

**Textural characteristics and morpho-sedimentary environment of foreshore zone
along Ganpatipule, Maharashtra, India**

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Abstract

The cross-shore profile and the textural distribution of foreshore sediments of Ganpatipule beach along Maharashtra coast covering two annual cycles are examined. Ganpatipule beach depicts erosion and accretion of the berm, reduction and widening of foreshore widths during the monsoon (June-September) and post-monsoon (October-May) respectively with net sediment accretion during the study period due to the changes in the wave characteristics. A direct correlation is observed between the median sediment grain size and beach face slopes signifying high wave energy ensuing to a gentle to very gentle slope. The sediments are mainly medium grain size, moderately well sorted, bimodal, very fine skewed to very coarse skewed and very platykurtic to very leptokurtic in nature. The binary plots of the textural parameters (mean, skewness, kurtosis and standard deviation) depicted a characteristic beach environment of deposition. The study shows that the sediment is concentrated in the environment of rolling and bottom suspension. The study on grain size distribution of sediments could be used to assess the wave energy condition prevailing along the coastal area.

Keywords: beach dynamics, cross-shore profile, beach sediments, surface waves, sediment transport

Introduction

The most important aspect of the beach is its dynamic behaviour due to the continuous response of the beach sediments to the changing waves and currents of the nearshore waters. The interaction of waves and currents in the coastal zone create major forces that drive cross-shore profile evolution (Dean and Dalrymple, 2002). On natural beaches, the changing waves give rise to an ever varying symmetry that the beach profile attempts to achieve but seldom does. The morphological response of the beaches to a given wave climate is governed by nearshore hydrodynamics (Pedrozo-Acuña et al., 2012). The coastal processes impacted by the erosion, accretion and sediment transport are persistently changing the coastline configuration. Granulometric studies of beach sediments provide a wealth of information on the intrinsic properties of sediments and their depositional environment (Angusamy et al., 2006). Valuable information on beach dynamics and the depositional environment can be established through the morphological and sedimentological studies (Dora et al., 2012). To quantify the sediment distribution response to forcing functions on the foreshore beach zone, a sediment sampling and analysis experiment was conducted. This research was designed to examine the natural beach sediment distribution and its relationship to profile change at Ganpatipule, Maharashtra along the central west coast of India.

The study area, Ganpatipule beach ($17^{\circ} 08' 40.8''\text{N}$; $73^{\circ} 15' 59.0''\text{E}$) is about 2.5km long located in Ratnagiri district on the Konkan coast of Maharashtra, India (Fig. 1). The geomorphological studies along the Ratnagiri coast have brought to light the geomorphic surfaces, alluvial terraces and littoral formations. 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 and Sukhtankar, 2011). Major and minor creeks intersect the area and drained by the streams that flow westwards. Ganpatipule beach is one of the most beautiful sandy beaches along the Konkan coast with a gentle slope. It is an idyllic getaway that attracts peace-seekers, beach lovers, and pilgrims alike. Geologically the area is mainly composed of Deccan basalts, which are invariably capped by laterite with a subordinate amount of bauxite (Suryawanshi, 2014). The study area shows the presence of economic beach deposits of Ilmenite (Gujar, 1995).

Oceanographic processes along the Maharashtra coast is influenced by the Indian summer monsoon during June to September. Tides are predominantly semi-diurnal, and the average spring tidal range is about 2m and the average neap tidal range is 0.6m. Diurnal variation in wave parameters is observed along the central west coast of India due to the sea and land breeze (Glejcin et al., 2013). Longshore current is predominantly southward at Ratnagiri (Kunte et al., 2001) and the annual net longshore transport of sediments along the west coast is also towards south

(Chandramohan et al., 1993; Kumar et al., 2006). In the present study, the monthly cross-shore beach dynamics along Ganpatipule coast is examined from May 2013 to May 2015, and analysis is carried out on the variation of textural characteristics of beach sediments. In this paper, an attempt has been made to study the depositional environment of beach sediments.

Materials and methods

Surveys for beach profiles were carried out every month for a period of two years (May 2013 to May 2015) using a dumpy level and a measuring staff at the time of low tide from the backshore to beyond the low water level. Three profiles; BM1, BM2 and BM3 (Fig. 2) from north to south of Ganpatipule were marked based on the morphological features along the coast and the cross-shore profiles were monitored. From the data collected, the monthly variations in beach profile were graphically represented to study the variability in beach profile configuration. The changes in the volume of sediments were calculated using trapezoid (trapezium) formula. The details are given in Dora et al. (2012).

Altogether 225 surface sediment samples were collected from high tide zone (high water line), mid tide zone (water level) and low tide zone (low water line) along each profile location to study the grain size parameters. The statistical measures (mean, standard deviation, skewness, and kurtosis) of individual sediments samples were obtained from the grain analysis package - GRADISTAT (Blott and Pye, 2001) following logarithmic (original) Folk and Ward (1957) Graphical Measures. Bivariant plots were drawn to know the inter-relationship between these parameters. The relation between sediment texture and transport was analyzed using the CM plot introduced by Passega (1964) in which C represents coarsest one percentile (D_{99}) and M is median (D_{50}). The beach face slope and mean grain size were also correlated to explain the hydrodynamic role in determining the morphology of beach.

The waves measured using the directional waverider buoy deployed at 15m water depth off Ratnagiri, 18km south of Ganpatipule was used to study the monthly average wave characteristics of the study area and its influence on the beach. The mean wave direction mentioned in this paper is the wave direction corresponding to the maximum spectral energy density.

