INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

Granulometric Analysis of Channel Sediments of Pedhi River, Maharashtra, India

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DOI: https://doi.org/10.51584/IJRIAS.2026.11070046

Received: 17 July 2026; Accepted: 22 July 2026; Published: 30 July 2026

ABSTRACT

This study presents a comprehensive granulometric investigation of the channel bed sediments of the Pedhi River, a major tributary of the Purna River in the Amravati district of Maharashtra. The research aimed to analyse the textural characteristics and statistical parameters of these sediments to reconstruct their transport history and interpret the dynamic energy conditions of their depositional environment. During the dry season, ten sediment samples were collected at regular 5 km intervals to ensure a representative spatial distribution. Following standardised laboratory preparation and chemical treatments to remove organic matter, the samples underwent mechanical sieve analysis. Statistical measures, including graphic mean, inclusive graphic standard deviation (sorting), skewness, and kurtosis, were calculated using the formulas established by Folk to provide a quantitative basis for environmental interpretation. The results reveal that the Pedhi River sediments are predominantly composed of coarse to very coarse sand, characterised as moderately sorted and very fine-skewed. This suggests a consistent yet fluctuating energy regime, with a noticeable amount of finer material remaining trapped within a coarse sediment matrix. Most samples exhibited a mesokurtic distribution, indicating a balanced sorting relationship between the central grain sizes and the distribution tails. Bivariate plots and C-M patterns further validate a fluvial origin, indicating that saltation is the primary mode of sediment transport. These findings collectively point to a moderate-energy depositional environment where varied grain sizes were deposited simultaneously under the dynamic hydrological conditions of a meandering river system.

Keywords: Granulometric Analysis, Pedhi River, Fluvial Environment, Statistical Parameters, Saltation, C-M Pattern.

INTRODUCTION

Grain size is a fundamental descriptive parameter and one of the most important textural characteristics used in sediment classification (Khaing et al., 2022). The distribution of grain sizes and related statistical parameters provides valuable information about sediment transport processes, depositional environments, and hydrodynamic conditions (Solohub & Klovan, 1970; Tiara & Scholle, 1979; Sly et al., 1983; Ayodele & Madukwe, 2019; Blott & Kenneth, 2000; Khaing et al., 2022; Fotie Lele et al., 2024). Grain movement and spatial distribution are influenced by particle size, transport energy, depositional mechanisms, and post-depositional diagenetic alterations (Folk, 1980; Lewis & McConchie, 1994; Cojan & Renard, 1995). Granulometric analysis is therefore widely applied to reconstruct depositional environments, determine sediment provenance, and understand the geological evolution of a region (Folk, 1980; Friedman & Sanders, 1978; Krumbein & Sloss, 1963; Syvitski, 2007).

To interpret granulometric characteristics meaningfully, it is essential to consider the geological and physiographic setting of the study area. Amravati District, located in the Vidarbha region of Maharashtra, northern India, borders Madhya Pradesh. It lies between 20°32′–21°46′ N latitude and 76°27′–78°37′ E longitude and covers approximately 12,208.77 km². The district is bounded by Nagpur and Wardha to the east, and Yavatmal, Akola, and Buldhana to the south and southwest, with the Wardha River forming its eastern boundary. The district is drained by the Tapi, Purna, and Wardha rivers. The Purna River originates in the Gavilgarh Hills and receives tributaries such as the Pedhi River, Arna River, Chandrabhaga River, and Shahnur River. These fluvial systems play a major role in sediment transport, deposition, and grain-size variation across the region.

Physiographically, the northern part of the district is hilly and forested, whereas the central region comprises the fertile Purna alluvial plain (~3,053 km²), composed mainly of silt, clay, and sand. The Bazada zone near the Satpuda foothills contains clay, boulders, and pebbles, representing transitional piedmont deposits. Geologically, about 25% of the district consists of alluvial and foothill deposits, while nearly 75% is underlain by Deccan Trap basalts characterized by jointed and vesicular volcanic formations. This geological framework directly influences sediment supply, grain-size distribution, and depositional patterns within the study area.

Study Area

The study area covers a section of the Pedhi River basin and includes ten villages located along or near its banks. Riddhapur, Belora, and Gopalpur are situated on the western (right) bank of the river, while Chincholi Kale, Tembha, Kamunja, and Nimbha lie on the eastern (left) bank. Rewsa, Ganuja, and Pingla are positioned slightly away from the main channel but are influenced by tributaries and seasonal streams connected to the Pedhi River system. The area is characterized by gently undulating terrain, with elevation decreasing from northwest to southeast, which controls the river's drainage pattern and flow direction. (Gazetteers Department, Government of Maharashtra)

