SECTION RESULTS

CHAPTER 1 HABITAT CHARACTERIZATION

1. INTRODUCTION

Habitat components for the biological assessment of benthic assemblages are hierarchical, and include the watershed, the near shore zone, the water column, and the sediment. An integrated assessment evaluates the condition of estuaries and coastal marine waters by aggregating data on components of both habitat and biota. The habitat component may be damaged by physical stress or chemical degradation from pollution. Thus, habitat studies may help identify causes of biological decline as well as being the important determinant of the types of biotic communities to be expected (Gibson et al., 2000). Habitat characterization is essential to the proper classification of sites. Although estuaries are by definition transitional zones between fresh water and the sea, and both estuaries and coastal marine waters incorporate many environmental gradients (e.g., salinity, sediment composition and depth), individual locations and conditions are often defined categorically. Thus, a site may be characterized as oligohaline or mesohaline with respect to salinity, or sandy muddy or loamy with respect to sediment composition. The composition of biological assemblages can vary dramatically along these habitat gradients, and valid comparisons of estuarine and coastal marine biological assemblages require that their habitats be correctly classified.

1.1 Water quality

Estuaries are cited among the most productive biomes of the world (Costanza et al., 1993, Van Damme, et al., 2005). They support important biogeochemical processes that are central to the planet's functioning, e.g. nutrient cycling (Billen and Somville 1983; Costanza et al., 1997). Estuaries are the interface between terrestrial and coastal waters. They often are characterized by steep chemical gradients and complex dynamics, and these can result in major transformations in the amount, chemical nature and timing of the flux of material along these river–sea transition zones. An important aspect of the high variability of tidal estuaries is related to the short-time effects of a tidal cycle on the physicochemical characteristics of the water. On a time scale of hours, ebb advection of fresh water and salt water intrusion during the flood determine strong changes of several fundamental parameters of the water column, such as salinity (Uncles and Stephens, 1996; Van Damme, et al., 2005), nutrients (Balls, 1994; Montani et al., 1998; Martin et al., 2008) and suspended particulate matter (SPM) (Renshun, 1992). The extent of such variations will vary significantly depending on spring-neap tidal state or amplitude (Yin *et al*., 1995a; Uncles and Stephens, 1996). Moreover, matters may be greatly complicated by other environmental variables, such as precipitation rate, affecting fresh water discharge (Schubel and Pritchard 1986), winds (Yin *et al*., 1995b) and current velocity (Renshun, 1992).

Rivers due to their role in carrying off the municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution (Singh et al., 2005; Pala et al., 2010). Furthermore, Estuaries receives heavy pollution load from industries waste waters. Alteration in the water quality can lead to various ecological consequences like changes in species composition, blooms of phytoplankton and decrease of oxygen concentrations (Cardoso et al., 2004; Martin et al., 2008). Owing to the effects of pollution on estuaries, it is vitally important to understand spatial pattern in water quality in these system. Recently extensive work has been done to assess water quality of Indian estuaries with reference to understand pollution source for the betterment of management strategies (Singh et al., 2005; Panda et al., 2006; Sundaray et al., 2006; Anila Kumari et al., 2007; Martin et al., 2008; Tripathy et al., 2008; Satpathy et al., 2009; Ravaniah et al., 2010). In Gujarat very less work has been done to evaluate water quality status of estuaries of Gujarat. Nirmal Kumar et al. (2009) has studied spatial and temporal Fluctuation in Water quality along the estuarine stretch of River Tapi where as water quality assessment with referenced to pollution status was carried out by Deshkar et al. (2008) and Patel & Vachhrajani (2013) in the estuaries of Gulf of Khambhat. Gor and Shah (2014) has studied water quality index of Mahi River passing through Vadodara district, Gujarat and concluded that water quality of

Mahi River falls under medium to bad category. Patel and Punita (2013) analysed water quality of Mini river, an important tributary of Mahi river, and stated that water quality of Mini river is deteriorating due to anthropogenic activities like industrial use of water and discharge in to the river without any pre-treatments. Furthermore, Industrial effluent channel opens at Sarod make downstream of estuary polluted.

