JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO 2582 – 2020
Vol. 43, Issue I, 2026, pp. 25 – 36

Delineation of Depositional Environment from Quaternary Sediments in Lendi River Sub-basin, Maharashtra, India

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ARTICLE INFO

KEY WORDS

Sediments;

Sieve analysis;

Grain size parameters;

Quaternary Geology

ABSTRACT

The grain size analysis of Quaternary sediments from the Lendi River sub-basin in Latur and Nanded districts of Maharashtra was conducted using the textural parameters and statistical measures to understand the depositional environment. A total of thirty-three samples were collected during the fieldwork and the samples were meticulously analyzed using the British Standard Sieve (BSS) method. The analysis reveals that the differential sorting of grains indicates significant environmental changes throughout geological history. Coarse sediments are prominently deposited over the country rock, forming a solid foundational layer. Above this coarse sediment layer, well-defined formations of sand and silty clay have been deposited. The presence of cross-bedding and graded bedding structures clearly indicates fluctuations in climatic conditions over time. The depositional environment of the coarse gravel sediments found in the bottom beds of the Lendi River at Halni, Mukaramabad, and Ravangaon suggests that these streams have relatively high energy, characterized by predominant bed load transport. In contrast, the fine clay and silt found at Hanuman Hipperga, Gojegaon, and other locations in the upper layers indicate that these streams have a low gradient and are influenced by seasonal climate variations.

INTRODUCTION

The traditional methods of grain size analysis, such as sieving and hydrometer, are complemented by modern techniques like laser diffraction and digital image analysis, as well as predictive models based on geochemical data. Each method has specific advantages, limitations, and suitability depending on the type of sediment and the research needs (Sperazza et al., 2004). Previous studies reveal that grain size analysis can provide insights into sediment transport direction, provenance, past transportation media, and depositional environments (Folk and Ward, 1957; Martins, 1965; Friedman, 1979; McLaren and Bowles, 1985; Bui et al., 1989). The Northwestern South China Sea sediment grain size study reveals that the quantitative distribution of sediment grain size could imply hydrodynamic conditions and composition; thus, it is indicative of sea-level fluctuations, regional sources, and climate changes (Ge et al., 2024).

For studying the grain size, after adopting the sieving technique, most sedimentologists have adopted the logarithmic method (Udden, 1898, 1914; Wentworth, 1922). Based on grain size analysis, researchers, namely Folk (1974), Eisma and Kalf (1987), and Okeyode and Jibiri (2012) observed that the presence of sediments predominantly consists of fine to medium-grained sand, suggesting deposition under low-energy conditions. This is because, in sedimentary environments, a decrease in the energy of the transporting medium typically results in the deposition of finer sediments. The new automated technique accurately estimates grain-size distributions from digital images of sediment, allowing for graphical sorting and skewness computations (Buscombe, 2008). According to Umehara et al. (2023), the digital image analysis method effectively determines grain-size distributions in muddy sediments, making it suitable for monitoring benthic ecosystem structures and functions in coastal areas. Another method of grain size analysis is the Laser diffraction method. It is a quick and accurate measure for very fine-grained sediments (to 10 m) with high precision, enabling high-resolution time-series data sets for paleohydrology studies (Sperazza et al., 2004).

The sediment grain size analysis provides the depositional environment of the sediments, which can be evaluated using multi-group, multivariate linear

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Email: bhagwangeo@gmail.com
DOI: https://doi.org/10.51710/jias.v43iI.460
Received 27 January 2026; Received in revised form 18 March 2026; Accepted 05 June 2026
Available online 30 June 2026

discriminant functions (Sahu, 1983). Sedimentologists are concerned with three aspects of particle size analysis: (a) techniques for measuring grain size and expressing it in terms of a grade scale, (b) methods for quantifying grain size data and presenting them in a graphic or statistical form and (c) the genetic significance of these data (Boggs, 2006). Physical factors like sediment transport, sediment aggregation, deposition, and gravitational circulation played a significant role in grain size distribution (Wai et al., 2004). Recent work on grain size analysis has been carried out by different researchers in different parts of the globe viz. Visher (1969), Hanamgond and Chavadi (1998), Blott and Pye (2001), Bhat et al. (2002), Ramamohanarao et al. (2003), Rajganapathi et al. (2013), and Oredein et al. (2014).

Ramamohanarao et al. (2003) carried out a grain size analysis of the Kota and Gangapur rocks of the Chintalapudi sub-basin of Gondwana. They found that those rocks are poorly to very poorly sorted, positively to very positively skewed, and leptokurtic to very leptokurtic. The grain size studies of fluvial provide the channel morphology and hydraulics of the stream (Di Stefano and Ferro, 2002; Surian, 2002). Systematic granulometric studies of both fluvial and marine sediments can give an overview of the depositional conditions and transport histories (Blott and Pye, 2001; Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011). Wan Mohtar et al. (2017). The Thiruchendur coast of south Tamilnadu, India, has been studied for grain size and textural parameters by Rajganapathi et al. (2013). The CM (C is one percentile in microns and M is medium grain size in microns) diagram was used for river sediments by Passega and Byramjee (1969) to distinguish rolling and saltation. Okeyode and Jibiri (2012) have carried out a grain size analysis of the sediments from Ogun River, southwestern Nigeria, using CM diagrams. They suggested that sediments within the river were deposited with the action of rolling, uniform and graded suspension. Grain size analysis from late upper Siwalik sediments of late Pliocene to early Pleistocene reveals that sediments are bimodal to polymodal and fine to medium-grained with moderately sorted (Singh and Chaudhri, 2013). In this study, an analysis of Quaternary sediments has been carried out to delineate the depositional environments.