Results and discussion

Variations in beach profile

The monthly changes in the beach profiles along the study area are given in Fig. 3. Record of monthly beach profiles obtained at the 3 benchmarks (BM) along the study area from May 2013 to May 2015 is used to evaluate the variations in the beach morphology and processes responsible for

the changes. In general, the changes in beach profile configuration are due to the onshore-offshore transport of sediments. The steep slope (1.4:1 to 1:1) of the beach denotes long-term erosion while the gentle slope (1:10 to 1:20) points out gradual accretion. Beach profiles respond to the physical energy imparted by the waves and currents. There are generally two shapes assumed by the beach; a low energy accretional profile and a high energy erosional profile (Shepard, 1963). Anfuso (2005) observed that the surface morphology of a beach especially with regard to the steepness, affect the intensity of the wave energy, and thus can influence the grain size distribution and sediment transport. The beach profile exhibited alternate erosion and accretion during the pre-monsoon period (February to May). The beach achieved its maximum growth during January and May with the development of broad foreshore and minor berm, attributable to calm wave condition. During this season, prevailing waves with significant wave height of 0.7m favour deposition (Fig. 4). During June to September, the beach experiences erosion due to high waves of southwest monsoon. The average significant wave height of the study area during the southwest monsoon (June to September) is ~2m and it is same during 2013 and 2014 (Fig. 4). The monthly average significant wave height (H_s) is maximum (~ 2.7m) during July. The beach is characterised by narrow foreshore with concave slope and absence of berm. The high energy (monthly average significant wave height >1.5m) waves (predominant wave period 4-6s) with near normal approach to the beach are considered to be responsible for the erosion of the beach. During the monsoon, 35% of the time waves are from 225-240°, 17% of time waves approached from 240-255°, and 16% of time, waves are from 255-270°. In inter-monsoon season (October to January), the beach experienced the surrogate of materials that were lost during monsoon season. Consequently, the beach along the study area displayed erosional profile, nearly uniform and gently sloping, slightly concave upward profile. In the study area over an annual cycle, waves amplitude less than 1 m represent more than 59% of the time, waves amplitude, $1\text{ m} < H_s < 2\text{ m}$ represent 23% and $2\text{ m} < H_s < 3\text{ m}$ represent 15% of the annual wave climate (Anjali and Kumar, 2016). During the non-monsoon, 75% of the time, waves are with height between 0.5-1 m and the predominant (53%) wave direction is 225-240° and 13.5% of time waves approached from 300-315°.

Beach volume

The monthly volume computation showed that beach experienced accretion through continuous cycles of erosion/accretion giving rise to a net gain of about $37.82\text{m}^3/\text{m}$ of sediments along the line of transect in all 3 stations together during the study period. For the period of 2013-2014, continuous accretion is exhibited by BM1 from July-December and BM2 from September-December, while BM3 displayed non-uniform changes. Likewise, during 2014-2015, steady accretion is observed at

BM2 from September to November and at BM3 from September to December. Furthermore, BM1 showed broken accretion and erosion order. At BM1, the highest beach change is found with erosion and the volume of eroded sediment is $26.30\text{m}^3/\text{m}$ during May to June in 2013-14 and accretion of $31.60\text{m}^3/\text{m}$ during September to October in 2014-15 (Table 1). At BM2, the maximum change in beach volume is found with sediment accretion and the volume of accreted sediment is $28.28\text{m}^3/\text{m}$ during July to August in 2013-14 while, erosion of about $50.16\text{m}^3/\text{m}$ is observed during May to June in the second annual cycle (2014-15). At BM3, during the first annual cycle, highest change in beach volume is found during January to February with sediment erosion ($\sim 40.34\text{m}^3/\text{m}$), whereas, in the second annual cycle, the maximum beach change is found during November to December with sediment accretion ($\sim 29.88\text{m}^3/\text{m}$). During the two years, a non-uniform change in beach volume is observed at the three selected locations.

Beach width-volume correlation

The correlation between beach volume and beach width are in good agreement with the monthly morphological changes. As it is discernible from Fig. 5, lowest beach width and volume is observed during September 2014, July 2013 and July 2014 (SW monsoon months) at BM1, BM2 and BM3 respectively. Peak volumes and widths are recorded in January 2014 at BM1 and in May 2014 at BM2, but BM3 exemplify peak width in January 2014 and peak volume in January 2015. Abrupt changes took place during the monsoon (erosion) and post-monsoon (accretion).

Beach-Face Slope

The beach-face slope is governed by the asymmetry of both wave and grain size of beach sediment. An increase of foreshore slope with coarse particle has been demonstrated in several studies (Bascom, 1951; Wiegell, 1964; McLean and Kirk, 1969; Dubois, 1972). Larger grain sizes allow increased percolation of wave up rush and a corresponding decrease in backrush volumes (Waddell, 1973). As it is noticeable from Fig. 6, clustering of data close to the high wave energy curve is seen where the beach face slope is gentle (1:33-1:50) to very gentle slope ($>1:50$) with fine and medium grain size (0.125-0.5mm). Fig. 6 shows that while the beach face slope is dependent on the sediment grain size, for high energy waves the beach face slope is gentle than that when it is exposed to low energy waves (Wright and Short, 1984).

Beach Sedimentology

Textural characteristics

The results of granulometric analysis of sediment from Ganpatipule beach have depicted sediments ranging from unimodal to polymodal in character. The sediments are bimodal (66%) and unimodal

(25%) in character with a subordinate amount of trimodal (8%) sediment (Table 2). The graphic mean size is a function of the size range of available materials represented by ϕ mean size and mainly an index of energy conditions impacted to the sediment which depends on the turbulence of the transporting medium. The mean size values of the analysed sediments range from 0.089 to 2.65 ϕ with an average value of 1.80 ϕ . This is indicative of fine-grained sand to medium grained sands with average value display the dominance of medium sand (MS). Grain size distribution has a relationship with the physical forces responsible for transport and deposition of sediments. The mean size indicates that the medium sand is deposited under moderate energy conditions. However, variations in mean size reveal the differential energy conditions, resulting in their deposition.

At all the locations, the mean grain size of the sediments shows an increase in medium grain size during the second annual cycle and decrease in fine grain size. During the first annual cycle, fine and medium grain size sediment exemplified similar proportion while coarse grain is present during the second annual cycle. Lowest mean grain size value is observed at BM2 during low water level (\sim 0.09m) in July 2013, while the highest size is during high water level (\sim 2.65m) in May 2015.

Standard Deviation (σ_1) measures the sorting of sediments and indicates the fluctuation in the kinetic energy (Sahu, 1964). It gives an indication of the effectiveness of the depositional medium in separating grains of different classes (Okeyode and Jibiri, 2013). About 12% of the samples are very well sorted, 23% well sorted, 42% moderately well sorted, 16% moderately sorted and 7% purely sorted in nature. The standard deviation of the sediment samples ranges in between 0.24 and 1.30 ϕ , which are within the range of very well sorted to poorly sorted class with an average of 0.58 ϕ . The variations in the sorting values are due to the continuous addition of finer/coarser materials in varying proportions. Fig. 7 exhibit most of the samples are well sorted to moderately well sorted with only a few poorly sorted thus indicating fairly high energy conditions (Friedman, 1961a; Blott and Pye, 2001).

