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# A Quantitative Geomorphological Analysis of Beach Sediments Along the Kanthi Coast of West Bengal and Odisha, India

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ABSTRACT

This research paper shows the beach segment-wise (viz., nearshore, surfing, sub-aerial, and backshore) textural characteristics and their impact on the formation of beach profiles. The grain size of the sediments is the most influential factor in the analysis of the geomorphological structure of sedimentation. The energy which is generated by waves and the grain size of sediments can change the structural pattern of the coastal beach. So it is obvious to study sedimentary textural distribution to know their influence on making coastal beaches. Through this research paper, the sedimentary textual distribution is analyzed and also gives their impact on beach shipping. Along longitudinal beach profile samples are collected. The work has been done based on the primary data source by using the field survey method. From this research work, it has been traced that beaches follow the concave pattern profile due to their fine sedimentary textural distribution. Consequently, the beaches of the Kanthi coast are dominantly facing the erosional configuration.

## INTRODUCTION

Coastal geomorphology is a branch of geomorphology in which the focus is on the area influenced by large bodies of water, including seas and oceans and a large lake (Davidson–Arnott, 2010). The landform which is covered by sand the in majority is known as a sandy beach. A coastal beach acts as a transitional zone between land and sea. As the coastal tract of the region falls in a transitional environment, it is subjected to both fluvial and marine erosional and depositional processes (Herlekar & Sukhtankar, 2011). According to Tanner (1974), the coast is referred to as a balanced tract of activity, three-dimensional geometry, and sedimentation. In the world, the coast is one of the most dynamic fields in nature. The most important aspect of the beach is its dynamic behavior due to the continuous response of the beach sediments to the changing waves and currents of the nearshore waters (Sharma et al. 2016). The study of textural characteristics has been carried out by many researchers along the east and west coasts of India (Dora et al., 2011; Natesan et al., 2012; Rajganapathi et al., 2013; Viveganandan et al., 2013; Neelima et al., 2017; Pradhan et al., 2020).

Grain size is one of the most significant physical properties of sediment and commonly used parameter for understanding the processes involved in the transportation and deposition of sediments (Inman, 1952; Folk & Ward, 1957; Mason & Folk, 1958; Friedman, 1961; Krumbein & Sloss, 1963; Nordstrom, 1977; Parthasarathy et al., 2016). Thus, the knowledge of sediment size and textural parameters is one of the better tools for differentiating various depositional environments of recent as well as ancient sediments (Inman, 1952; Mason & Folk, 1958; Friedman, 1961; Folk, 1974; Nordstorn, 1977; Dyer, 1986; Kumar et al., 2010). Besides, sediment texture acts as an instrument for fundamental analysis of the origin of coastal sediments, the prevalence of oceanographic conditions, and sediment transport processes (Komar, 1998; Pentney & Dickson, 2012; Pradhan et al., 2020). Accordingly, spatial and temporal changes in grain size parameters are used to understand coastal processes (e.g., net, longshore, and cross-shore sediment transportation) along with hydrodynamics and engineering applications (Amalan et al., 2018; Ratnayake et al., 2018; Gunasinghe et al., 2021; Perera et al., 2023).

The prime objective of the said research paper is to examine the sedimentary textural distribution at the different beach segments of the Kanthi coast. In addition, grain size analysis provides important information in ecological conservation for understanding habitat suitability, water quality and resource availability, and nutrient cycling (Siqueira-Silva et al.. 2020). Sediment grain size is a critical parameter in the beach nourishment process, affecting (i) stability (larger grain sizes like gravel, and cobble are resistant to erosion), (ii) beach profile (selection of sediment grain size depends on the desired beach profile), (iii) habitat (coarse sediments provide better habitat for larger organisms like crabs, whereas fine sediments provide better habitat for smaller organisms like worms), and (iv) cost (coarse grains are generally having high operation cost) (Ratnayake et al., 2019; Gunasinghe et al., 2022; Saengsupavanich et al., 2023). It has been observed that beaches of the Kanthi coast are made by finely sorted fine grain size. The lower standard deviation values indicate well-sorted samples under low-energy depositional conditions (Lopez, 2017; Yun et al., 2023). Beaches are characterized as swell Profiles with low beach angles. Accordingly, beach erosion is one of the main issues in coastal zone management (Palamakumbure et al., 2020; Ratnayake & Perera, 2022; Perera et al., 2023).

The study area lies along the east coast of India, which has an extensive coastline of about 3480km with diverse oceanographic conditions (Pradhan et al., 2020). The Kanthi Coast belongs to the emergent shoreline category of the N. Circas coast. Emergent straight shoreline, gentle slope, non-marshy shore beach, dunes, and spits are the dominant features of this beach. The sedimentary geology of the Great Bengal basin has been controlled by regional tectonic activities, quaternary as well as Holocene sea-level fluctuation and sedimentation history (Banerji, 1984; Hutchison, 1989; Achharyya et al., 2000; Goodbred & Kuehl, 2000; Morley, 2002; Alam et al., 2003; Sikder et al., 2003; Mukharjee et al., 2009; Jana et al., 2018). Kanthi coast is associated with seven beaches, viz. Junput, Shoula, Mandarbani, Tajpur, Shankarpur, Digha, and Talsari from east to west (Figure 1).

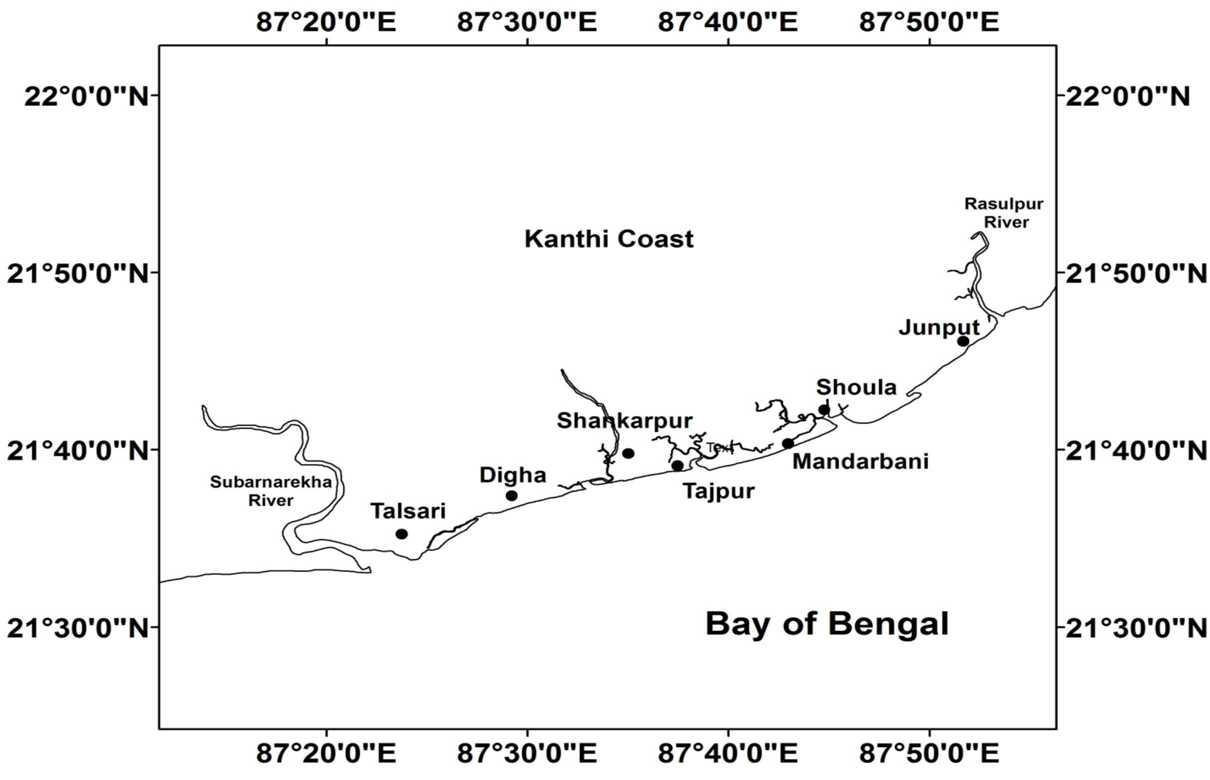


Figure 1. Location Map

The main objective of the said research is to determine how beach sedimentary configuration pronounces the wave energy for shaping the beach profile.

## METHODS

The grain size of the sediment is the most dominant factor in gathering the physical characteristics of the sediment. The depositional nature, the amount, and the velocity of the sediment transportation can easily be calculated by the grain size analysis method. According to Folk & Ward (1957), and Friedman (1979), the hydrodynamic and transportation properties are analyzed by some important sedimentary parameters viz., geographic mean, standard deviation, skewness, and kurtosis. Coastal sedimentology and morphodynamics are controlled by a variety of factors, including tides and waves, sea-level changes, rate of sediment supply, climatic and oceanographic settings, and geology (Wang, 2012; Kamble et al., 2022). The formula for calculating the graphic mean, standard deviation, skewness, and kurtosis is depicted (Baiyegunhi et al., 2017) in Table number 1. The parameters employed to describe the grain size distribution are categorized into four main groups that include, the mean, standard deviation, skewness, and kurtosis (Baiyegunhi et al., 2017). Since the end of the 19th century, these four parameters have been very significant in classifying sediments. Several formulas have been proposed by different workers to calculate four main statistical parameters viz. graphic mean, graphic standard deviation, graphic skewness, and graphic kurtosis (Wentworth, 1922; Friedman, 1961; Passega, 1964; Sahu, 1964; Venkatesan et al., 2017).

1. Mean Grain Size

Graphic Mean (Mz) is a measure of central Tendency (Suganraj et al., 2013). The collected sediment samples have been measured through the ASTM sieve in mm. However, it is complicated to measure mean grain size in the previously mentioned unit. To avoid this complication Krumbein (1934) introduced the Phi (ϕ) grain size, with the help of log2 transforms. The said transformation converted each of the Wentworth class limits into integers by the following equation.

$$\Phi = -\log 2\, d \qquad \text{------------- Eq1}$$

Where,

d = Sediment grain size diameter in mm.

Mean grain size (MZ) is a descriptive parameter of grain size that measures the arithmetic average size of all the particles in a sample (Baiyegunhi et al., 2017).

$$Mz\,(\phi) = \frac{\phi 16+\phi 50+\phi 84}{3} \text{ ---------------------Eq2}$$

The mean size of the sediments is influenced by the source of supply, medium of transportation, etc. Iwaki & Noda (1963) and Pethick (1984) stated that the diameter of the beach sediment and wave height are necessary for the transformation of beach steepness from a steep slope to a gentle slope and vice versa. According to Sahu (1964), the average kinetic energy and energy conditions of the depositing media are influenced by mean grain size. The scale factor is the method by which one can clearly understand the changes in the media and kinetic energy.

2. Standard Deviation (Sorting)

Standard deviation or grain-size sorting is a measure of the range of grain sizes present and the degree of spread or scatter of these sizes around the average or mean size (Baiyegunhi et al., 2017). The graphic standard deviation (σ1) is the measure of sorting or uniformity of particle size distribution (Suganraj et al., 2013). The inclusive graphic standard deviation is the mathematical expression for sorting (Baiyegunhi et al., 2017).

$$SD = \frac{(\phi 84-\phi 16)}{4} + \frac{(\phi 95-\phi 5)}{6.6} \qquad \text{----------Eq3}$$

Sahu (1964) examined, standard deviation measures for the sorting of sediments that assign the impatience of the kinetic energy or velocity conditions of the depositing agent. Sorting has an inverse relation with the standard deviation (Venkatesan et al., 2017). The fine sediments are finely sorted than coarser and medium sediments. The well-sorted character of sediments indicates a sudden winnowing or back-and-forth motion by the depositing agent (Suganraj et al., 2013). The sediments have a well-sorted nature indicating the many layers from breaking waves.