STUDY AREA

The Lendi River, a tributary of the Manjra River, originates from the Balaghat hill range in the Latur district of Maharashtra, India, bounded by 18°17'20"N to 18°41'26"N and 76°53'23"E to 77°45'9"E (Fig. 1). The basin covers an area of about 2536.3 sq. km. The highest elevation in the area is 688 m and the lowest is 343 m above mean sea level (MSL) near Tamlur village in Degloor tehsil of Nanded district of Maharashtra. The Lendi River sub-basin is not limited to any particular administrative unit like a district or tehsil, but it falls in three states, Maharashtra (Latur and Nanded districts), Telangana state (Nizamabad district) and Bidar district in Karnataka. Out of a 2536.3 sq. km. area, 1874.18 sq. km., i.e. 73.90%, falls in Maharashtra state, in Telangana state; it is 441.67 sq. km., i.e. 17.41% and in Karnataka state is 216.41 sq. km., i.e. 8.53%. The basin lies within four tehsils in Maharashtra state, namely Udgir and Ahmadpur in Latur district, Degloor/Diglur and Mukher in Nanded district, Madhnur tehsil in Nizamabad district, and Aurad tehsil in Bidar district. The Lendi River spreads in the southern part of central Maharashtra and the north-western part of Telangana state. The climate of the study area is semi-arid, sub-tropical dry, with a characteristically hot summer. The rainfall in the area is mainly due to the SW monsoon winds. The post-monsoon or retreating monsoon rainfall is in October and November.

GEOLOGY

In the Lendi River, three litho types are observed during the fieldwork, namely: Deccan Volcanic Basalt (DVB), Peninsular Gneissic Complex (PGC) and Quaternary sediments deposited along the river channel and alluvial plain of the river (Babar et al., 2019; Gurav, 2019; Gurav and Babar, 2021). DVB is horizontally disposed Continental Flood Basalt (CFB) formed due to a fissure-type of lava eruption (Watts and Cox, 1989). It is of Upper (Late) Cretaceous to Lower (Early) Eocene age. This type of lava flow occurs in the study area and, in some places, is separated by red bole beds (Sharma et al., 2025). The Proterozoic Granitoid (2074 to 2385 Ma) exposed in the southern part of Nanded district, Maharashtra, marks the north-eastern extension of PGC in Eastern Dharwar Craton (EDC) and belongs to its younger phase (Banerjee et al., 1993, 2008; Wesanekar and Patil, 2000, 2016); Babar et al., 2019. Babar et al. (2019) called this terrain 'Degloor South East Strike Slip Zone' (DSESSZ) based on fault evidence observed near Degloor village.

The younger alluvial (fluvial) deposit shows a mixture of pebbles, cobbles, sand, silt and clay. These are weathered granites and basaltic rock fragments deposited along the Lendi River (Gurav and Babar, 2021). The study indicates that the sediment load rate of tropical rivers in peninsular India has declined due to changes in rainfall patterns and human activities (Panda et al., 2011). This decline also reflects a younger stage in the stratigraphic succession. The highest thickness of these sediment deposits is found near Gundappan Dapka. Studies conducted at nineteen locations in the area showed that the thickness of the unconsolidated or semi-consolidated sediments varies between 2.0 m and 8.0 m.

METHODOLOGY

A total of 33 sediment samples were collected from the study area. The sample locations are, Halni (1), Mukarmabad (2 to 7), Ravangaon (8 and 9), Sangavi Bhadev (10), Malkapur (11 and 12), Degloor (13), Bagam Takali (14 to 17), Hawarga (18), Hanuman Hipperga (19 to 21), and Gojegaon (22 to 24), Mukarmabad (25), Bhamani (26), Tagyal (27), Kalambar (28 and 29), Gundappan Dapka (30 to 32) and Atnur (33), shown in Fig. 1 and Table 3. The Quaternary sedimentary formations along the Lendi River and its tributaries exhibit a diverse range of depositional environments, reflecting varying energy conditions and climatic influences over time. Field observations, as shown in Fig. 2 (a to d) at Halni, Ravangaon, Kalambar, and Mukarmabad sites, highlight distinct stratigraphic sequences indicative of dynamic fluvial processes.

Before sample collection, the stratum was carefully studied for its thickness, sediment behavior and its grain arrangements, cementing material and sediment fragments. The samples collected were placed in polythene bags and labeled. These samples are analyzed by the British Standard Sieve (BSS) method of sieve analysis. The grain size analysis (Table 1) of Quaternary sediments in Lendi River was undertaken following the arithmetic method of statistical analysis technique. The weight percentage frequency data obtained in the laboratory were statistically analyzed and they were converted into

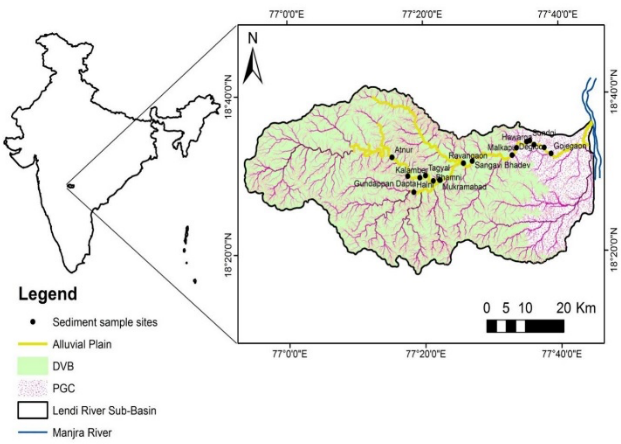

Fig. 1. Location map of the Quaternary sediment sample collected sites, with geology and drainage in the Lendi River basin

cumulative percentage (Table 2). The curves were constructed based on weight percentage data, which served as a basic tool for the generation of other statistical parameters proposed by Folk and Ward (1957), Folk (1974) and Reineck and Singh (1980). The obtained results are tabulated in Table 3.