1.2 Sediment quality

Heterotrophic benthic marine organisms are predominantly either suspension feeders or deposit feeders. Organisms that feed exclusively on deposited feed would be expected to reach maximum diversity and biomass on fine grained organic muds containing an abundant food supply. A population that feed on suspended material are influenced by the quality and quantity of the suspended material in the water column. Hence, deposit feeders are more influenced in its distribution by the type of substratum than suspended feeders (Rhoads and Young, 1970). When examine the structure and function of intertidal shores and associate biotic communities, it is necessary to consider: (1) The impact of environment factors on biota (2) The influence of biota on the composition of benthic communities (3) The impact of biota on their environment (Gibson, et al., 2007). Biota living on the intertidal zone of estuaries is adapted to a dynamic environment (Pandya and Vachhrajani, 2011) dominated by the flooding and ebbing of water with periods of aerial exposure. Process of sediment erosion and deposition are central to the behaviour and ecology of intertidal and sub tidal organisms (Widdows and Brinsley, 2002).

The sediment–water interface is a transition zone between the water and the underlying sediment (Santschi et al., 1990). The surface is constantly affected by the deposition of organic matter. Organic matter (OM) content increases with time before it reaches a steady state, depending on the accumulation and decomposition rates (Avnimelech et al., 2001). The percentage of OM is one of the basic properties of the sediment and is related to other important properties of the sediment such as the density of heterotrophic microbial community (Krichman and Mitchell, 1982) and adsorption capacity toward organic components and pollutants (Gibson et al., 2000). Soils are often described and classified by their structure and composition. Water content, bulk density and porosity are important properties of bottom sediments (Avnimelech et al., 2001). Bulk density and pore space or porosity provides a more useful physical description of soil (Hakansson and Lipiec, 2000). Soil bulk density is a measure of soil compaction and strength. Porosity also provides some estimate of compaction and the maximum space available for water (at saturation) or air. The porosity affects the diffusion and transfer of dissolved species between the sediment and the overlying water (Munsiri et al., 1985). Diffusion of dissolved substances within the sediment takes place only in the pores and thus is approximately linearly depended on porosity (Site, 2001). The dry bulk density is related, directly or indirectly to the softness (or hardness) of the sediment, its vulnerability to erosion, resuspension and other mechanical properties (Avnimelech, 2001).

2. RESULTS

2.1 Characterization of lower estuarine region: Kamboi and Sarod

Most of the downstream of Mahi estuary isdominated by open mudflat.Many of the sites like Kamboi, Khambhat, Nahar, Sarod and Dhuvaran representing a vast intertidal area during the low waters and showing regular estuarine process with a river channel passing and opening into the gulf. Amongst them, Kamboi-Khambhat (11.5 km) and Sarod-Dhuvaran (6.5 km) are in opposite to each other (Figure 1). Kamboi and Sarodare representing different zonation in term of sedimentological aspects and even different microhabitats as a result of hydrodynamics and morphological features.Topographical feature of an area affects directly the hydrodynamics and the depositional and erosional processes of an area. This process further controls sediment sorting and creates different zones.These microhabitats effectively occupied by different kind of benthic forms.

2.1.1 Sarod

A beach slope was seen from upper intertidal area to lower intertidal area atSarod. Overall, an elevation difference of 7.5 m was found over the study area, from the upper surf zone to the lower intertidal zone. Based on sediment analysis, three distinct zones were identified at Sarod*viz.*zone 1; sandy-silty, zone 2; silty-clayey and zone 3; silty -sandy (Figure 2).

Zone 1: This zone remains dry with loose silty sand eroded from wind as well as adjacent cliff. The zone confined to 35 meters and in first 20 meters areano microhabitats were seen. Last 15 meter of zone contains occasional distribution of a brachyuran crab species*Uca lactea* and some gastropods.

Zone 2: Due to its regular tidal exposure and the suitable substrata, it was rich zone in terms of brachyuran fauna (i.e.*Ilyoplax sayajiroai*). The zone showed a prominent beach slope with a plain sandy mosaic. The terminal part of zone 2 showed rich watery area with a runnel system and soup ground.

Zone 3: The lowermost intertidal area was mostly comprised by fine sand.This area was dominated by fine sandy plains with ripples. Zone 3 represents typical characteristics of water and sediment churning at sediment water interface usually form very small ripples.The zone was rich in density of brachyuran crabs (mainly *Dotilla sp*.).