3. Graphic Skewness (Sk)

Sediment skewness is defined by deviating from the mean sediment size and sediment distribution (Yadhunath et al., 2014). Skewness is the measure of the asymmetrical distribution of sediment. It is an indicator of sub-population mixing. Duane (1964) observed that positive skewness characterizes the area of deposition and the sediments are negatively skewed owing to the influence of the cyclic current pattern, indicative of the high-energy environment prevailing there (Venkatesan et al., 2017).

$$Sk = \frac{(\phi16 + \phi84 - 2\phi50)}{2\,(\phi84 - \phi\,16)} + \frac{(\phi95 - \phi5)}{2\,(\phi95 - \phi5)} \quad \text{----Eq4}$$

Skewness is an expression of environmental energy. There is a correlation between environmental energy and skewness. Skewness is an expression of environmental energy. Positive skewness indicates sediment deposition under low-energy circumstances and negatively skewed sediment expresses deposition under high-energy environments. The skewness also reflects the variation in the energy conditions of the sedimentary process (Lopez, 2017; Mohanty et al., 2023).

4. Graphic Kurtosis (kG)

Graphic kurtosis (KG) is the peakedness of the distribution and measures the ratio between the sorting in the tails and the central portion of the curve (Parthasarathy et al., 2016; Shinde et al., 2020). The ratio of sorting between the finer and coarser deposits is measured by Graphic Kurtosis. This method also measures the central and normal distribution of deposits. The concentrated values and the highest accumulated values are measured with the help of Kurtosis. Through kurtosis, the sorting grade of the curve, the central part is compared with the two tails.

$$kG = \frac{(\phi95 - \phi5)}{(2.44\,(\phi75 - \phi25)\,)} \quad \text{-------Eq5}$$

According to Mason & Folk (1958), and Duane (1964), it has been observed that Kurtosis is the important textural parameter to evacuate the sedimentary environment. If the tails are better sorted than the central portions, then it is termed as platykurtic, whereas, leptokurtic, if the central portion is better sorted (Suganraj et al., 2013). If both are equally sorted then the mesokurtic condition prevails (Parthasarathy et al., 2016). The different kinds of values in Kurtosis represent the flow characteristics of the deposits.

## RESULTS AND DISCUSSION

### Beach Profile and Sedimentary Textural Analysis

Frequency distributions of sediment grain size (namely mean, sorting, skewness, and kurtosis) were used frequently to interpret the precipitation of sediment when they re-enter the natural environment (Folk & Robles, 1964; Dyer, 1986; Weltje & Von Eynatten, 2004; Wachecka-Kotkowska & Kotkowski, 2011). This research expresses the textural characteristics of the beaches and also analyses the nature of deposition (Table 1).

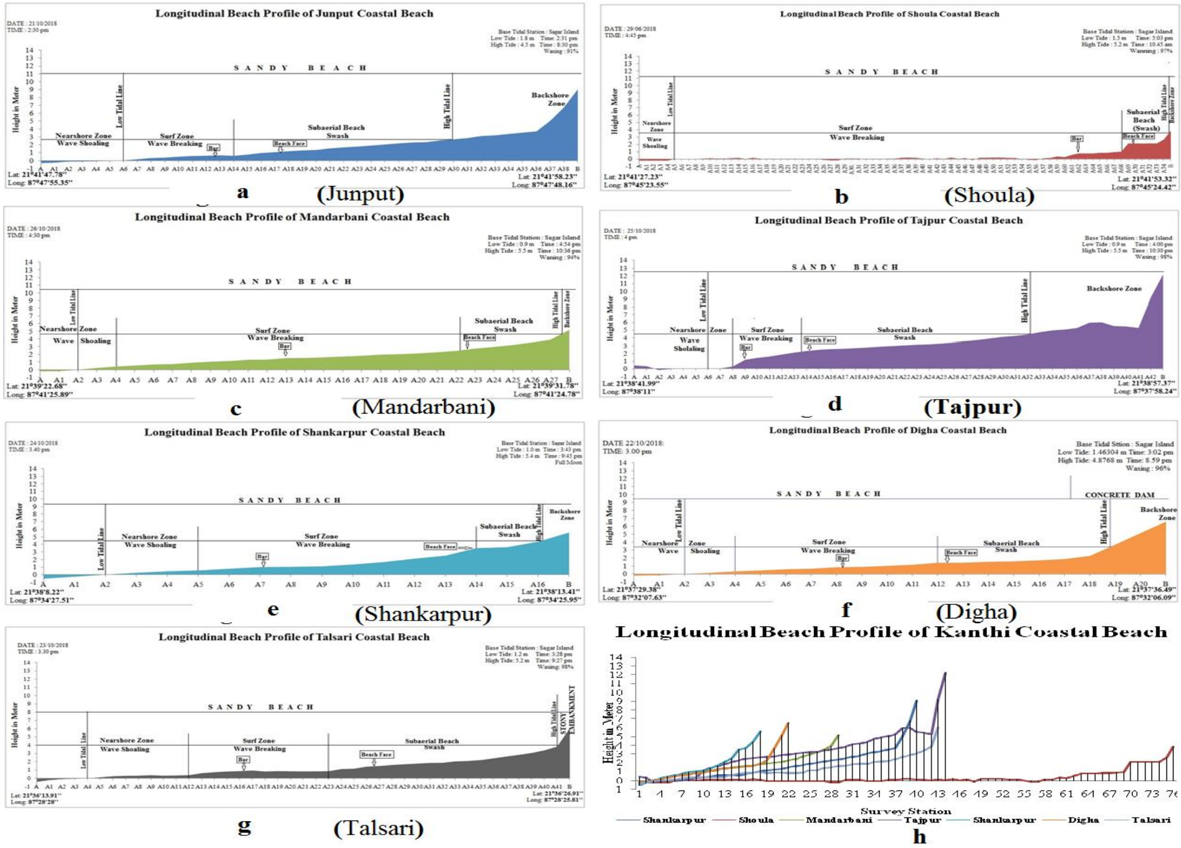


Figure 2. Longitudinal Beach Profile of Kanthi Coastal Beaches

Table 1. Sedimentary Textural Distribution of Kanthi Coastal Beaches

| Beach | Section of Beach Cross Profile | Sedimentary Texture (ϕ) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mz | | M | SD | | Sk | | kG | |
| Junput | Nearshore | 2.853 | FS | 2.95 | 0.569 | MWS | -1.046 | SCS | 1.917 | VL |
| | Surf | 3.317 | VFS | 3.4 | 0.471 | WS | -1.641 | SCS | 1.553 | VL |
| | Sub-aerial | 3.135 | VFS | 3.155 | 0.51 | MWS | -1.286 | SCS | 1.475 | L |
| | Backshore | 2.783 | FS | 2.8 | 0.545 | MWS | -1.169 | SCS | 0.871 | P |
| Shoula | Nearshore | 3.402 | VFS | 3.4 | 0.412 | WS | -2.235 | SCS | 1.152 | L |
| | Surf | 2.835 | FS | 2.9 | 0.501 | MWS | -1.360 | SCS | 1.037 | M |
| | Sub-aerial | 2.917 | FS | 2.95 | 0.515 | MWS | -1.236 | SCS | 0.554 | VP |
| | Backshore | 3.118 | VFS | 3.2 | 0.461 | WS | -1.445 | SCS | 1.338 | L |
| Mandarbani | Nearshore | 2.693 | FS | 2.605 | 0.830 | MS | -0.261 | CS | 1.248 | L |
| | Surf | 2.637 | FS | 2.605 | 0.565 | MWS | -0.825 | SCS | 1.123 | L |
| | Sub-aerial | 2.583 | FS | 2.6 | 0.441 | WS | -1.189 | SCS | 1.865 | VL |
| | Backshore | 2.468 | FS | 2.55 | 0.370 | WS | -1.569 | SCS | 1.388 | L |
| Tajpur | Nearshore | 2.685 | FS | 2.7 | 0.524 | MWS | -1.261 | SCS | 0.743 | P |
| | Surf | 2.62 | FS | 2.805 | 0.805 | MS | -0.699 | SCS | 1.071 | M |
| | Sub-aerial | 2.538 | FS | 2.505 | 0.542 | MWS | -1.024 | SCS | 0.776 | P |
| | Backshore | 2.355 | FS | 2.355 | 0.445 | WS | -1.124 | SCS | 1.321 | L |
| Shankarpur | Nearshore | 2.703 | FS | 2.65 | 0.585 | MWS | -0.908 | SCS | 0.820 | P |
| | Surf | 2.868 | FS | 2.9 | 0.559 | MWS | -1.245 | SCS | 0.825 | P |
| | Sub-aerial | 2.287 | FS | 2.305 | 0.373 | WS | -1.189 | SCS | 1.290 | L |
| | Backshore | 3.27 | VFS | 3.25 | 0.322 | VWS | -2.535 | SCS | 1.441 | L |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Digha | Nearshore | 3.283 | VFS | 3.40 | 0.216 | VWS | -0.941 | SCS | 3.484 | EL |
| | Surf | 2.817 | FS | 2.90 | 0.563 | MWS | -0.267 | CS | 0.615 | VP |
| | Sub-aerial | 2.950 | FS | 3.0 | 0.480 | WS | -0.298 | CS | 1.311 | L |
| | Backshore (Dune) | 2.753 | FS | 2.755 | 0.556 | MWS | -1.123 | SCS | 0.871 | P |
| Talsari | Nearshore | 2.783 | FS | 2.8 | 0.525 | MWS | -1.305 | SCS | 0.919 | M |
| | Surf | 2.85 | FS | 2.95 | 0.512 | MWS | -1.36 | SCS | 0.778 | P |
| | Sub-aerial | 2.652 | FS | 2.555 | 0.511 | MWS | -1.011 | SCS | 0.797 | P |
| | Backshore | 2.652 | FS | 2.555 | 0.511 | MWS | -1.011 | SCS | 0.797 | P |

Source: Field Survey and Observation (2016-18), Researcher Computation

**Note:** FS – Fine Sand, **VFS** - Very fine sand, **VWS** - Very well sorted, **WS** - Well sorted, **MWS** - Moderately well sorted, **MS** - Moderately sorted, **SCS** – Strongly Coarse Skewed, **CS** – Coarse Skewed, **VP** – Very Platykurtic, **P** - Platykurtic, **M** - Mesokurtic, **L** - Leptokurtic **VL**- Very Leptokurtic, **EL**- Extremely Leptokurtic.

**Beach Profile and Mean Grain Size**

1. Junput

Quantification of mean sediment grain size is a good indicator of coastal processes. The nearshore zone of Junput coastal beach is associated with fine sand particles (2.853 ϕ) due to depositional work by fluvial processes by the Rasulpur River and the fine sediment also due to depositional work by the tidal current in the past which is the major proof of seawater regression contends the backshore section (Table 1). The wave steepness is very low at the Junput coastal beaches. This circumstance is most favorable for a huge concentration of fine grain. The sub-aerial portion also consisted of very fine sand (3.135 ϕ) that indicates wind depositional work. Consequently, Junput coastal beach is shaped as a tide-dominated flat beach with a gentle beach face.

2. Shoula

Shoula is considered the semi-enclosed shoreline. The nearshore section of the Shoula beach cross profile has consisted of very fine sand (3.402 ϕ) particles due to deposition work by the tidal inlet (Table 1). The platform of the Shoula beach profile is longer than other beaches of the Kanthi coast due to depositional work by the fluvial process. Due to depositional work, the surfing portion of Shoula Beach is associated with a flat and long profile. It is concluded the tide-dominated area has experienced a high amount of sediment deposition. The backshore of the Shoula coast is furnished with a foreshore dune that is developed by wind action.

3. Mandarbani

About 12 km long shoreline is experienced as the largest shoreline of the Kanthi coast. The research has addressed that the beach cross profile consists of fine sand particles which predict the winnowing action, but it is negligible due to low wave steepness statistics (Table 1).

4. Tajpur

The Tajpur coastal beach is associated with fine grain particles that increase towards the backshore region (Table 1). It seems that the backshore portion of the said coastal beach is formed by the storm surgical wave.