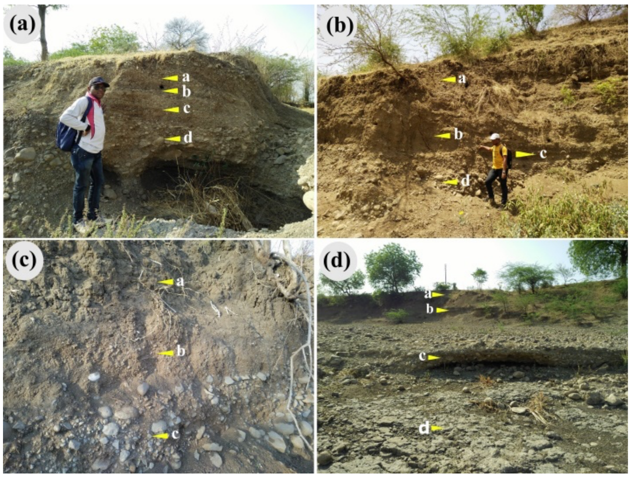

Fig. 2. Field photographs of Quaternary formations in Lendi River. (2a) sediment section of the left bank at Halni village, 'a' coarse sandy silt, 'b' clay formation, 'c' coarse sandy silt formation, and 'd' pebbly gravel formation, (2b) sediment section of the left bank at Ravangaon village, 'a' Black cotton soil, 'b' sandy silt formation, 'c' coarse sandy silt formation, and 'd' pebbly gravel formation, (2c) Sediment section at Kalambar, 'a' black cotton soil, 'b' coarse sand, gravel formation, and 'c' coarse pebbly gravel formation, (2d) Sediment section at the Mukarmabad village, 'a' black cotton soil, 'b' sandy silt formation, the 'c' pebbly graves, and 'd' Deccan Volcanic Basalt (DVB) formation

Table 1: Grain Size analysis parameters

Parameters	Reference	Value and inference
Arithmetic mean (u1)	Folk and Word (1957)	0 to 1.00= coarse, 1.01 to 2.00= medium, 2.01 to 3.00= fine, 3.01 to 4.00= very fine
variance (u_2)		-
Standard Deviation (σ1)		< 0.35= very well sorted, 0.35 to 0.50= well sorted, 0.50 to 0.70= moderately well sorted, 0.71 to 1.00= moderately sorted, 1.00 to 2.00= poor sorted, 2.00 to 4.00=very poor sorted
Skewness (SKI)		>1.0= strongly fine skewed, 1.0 to 0.3= very fine skewed, 0.3 to 0.1=fine skewed, 0.1 to -0.1= nearly symmetrical, -0.1 to -0.3= coarse skewed, <-0.3= very coarse skewed
Kurtosis (KG)		< 0.67= very platykurtric, 0.67 to 0.90= platykurtric, 0.90 to 1.11= mesokurtric, 1.11 to 1.50= leptokurtic, 1.50 to 3.00= very leptokurtic, >3.00=extremely leptokurtic

All samples were analyzed at -1/2 phi (ø) interval in a Ro-Top Sieve shaker using BSS method for 15 min. The samples retained on each sieve were weighed on a single pan balance up to an accuracy of 0.001 grams and the weight-cumulative weight percentage (arithmetic curve) was calculated, which was further utilized for grain size analysis using mathematical equations given by Folk and Ward (1957) and Friedman (1962). The method proposed by Folk and Ward (1957) is quicker and more accurate for near-normal distribution curves. The cumulative percentage curve (arithmetic scale) was plotted