The graphic skewness (Sk) is the measure of symmetrical distribution, i.e. preponderance of coarse or fine sediments. Skewness is useful in environmental diagnosis because it is directly related to the fine and coarse tails of the size distribution, and hence suggestive of energy of deposition (Okeyode and Jibiri, 2013). The skewness values of the samples range from -0.69 to 0.39 with an average of -0.02. The symmetry of the sample ranges from dominant negative to positive skewness. The positive values indicate skewness towards the finer grain sizes and the negative values indicate skewness towards the coarser grain sizes. Negatively skewed sediments indicate deposition at high

energy environments, whereas positively skewed sediments indicate the deposition of the sediments in sheltered low energy (Reddy et al., 2008).

Kurtosis (KG) measures the ratio of sorting between the tail and central portions. In the study area, the range of kurtosis is from 0.55 to 2.48, with an average of 1.12 suggesting good sorting. The nature of distribution of about 31% of samples in the study area is platykurtic, 15% mesokurtic, 29% leptokurtic and 17% very leptokurtic. The sample analysis has typified similar quantity of platykurtic and leptokurtic character but predominantly platykurtic type. The variation in the kurtosis values is a manifestation of the flow characteristics of the depositing environment (Seralathan and Padmalal, 1994; Baruah et al., 1997).

Sedimentary environment

Bivariate plots: The inter-relationship between certain textural parameters are significant to interpret mode of deposition, energy condition and medium of transport as these parameters of the sediment are often environmentally sensitive (Folk and Ward, 1957; Passega, 1957; Friedman, 1961, 1967; Moiola and Weiser, 1968; Visher, 1969). Inman (1952), Folk and Ward (1957), Friedman (1961 and 1978) have effectively used the scatter plots for understanding the geological importance of the four size parameters. The bivariate plot between mean size and standard deviation of the study area shows that the nature of the sediments are dominantly bimodal, of which, the dominant constituent is medium sand. The sediments display a better sorting, as the mean size of almost all the samples increases. The plot between skewness and standard deviation shows clustering of grains in 0.3ϕ to 0.8ϕ sector with sediment ranging from negative to positive skewed. The mean v/s skewness shows sinusoidal nature due to the mixture of two size classes of sediments. The present values were chiefly falling in the negatively skewed zone of the graph with medium grain size. The plot for kurtosis and skewness has registered the presence of predominant marine environment by the maximum concentration of samples in the beach. The bivariate plot has clearly attested to the predominance of beach environment in all the zones of the study area (Fig. 8). It is identified from the study that the scatter plots are considered as a powerful tool in isolating the different environmental conditions of the study area.

CM Plot: To assert the flow type that transported the sediment to the study area, the samples were plotted on a logarithmic diagram by representing two parameters of their grain size distribution: C, the one percentile and M, the median diameter for the sediments from different environments (Passega, 1957, 1964). The CM plot of the sedimentary environment helps in analyzing transportation mechanism, depositional environment with respect to size, range and energy level of

transportation. It also determines the process and segregates characteristic agents that are responsible for the formation deposits. CM plot is subdivided into four segments representing different transport processes. Corresponding to the four segments, the segments NO, PQ, QR and RS respectively represent rolling, bottom suspension and rolling, graded suspension and no rolling and uniform suspension during the transport of sediments. During the study period, CM plot shows that most of the sediment samples fall in the intermediate position between N and Q and this denotes that Ganpatipule sediments underwent the rolling and bottom suspension which are the prime factors for transportation on the beach. The majority of the sediments are segregated in the region of fine to medium grain size (125-400microns) set down by suspension action while little sediment showing coarse grain of more than 500micron size deposited from rolling (Fig. 9). Finally, it may be summarized that the sediments were deposited due to rolling and suspension, under traction current.

Conclusion

The present study reveals that the beach morpho-sedimentary of foreshore profile and textural characteristics along Ganpatipule beach are influenced by monsoon. The prominent changes include erosion and accretion of the berm, widening and reduction of foreshore widths and changes in the slope. During the monsoon period (June- September), the berm is eroded and foreshore width is reduced due to the increase in the wave height. The average significant wave height before the monsoon is 0.7 m and it increased to 2 m during the monsoon period. The field surveillance on beach dynamics during May 2013 to May 2015 showed both erosion and accretion and the net result over two annual cycles was sediment accretion. Furthermore, the study presented a direct correlation between median sediment grain size and beach face slopes thereby signifying high wave energy ensuing to gentle - very gentle slope. Textural analysis indicates the dominance of medium to fine grain size sand, moderately well sorted, fine skewed to coarse skewed, platykurtic to leptokurtic and with bimodal to unimodal character. The bivariate plots of the textural parameters (mean, skewness, kurtosis and standard deviation) depicted a characteristic beach environment of deposition. CM plot divulges that the sediments are transported mainly by rolling and bottom suspension. The grain size distribution of sediments could be used to assess the energy condition prevailing along the coastal area.

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Table 1. Monthly change in beach volume (m³/m)

Time Duration		Change in volume (m ³ /m)		
		BM1	BM2	BM3
May 2013-May 2014	Monthly			
	May-Jun	-26.30	-28.25	-26.30
	Jun-Jul	-15.95	-2.94	10.35
	Jul-Aug	11.22	28.28	27.17
	Aug-Sep	0.37	-3.50	-10.85
	Sep-Oct	17.99	19.05	17.62
	Oct-Nov	5.14	4.24	-12.85
	Nov-Dec	5.10	7.55	-0.04
	Dec-Jan	18.79	12.56	13.69
	Jan-Feb	-21.56	-7.55	-40.34
	Feb-Mar	-0.67	0.22	20.89
	Mar-Apr	-2.04	0.35	-1.37
	Apr-May	2.68	11.98	4.72
	Annually	-5.24	41.99	2.68
May 2014-May 2015	May-Jun	-10.53	-50.16	-18.85
	Jun-Jul	-20.16	1.19	-24.82
	Jul-Aug	0.52	3.75	3.79
	Aug-Sep	-20.78	-15.68	-6.54
	Sep-Oct	31.60	6.94	19.31
	Oct-Nov	-6.95	9.74	5.15
	Nov-Dec	27.80	26.95	29.88
	Dec-Jan	-6.13	-15.68	2.32
	Jan-Feb	0.14	-8.35	-15.24
	Feb-Mar	-0.04	20.53	0.38
	Mar-Apr	-2.07	-6.08	13.62
	Apr-May	14.25	4.31	4.28
	Annually	7.66	-22.54	13.28

Table 2. Textural classification (%) of surface sediments collected at Ganpatipule beach