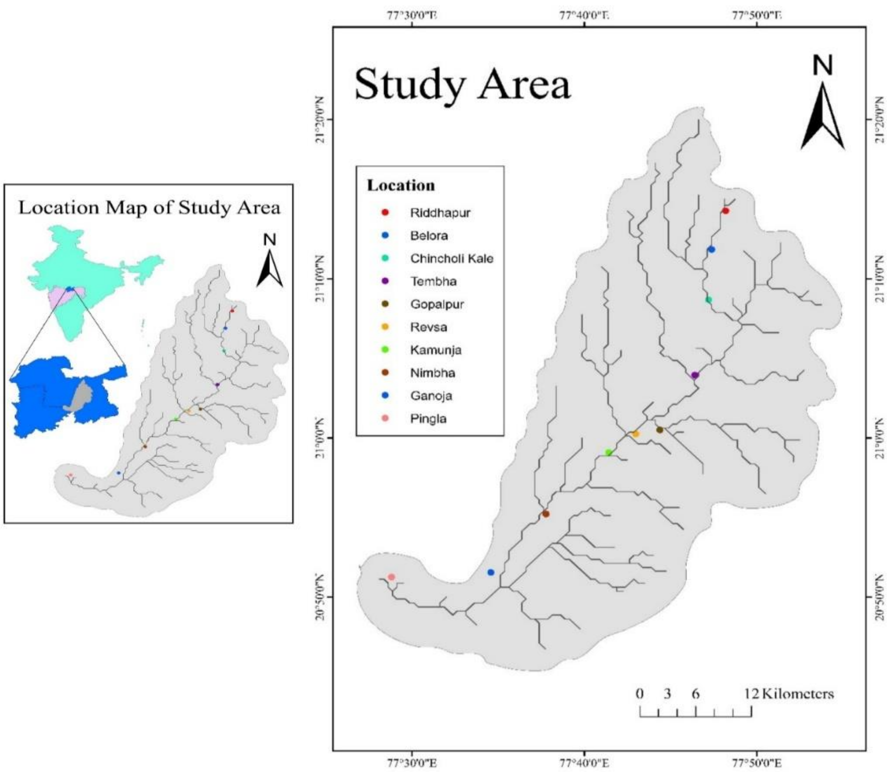

Figure 1: Location map of the Study Area

METHODOLOGY

For granulometric analysis, ten sediment samples were collected at ~5 km intervals along a longitudinal section of the Pedhi River to ensure representative spatial coverage. The samples were air-dried, and representative subsamples were prepared using the coning-and-quartering method.

Prior to sieving, samples were chemically treated to remove cementing agents: carbonates were dissolved using 10% HCl, organic matter was removed with 0.6% oxalic acid, and sodium hexametaphosphate was added as a dispersing agent to prevent flocculation. A 100 g portion of each treated sample was analyzed using the standard dry sieve technique.

The sieve stack was arranged in descending order according to the phi (Φ) scale and included 18 mesh (0 Φ), 35 mesh (1 Φ), 60 mesh (2 Φ), 120 mesh (3 Φ), and 230 mesh (4 Φ), with a bottom pan to collect finer particles.

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Samples were mechanically shaken for 30–40 minutes, and the weight retained on each sieve was recorded as percentage and cumulative weight.

These data were used to calculate mean grain size, sorting (standard deviation), skewness, and kurtosis following the graphical method proposed by Robert L. Folk (1980), a standard approach in sedimentological studies.

RESULTS AND DISCUSSION

The table presented below displays the cumulative weight of material retained on each sieve during the sieving process. (Table 1)

Table 1: Cumulative weight percentage frequency of sediment samples from different areas

VILLAGE											
MESH SIZE	PHI VALUE	Ri	Be	Ck	Te	Gp	Re	Ka	Ni	Ga	Pi
18	0	48	51	60	62	60	62	49	48	49	49
35	1	94	90	96	91	95	92	70	90	82	77
60	2	98	99	99	99	98	99	95	99	95	93
120	3	98.83	99.44	99.17	99.18	98.3	99.41	98.33	99.14	99.68	95.62
230	4	98.919	99.56	99.19	99.24	98.61	99.58	99.02	99.18	99.02	97.86
Bottom Pan	4.25	99.069	99.61	99.27	99.33	98.98	99.57	99.29	99.26	99.02	98.11

The table below shows the graphic measures and statistical parameters calculated using standard formulas. (Table 2)

Table 2: Graphic mean and statistical parameter of the sample.

Village/ Phi value	Φ95	Φ84	Φ75	Φ50	Φ25	Φ16	Φ5	Φ1	Mz	σ1	Sk1	KG	C in Micron	M in Micron
Ri	1.6592	0.8792	0.6596	0.0596	-0.5404	-0.6808	-0.8404	-0.9898	0.086	0.7687	0.3051	0.8536	1981.9	967.1
Be	1.6808	0.9404	0.7004	0.0404	-0.5392	-0.6592	-0.7996	-0.9796	0.1072	0.7757	0.3852	0.9390	1962.6	972.1
Ck	1.1396	0.6596	0.3596	-0.1408	-0.5404	-0.6604	-0.9004	-0.9208	-0.0472	0.6390	0.2339	0.9289	1854.4	1014.7
Te	1.6796	0.7196	0.5204	-0.1804	-0.6196	-0.6602	-0.8596	-0.9796	-0.0403	0.6933	0.3847	0.9275	1962.6	1027.4
Gp	1.2392	0.6992	0.4184	-0.4612	-0.2812	-0.7012	-0.8212	-0.9412	-0.1544	0.6622	0.6508	1.2070	1897.7	1120.8
Re	1.4192	0.7796	0.44	-0.1408	-0.5608	-0.7408	-0.8608	-0.9004	-0.102	0.7255	0.2895	2.0008	1815.3	1014.7
Ka	2.4992	1.7396	1.3796	-0.0004	-0.3808	-0.6208	-0.8602	-0.9804	0.3728	1.0991	0.4811	0.7821	1964.3	1000.3
Ni	1.5608	0.8804	0.5204	0.1208	-0.4396	-0.5992	-0.8392	-0.9756	0.134	0.7335	0.1133	1.024	1955.5	917.6
Ga	2.3966	1.1396	0.8192	0.0992	-0.3808	-0.6208	-0.8404	-0.9808	0.206	0.9305	0.3007	1.1055	1965.1	930.6
Pi	2.8604	1.4396	1.0004	0.0596	-0.4996	-0.6796	-0.7804	-0.9796	0.74688	1.0814	0.4203	0.9947	1962.4	967.1