5. Shankarpur

The nearshore, surf, and Sub-aerial zone of Shankarpur coastal beach are associated with fine sand particles and the grain diameter increases towards the surfing zone (Table 1). Thus, the Shankarpur longitudinal beach profile is characterized as a Steep beach face. However, the Backshore section has consisted of erosional dune features which are associated with very fine sand (3.27 ϕ) due to depositional work by the wind in the past.

6. Digha

Digha Beach has consisted of a fine-grained size (Table 1). Due to high steepness, the fine-grained profile is shaped as concave for the winnowing action. Therefore, it has been predicted that Digha is considered an erosional beach profile.

7. Talsari

The flat beach profile is associated with the fine sand particle that indicates the depositional work under the fluvial-environment circumstance of the Subarnarekha River at its estuarine region (Table 1).

**Beach Profile and Median Grain Size**

The median value of grain size occupies the value of fifty percentile. Sedimentary textural distribution and coastal waves play a dynamic behavior to shape and modification of the beach longitudinal profile. The high fluctuation of the median value predicts different work scenarios along with the beach cross profile and vice versa. Except for Mandarbani coastal beach, the rest of the beaches are experienced a high fluctuation of median grain size value that predicts different coastal processes in a different section of the beach cross profile (Table 1). However, the median value of Mandarbani coastal beach is the same at all sections of the beach which predicts the same coastal processes and their intensity is employed on the total Mandarbani beach.

**Beach Profile and Standard Deviation**

1. Junput

The nearshore (0.569 SD), Sub-aerial (0.51 SD), and backshore (0.545 SD) zone of Junput Beach is considered as the moderately well-sorted platform that indicates the moderate wave energy impaction on beach profiling (Table 1 & Figure 2a). However, the surfing (0.471 SD) zone of the beach is associated as a well-sorted platform that predicts to moderate to high wave dissipation on the beach (Table 1 & Figure 2a).

2. Shoula

The Nearshore (0.412 SD) section of the Shoula beach profile is termed as well sorted platform due to fine sand particles deposition by Pichhaboni and Kanthi Khal, the tidal inlets that predict moderate to high energy action by the coastal wave (Table 1 & Figure 2b). The Surf (0.501 SD) zone is considered as a moderately well-sorted flat platform that experienced moderate to low wave energy employment (Table 1). The Sub-aerial (0.515 SD) beach of the Shoula coast is associated as a moderately well-sorted platform with a steep beach face that indicates low wave energy impaction. The rest portion of Shoula, the backshore (0.461 SD) zone is quantified as well well-sorted platform due to the depositional work by the wind action (Table 1 & Figure 2b).

3. Mandarbani

From the median calculation of the beach, the profile has been interrelated in that the Mandarbani coast is a low-fluctuated beach platform. The said things are also revealed in the sorting quantification. The nearshore (0.830 SD) portion is considered as a moderately sorted platform that predicts stable beach conditions with low wave energy's wave impaction (Table 1 & Figure 2c). The wave surfing (0.565 SD) zone at Mandarbani coastal beach is a moderately well-sorted platform where wave energy dissipates in a very low account (Table 1). Also, the Sub-aerial (0.441 SD) and backshore (0.370 SD) zone is characterized as a well-sorted platform (Table 1 & Figure 2c).

4. Tajpur

The moderately well-sorted nearshore (0.524 SD) beach profile at Tajpur experienced moderate to low wave energy impaction (Table 1). The steep beach surfing zone faces low wave energy impaction on beach shaping due to moderately sorted tract that is a positive influence of depositional work (Table 1 & Figure 2d). The Sub-aerial (0.542 SD) section of the Tajpur beach profile is characterized as a moderately well-sorted tract due to the introduction of wind action during the dry time (Table 1 & Figure 2d). The rest portion, backshore (0.445 SD) of the Tajpur coast experiences wind deposition work that was predicted from the sorting assessment as well sorted.

5. Shankarpur

The nearshore (0.585 SD) and surf zone (0.559 SD) of Shankarpur sea beach is a moderately well-sorted lying sandy tract that experiences low wave energy impaction (Table 1 & Figure 2e). The Sub-aerial (0.373 SD) portion is associated with a steep well-sorted beach face (Table 1 & Figure 2e). Thus, maximum energy reflection has occurred towards the sea which helps to generate edge waves also. The erosional dune is located along the shoreline and backshore (0.332 SD) portion of the Shankarpur beach cross profile which had been formed due to depositional work of wind (Table 1 & Figure 2e). It has also been predicted from the quantification of sorting which is very well sorted.

6. Digha

The computation of standard deviation indicates well-sorted sedimentation in Digha coastal beach. Thus, the winnowing action is employed on the coastal beach. Due to erosional work, the Digha coast is shaped as a concave pattern that indicates

Digha as an erosional beach through moderate to high energy implications (Table 1 & Figure 2f).

7. Talsari

All portion of the Talsari beach profile is considered as a moderately well-sorted sand-lying tract. Thus, Talsari coastal beach is experienced Moderate to low wave energy implication to beach profiling which makes it a depositional coastal beach profile (Table 1 & Figure 2g). The Kanthi coastal beaches have consisted of very fine to fine sand particles. So these sand particles belong to sorted to moderately sorted categories. According to their sorting and wave steepness, the beaches have been shaped.

**Beach Profile and Skewness**

The aforesaid research work addresses, Junput, Shoula, Mandarbani, Tajpur, Shankarpur, and Talsari beaches profiles are strongly coarse skewed or negative skewness that indicates sediment deposition could be dominated by the high energy environment (Table 1). However, the skewness index of the Digha beach profile is coarse skewed or negative skewness that indicates the winnowing action of fine particles with high wave energy (Table 1).

**Beach Profile and Kurtosis**

1. Junput

At nearshore (1.917 kG) and surf (1.553 kG) beach portions of the Junput coast, the gradation of kurtosis is considered very leptokurtic where winnowing action has been entertained by multiple processes with good sorting and characterized as a very peaked curve (Table 1). The Sub-aerial (1.475 kG) portion is experienced as multiple processes have been employed to sediment erosional work with a moderately well-sorting platform. According to grain size, sediment distribution is characterized as a peaked curve. The rest zone, backshore (0.871 kG) is classified as platykurtic, where Particles concentrate in the center. Poor winnowing action is entertained at the backshore section without any sorting.

2. Shoula

The Nearshore (1.152 kG) zone of the Shoula coast is graded as leptokurtic which refers to a peaked curve. Multiple coastal processes of sediment erosion are employed with moderate well sorting at the nearshore zone (Table 1). The Kurtosis gradation of the Surf zone (1.037 kG) is considered as mesokurtic and sand particles concentrate in the middle. Sedimentary depositional work has been employed with moderately sorting littoral tracks. The Sub-aerial (0.554 kG) portion of Shoula coastal beach is characterized as very platykurtic where maximum particles concentrate at the center. As a nearshore zone, the backshore (1.338 kG) section of Shoula coastal beach is graded as leptokurtic (Table 1).

3. Mandarbani

The nearshore (1.248 kG), surf (1.123 kG), and backshore (1.388 kG) zone is considered as leptokurtic which indicates the peaked curve (Table 1). Multiple coastal processes are entertained low account sediment erosion with the moderately well-sorting sand platform. The Sub-aerial (1.865 kG) portion of the Mandarbani coast is graded as very leptokurtic which indicates to very peak curve and low to moderate sediment erosion by the multiple coastal processes.

4. Tajpur

The nearshore (0.743 kG) and Sub-aerial (0.776 kG) portion of the Tajpur coastal beach cross profile are classed as platykurtic which indicates that particles concentrate in the center and Poor winnowing is employed without any sorting. The surfing (1.071 kG) zone is considered as mesokurtic means particles concentrate in the middle (Table 1). Sediment deposition is a concerning incident with moderately sorting sandy platforms. The backshore (1.321 kG) zone is graded as leptokurtic by the previously mentioned computation indicating to peaked curve with the moderately well-sorted sand-lying platform (Table 1).

5. Shankarpur

The nearshore (0.820 kG) and surf zone (0.825 kG) are considered as platykurtic which indicates to maximum sand Particles concentrated in the centre (Table 1). Poor winnowing action is charged at the zones without any sorting. The rest portion, at the Sub-aerial (1.290 kG) and backshore (1.441 kG) zone, is graded as leptokurtic indicates to the peaked curve of sediment distribution, and is characterized as a moderately well-sorted platform (Table 1).

6. Digha

At the nearshore (3.484 kG) zone, Digha coastal beach is graded as extremely leptokurtic indicating the extremely peaked curve of sediment distribution. Multiple coastal processes have been employed to sedimentary erosional work on the very well-sorted nearshore platform (Table 1). The gradation of kurtosis is very platykurtic that predicts very poor winnowing action without any sorting at the surf zone (0.615 kG). The measurement of kurtosis at the Sub-aerial (1.311 kG) zone of the Digha coastal beach, is considered as leptokurtic indicating on the multiple processes engagement in the winnowing action of very fine particles on a moderately well-sorted platform (Table 1). Backshore (0.871 kG) dune is also graded as platykurtic where sand particles concentrate at the centre.

7. Talsari

The Nearshore (0.919 kG) zone of the Talsari coast is revealed as mesokurtic where maximum sand particles are lying in the middle (Table 1). In addition, it also indicates sediment depositional work on moderately sorted tracts. The rest portions of the beach cross profile at the surf (0.778 kG), Sub-aerial (0.797 kG), and backshore (0.797 kG) zone are characterized as platykurtic where sediments concentrate at the center (Table 1). The poor winnowing action is employed without any sorting.

**Beach Profile and Bi-variate Plots of Statistical Parameters**

Al-Ghadban, (1990); Sutherland & Lee, (1994); Martins, (2003); Srivastava & Mankar, (2009); Srivastava et al. (2010), and Srivastava et al. (2012) have a strong opinion that bivariate plots are a key tool to revealed the sedimentary depositional environment. The bivariate plot of skewness against standard deviation, skewness versus mean, kurtosis against skewness, and standard deviation versus mean was used to distinguish between the different depositional settings (Baiegunhi et al., 2017). The bivariate plots are based on the assumption that statistical parameters reliably reflect differences in the fluid-flow mechanisms of sediment transportation and deposition (Sutherland & Lee, 1994; Baiegunhi et al., 2017).

Table 2. Correlations of Sedimentary Statistical Parameters

| | | Mean Grain Size in Phi | Median Grain Size | Sorting of Grain Size | Skewness of Grain Size | Kurtosis of Grain Size |
|---|---|---|---|---|---|---|
| Mean Grain Size in Phi | Pearson Correlation | 1 | .977** | -.300 | -.434* | .343 |
| | Sig. (2-tailed) | | .00000 | .121 | .021 | .074 |
| Median Grain Size | Pearson Correlation | .977** | 1 | -.298 | -.404* | .392* |
| | Sig. (2-tailed) | .000 | | .123 | .033 | .039 |
| Sorting of Grain Size | Pearson Correlation | -.300 | -.298 | 1 | .549** | -.507** |
| | Sig. (2-tailed) | .121 | .123 | | .002 | .006 |
| Skewness of Grain Size | Pearson Correlation | -.434* | -.404* | .549** | 1 | -.066 |
| | Sig. (2-tailed) | .021 | .033 | .002 | | .737 |
| Kurtosis of Grain Size | Pearson Correlation | .343 | .392* | -.507** | -.066 | 1 |
| | Sig. (2-tailed) | .074 | .039 | .006 | .737 | |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Source: Researcher Computation

The above computation declares that there is a positive relationship between mean grain size and medium grain size (Table 2). But there no significant relation of sorting and kurtosis of the soil exists.