Table 2: Cumulative weight frequency of samples in Lendi River

ø	Sample numbers										
	1	2	3	4	5	6	7	8	9	10	11
-0.75	55.9	5.84	45.2	0.65	32.7	16.8	1.52	37.2	67.0	2.93	1.86
-0.25	58.8	8.03	48.6	1.54	34.5	18.3	3.72	40.4	69.4	4.66	4.04
0.25	71.1	21.0	62.2	8.05	46.3	25.9	6.43	58.7	77.5	7.33	6.97
0.75	76.1	28.9	69.9	12.7	52.9	31.9	10.15	65.4	81.7	12.5	10.9
1.25	76.7	29.8	70.6	13.3	53.5	32.8	10.22	66.4	82.1	16.5	13.9
1.75	87.0	45.6	86.1	19.7	71.2	56.9	20.03	78.7	90.5	22.9	20.6
2.25	90.7	52.8	90.2	27.6	79.0	69.9	29.80	83.1	93.6	32.4	31.1
2.75	90.9	53.1	90.4	27.8	79.3	70.2	29.83	83.4	93.6	34.4	31.7
3.25	91.7	55.2	91.5	29.1	81.3	72.2	32.34	84.7	94.2	44.2	34.8
3.75	94.4	62.0	93.9	36.6	86.9	80.4	44.89	88.2	95.9	47.2	46.4
4	100	100	100	100	100	100	100.0	100	100	100	100
ø	12	13	14	15	16	17	18	19	20	21	22
-0.75	52.7	1.72	0.36	28.3	42.8	44.9	15.1	2.60	0.31	1.27	22.9
-0.25	58.2	4.51	0.80	30.9	44.9	47.9	17.4	4.61	0.62	1.70	26.0
0.25	75.9	9.15	5.99	45.5	54.4	59.6	30.6	4.98	1.66	5.74	43.2
0.75	82.7	10.2	13.2	56.4	58.6	65.9	37.8	8.91	5.16	12.5	50.1
1.25	83.1	25.9	14.1	57.7	59.2	66.6	38.7	14.8	5.61	13.2	51.0
1.75	91.8	31.8	34.9	83.7	72.1	82.2	55.5	21.9	14.1	47.7	66.9
2.25	94.1	31.9	45.9	89.8	79.8	88.1	63.0	32.1	21.6	76.0	73.9
2.75	94.4	34.8	46.3	89.9	80.1	88.3	63.2	34.3	21.9	76.4	74.6
3.25	95.0	35.6	48.0	90.9	82.2	89.2	65.0	41.2	23.4	79.8	76.8
3.75	96.5	47.7	55.8	95.1	88.3	92.3	71.7	48.0	28.9	89.3	83.2
4	100	100	100	100	100	100	100	100	100	100	100
ø	23	24	25	26	27	28	29	30	31	32	33
-0.75	17.2	76.8	1.90	57.2	1.66	4.36	38.3	60.1	27.5	45.7	52.8
-0.25	18.8	77.8	3.96	61.2	4.01	5.33	40.8	62.3	29.9	50.6	55.2
0.25	28.6	85.1	8.62	73.1	5.94	12.5	57.9	74.6	52.1	70.6	65.9
0.75	36.2	88.1	12.0	77.7	10.1	16.4	67.9	80.3	67.6	79.9	71.2
1.25	37.2	88.3	12.8	78.3	11.4	16.9	68.6	80.7	68.9	80.7	71.9
1.75	63.8	94.5	26.9	85.7	22.8	25.6	86.3	89.9	92.6	93.1	86.7
2.25	73.1	96.4	35.4	89.1	31.7	30.2	90.8	91.9	95.8	95.4	90.9
2.75	73.4	96.4	35.6	89.4	32.4	30.4	91.7	92.5	96.0	95.5	91.1
3.25	75.9	96.8	38.4	90.5	35.1	31.7	92.2	94.0	96.6	95.6	92.2
3.75	87.8	97.7	48.1	93.6	46.9	38.9	94.8	99.9	97.4	96.6	95.0
4	100	100	100	100	100	100	100	100	100	100	100

against phi (ϕ) with the help of excel tools (Fig. 4). According to Wentworth (1922), percentage frequency of mean grain size versus class limit for six type curves (A, B, C, D, E and F) for 33 Quaternary samples of Lendi River is shown in Fig. 5. The graphical method represents the depositional environment of the sediments as shown in Fig. 6 (a) and (b).

RESULT

a. GRAIN SIZE ANALYSIS OF QUATERNARY SEDIMENTS USING SIEVE ANALYSIS

In the present study, statistical analysis has been carried out using a frequency curve to obtain mean, standard deviation, skewness, and kurtosis. Earlier, the statistical parameters like mean, standard deviation, skewness, and kurtosis values were calculated by central moment and were successfully used by Williams (1973) and Ray et al. (1975) to differentiate between various beach zones.

a.1. Frequency curve

The weight percentage frequency curves show grain size distribution. These curves were plotted on a scale from 1 to 100 against phi (ϕ) values that range from -0.75 to 4.00 (Fig. 4). It is observed that the Lendi River has different sorting of grains from fine sand to coarse gravel.

a.2. Arithmetic mean (MZ) (first movement)

Average kinetic energy, velocity of depositional agent is indicated by mean size (Sahu, 1964; Ramamohanarao et al., 2003; Rao et al., 2005). The graphic mean is the best measure for determining the overall size of sediments (Folk, 1974). This is calculated by using the formula,

$$MZ = \frac{\Sigma(fi \times mi)}{\Sigma fi} \quad (01)$$

Where, arithmetic mean (MZ), fi is the total weight of the sieve sample and mi is the mid value of

the sedimentary sieve sample. Based on this formula, the average grain size of the sediments was calculated, which ranges from 0.011 to 3.456 (Table 3). The lowest value of 0.011 was noted at sample 09 at Rawangaon and the highest value of 3.456 for sample 20 at Hanuman Hipperga.

a.3. Standard Deviation (σ1)

It measures the sorting of sediments and indicates the fluctuation in the kinetic energy or velocity condition of the depositional agents (Sahu, 1964). The standard deviation (σ) is a good measure of sorting and is computed using the formula,

$$\sigma 1 = \sqrt{v} \quad (3)$$

The average grain size calculated for the sediments ranges from 1.0274 to 2.3258 (Table 3). The lowest value 1.0274 was obtained for the sample 20, consolidated sediments at Hanuman Hipperga and the highest value 2.3258 was noted for the sample 02 soil sample in Mukarmabad.

a.4. Skewness (SKI)

Folk, in 1974, observed that the skewness covers the central 68% of the curve. Skewness values were calculated using the formula,

$$SKI = \frac{\Sigma\{(mi - u1)3 \times fi)\}}{v^2} \quad (4)$$

The skewness (SKI) values of grain size analysis data showed a range from 0.000005 to 4.0618 (Table 3). The lowest value, 0.000005, was recorded for sample 23 consolidated sediments in Gojegaon village and the highest value, 4.0618, was obtained for the sample white clay 07 in Mukarmabad.