Cumulative frequency curve

A frequency curve was generated by plotting the cumulative weight percentage of sediment particles against their corresponding grain sizes. This curve provides insights into the distribution and sorting of grains within the sample.

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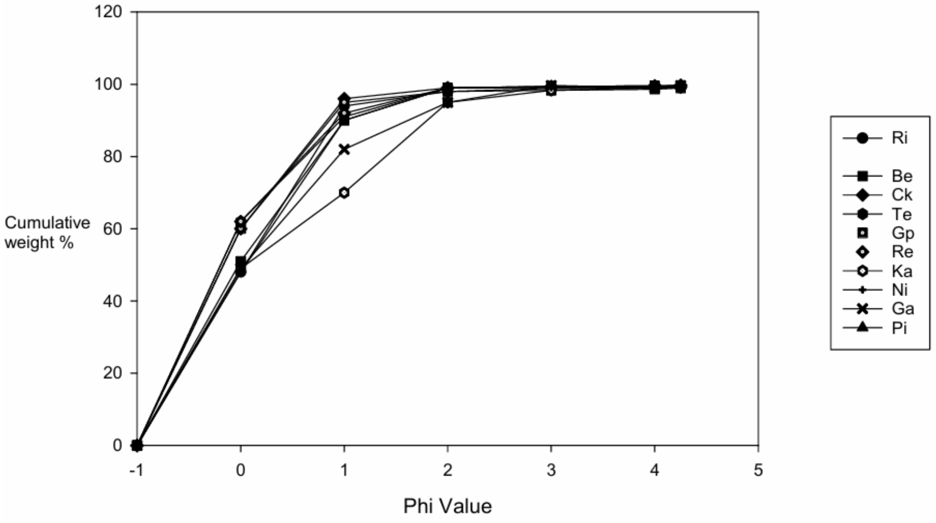

Figure 2: Cumulative frequency curve

Statistical Parameters

Graphic Median (Φ50):

The median grain size, first introduced by Paul D. Trask (1930), represents the grain diameter at which 50% of the particles (by weight) are finer, and 50% are coarser. It is determined from the 50th percentile (Φ50) of the cumulative frequency curve (Folk, 1966) and is commonly expressed in phi (Φ) units to allow comparison across a wide range of grain sizes. The median serves as an indicator of depositional energy, with coarser values suggesting high-energy environments and finer values reflecting lower-energy settings.

In the present study, median values range from –0.4612Φ to 0.1208Φ, with an average of –0.0544Φ, indicating dominance of coarse gravel close to the fine-gravel boundary. However, samples from Riddhapur, Nimbha, Ganuja, and Pingla show slightly higher (positive) Φ values, suggesting the presence of relatively finer material within the sediment admixture.

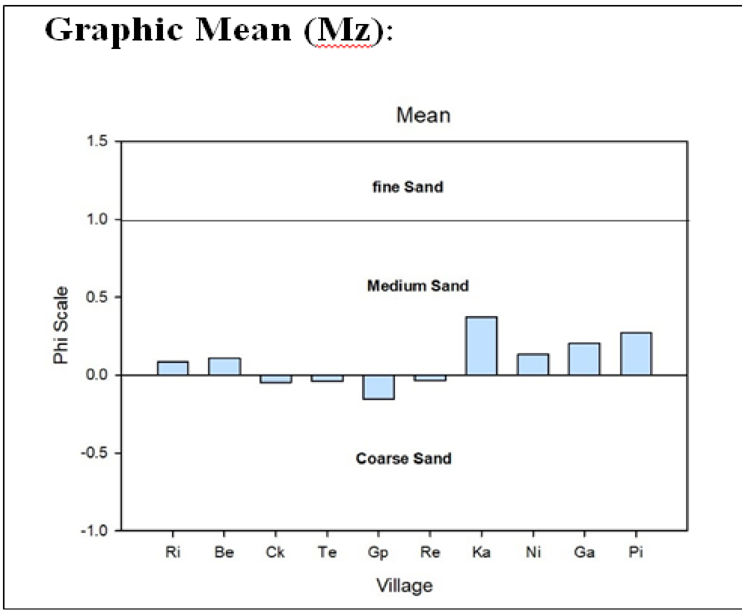

Figure 3: Graphic mean value of all samples

The Graphic Mean (M_z) (Figure 3) introduced by Robert L. Folk is regarded as the most suitable graphic parameter for estimating the overall average grain size. It is calculated as:

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$M_Z = \boxed{(\Phi16 + \Phi50 + \Phi84) / 3}$

This parameter closely approximates the arithmetic mean calculated by the method of moments, but is much simpler to compute. Because it incorporates three percentile values, it provides a more reliable measure of central tendency than the median, which is based on a single percentile. For this reason, it is widely preferred as the standard measure of mean grain size (Folk, 1980). In contrast, Donald L. Inman (1952) proposed calculating mean size using (Φ16 + Φ84) / 2; however, this approach is less dependable for skewed distributions, as it does not adequately account for asymmetry in the grain-size curve. The calculated values range from -0.1544Φ to 0.74688Φ, with an average of 0.1310φ, indicating the coarse-to-very-coarse nature of the sediment. However, Chincholi kale, Tembha, Gopalpur, and Rewsa are high, i.e. -0.0472Φ, -0.0403Φ, -0.1544Φ and -0.102Φ, fall under the very coarse category.

Graphic Standard Deviation (σ_I)

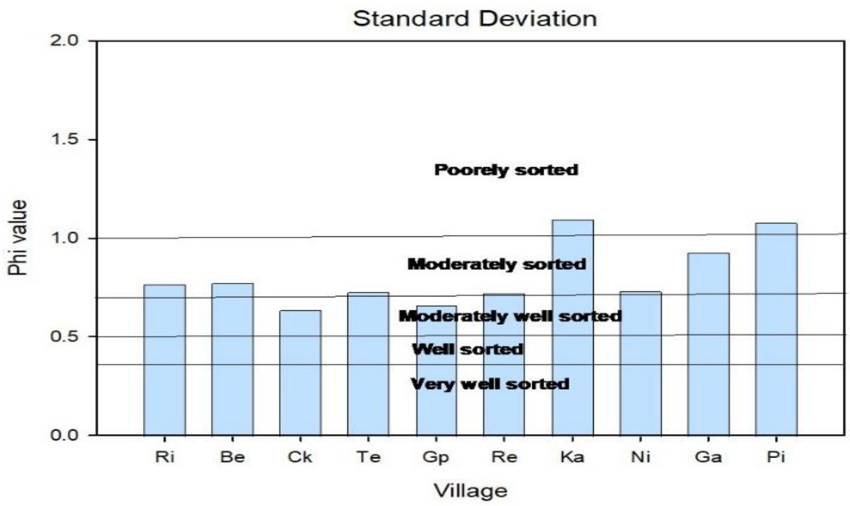

Figure 4: Standard deviation of all samples

Sorting refers to the degree of uniformity in grain sizes within a sediment sample. Well-sorted sediments consist of particles of similar size, whereas poorly sorted sediments contain a wide range of grain sizes. To quantify sorting, Robert L. Folk (1968) introduced the inclusive graphic standard deviation (σ_1), which is calculated from selected percentiles of the cumulative grain-size distribution curve.

$$\boxed{\sigma_1 = \{(\Phi84-\Phi16)/4\} + \{(\Phi95-\Phi5)/6.6)\}}$$

The range of calculated values of graphic standard deviation is from 0.6390Φ to 1.0991Φ, with an average value of 0.8109Φ, i.e., moderately sorted (Figure 4).

Inclusive Graphic Skewness (Sk_i)

Skewness refers to the extent to which a cumulative grain-size curve deviates from perfect symmetry. Even if two sediment samples have identical average grain sizes and sorting, they can still differ in the symmetry of their grain-size distributions. Folk's "inclusive graphic skewness" method (1968) calculates skewness using an equation based on specific percentile values, similar to those used in sorting. This method accounts for both the central part of the distribution and its extreme ends, or "tails." In contrast, earlier methods by Inman (1952)

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Trask (1950) do not consider the tails. A perfectly symmetrical distribution has a skewness value of 0.00. Samples with more fine particles show positive skewness, while those with more coarse particles show negative skewness. According to Folk's classification (1968), skewness values between +0.10 and -0.10 are considered nearly symmetrical; values from -0.10 to -0.30 indicate coarse-skewed distributions; and those ranging from -0.30 to -1.00 represent strongly coarse-skewed sediments.

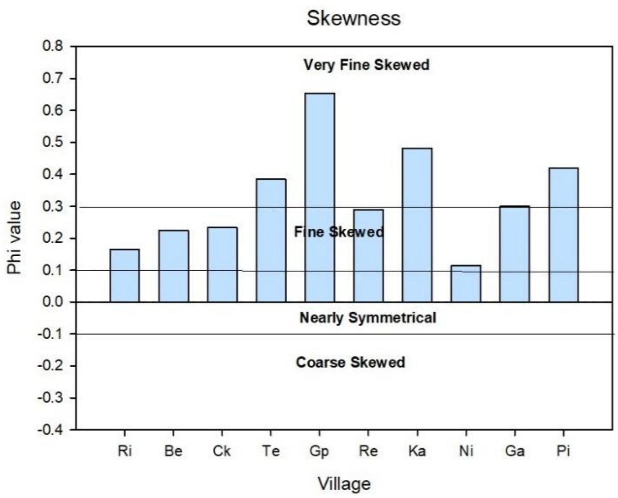

Figure 5: skewness of all samples

$$SkI = \frac{\Phi 16 + \Phi 84 - 2\Phi 50}{2(\Phi 84 - \Phi 16)} + \frac{\Phi 5 + \Phi 95 - 2\,\Phi 50}{2(\Phi 95 - \Phi 5)}$$

The obtained value ranges from 0.1133Φ to 0.6508Φ with an average of 0.32668Φ, which indicates the very fine skewed (positive skewed) nature of sediments, i.e. presence of medium to coarse size grains (Figure 5).