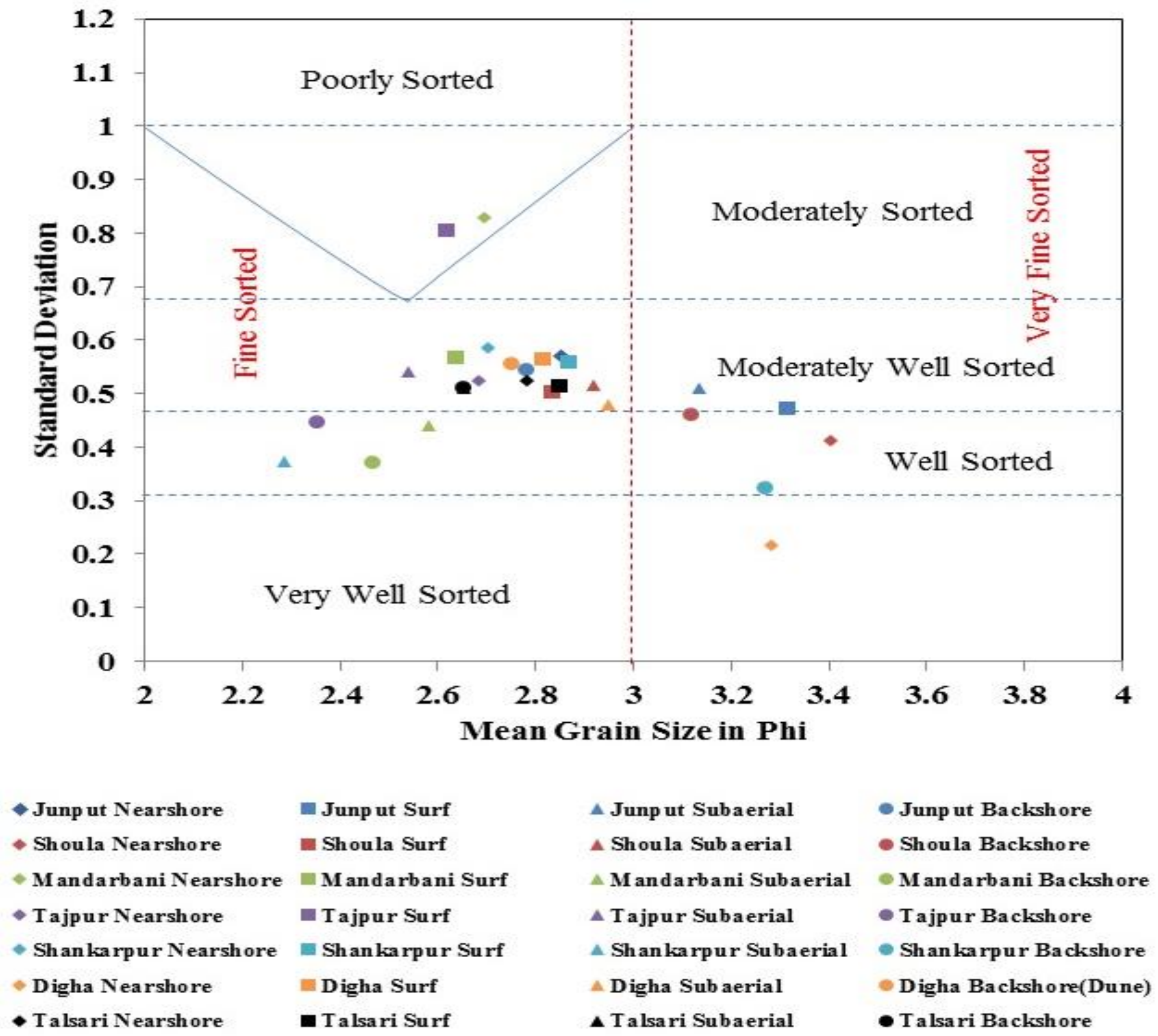


Figure 3. Sedimentary Textural Analysis by The Bi-variate Plotting (Mean Grain Size vs. Standard Deviation) After Folk and Ward (1957)

1. Mean Grain Size vs. Standard Deviation

At the M-shaped segment, the Wide range of grain diameter is pointed and at the V-shaped segment, the fine grain is pointed. According to Folk & Ward (1957), the Minima of best sorting coincides with prominent modes in the sediment, and maxima (poorest sorting) corresponds to mean sizes midway between modal diameters. The sediment samples of nearshore, surf, Sub-aerial, and backshore segment of Kanthi coastal beach is hooked at the base of a V-shaped trend which indicates that the said platform is characterized as well-sorted to moderately well-sorted platform due to very fine particle deposition (Figure 3).

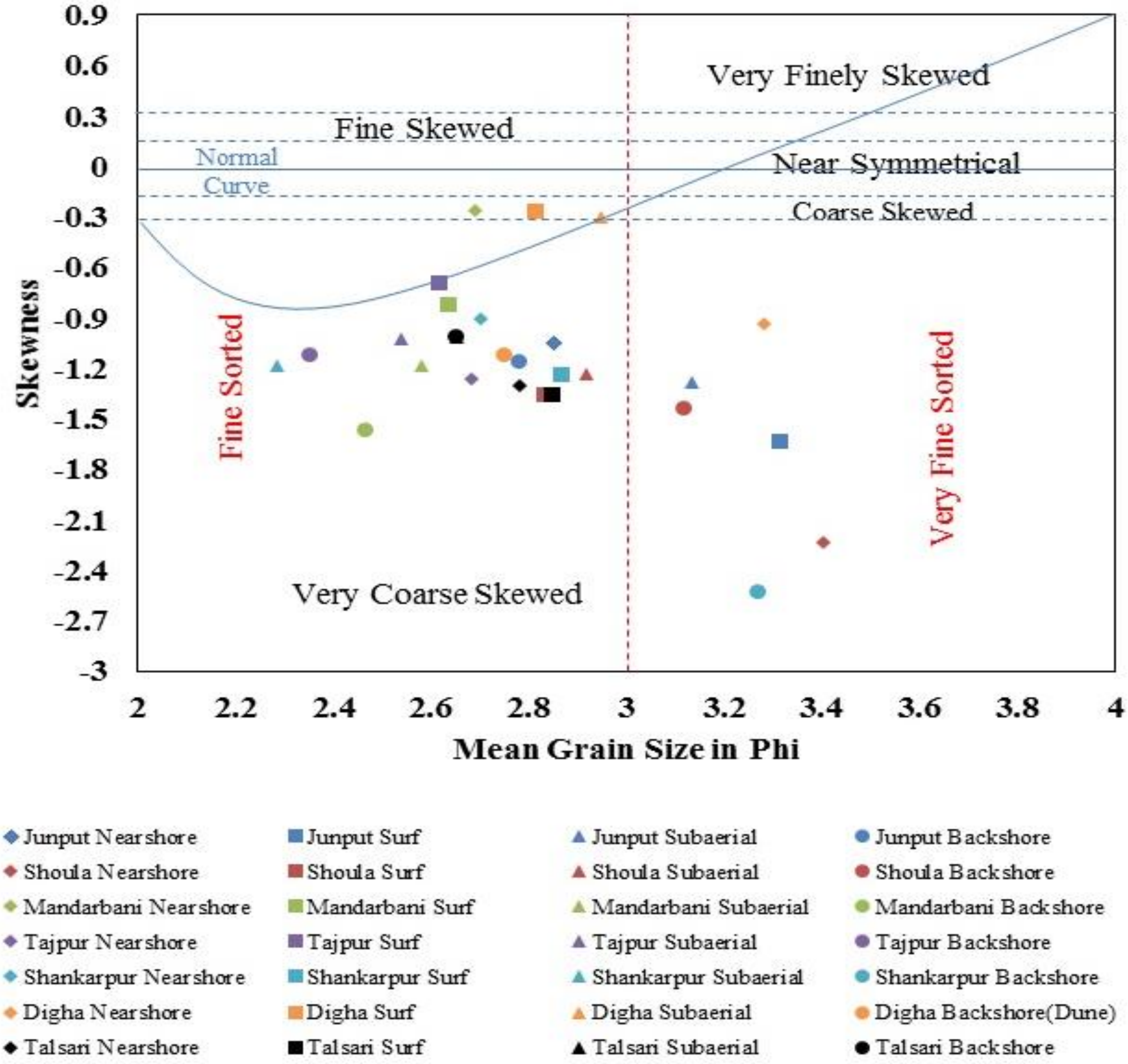


Figure 4. Sedimentary Textural Analysis by The Bi-variate Plotting (Mean Grain Size vs. Skewness) After Folk and Ward (1957)

2. Mean Grain Size vs. Skewness

The said bivariate relation is introduced about grain deposition and deduction by the coastal processes. A sinusoidal trend line has been marked in the scatter to show equality and stable conditions. Below the trend line, if sediment samples are pointed then will be considered as the negative depositional environment and vice versa. Kanthi coastal beaches are associated with very fine to moderately fine sand under the coarse skewed to strongly coarse skewed or under the negative depositional environment (Figure 4).

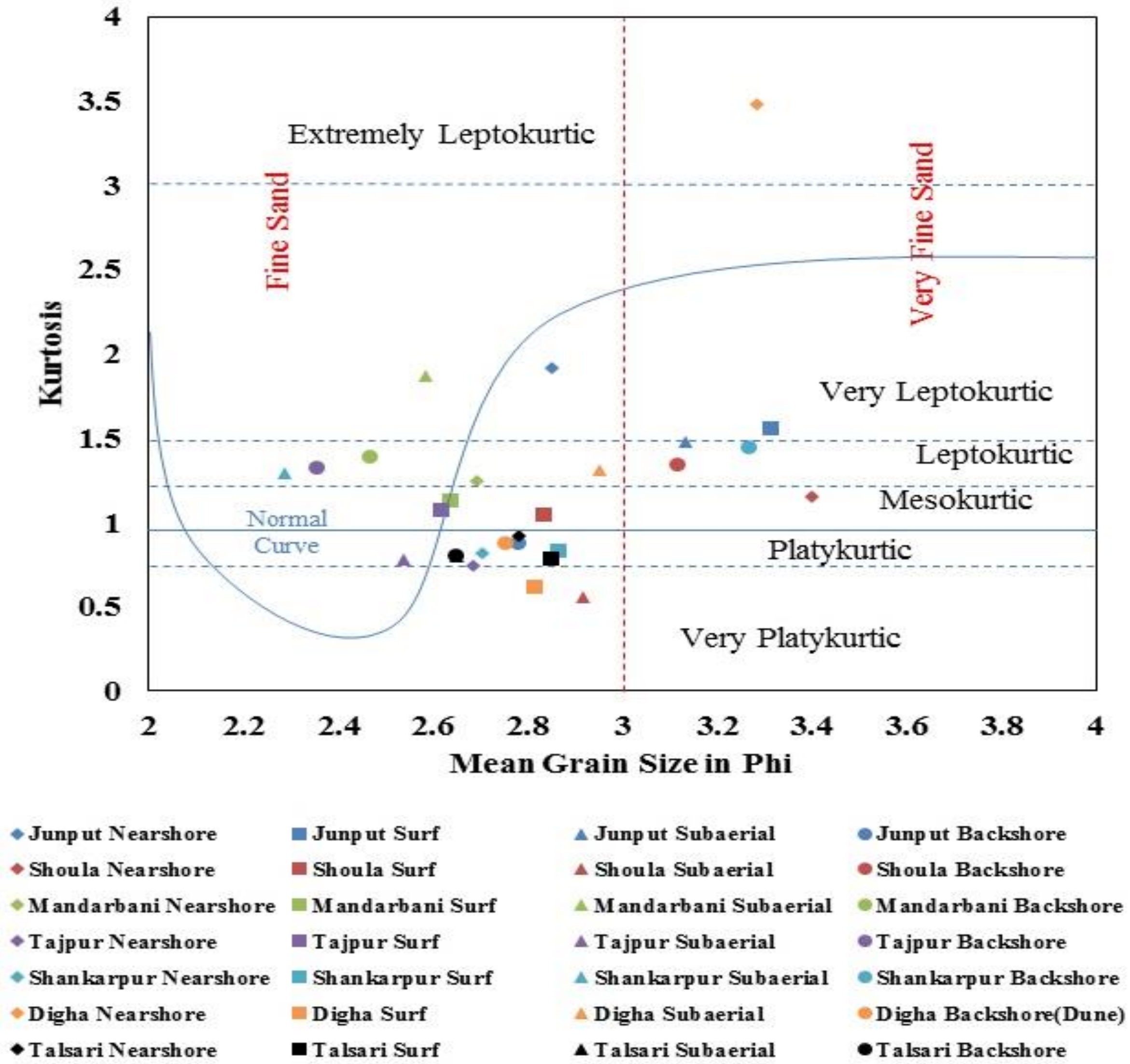


Figure 5. Sedimentary Textural Analysis by The Bi-variate Plotting (Mean Grain Size vs. Kurtosis) After Folk and Ward (1957)