a.5. Kurtosis (KG)

Friedman (1962) suggested that extremely high or low values of kurtosis mean that part of the sediment achieved its sorting elsewhere in a high-energy environment. The kurtosis is the highest of the distribution ratio between the sorting in the trails and the central portion of the curve. If the trails are well sorted than the central portions, then it is termed as platykurtic, whereas leptokurtic, if the central portion is better sorted. This is calculated by using the formula,

$$KG = \frac{\Sigma\{(mi - u1)4 \times fi)\}}{v^2} \quad (5)$$

The Kurtosis (KG) of grain analysis data (Table 3) shows that they range from 0.4278 to 5.1224. The lowest value 0.4278 was obtained for sample 01 soil sediments, sample number LR2 in Mukarmabad village and the highest value 5.1224 for the sample 12 unconsolidated sediments sample in Mukarmabad.

b. CLASSIFICATION OF MEAN SIZE FREQUENCY CURVES

The percentage frequency curve graphs were studied based on their unimodal or bimodal nature. For this, the actual percentage frequency corresponding to the different grain sizes was plotted in the form of graphs for the 33 representative samples. The classifications of these graphs are carried out based on the method proposed by Wentworth (1922). Some graphs show a typical unimodal (single population) distribution, while some other show a bimodal (double population) distribution. In some other, numerous sub-populations have been observed. Based on this, six different categories of curves have been distinguished, and their characteristics are presented in Table 5. The curves obtained (Table 5) reveal that, 14 curves belong to type curve 'A', 04 curves belong to type curve 'B', 07 curves belong to type curve 'C', 01 curves belong to type curve 'D', 05 curves belong to type curve 'E' and 02 curves belong to type curve 'F'.

c. DEPOSITIONAL ENVIRONMENT OF THE SEDIMENTS IN LENDI RIVER THROUGH PERCENTAGE FREQUENCY CURVE

The various litho-units studied during the fieldwork, on the basis of the order of superposition, structures and grain size arrangements, have helped to understand the environment of deposition. The shape and sizes of grains, the quality and quantity of the different grains and the composition of the rocks were also studied. The parameters utilized in the study of Quaternary sediments are mean size, kurtosis, skewness and standard deviation. Further, two parameters at a time are used to determine the interrelation between them. For this, three parameters are considered: kurtosis, standard deviation and mean size.

Table 3: Size parameters and characteristics of Quaternary sediments in Lendi River

Sample site	Sample no.	Mean	Variance	Std. Deviation	Skewness	Kurtosis
Lendi River main channel						
US	1	0.270	2.1668	1.4720	1.8336	3.6584
Soil	2	2.343	5.4095	2.3258	0.0189	0.4278
US	3	0.508	2.2793	1.5097	1.0471	2.9223
Soil	4	3.208	1.6965	1.3025	1.9167	3.4444
US	5	1.120	3.0162	1.7367	0.6737	1.8025
US	6	1.821	2.7445	1.6566	0.0231	1.8319
W. Clay	7	3.168	1.6441	1.2822	4.0618	2.8836
Soil	8	0.786	2.7849	1.6688	0.6883	2.3407
US	9	0.011	1.7845	1.3358	3.1015	5.0492
Soil	10	2.994	1.8874	1.3738	1.4132	3.2530
Soil	11	3.104	1.7636	1.3280	0.3840	3.5467
CS	12	0.112	1.5556	1.2472	2.7419	5.1224
Soil	13	2.947	2.1195	1.4558	0.9839	2.4833
Soil	14	2.813	1.7109	1.3080	0.3337	1.9725
CS	15	0.896	2.0385	1.4277	0.3421	2.4398
CS	16	0.906	3.2129	1.7924	0.3503	1.8351
CS	17	0.605	5.2762	2.2970	1.1331	1.7241
Soil	18	1.890	3.1558	1.7764	0.0099	1.5436
Soil	19	3.056	1.7040	1.3053	1.6076	3.6179
CS	20	3.456	1.0556	1.0274	3.0998	5.0014
CS	21	2.205	1.2759	1.1293	0.0022	2.2932
Soil	22	1.376	3.1079	1.7629	0.0850	1.6317
Clay	23	1.672	2.6613	1.6313	0.000005	1.8497
CS	24	0.247	1.2129	1.1013	5.7687	8.1793
Soil	25	3.004	1.871	1.3679	1.2598	3.0137
Soil	26	0.285	2.4091	1.5521	1.8982	3.5526
Soil	27	3.108	1.6569	1.2872	1.7896	3.7071
Soil	28	3.018	2.2848	1.5115	1.5278	3.0737
RCS	29	0.606	2.0489	1.4314	0.7681	2.8625
Soil	30	0.119	1.7877	1.3370	2.3028	4.2276
US	31	0.622	1.3779	1.1738	0.4560	3.1574
US	32	0.255	1.6110	1.2692	1.9428	4.3982
Soil	33	0.372	2.2039	1.4845	1.2637	3.0953

Where, unconsolidated sediments (US), consolidated sediments (CS), river channel sediments (RCS), white clay (w. clay).