Characteristics and behaviours		Range	BM1	BM2	BM3	Average %
Mode	Unimodal (U)	-	24	24	28	25
	Bimodal (B)	-	61	69	68	66
	Trimodal (T)	-	13	7	4	8
	Polymodal (P)	-	1	0	0	0
Mean (ϕ)	Fine sand (Fs)	3	31	33	32	32
	Medium sand (Ms)	2	64	56	61	60
	Coarse sand (Ts)	1	5	11	7	8
Sorting (ϕ)	Very well sorted	<0.35	15	13	9	12
	Well sorted	0.35 - 0.50	16	23	29	23
	Moderately well sorted	0.5 - 0.7	51	36	40	42
	Moderately sorted	0.7 - 1.00	11	17	19	16
	Poorly sorted	1.00 - 2.00	8	11	3	7
Skewness	Very poorly sorted	2.00 - 4.00	0	0	0	0
	Very fine skewed	+0.33 to +1.0	21	17	16	18
	Fine skewed	+0.1 to +0.3	21	21	21	21
	Symmetrical	+0.1 to -0.1	16	23	19	19
	Coarse skewed	-0.1 to -0.3	24	17	21	21
Kurtosis	Very coarse skewed	-0.3 to -0.1	17	21	23	20
	Very Platykurtic	<0.67	7	11	8	8
	Platykurtic	0.67 - 0.90	33	29	29	31
	Mesokurtic	0.90 - 1.11	19	16	11	15
	Leptokurtic	1.11 - 1.50	24	31	32	29
	Very leptokurtic	1.5 - 3	17	13	20	17
	Extremely Leptokurtic	>3	0	0	0	0