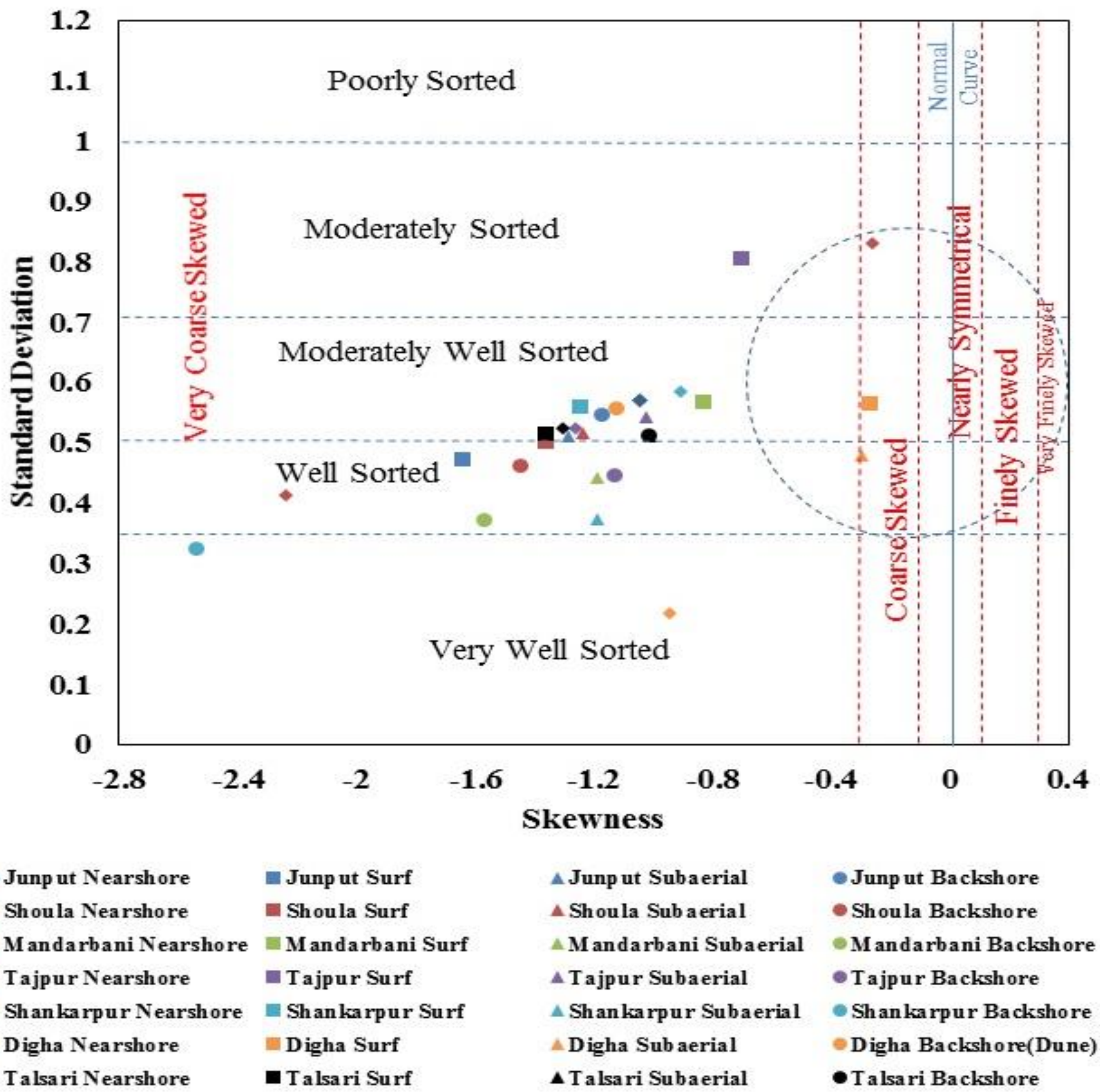


Figure 6. Sedimentary Textural Analysis by The Bi-variate Plotting (Skewness vs. Standard Deviation) After Folk and Ward (1957)

3. Mean Grain Size vs. Kurtosis

The sinusoidal curve is termed as a normal curve. Through this interaction, the depositional environment has been explored. Based on the model plot, it could be inferred that the scattering led to the mixing of two or more grain size classes, which influenced the sorting in peak and tails (index of kurtosis) as well as the inverted 'V' trend (Baiyegunhi et al., 2017). The beaches of the Kanthi coast consist of very fine sand to fine sand deposition, on well-sorted to moderately sorted platforms due to multiple coastal processes (Figure 5).

4. Graphic Standard Deviation vs. Skewness

The relation between skewness and the graphic standard deviation is addressed by the sedimentary depositional symmetrical. The area circular ring is termed a normal curve. The Clustered sediment samples of the beaches of Kanthi coast are plotted at the outside of the circular ring (Figure 6). It could be inferred that the scattering led to good sorting in unimodal sediments grain size class (Baiyegunhi et al., 2017), on well-sorted to moderately sorted track.

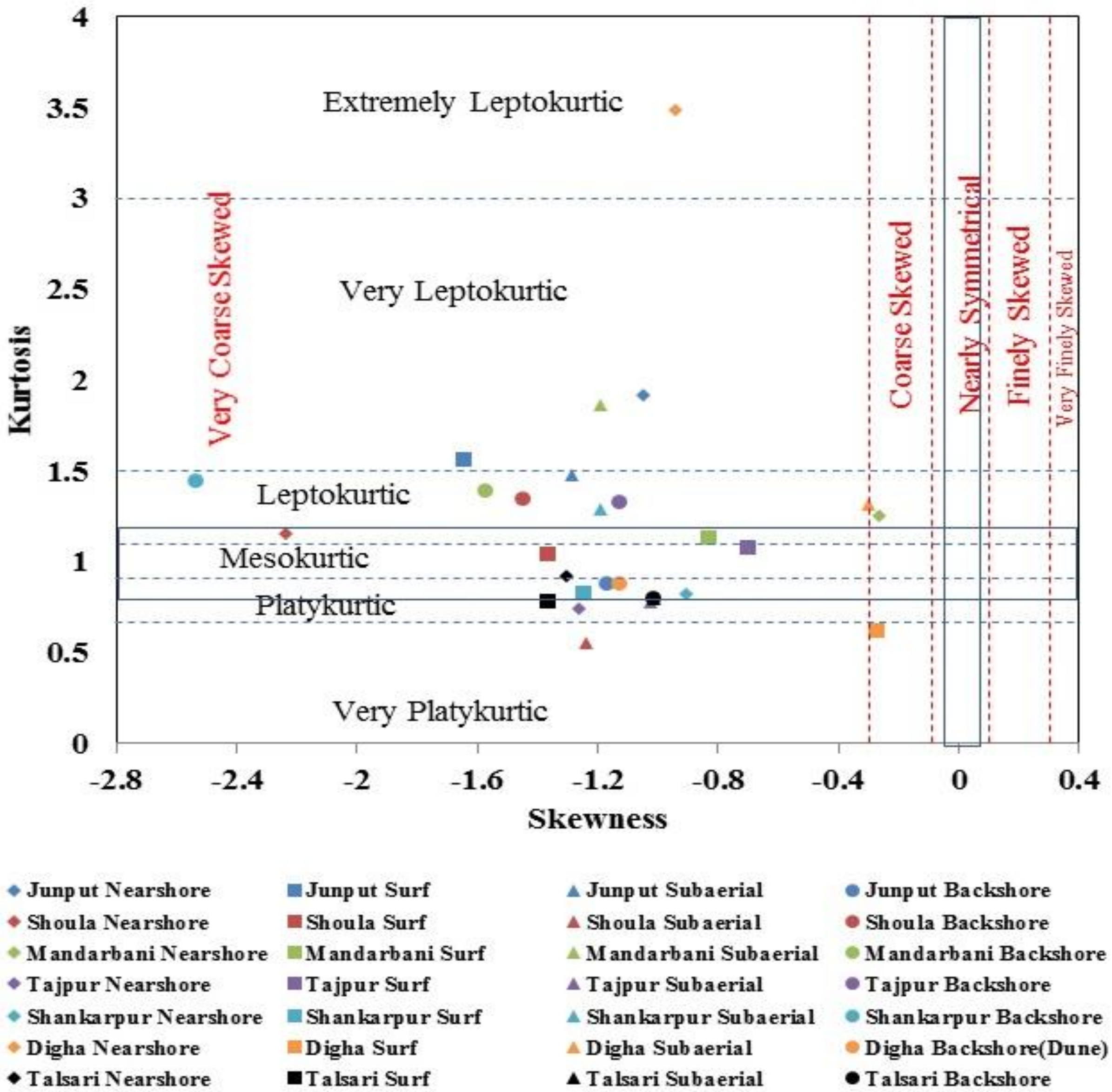


Figure 7. Sedimentary Textural Analysis by The Bi-variate Plotting (Skewness vs. Kurtosis) After Folk and Ward (1957)

5. Skewness vs. Graphic Kurtosis

For distinguishing the sediment bimodal characteristics, skewness and kurtosis are important parameters (Bramha et al., 2017). The bivariate plot of kurtosis against the skewness of a given sediment population is a powerful tool for distinguishing between depositional environments (Baiyegunhi et al., 2017). Based scatter plot, it has been concluded that the samples range from platykurtic to leptokurtic under the negative depositional environment (Figure 7).

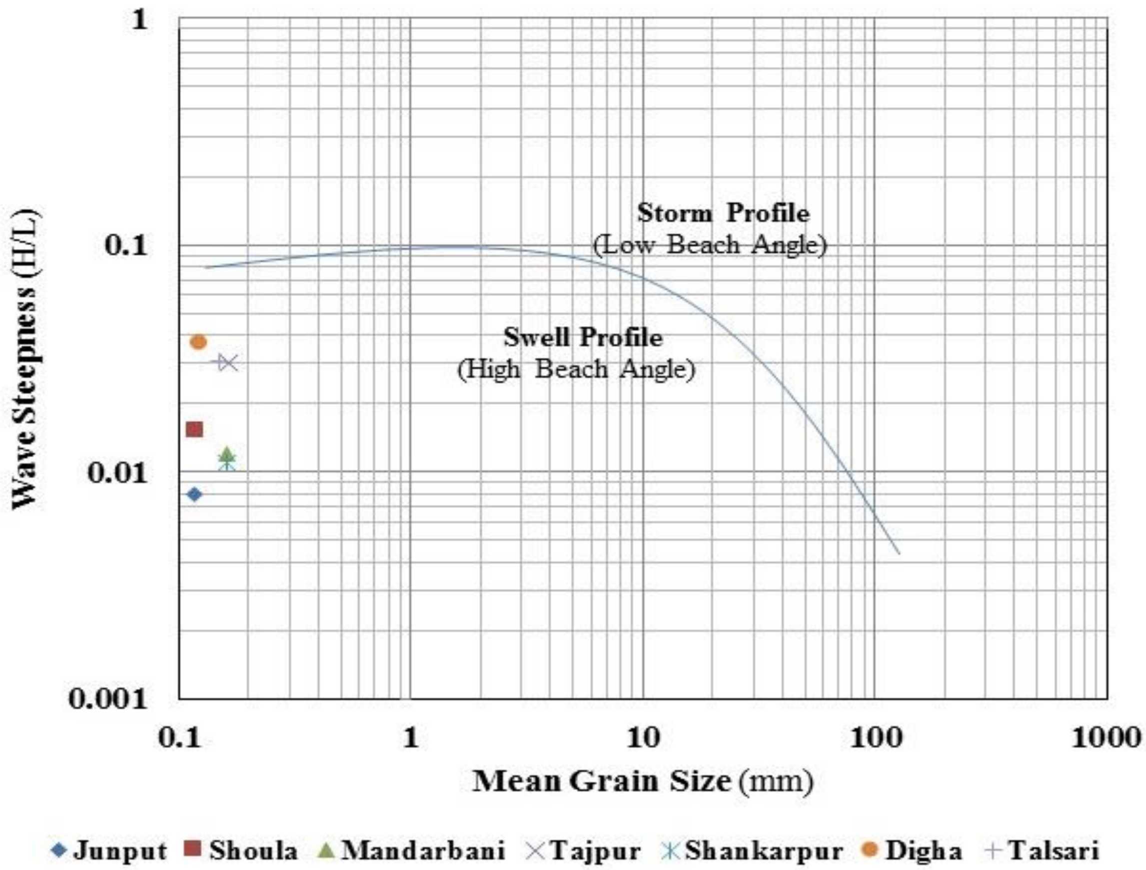


Figure 8. Mean Grain Size vs. Wave Steepness and Beach Profile of Kanthi Coast (After Iwagaki and Noda, 1963)