Inclusive Graphic Kurtosis (K_G)

Kurtosis describes how peaked a grain-size distribution curve is. Using Robert L. Folk's (1968) percentile-based formula, a normal (Gaussian) distribution has a kurtosis of 1.00, indicating equal sorting in the centre and tails. Values greater than 1.00 indicate a leptokurtic (sharply peaked) distribution with grains concentrated near the centre, while values less than 1.00 indicate a platykurtic (broadly peaked) distribution with better sorting in the tails than at the centre. The value of the range with respect to the nature of the distribution is given below.

The obtained value ranges from 0.7821Φ to 2.0008Φ, with an average of 1.07661Φ, indicating a mesokurtic distribution. However, Gopalpur shows a leptokurtic distribution with a value of 2.0008Φ (Figure 6).

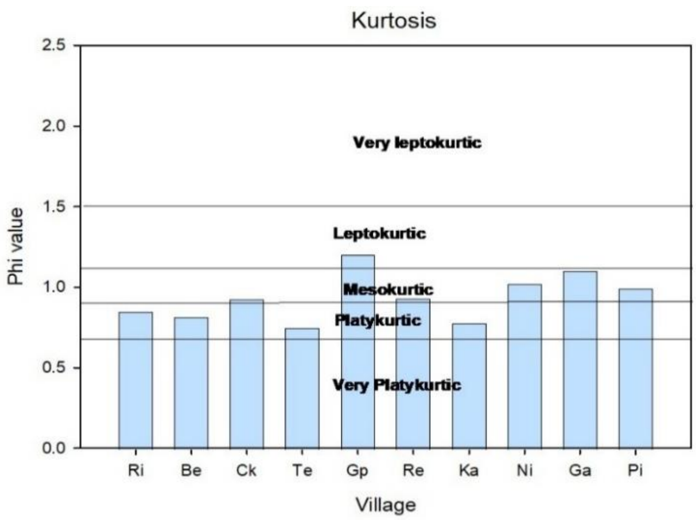

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Figure 6: Kurtosis of all samples

Bivariate plots

Bivariate plots illustrate how specific grain-size parameters relate to one another and are valuable tools for interpreting sedimentation patterns, modes, and depositional environments, as described by Folk and Ward (1957). Bivariate plots illustrate how specific grain-size parameters relate to one another and are valuable tools for interpreting sedimentation patterns, modes, and depositional environments, as described by Folk and Ward (1957).

The skewness values were plotted against the graphic mean to show that most of the sediments are fine- to very fine-skewed. At the same time, the diagram also reveals that the sediments are generally coarse to very coarse in grain size. This combination suggests that the energy of the transporting medium has varied over time, strong enough to carry and deposit coarse grains, but with occasional drops in energy that allowed finer particles to settle as well (Figure 7).

The Relationship between mean size and kurtosis is complex and theoretical (Folk & Ward, 1957). The plot of the present value indicates a dominance of the mesokurtic category. It suggests that most particles are close to the average size, with a balanced amount of finer and coarser grains (Figure 8).

The mean-versus-standard-deviation plot provides valuable insights into the depositional environment. When a broad spectrum of grain sizes—from gravel to clay—is present, the data points typically form a scattered band resembling part of a widened M-shaped pattern. In contrast, a narrower grain size range results in a V-shaped or inverted V-shaped trend, and if the size range is extremely limited, only one arm of the V-shape may be visible.

The graph plotting mean grain size against standard deviation shows that most data points are clustered within a narrow range of mean on the right side of the inverted V-shaped trend described by Folk and Ward (1957), with standard deviation values falling within the range of 0.7 to 1.0, indicating moderately sorted material (Figure 9).