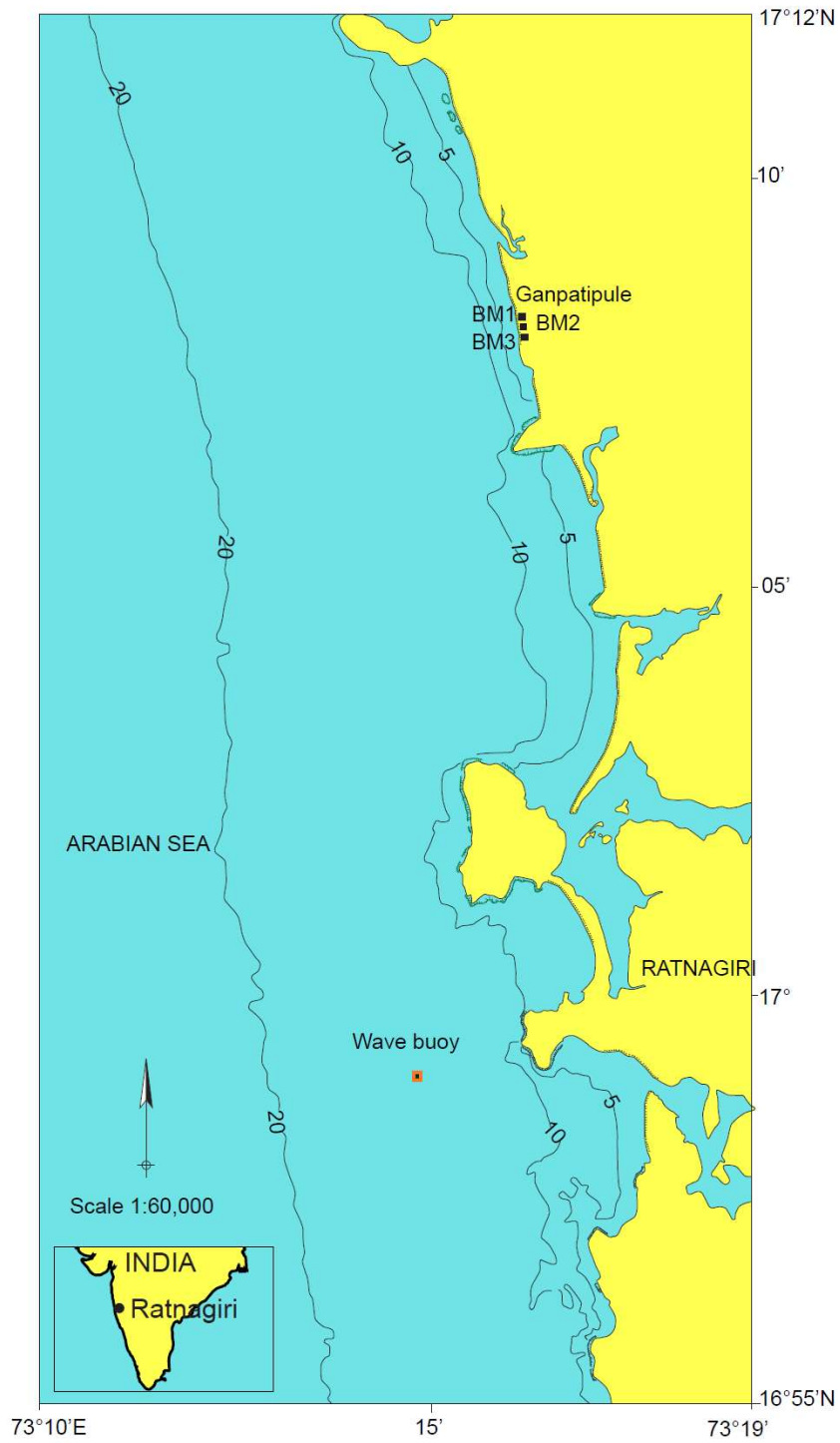


Figure 1. Study area along with the 3 beach profile locations



Figure 2. Field photographs of Ganpatipule