Table 4: Classification of type of size, type of sorting, type of skewed, type of kurtosis of Quaternary sediments along Lendi River

Ratio	sample numbers	Total samples	Percentage	Type of Size
Graphic mean size				
0 to 1.00	1, 3, 8, 9, 12, 15, 16, 17, 24, 26, 29, 30, 31, 32, 33.	15	45.5	Coarse
1.01 to 2.00	5, 6, 18, 22, 23.	05	15.2	Medium
2.01 to 3.00	2, 10, 13, 14, 21.	05	15.2	Fine
3.01 to 4.00	4, 7, 11, 19, 20, 25, 27, 28.	08	24.2	Very Fine
Standard Deviation				
< 0.35	-	00	0.00	Very Well Sorted
0.35 to 0.50	-	00	0.00	Well Sorted
0.51 to 0.70	-	00	0.00	Moderately Well Sorted
0.71 to 1.00	-	00	0.00	Moderately Sorted
1.01 to 2.00	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33	31	94.0	Poorly Sorted
2.01 to 4.00	2, 17	02	6.00	Very Poorly Sorted
Skewness				
>1.0	1, 3, 4, 7, 9, 10, 12, 17, 19, 20, 24, 25, 26, 27, 28, 30, 32, 33.	18	54.6	Strongly fine Skewed
1.0 to 0.3	5, 8, 11, 13, 16, 29, 31	07	21.2	Very fine Skewed

0.3 to 0.1	2, 14, 15.	03	9.10	Fine Skewed
0.1 to -0.1	6, 18, 21, 22, 23.	05	15.2	Nearly Symmetrical
-0.1 to -0.3	-	00	0.00	Coarse Skewed
<-0.3	-	00	0.00	Very Coarse Skewed
Kurtosis				
< 0.67	2	1	3.03	Very Platykurtric
0.67 to 0.90	-	0	0.00	Platykurtric
0.90 to 1.11	-	00	0.00	Mesokurtric
1.11 to 1.50	-	00	0.00	Leptokurtic
1.50 to 3.00	3, 5, 6, 7, 8, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 29	17	51.5	Very Leptokurtic
> 3.00	1, 4, 9, 10, 11, 12, 24, 25, 26, 27, 28, 30, 31, 32, 33	15	45.5	Extremely Leptokurtic

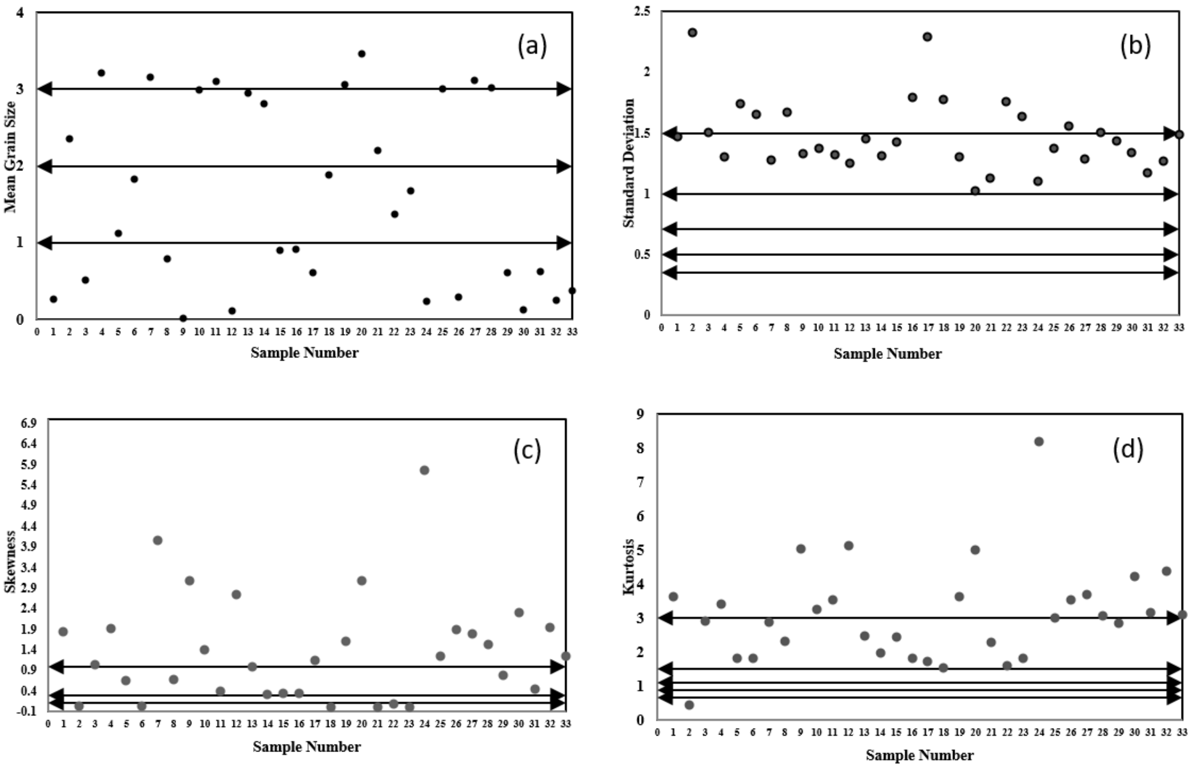

Fig. 3. Graphical representation (a) sample number versus corresponding values of Mean Grain Size, (b) sample number versus corresponding values of Standard Deviation, (c) sample number versus corresponding values of Skewness and (d) sample number versus corresponding values of Kurtosis

Friedman and Sanders (1978) distinguished river environment from that of beach by plotting the values of Skewness versus those of Standard deviation (Fig. 6a), and another graph suggested by Moiola and Weiser (1968) based on bivariate plot of mean size versus Standard deviation to demark the river environment from beach (Fig. 6b). Based on both the methods when the present samples were plotted, it was found that all the 33 Quaternary sediment samples of Lendi River fall in the river environment.