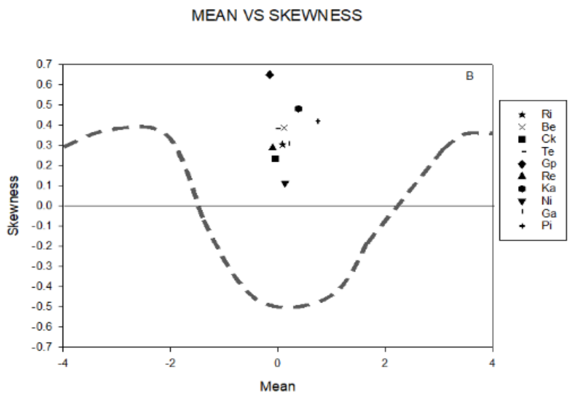

Figure 7: Mean vs Skewness

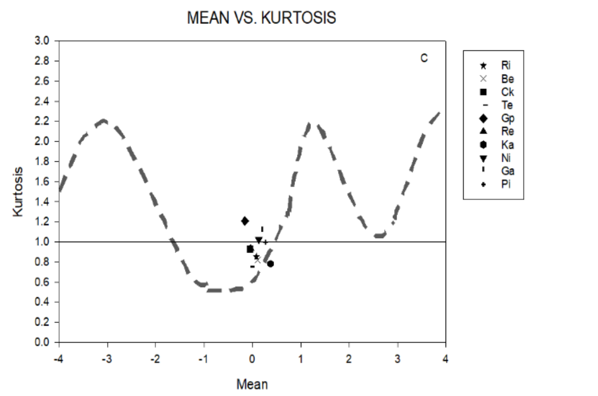

Figure 8: Mean vs Kurtosis

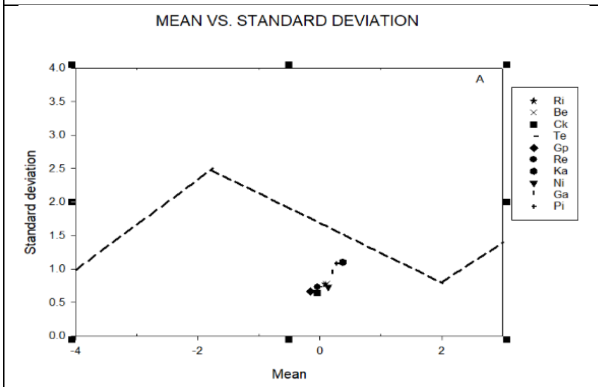

Figure 9: Mean vs Standard deviation

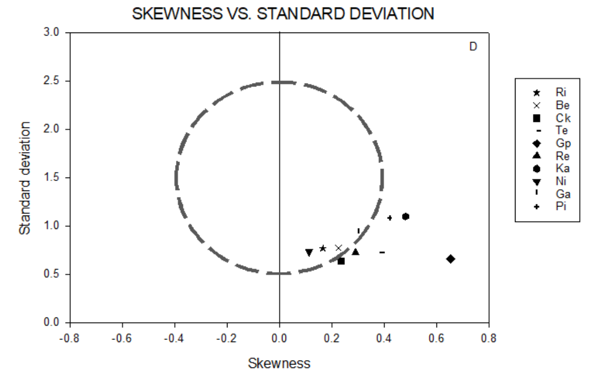

Figure 10: Skewness vs Standard deviation

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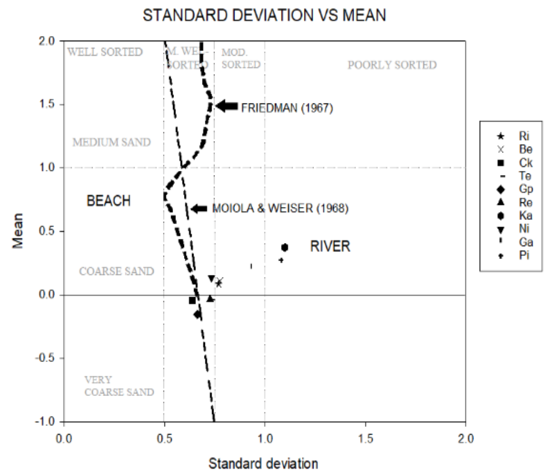

Figure 11: Standard deviation vs Mean

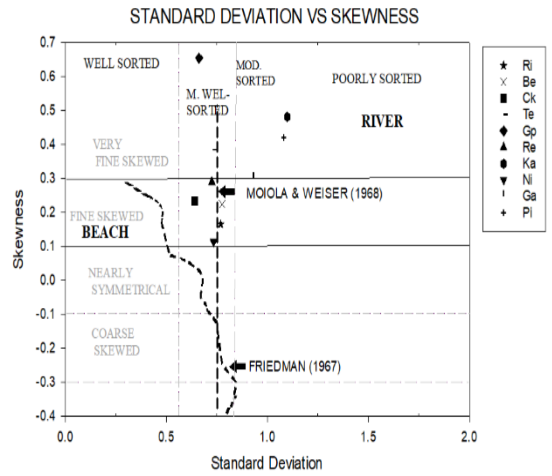

Figure 12: Standard deviation vs Skewness

The graph of skewness versus standard deviation shows a scattered pattern forming an almost circular ring, as noted by Folk and Ward (1957). The present values on the graph clearly indicate very fine, skewed, moderately sorted sediments (Figure 10).

The graphs of standard deviation versus mean and standard deviation versus skewness, as suggested by Moiola and Weiser (1968) and Friedman (1961, 1967), were also used to validate our findings. These plots are effective in distinguishing between river and beach sediments. As anticipated, our sediment samples aligned with the characteristics typical of riverine environments, consistent with the criteria established by Moiola and Weiser (1968) and Friedman (1961, 1967). (Figure 11& 12).

C-M Pattern

Passega (1957, 1964, and 1977) developed the C-M diagram to analyze the influence of hydrodynamic tractive currents involved in sediment deposition. This plot represents the relationship between C, the coarsest 1st percentile grain size (in microns), and M, the median grain size (also in microns), using a logarithmic probability scale. The C-M plot helps identify the energy conditions and transport mechanisms active during sedimentation.