beach during monsoon month

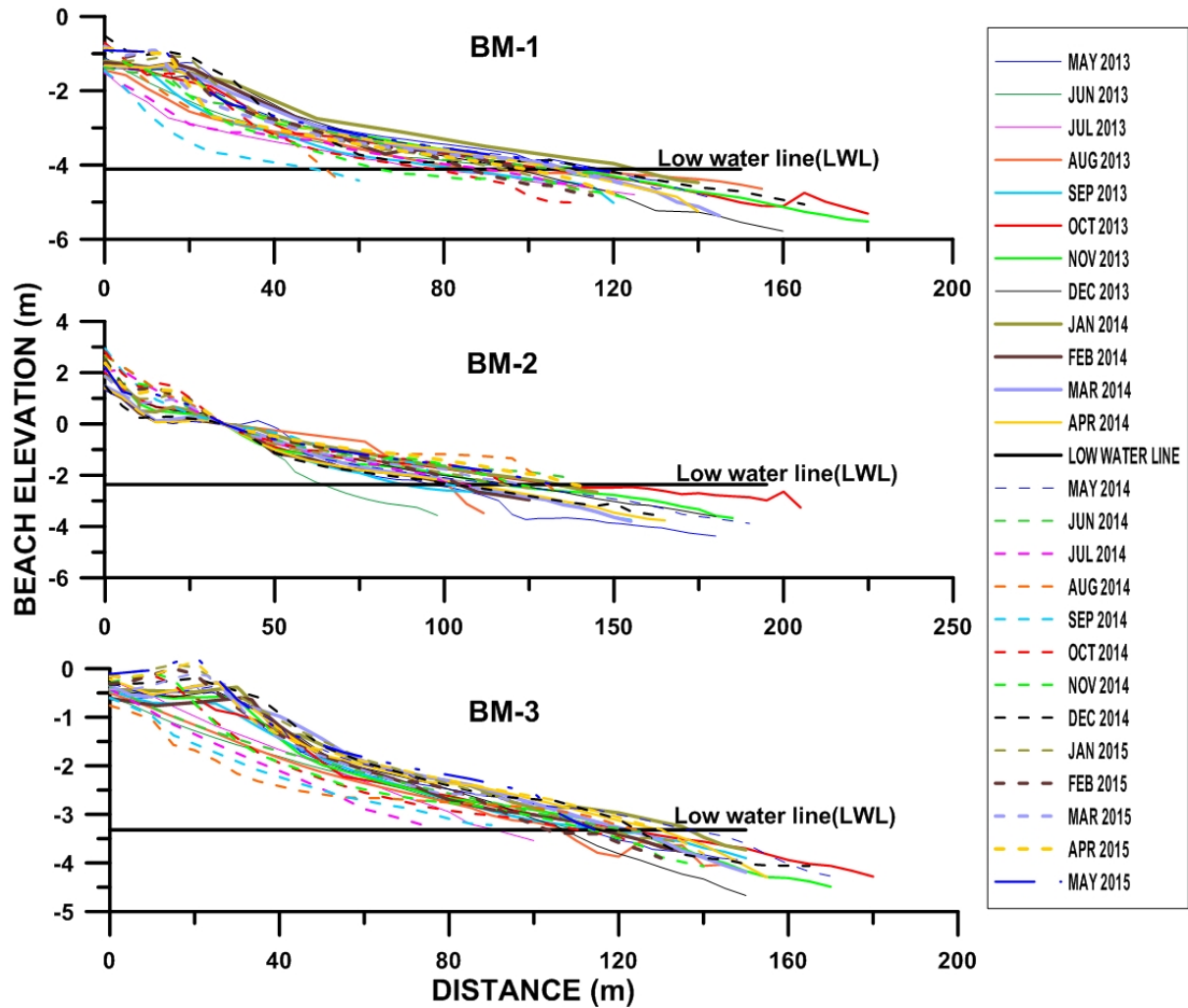
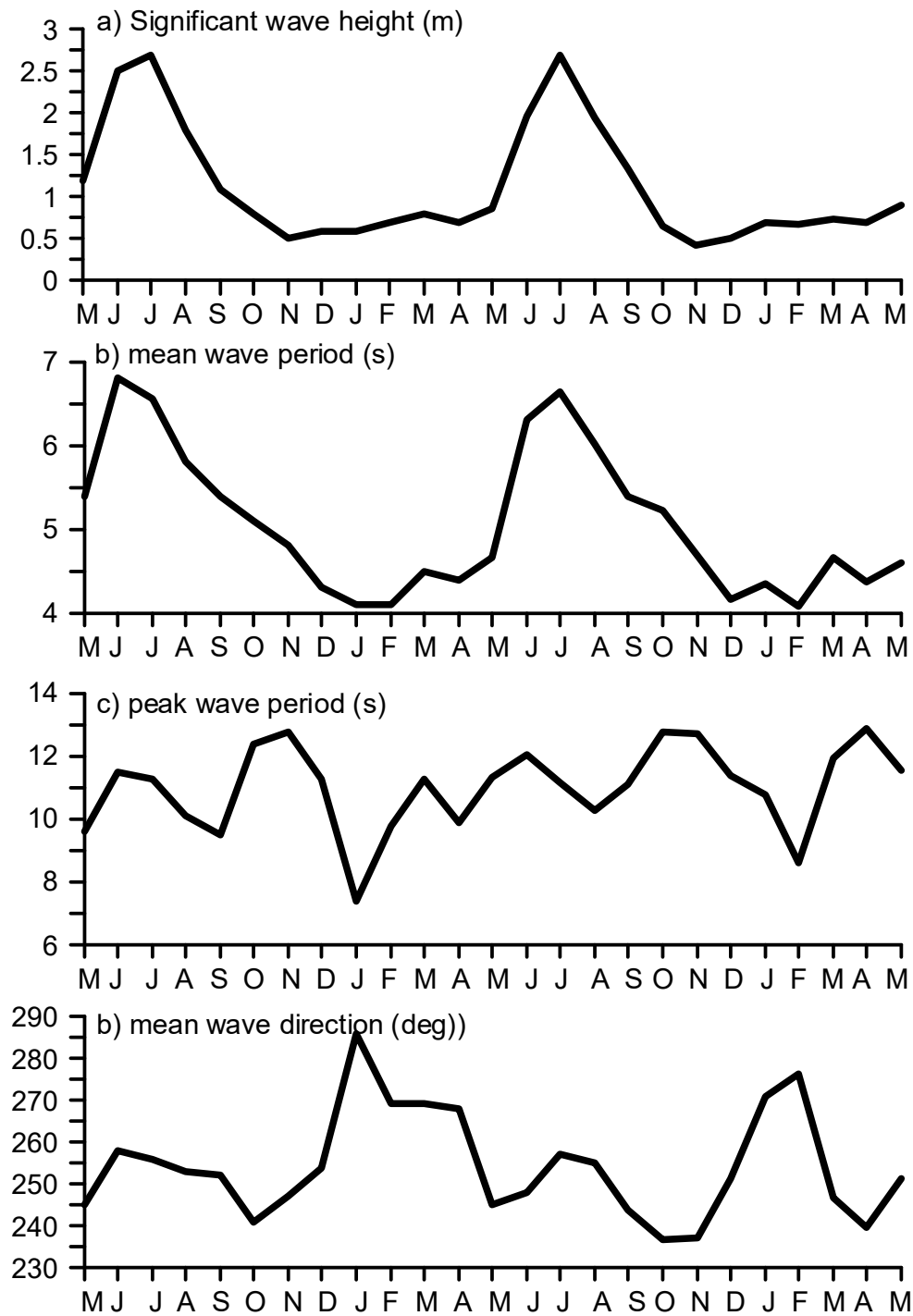
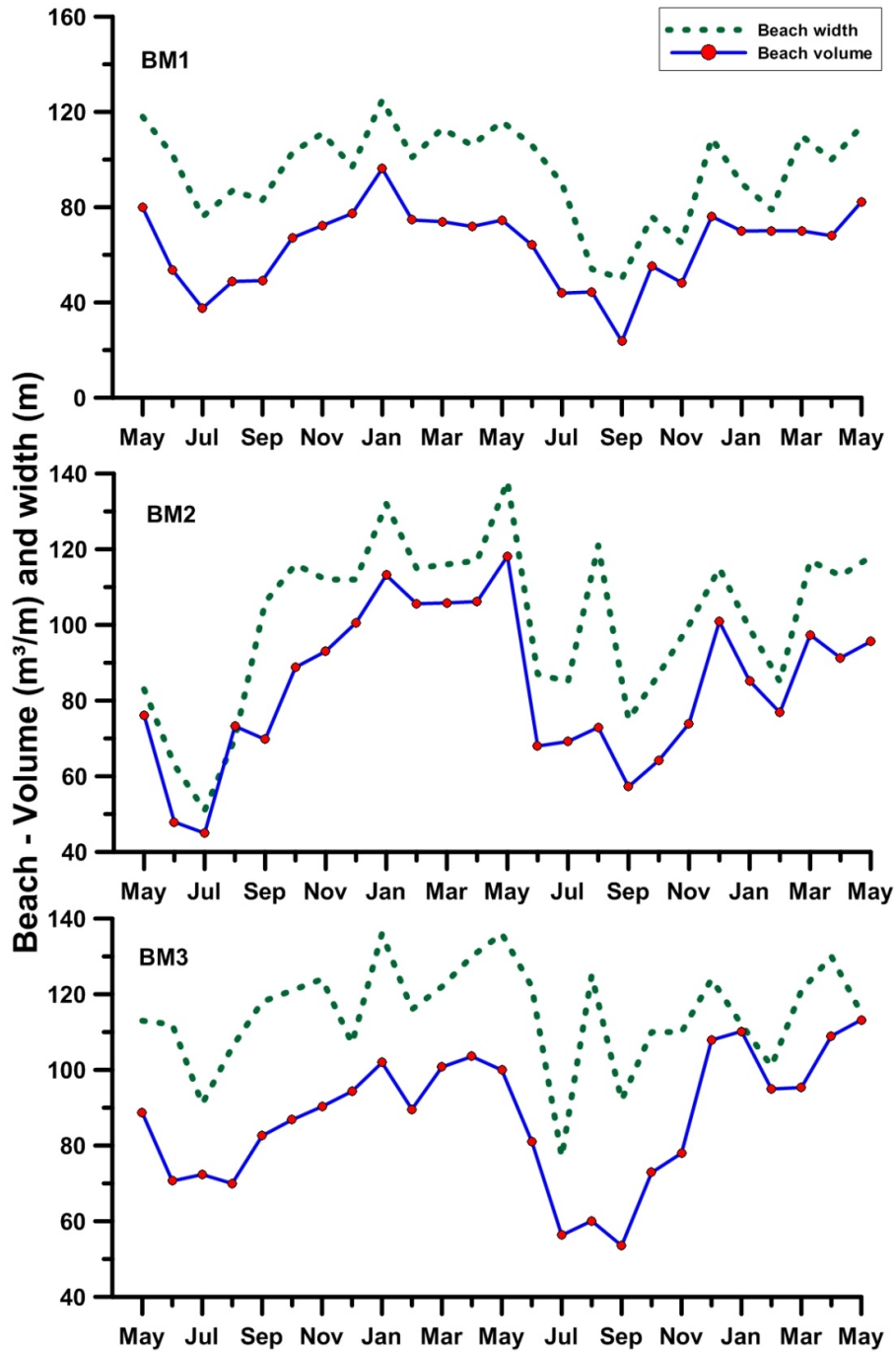