**Beach Mean Grain Size vs. Wave Steepness**

Coastal beach morphology depends on the Beach's mean grain size and wave steepness. The changing sediment property depends on the acting forces and various source materials (Vasudevan et al., 2023). The ratio between wave height and wavelength or wave steepness shapes the beach cross profile. After wave breaking, energy dissipates on the beach but its intensity of impaction is determined by the mean beach grain size. According to Iwagaki & Noda (1963), it is necessary to study beach profiling by multiple coastal geomorphological processes. Formation of the swell or stormy beach profile depends on the correlation between the wave height and sediment transport which is influenced by the grain diameter.

Table 3. Mean Grain Size vs. Wave Steepness and Beach Profile of Kanthi Coast (After Iwagaki and Noda, 1963)

| Beach | Mean Grain Size (mm) | Wave Steepness (H/L) | Beach Condition |
|---|---|---|---|
| Junput | 0.117 | 0.008 | Swell Profile with low beach angle |
| Shoula | 0.120 | 0.015 | Swell Profile with low beach angle |
| Mandarbani | 0.160 | 0.012 | Swell Profile with low beach angle |
| Tajpur | 0.164 | 0.030 | Swell Profile with a Relatively high beach angle |
| Shankarpur | 0.161 | 0.011 | Swell Profile with a Relatively high beach angle |
| Digha | 0.123 | 0.037 | Swell Profile with low beach angle |
| Talsari | 0.148 | 0.031 | Swell Profile with low beach angle |

Source: Field Survey and Observation (2016-18), Researcher Computation

The beaches of Kanthi coast are characterized by a low beach angle profile which is developed by the swell wave. Thus, it is also recognized as a swell beach profile (Table 3 & Figure 8).

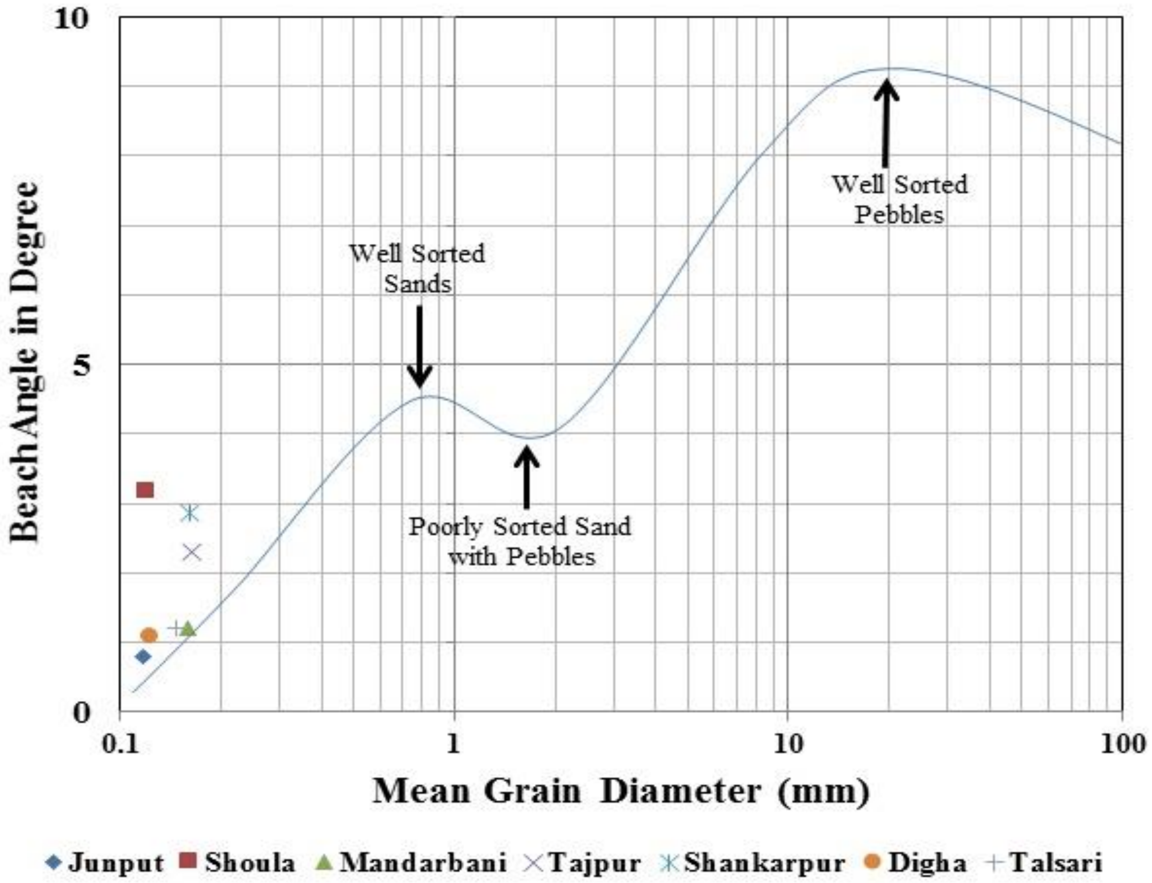


Figure 9. Beach Profile and Sediment Grain Size (After McLean and Kirk, 1969)

**Beach Angle and Mean Grain Diameter**

Bascom (1951), Shepard (1963), and Inman & Bagnold (1963) have researched the relationship between beach angle or gradient and sediment diameter. According to Inman & Bagnold (1963), a low-angle facet to seaward is associated with finer materials, and a steep landward facet formed in the coarser shingle. McLean & Krik (1969) have observed that the beach face angle depends on the sorting of sediments as well as mean grain size. The poorly sorted material in the center of this distribution is associated with low beach angles, due to reduced percolation rate.

Table 4. Relations between Beach Angle and Mean Grain Diameter (After McLean and Krik 1969)

| Beach | Mean Grain Size (mm) | Beach Angle | Beach Condition |
|---|---|---|---|
| Junput | 0.117 | $0^{0}48'07.43''$ | Well-Sorted Sand Zone |
| Shoula | 0.120 | $3^{0}10'15.19''$ | Well-Sorted Sand Zone |
| Mandarbani | 0.160 | $1^{0}12'44.99''$ | Well-Sorted Sand Zone |
| Tajpur | 0.164 | $2^{0}01'46.76''$ | Well-Sorted Sand Zone |
| Shankarpur | 0.161 | $2^{0}51'29.72''$ | Well-Sorted Sand Zone |
| Digha | 0.123 | $1^{0}05'18.45''$ | Well-Sorted Sand Zone |
| Talsari | 0.148 | $1^{0}11'36.47''$ | Well Sorted Sand Zone |

Source: Field Survey and Observation (2016-18), Researcher Computation

According to the model of McLean & Krik (1969), soil-clustered samples of Kanthi coastal beach are in a well-sorted sand zone (Table No 4 & Figure 8).

**Beach Profile and Percolation Rate**

The percolation rate is the volume of water, that will pass through the pore of sediment. Inman and Bagnold (1963) researched that there is a causal link between sediments and beach gradient size. The rate of percolation depends on the sediment grain size. As a result, when the swash moves up to the beach the amount of water is very low. Therefore, the surface flow and backwash are very reduced. This slow movement of water increased the sediment deposition and helped to create a beach. The rate of percolation is very low in the case of fine sediment deposition. In this situation, the energy of swash and backwash is more or less the same. Thus, the mean grain size controls the percolation rates. Besides, the gravitational force acts down-slope movement to occur an offshore sediment movement. Therefore, upper-beach erosion or accretion of a long-shore bar decreases with beach gradient. According to Krumbein & Grabill (1965), it has been examined that the poorly sorted steeper beach is experienced the same as the well-sorted track. The beaches of Kanthi coast consist of very fine to moderately fine sand particles lying as well to the moderately sorted platform. According to this circumstance, a low percolation rate occurs and maximum energy dissipates on the beach. Therefore, the beaches of the Kanthi coast are shaped as concave to flat.

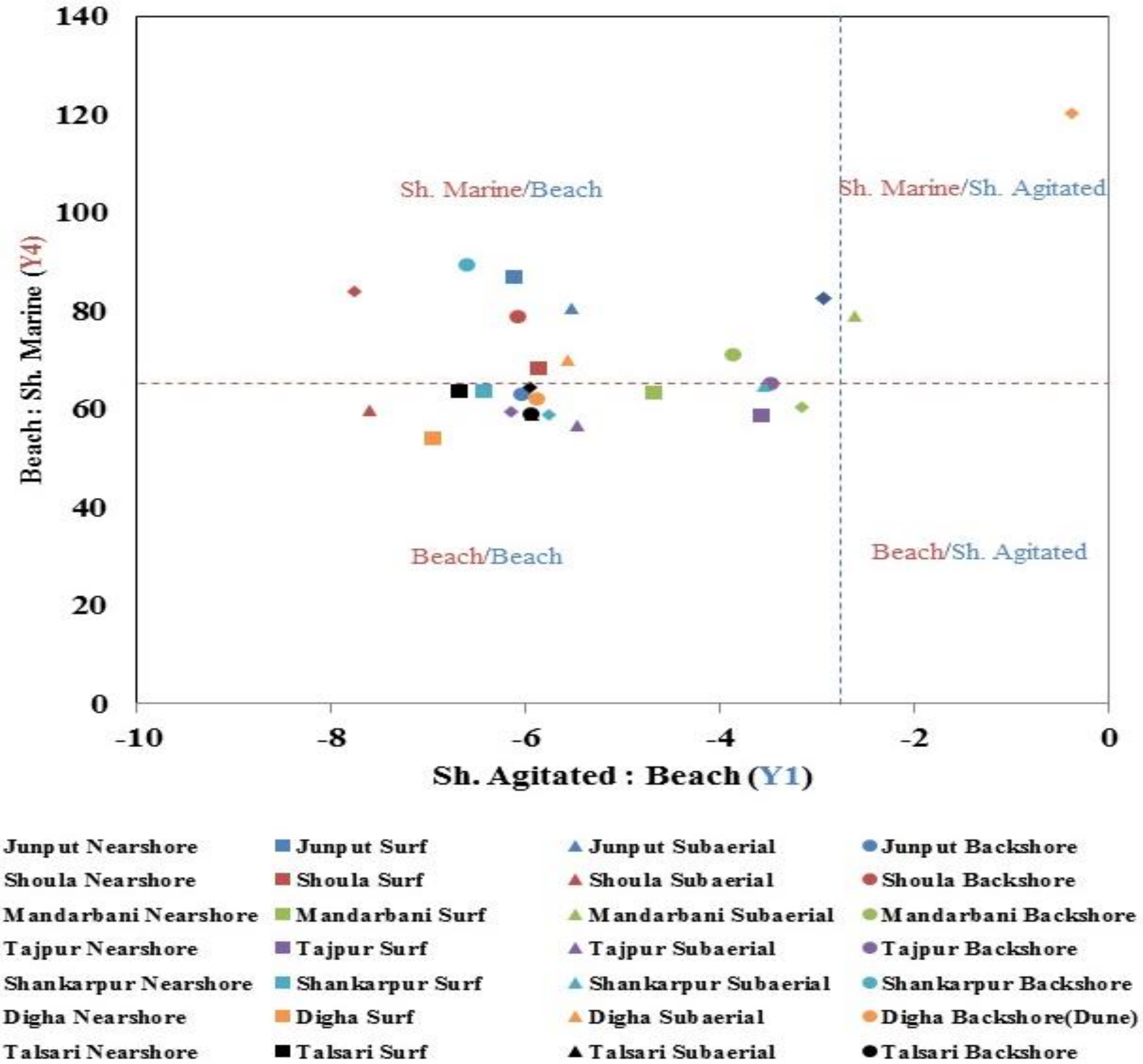


Figure 10. Beach Profile and Depositional Environment Y1 vs. Y4 (After Sahu, 1964)