The C–M plot shows that the coarsest grain sizes (C) exceed the median (M), with data points lying above and to the right of the C = M (1000) line. This indicates a saltation transport condition, in which sediments are moved by moderate river energy in short hops along the bed. It suggests that the river flow was strong enough to briefly lift particles but not to sustain full suspension, typical of dynamic fluvial environments.

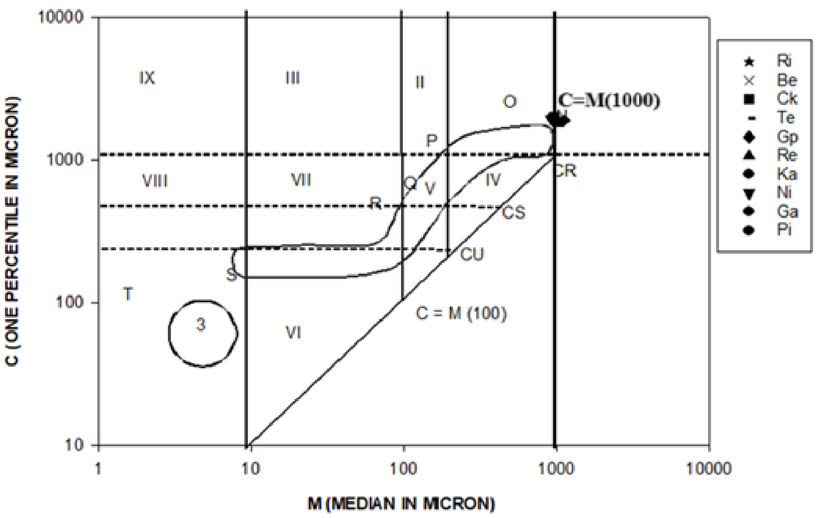

Figure 13: C-M Pattern

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Log probability curves

Log probability curves, introduced by Visher (1969), display cumulative grain-size distributions on probability paper. These curves are especially useful for distinguishing sediment transport modes, such as traction, saltation, and suspension, based on the shape and slope of different segments of the curve.