Figure 3. Monthly monitored cross-shore profiles at 3 benchmarks (BM1, BM2 and BM3) locations in Ganpatipule beach during May 2013 to May 2015



Month from May 2013 to May 2015

Figure 4. Monthly average wave parameters a) significant wave height, b) mean wave period, c) peak wave period and d) mean wave direction (direction corresponding to maximum spectral energy) during May 2013 to May 2015



Months from May 2013 to May 2015

Figure 5. Time series plot of monthly beach volume and beach width during May 2013 to May 2015

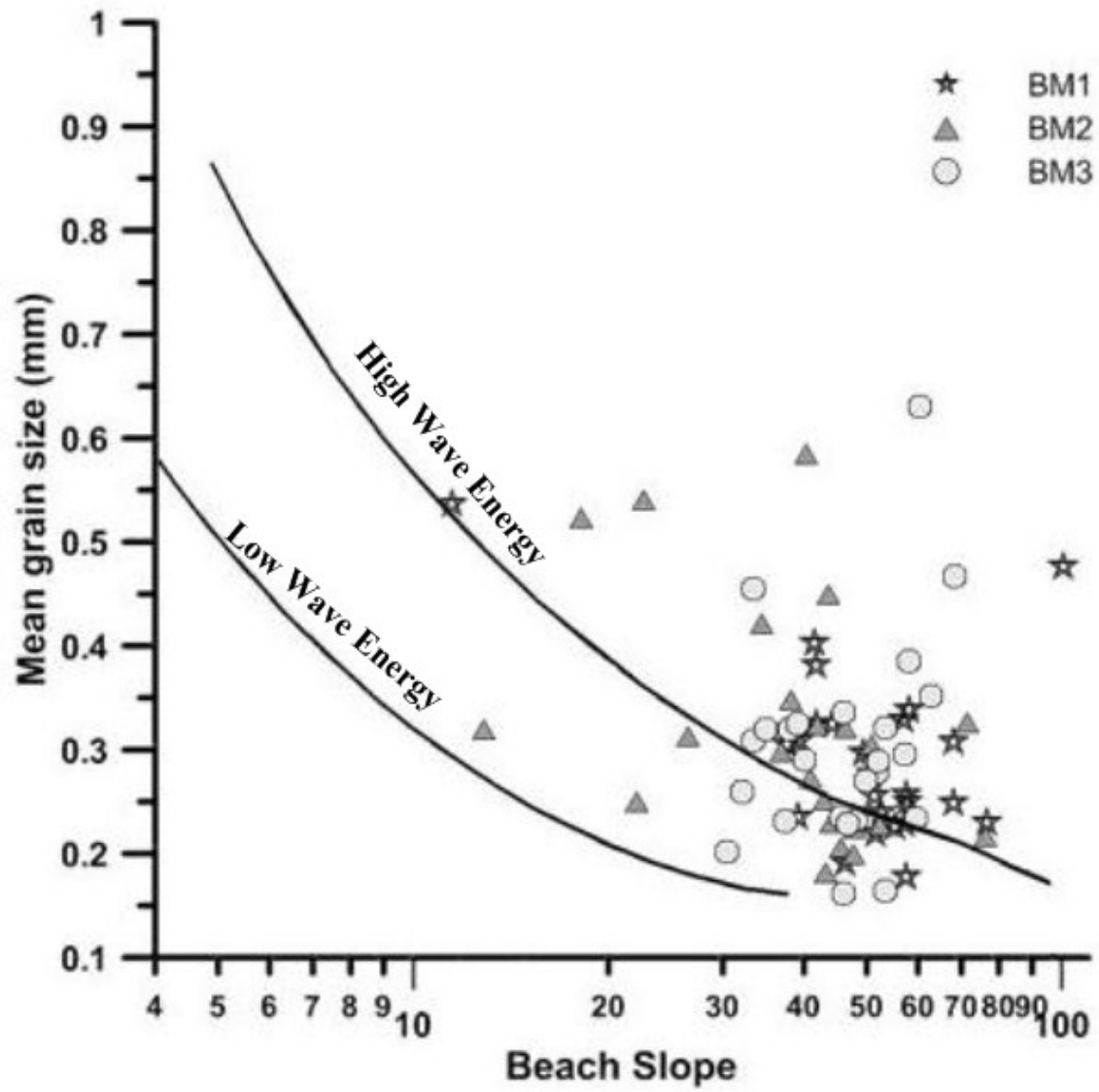


Figure 6. The correlation between median sediment grain size and beach face slope