**Beach Profile and Depositional Environment**

The foreshore zone is highly dynamic, for the sedimentary process is governed by nearshore hydrodynamics and associated with beach morphology (Pedrozo-Acuna et al., 2012). The use of statistical analysis to interpret the variations in energy and fluidity factors during/before sediment deposition seems to have a very good correlation with the different processes and depositional environments (Sahu, 1964; Baiyegunhi et al., 2017). Statistical parameters such as mean (M), standard deviation (SD), skewness (Sk), and kurtosis (K) expose the source of sediment and depositional condition of the beach environment (Folk & Ward, 1957; Friedman, 1961; Rajganapathi et al., 2013). Sahu (1964) introduced the linear discriminate functions for environmental interpretation and the method uses all the grain size parameters in the form of a single linear equation, in which Y1 (Aeolian: beach), Y2 (fluvial: turbidity), Y3 (shallow marine: fluvial) and Y4 (beach: shallow marine) values were analyzed (Venkatesan et al., 2017). There is a perfect relationship between variation in energy and fluidity factors. These change according to different processes and the circumstances of the deposition. The Y1, Y3, and Y4 discriminate functions have been employed to bring out the relation between aeolian, beach, shallow marine environment, and shallow agitated water process through the sedimentary statistical analysis of graphic mean grain size, standard deviation or sorting, skewness, and kurtosis.

Table 5. Sedimentary Depositional Environment and Kanthi Coastal Beach Profile (After Sahu, 1964)

| Beach | Section of Beach Cross Profile | Sedimentary Depositional Environment | | |
|---|---|---|---|---|
| | | Y1 | Y3 | Y4 |
| Junput | Nearshore | Beach | Sh. Marine | Sh. Marine |
| | Surf | Beach | Sh. Marine | Sh. Marine |
| | Sub-aerial | Beach | Sh. Marine | Sh. Marine |
| | Backshore | Beach | Sh. Marine | Beach |
| Shoula | Nearshore | Beach | Sh. Marine | Sh. Marine |
| | Surf | Beach | Sh. Marine | Sh. Marine |
| | Sub-aerial | Beach | Sh. Marine | Beach |
| | Backshore | Beach | Sh. Marine | Sh. Marine |
| Mandarbani | Nearshore | Beach | Sh. Marine | Beach |
| | Surf | Beach | Sh. Marine | Beach |
| | Sub-aerial | Sh. Agitated | Sh. Marine | Sh. Marine |
| | Backshore | Beach | Sh. Marine | Sh. Marine |
| Tajpur | Nearshore | Beach | Sh. Marine | Beach |
| | Surf | Beach | Sh. Marine | Beach |
| | Sub-aerial | Beach | Sh. Marine | Beach |
| | Backshore | Beach | Sh. Marine | Beach |
| Shankarpur | Nearshore | Beach | Sh. Marine | Beach |
| | Surf | Beach | Sh. Marine | Beach |
| | Sub-aerial | Beach | Sh. Marine | Beach |
| | Backshore | Beach | Sh. Marine | Sh. Marine |
| Digha | Nearshore | Sh. Agitated | Sh. Marine | Sh. Marine |
| | Surf | Beach | Sh. Marine | Beach |
| | Sub-aerial | Beach | Sh. Marine | Sh. Marine |
| | Backshore(Dune) | Beach | Sh. Marine | Beach |
| Talsari | Nearshore | Beach | Sh. Marine | Beach |
| | Surf | Beach | Sh. Marine | Beach |
| | Sub-aerial | Beach | Sh. Marine | Beach |
| | Backshore | Beach | Sh. Marine | Beach |

Source: Field Survey and Observation (2016-18), Researcher Computation

1. Sh. Agitated: Beach (Y1)

To discriminate between shallow agitated and beach sediment samples of the different sections of beach profile of Kanthi beach profile, according to Sahu's (1964) linear discriminate function is calculated by the following formula.

$$Y1 = -3.5688\ (Mz) + 3.7016\ (SD)^2 - 0.0766\ (SK) + 3.1135\ (kG) \quad \text{-------------Eq6}$$

If the value of Y1 is <-2.7411 that indicates the shallow agitated depositional environment and if the Y1 is >-2.7411 that explains to beach depositional environment. Concerning Y1 value, 100% of beaches cross profile at Junput, Shoula, Tajpur, Shankarpur, and Talsari coasts 75% of sediment samples of Mandarbani and Digha coastal beaches are deposited under the beach environment (Table 5; Figures 10 & 11). Besides, 25% of sediment samples of Digha Beach (nearshore zone) and Mandarbani (Subaerial zone) are deposited under the shallow agitated water processes (Table 5 & Figure 10).

2. Sh. Marine: Sh. Agitated (Y3)

As per B. K. Sahu (1964), by the following equation sediment samples are distinguished between shallow marine and shallow agitated.

$$Y3 = 0.2852\ (Mz) - 8.7604\ (SD)^2 - 4.893\ (SK) + 0.0482\ (kG) \quad \text{------------------Eq7}$$

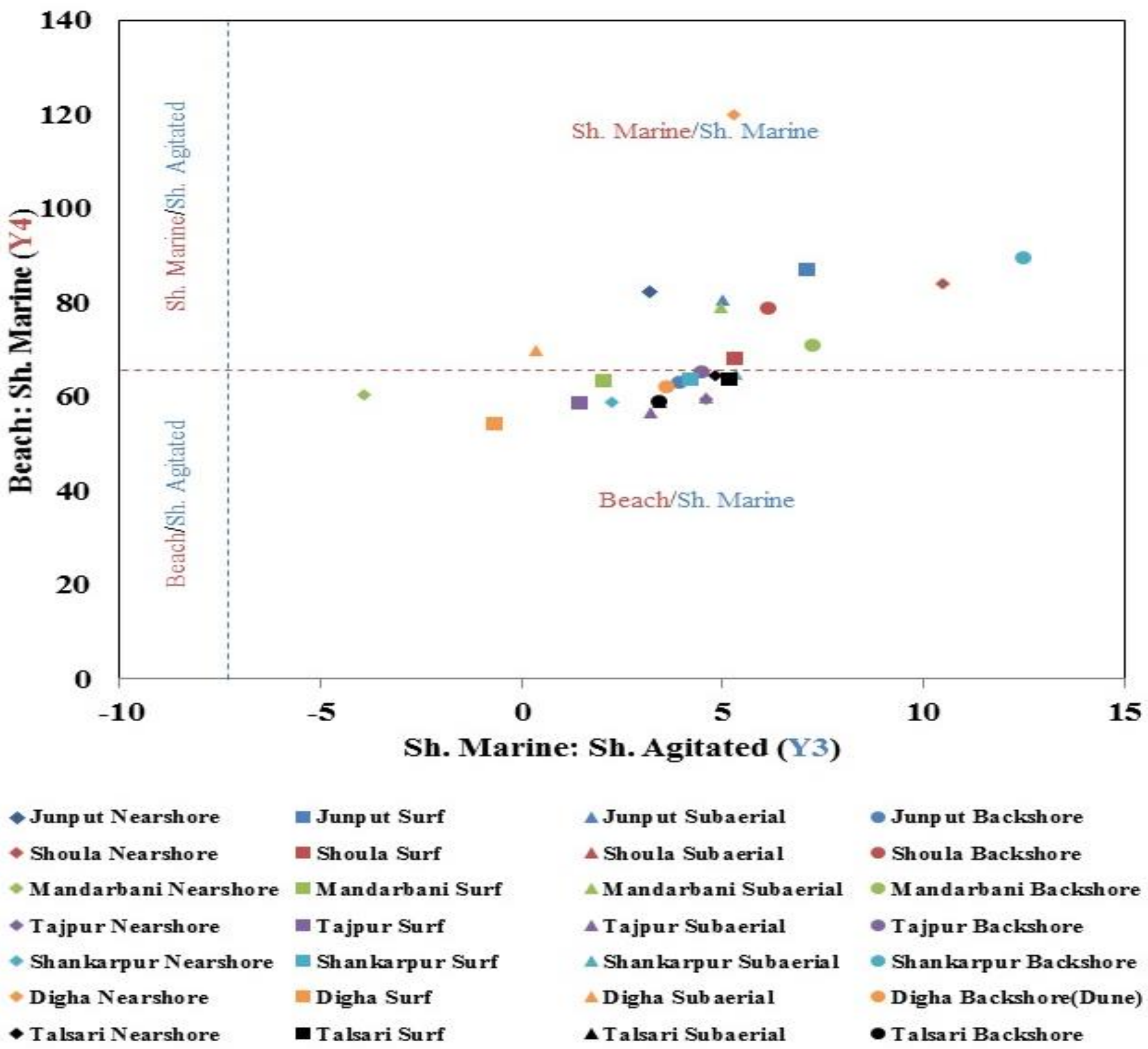


Figure 11. Beach Profile and Depositional Environment Y3 vs. Y4 (After Sahu, 1964)

If the value of Y3 is <-7.4190 that indicates deposition under environment shallow agitated water processes and if the Y1 is >-7.4190 that explains to shallow marine depositional environment. With reference Y3 value, 100% of sediment samples of the beaches of Kanthi coast are deposited under the shallow marine environment expressed to moderate to the high tidal range (Table 5, Figures 10 & 11).

3. Beach: Sh. Marine (Y4)

According to Sahu (1964), to distinguish the depositional environment between the beach and shallow marine sediment samples of the different sections of the beaches of Kanthi coast is been quantified by the following formula.

$$Y4 = 15.6534 (Mz) - 8.7604 (SD)^2 - 4.8932 (SK) + 18.5043 (kG) \quad \text{-----Eq8}$$

If the value of Y4 is <65.3650 that indicates to deposition of sediment under the beach environment and if the Y4 is >65.3650 that refers to a shallow marine depositional environment. From the quantification of Y4, it has been concluded that about 75 % beach area of Junput (nearshore, surf, sub-aerial) and Shoula (nearshore, surf, and backshore), about 50 % beach area of Mandarbani (Sub-aerial and backshore) and Digha (nearshore and sub-aerial), about 25% beach area of Shankarpur (backshore) is developed under the shallow marine environment (Table 5 & Figure 11). Moreover, the sediment of the rest of the portion of all beach profiles is deposited under the beach environment.