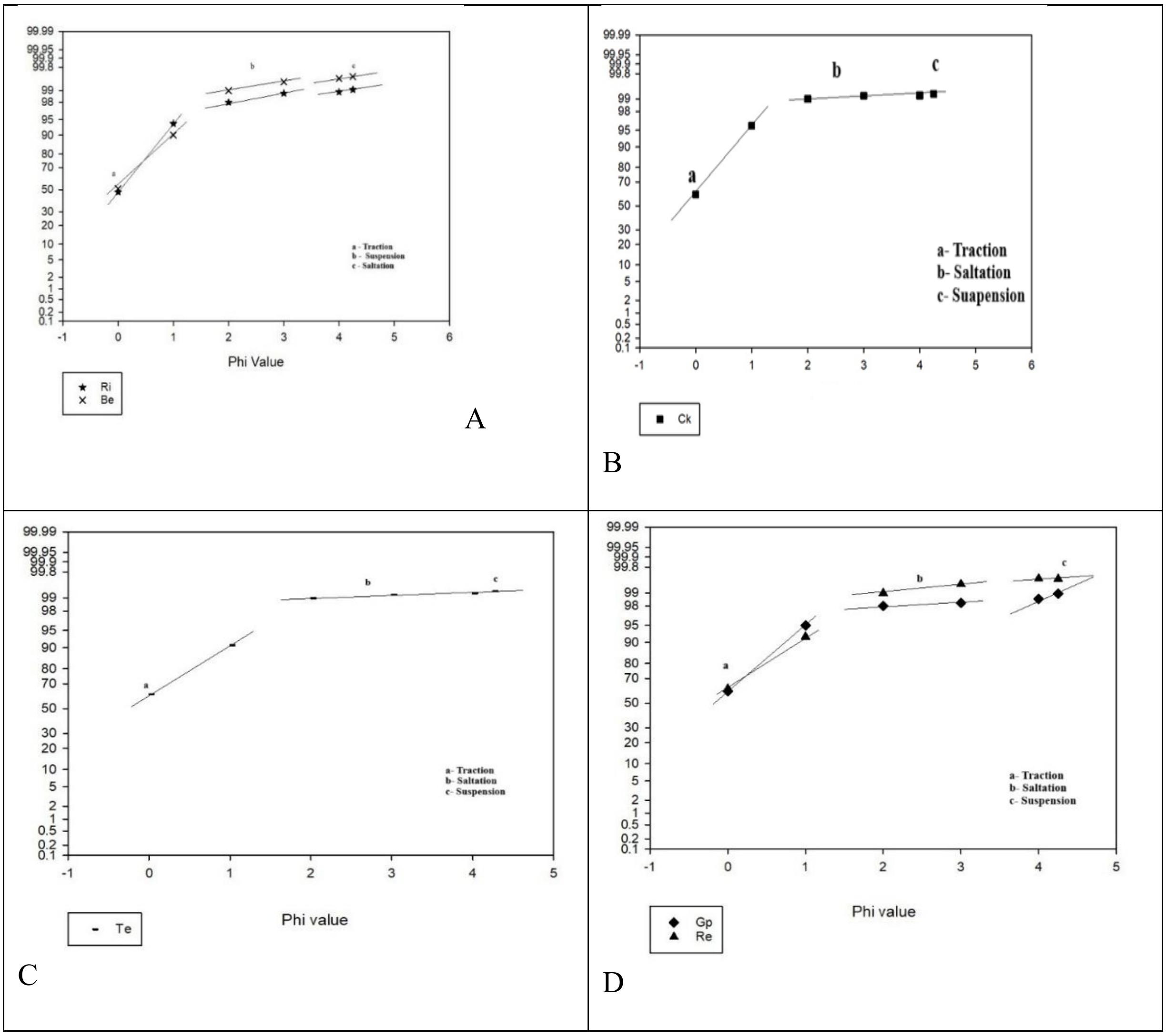

Figure 14: Arithmetic curve (A-D) showing the trend of traction (a), Saltation (b) and suspension (c)

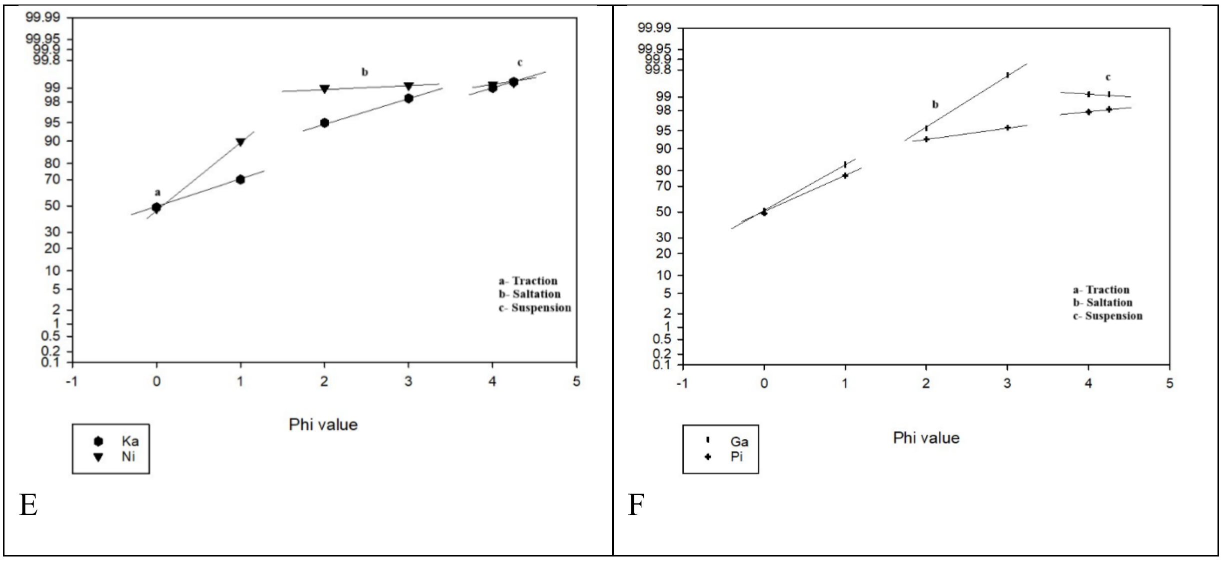

Figure 15: Arithmetic curve (E & F) showing the trend of traction (a), Saltation (b) and suspension (c)

The graph shows that saltation is the main sediment transport mode, meaning medium-sized particles are moved in short hops. Traction is minimal, indicating few large particles, and suspension is low, suggesting little very fine sediment or low turbulence. This suggests a moderate-energy environment like a riverbed or wind-blown surface

CONCLUSION

A total of ten sediment admixture samples collected from the Pedhi River basin were analyzed to determine their textural characteristics and statistical parameters. The cumulative frequency curves indicate a dominance of coarse to very coarse sand, which is consistent with the calculated graphic mean values. Overall, the sediments are moderately sorted, predominantly very fine skewed, and largely mesokurtic in nature. Interrelationship plots of mean grain size, standard deviation, skewness, and kurtosis were interpreted following the method of William C. Krumbein and William C. Ward (1957). The skewness versus mean plot reveals that although the sediments are mainly coarse to very coarse grained, they display fine to very fine skewness, indicating the presence of a noticeable proportion of finer material mixed with larger grains. This pattern reflects fluctuating energy conditions typical of dynamic depositional environments, where both coarse and fine particles are deposited together, resulting in incomplete sorting. The relationship between mean grain size and kurtosis demonstrates the predominance of mesokurtic sediments, suggesting a concentration of particles around the average size with a balanced distribution of finer and coarser fractions. The mean versus standard deviation plot shows clustering within a narrow mean range with moderate sorting, while the skewness versus standard deviation graph confirms very fine skewed, moderately sorted sediments. Additional bivariate plots based on the works of Robert J. Moiola and William C. Weiser (1968), and Gerald M. Friedman (1967), indicate a fluvial origin for the sediments. Furthermore, log-probability curves suggest that saltation was the dominant mode of sediment transport.

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