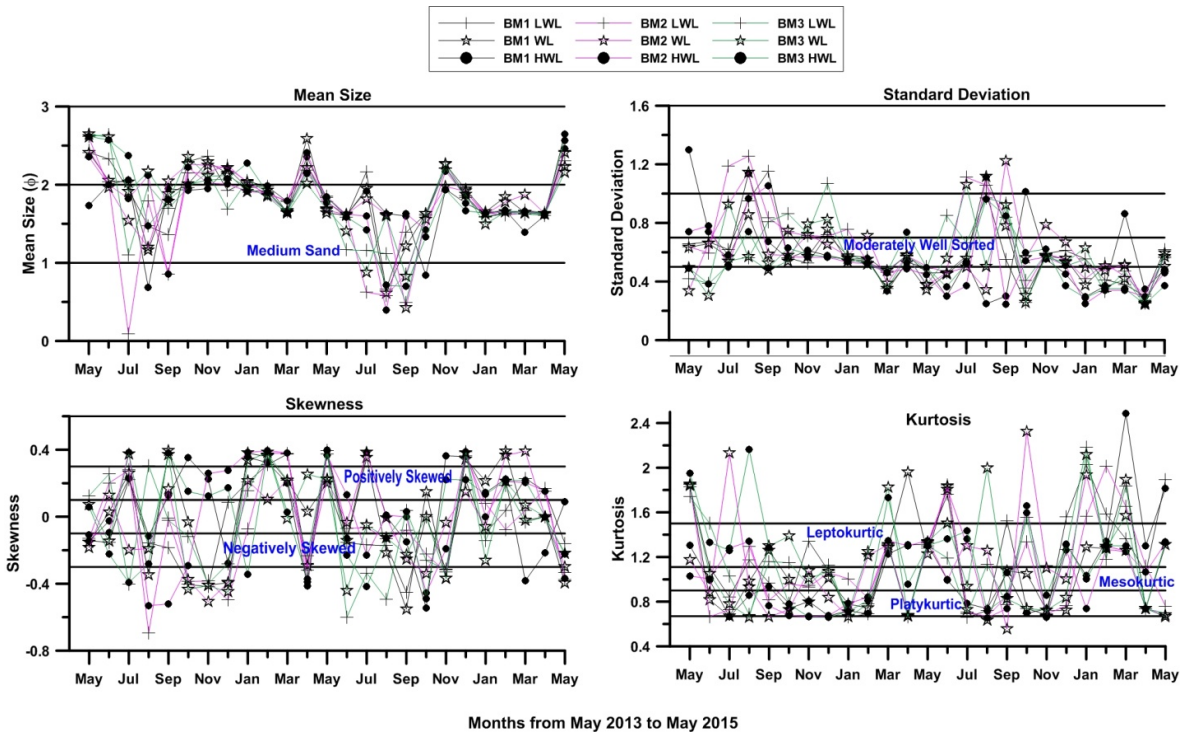


Figure 7. Monthly textural trend of all the samples

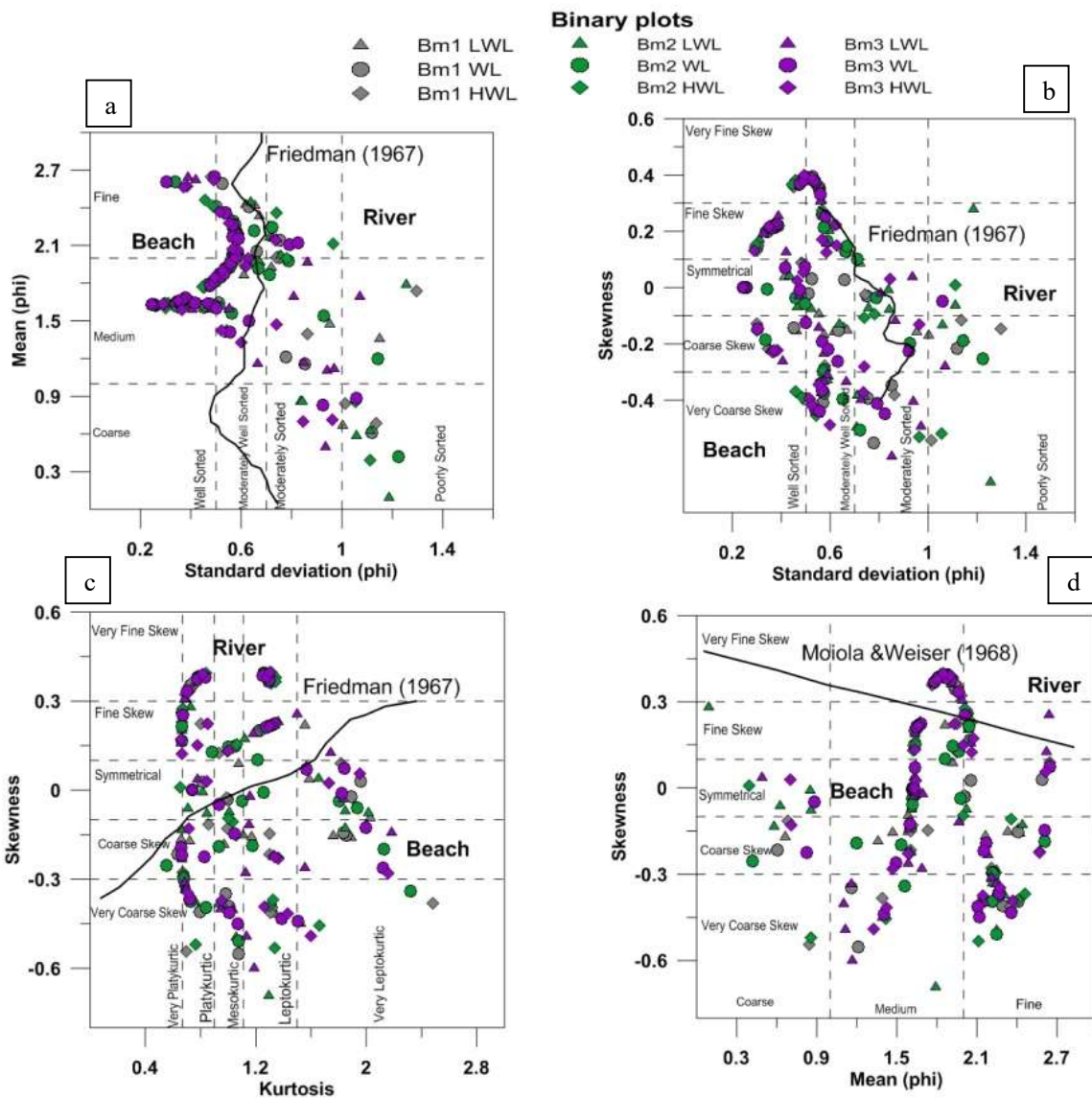


Figure 8. Binary plots of a) mean vs standard deviation, b) skewness vs standard deviation, c) skewness vs kurtosis and d) skewness vs mean

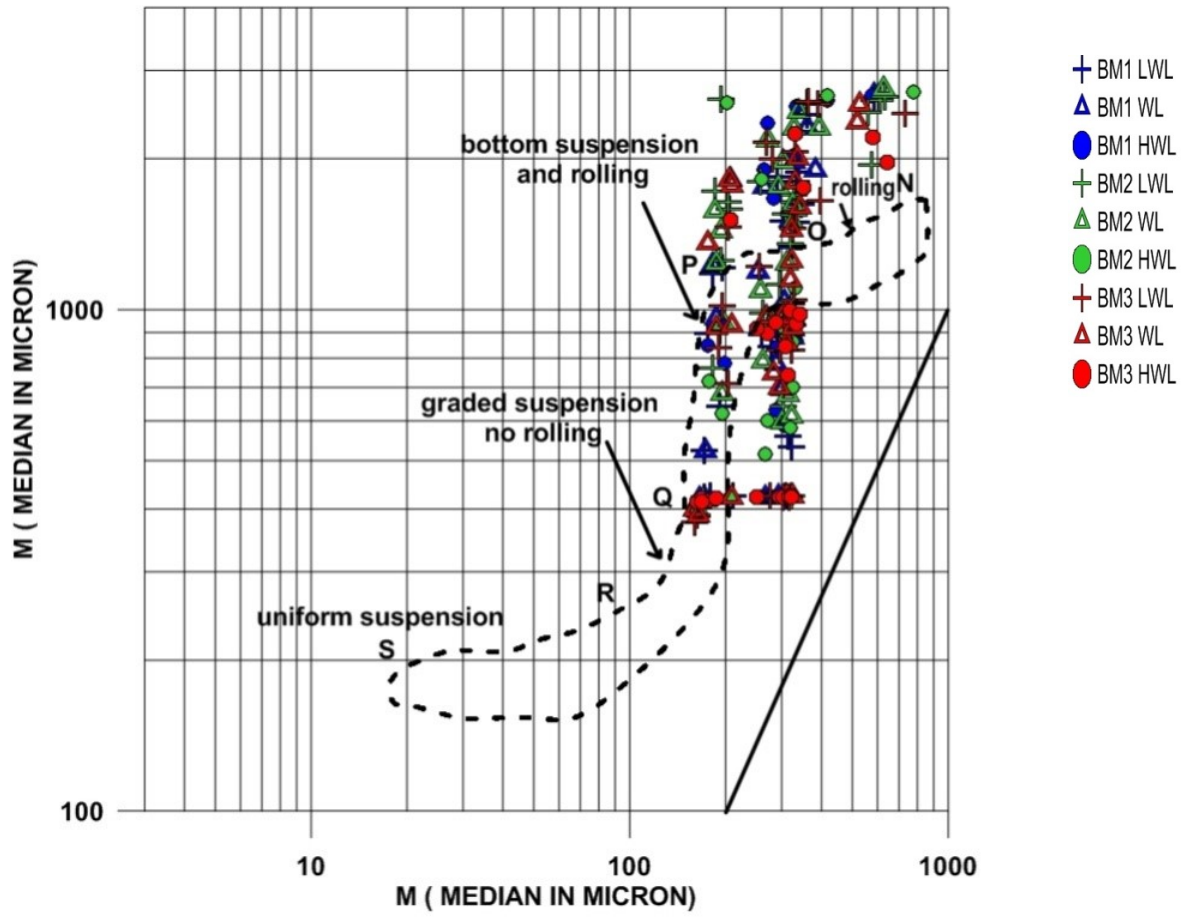


Figure 9. CM plot for all the data used in the study