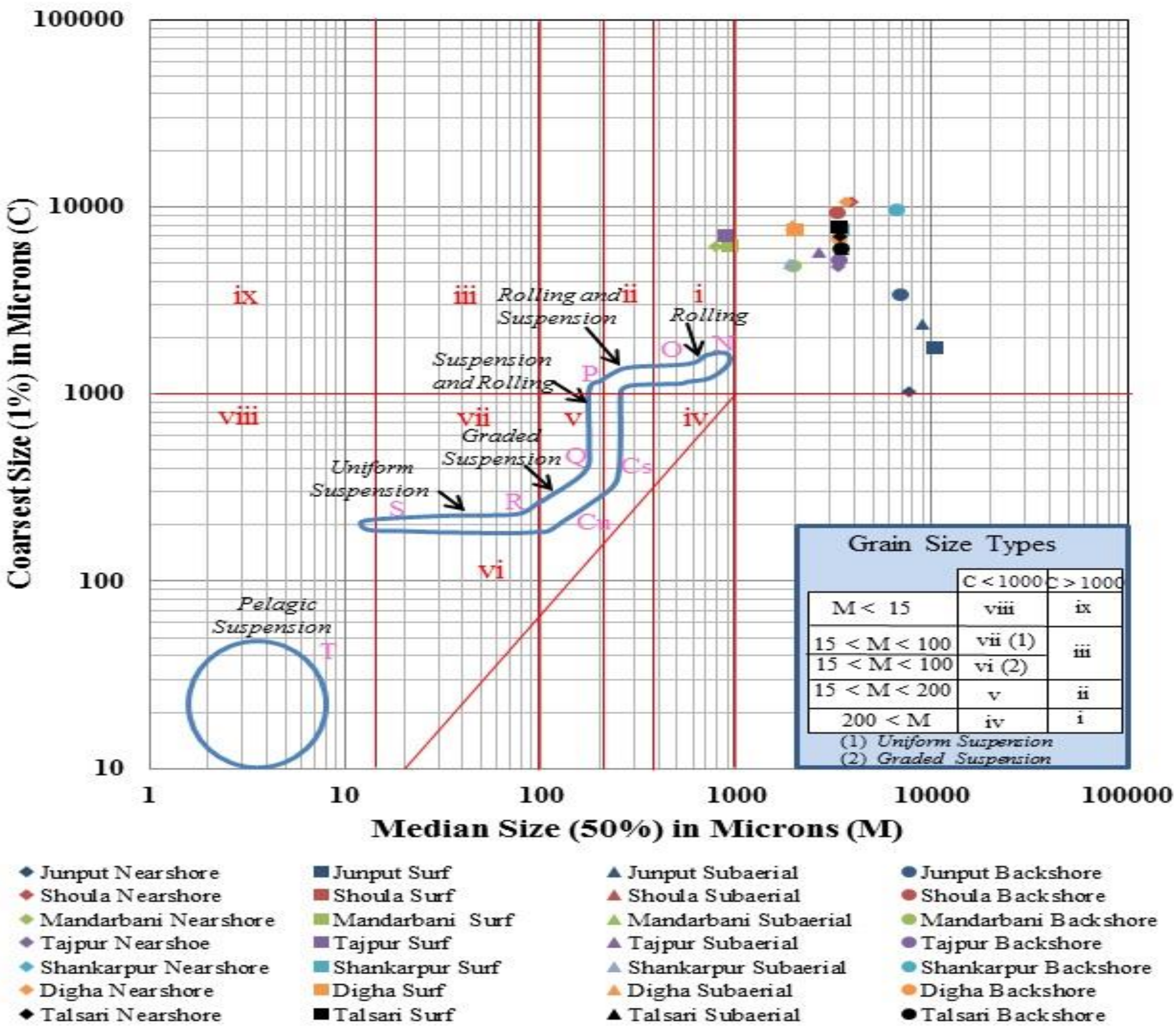


Figure 12. C – M Plot of Beaches of Kanthi Coast (After Passega, 1957; 1969)

**Beach Profile and Transportation Mechanism**

On a long-term basis, knowledge about sediment movement in the nearshore environment is a prerequisite for designing shoreline structures for protection (Saravanan & Chandrasekar, 2010; Vasudevan et al., 2023). Grain size distribution provides information on sediment sources, transportation, and deposition (e.g., Folk & Ward, 1957; Friedman, 1979; Angusamy & Rajamanickam, 2006; Nugroho, 2013; Nugroho & Basit, 2014). When the breaking waves strike the shore at an angle, alongshore currents are triggered by the breaking waves, and sediment transport along the beaches begins (Bergillos, Masselink & Ortega-Sanchez, 2017a; Vasudevan et al., 2023). Tidal currents can play a major role in changing the textural characteristics of foreshore sediment in an estuarine zone (Thakur & Ojha, 2010; Hoque et al., 2010). The sedimentary analysis is an investigation process, through which the size and distribution of the population of sediment grain size focus on environmental processes. The analysis of sedimentary analysis has two objectives, viz. assessment of sediment transportation and formation of associated landforms. According to Cornish (1898), Johnson (1919), Bagnold (1940), King (1972), and Komar (1976) the relation between flow asymmetry and sediment transport is proportional. To study the sediment transportation mechanism C-M plot (After Passega, 1957) and the Tractive Current plot (After Visher, 1969) are necessary.

1. C-M Diagram

The C-M plot is a binary plot of a coarser one-percentile value (C) in microns against the median value (M) in microns on a log-probability scale (Baiyegunhi et al., 2017). In the present study, the C-M plot proposed by Passega (1964) is used to understand the dominant mode of transportation and the environment of deposition (Venkatesan et al., 2017). Several sediment types and energy of transportation medium are linked to their nature in the case of C and M. With the help of the C-M plot, all hydrodynamic forces that are involved in the sediment deposition have been analyzed and interpreted. The Passega diagram depicted in Figure number 12 shows several fields (rolling-NO, rolling and suspension-OP- OP, suspension and rolling-PQ, graded suspension-QR, uniform suspension-RS, and pelagic suspension-T) that correspond to the various transport and sedimentation conditions in the marine and littoral/fluvial environments (Baiyegunhi et al., 2017). The plotting of one percentile value of the sedimentary size distribution (C) in microns against the median of collected sediment samples is interpreted as the sediment transportation mechanism at the beaches of Kanthi Coast (Figure 12). The sediment of the nearshore zone of Mandarbani and the sediment of the surfing zone of Mandarbani and Tajpur have experienced the rolling mechanism to sediment transportation, due to their location between O and N. Other sediment samples of the beaches of the Kanthi coast contain a value of Coarse (C) size greater than 1 mm. These sediments are rolled grain. These are either found near their source or transported across where the sedimentation suspensions are scared.

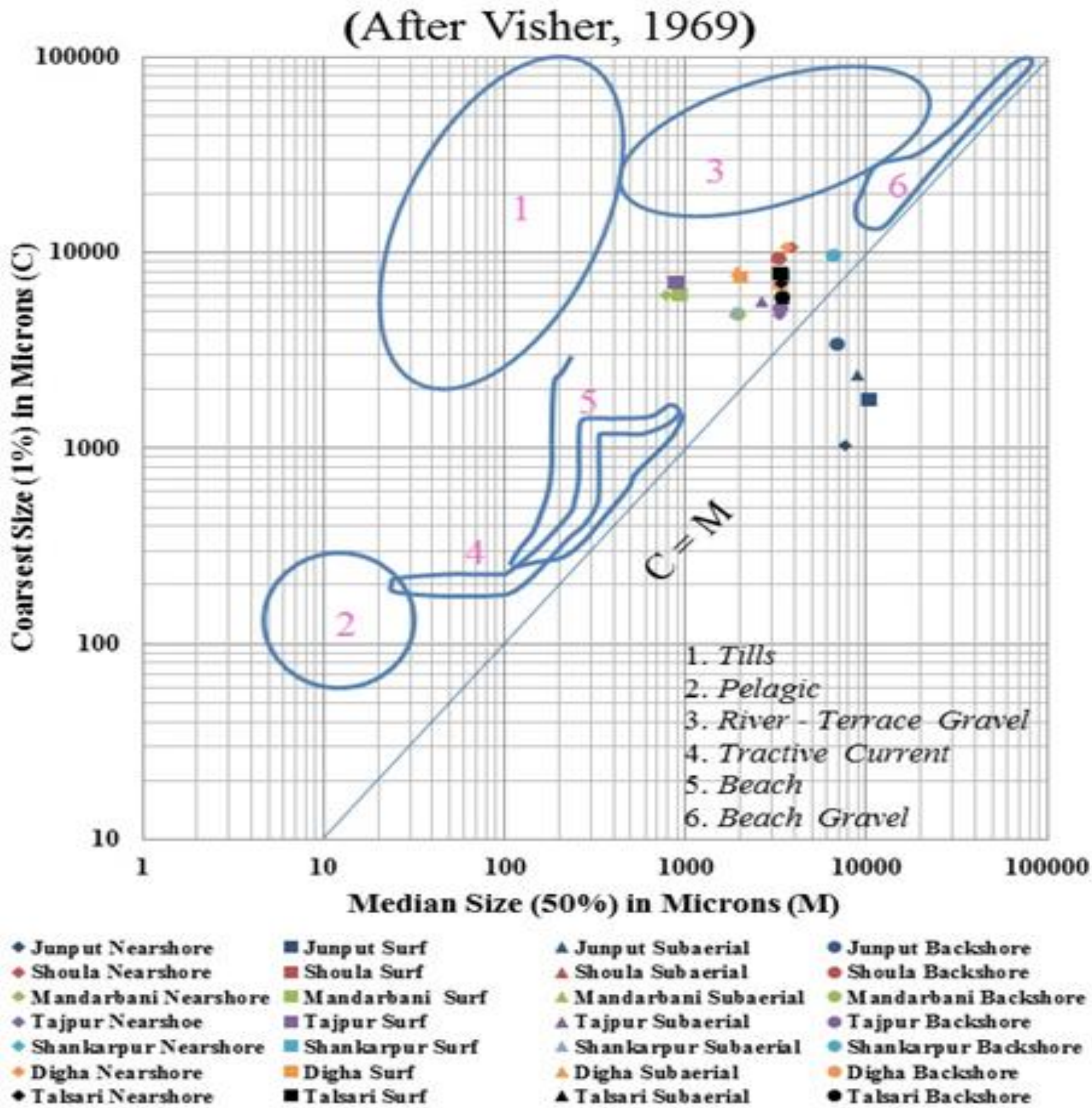


Figure 13. Tractive Current Plot of Beaches of Kanthi Coast (After Visher, 1969)

2. Tractive Current Diagram

It is observed that sediment samples of Junput beaches, fall in the N-O segment indicating a dominant rolling pattern (Figure 13). Sediments are hooked in the N-O segment, indicating suspension sediment deposition under a fluvio-tidal environment. The plotting of the Tractive diagram is also drawn which indicates maximum sediment samples are hooked at the beach environment (Figure 13). That is by interaction with wave action (Kulkarni et al., 2015).

## Conclusion

This study and other ocean dynamic studies will be needed to comprehend the regional sedimentary processes necessary for planning and decision-making of the coastal projects (Abdulkarim et al., 2011) along the coastal beach system. Grain size parameters of beach sediments provide wealthy geological information on sediment transportation history, depositional environment, and sedimentary geochemistry (Folk & Ward, 1957; Medina et al., 1994; le Roux & Rojas, 2007; Nugroho & Putra, 2018; Lepesqueur et al., 2019; Woodruff et al., 2021; Perera et al., 2023). Wave/tidal actions, littoral currents, river discharges (or runoff), and source area compositions are also important factors in controlling the sediment composition of the coastal area (Venkatramanan et al., 2011; Mohanty et al., 2023). Hence the result of this study will be useful for the understanding of the sedimentary processes (Abdulkarim et al., 2011), along the beaches of Kanthi coast.

This research paper made a brief assessment of how beach sedimentary textural parameters is playing a major role in beach morphology and geomorphological stability. The level of energy fluctuations configures the distribution of grain size. The beaches of the Kanthi coast consisted of a fine sedimentary track. Consequently, the beaches are dominantly shaped as concave patterns due to their very well-sorted sedimentary platform. From the study of Skewness and kurtosis, it has been revealed that most of the beaches of the Kanthi coast is experiencing high to moderate winnowing activity by multiple processes. Due to the predominance of finer sediments in nearshore, eroded material mobilized by suspension has been plotted in C-M and tractive current plotting. But at the surfing zone beaches of Tajpur, waves follow the rolling process to mobilize sediment for coarse sediment. Coarse sediment configured beach is more geomorphologically stable and makes a beach profile convex. In addition, coarse sediment consists of a moderate to poor sorted track that reduces the wave energy dissipation ratio by the increasing percolation ratio and makes a beach geomorphologically sustainable.

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