DISCUSSION

The textural parameters of sediments like mean, standard deviation, skewness and kurtosis are widely used to reconstruct the depositional environment of the sediments and sedimentary rocks (Komar, 1998; Poppe and Eliason, 2008; Mir and Jeelani, 2015; Mostafa et al., 2025). A graphical representation (Fig. 3a) of sample number versus mean grain size helped to classify them as coarse samples 15 with 45.0%, medium grain sizes 05 with 15.2%, fine grain sizes 05 with 15.2% and very fine grain sizes 08 with 24.2% (Table 4). It is known that the change in the transporting power of the river depends upon the climatic conditions of the area. The mean value of each stratum is not constant and hence it is an indication of a change in climatic conditions. The changes in sedimentary stratum mean values from bottom to top reveal a cycle of high and low energy levels in the area. In their research, Oredein et al. (2014) observed that during the dry season, the transporting medium in the Ogbesse River generally has low energy, whereas during the rainy season, it attains its maximum velocity depending on the amount of rainfall in the area. The changes observed in the mean grain size value of Quaternary sediments deposited in the Lendi River can be explained by considering similar approaches. Fig. 5b shows a graphical representation of sample numbers versus standard deviation, which recorded a number of samples 31 with 93.9% between 1.01 and 2.00 standard deviation values, indicating poorly sorted. Between 2.01 and 4.00, the number of samples is 02, with 06.6% representing very poorly sorted (Table 4).

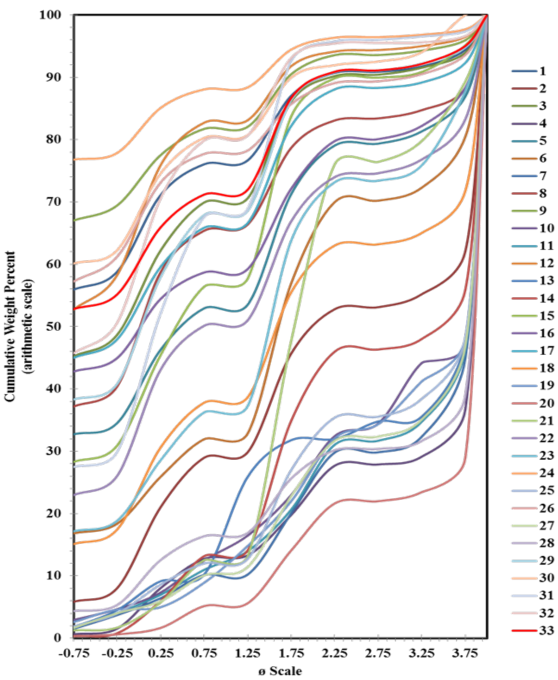

Fig. 4. Superimposition of values of Cumulative frequency percentage curves of mean grain size drawn versus class limit (ø Scale) (Wentworth, 1922)

The number of samples versus skewness (Fig.3c) when plotted, recorded that the sample ranges from strongly fine skewed to coarse skewed (Table 4). The classification of skewed values >1.0 covers 18 samples with 54.5% that are strongly fine skewed, the range 1.0 to 0.3 is very fine skewed, covering 07 samples with 21%, fine skewed (0.3 to 0.1) samples are 03 with 9.0% and < 0.1 is for coarse skewed and samples are 05 with 15.2%.

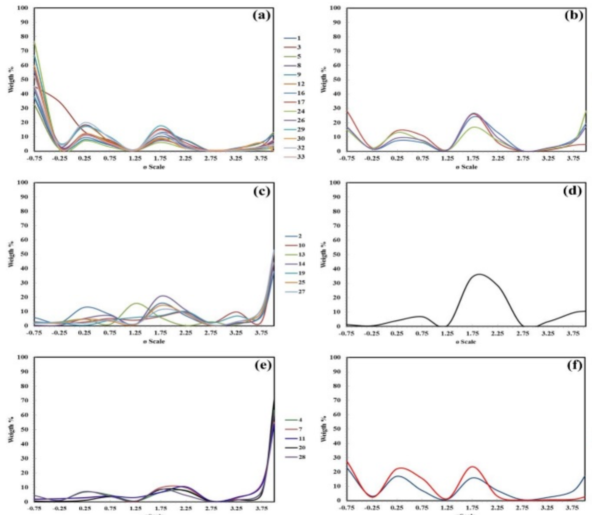

Fig. 5. Superimposition of values of Percentage frequency of mean grain size versus class limit (Wentworth, 1922) for six type curves (a, b, c, d, e and f) for 33 Quaternary samples of Lendi River. (5a) Type curve is A, (5b) type curve is B, (5c) type curve is C, (5d) type curve is D, (5e) type curve is E and (5f) type curve is F

Based on this, the Lendi River samples can be classified as strongly fine-skewed to coarse-skewed (Fig. 3c).

The number of samples versus kurtosis is divided into six classes, but all the samples fall into only three classes namely, very Platykurtric (< 0.67) category only one sample with 3.03%, 17 samples fall in 1.50 to 3.00 range amounting to 51.5%, are very Leptokurtic and 15 samples are in > 3.00 amounting to 45.5% are Extremely Leptokurtic (Table 4). Based on this, all the samples of Lendi River can be classified into very Leptokurtic to Extremely Leptokurtic except sample 2, which shows a very Platykurtric nature (Fig. 3d).

