsang river sediments as depicted by the log Na_2O/K_2O vs. SiO_2/Al_2O_3 plot (Fig. 4), which supports our observation that the sediments have undergone minimal transportation and incipient to moderate chemical weathering. In summary, the low CIA values in our samples can be attributed to the supply of incipient to moderately weathered detritus from semi-arid oxidizing conditions.

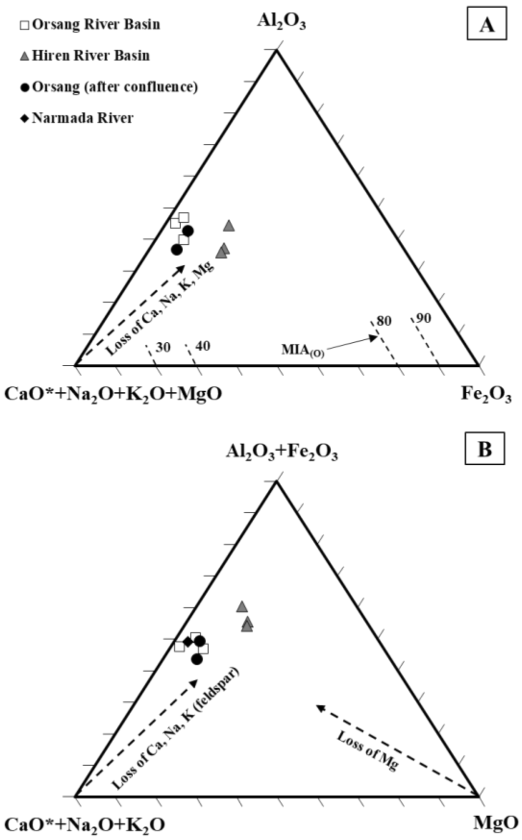

Figure 8. A) A-F-CNKM and **B)** AF-M-CNK plots (Nesbitt and Young, 1989 and Babechuk et al., 2017, respectively) showing Ca + Na + K + Mg loss from sediments. The basaltic provenance and oxidative weathering are reflected in the Fe_2O_3 concentration of the Hiren river sediments.

CONCLUSIONS

In this study, the grain size variations and geochemical characteristics of channel sediments in the Orsang and Hiren rivers are explored. The sediments from both rivers are poorly to moderately sorted, very finely skewed, indicating that the sediments derived from the river channel are transported from various sources. However, the kurtosis value indicates a very leptokurtic to extremely leptokurtic nature, indicating high energy depositional environment and sorting of the central portions. The observed variations in the grain sizes of Orsang and Hiren river basin sediments can be attributed to the provenance, degree of weathering and transportation. We inferred a higher proportion of sand and a lower proportion of gravel in the Orsang sediments due to their granitic source, but the Hiren river sediments composed of more gravel than the Orsang river, which might be due to their basaltic provenance. Sediments collected after the confluence of Orsang and Hiren rivers and from Narmada river points towards felsic provenance, which suggest that the proportion of sediment supply from Orsang river far outweighs that from Hiren River. The low CIA values and arkosic-litharenite nature of Orsang river sediments points towards less transportation and moderate chemical weathering, while Hiren river sediments CIA values point towards slightly higher degree of weathering. The sediments of Orsang and Hiren rivers are sourced from minimally weathered detritus from granitic and basaltic provenances, respectively and deposited in a semi-arid condition.

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DECLARATION OF CONFLICTING INTEREST

The Authors hereby declare that they have no conflicting interests related to the research conducted and data reported in this paper.

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