Grain size distribution analysis in the Quaternary sediments of the Lendi River has helped to categorize sediments into six distinct percentage frequency curve types, labeled A through F and presented in Fig. 5. All the superimposed curves help to depict the patterns in sediment characteristics. This method reveals that Curve A is the most prevalent among the samples, followed by Curves C, E, B, F, and D, indicating the sequence of dominance as A > C > E > B > F > D.

Each curve type represents specific grain size distribution patterns, which are indicative of different depositional environments and sediment transport mechanisms. For instance, a dominance of Curve A suggests deposition under high-energy conditions, resulting in poorly sorted sediments. Conversely, the presence of other curve types points to variations in energy conditions and sediment supply during deposition. Thus, it can be inferred that the distribution pattern of grains in the Quaternary sediments of the Lendi River sub-basin includes coarse-grained sediment subpopulations along with medium and fine-grained sediments. Coarse sediments are associated with high-energy flow regimes, whereas fine sediments are deposited in low-energy environments with a sediments subpopulation of medium and fine grade. High energy flow regime close to coarser sediments, whereas fine sediments found in a low energy environment were also reported earlier by Folk (1966), Moiola and Weiser (1968), Singh et al. (2015) and Ahmad et al. (2017).

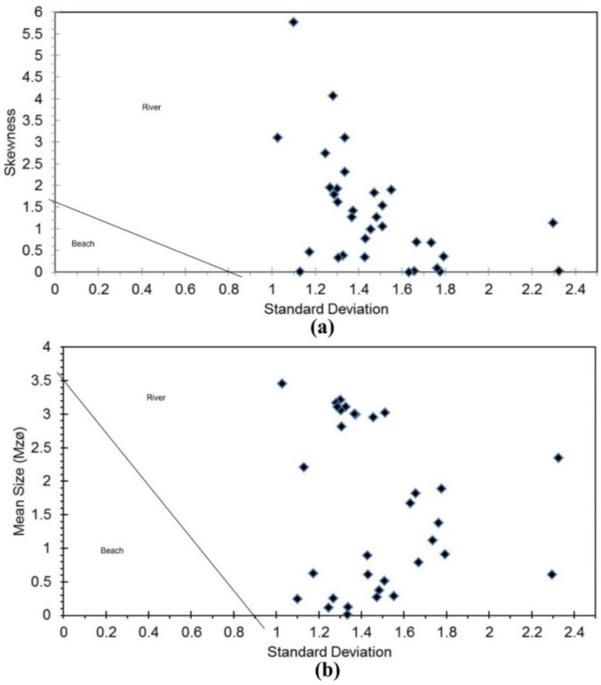

Fig. 6. (a) Bivariate plot of Standard deviation versus Skewness (after Friedman and Sanders, 1978), (b) Bivariate plot of Standard deviation versus Mean Size (Moiola and Weiser, 1968)

Table 5: Classification of frequency percentage curves

Type curve	Characters of the curves	Sample Number	Total No. of Samples	Standard Deviation (σ_1)	Skewness (σKi)
A	Unimodal peak in coarse grade with sub population of medium and fine grade	1, 3, 5, 8, 9, 12, 16, 17, 24, 26, 29, 30, 32, 33	14	Poorly sorted	Strongly fine Skewed
B	Unimodal peak in medium grade with sub population of coarse and fine grades	6, 15, 18, 23	04	Poorly sorted	Fine Skewed
C	Unimodeal peak in fine grade with sub population of coarse and medium grades	2, 10, 13, 14, 19, 25, 27	07	Poor to very poorly sorted	Strongly to Fine Skewed
D	Unimodel peak in medium grade	21	01	Poorly sorted	Fine Skewed
E	Unimodel peak in fine grade	4, 7, 11, 20, 28	05	Poorly sorted	Strongly fine Skewed
F	Bimodal curve	22, 31	02	Poorly sorted	Very fine Skewed to Symmetrical

CONCLUSIONS

The statistical analysis of textural parameters has provided valuable insights into the depositional environment of sediments in the Lendi River. At the locations of Halni, Mukaramabad, and Ravangaon, the data indicate that the streams have relatively high energy levels, characterized by the predominant transport of coarse gravel sediments found on the riverbed. In contrast, fine clay and silty materials observed at the Hanuman Hipperga and Gojegaon sample sites, which are located in the upper layers of the stream with a low gradient, suggest fluctuations in climatic conditions controlled by fluvial action. Grain size analysis reveals that variations in grain sorting are indicative of past environmental changes. Coarse sediments are deposited over the country rock, with sand and silty clay exhibiting graded bedding structures. The depositional environment in the upper reaches of the Lendi River valley, with its coarse pebbles and gravel sediments showcasing cross-bedding structures, indicates that the streams were high-energy environments with prevalent bed load transport. Conversely, the fine clay and silt formations found in the lower reaches of the river suggest a low-gradient, high-sinuosity stream environment.

AUTHORS' CONTRIBUTIONS

Chandrakant Gurav: Data Collection, Investigation, Conceptualization, Writing-Original Draft, Formal Analysis. Md. Babar: Supervision, Writing- Original Draft, Visualization, Reviewing and Editing. Sanjay. V. Pathare : Visualization, Reviewing and Editing. and Bhagwan Ghute: Supervision, Visualization, Reviewing and Editing.

ACKNOWLEDGEMENTS

The authors are thankful to A. J. Bodake, Principal, Rajaram College, Kolhapur for consistent support during the research. Also thankful to Prof. G. N. Nayak, Editor in Chief, JIAS and anonymous reviewers for their constructive comments and suggestions, which helped improve the clarity and quality of the manuscript.

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