2.1.2 Kamboi

A similar beach slope like Sarod was found from upper intertidal area to lower intertidal area at Kamboi. The elevation difference of 8.5 m was found over the study area, from the upper surf zone to the lower intertidal area (Figure 3). Based on sediment analysis, five distinct zones were identified from upper to lower intertidal area respectively which are zone 1; sandy-silty, zone 2;silty-sandy, zone 3; silty-clayey, zone 4; clayey-silty and zone 5; silty-sandy (Figure 4). The detailed description of different zones is presented herewith:

Zone 1: The uppermost surf zone occasionally gets the water inundation during highest high tides. Rest of the days the zone remains dry with loose silty/clayey sand eroded from wind. The belt is used as a track by the local people and isolated vehicles. The zone confined to hardly 10 meters and no different microhabitats were seen. The zone was more or less free from any benthic fauna due to human disturbance and dryness; hence it was excluded from the study.

Zone 2: This zone represented a belt of coastal grass spread through the area. The Zone due to its coastal grass cover and hardsubstratum represented a sparse faunal diversity (Figure 5a).

Zone 3: The zone was muddy in nature and topographically with high slope. Due to its regular tidal exposure and the suitable substrata, it was one of the richest zones in terms of diversity and density. Yet the zone was a homogenous mudflat with no other microhabitat seen within it (Figure 5b).

Zone 4: This zone was following Zone 3 n terms of diversity and density with a prominent beach slope and a mosaic of muddy habitat. The terminal part of zone 4 was a rich watery area with runnel system and soup ground (Figure 5c).

Zone 5: The lowermost intertidal area zone 5 was mostly coveredwith fine sand. The initial part of the zone was interrupted by hard substratum (partially hardened soil) in patches. The area also possessed intertidal pools seen in between the hard substratum (Figure 5d). Remaining area was dominated by fine sandy plains with ripples.In case of smaller to medium sized ripples; the base (slope) of the crest was ideally used as a microhabitat by *Macrophthalmus sulcatus* where in other case the crest of ripple used as a microhabitat for burrowing by *Dotilla sps*.

2.2 Water quality of downstream of Mahi estuary

Four sites were selected for water quality analysis*viz.*Dabka, Sarod, Nahar and Kamboi. Water samples were collected during high tide and low tide to understand the effect of tidal circulation at downstream of Mahi estuary. Detailed results of water quality analysis are given in Table 1.

Acidity: Acidity was recorded high at Sarod (125 ±18.03 mg/L) followed by Nahar (70±22.91 mg/L) anda general trend was observed that acidity was high during high tide compared to low tide at all the sites (Figure 6).

Alkalinity: Alkalinity was recorded high at Sarod (523.33±51.32 mg/L)followed by Nahar (410±36.06 mg/L) and a general trend was observed that alkalinity was high during low tide compared to high tide with an exception at Dabka where alkalinity was recorded high during high tide (Figure 6).

Total Hardness: Total hardness was recorded high at Nahar (3426.67 ±257.94 mg/L) followed by Kamboi (3096.67 ±345.59 mg/L)andSarod (2886.67 ±295.69 mg/L). Total hardness was recorded high duringhigh tide compared to low tide with an exception at Dabka where total hardness was recorded high during low tide (Figure 6).

Ca Hardness: Ca hardness was recorded high at Kamboi (350 ±26.46 mg/L) followed by Sarod (290 ±36.06 mg/L) (Figure 6).

Chloride: Chloride was recorded high at Nahar (16133.33 ±450.04 mg/L) followed by Kamboi (15880 ±563.54 mg/L) and Sarod (15009 ±385.96 mg/L). Chloride recorded high during high tide compared to low tide at all four sites (Figure 7).

Total Solids: Total solids recorded high at Kamboi (29479.33 ±1035.72 mg/L) followed by Nahar (28623.33 ±552 mg/L) and Sarod (27208.67 ±985.21 mg/L) and a general trend was observed that total solids recorded high during high tide compare to low tide at all four sites (Figure 7).

Phosphate: Phosphate recorded high in Sarod (1.28 ±0.30 mg/L) followed by Nahar (1.02 ±0.39 mg/L). It was recorded high during low tide compare to high tide in all four sites (Figure 7).

Salinity: Salinity was recorded high at Kamboi (32.18 ±0.67 ppt) followed by Nahar (31.31 ±0.89 ppt) and Sarod (27.81 ±0.62 ppt). It was recorded high during high tide with an exception at Kamboi where it was recorded high during low tide (Figure 7).

2.3 Sediment analysis of downstream of Mahi estuary

2.3.1 Sarod

Sediment samples of two zones (Zone 2 and Zone 3) were analysed up to depth of 60 cm (surface, 20 cm, 40 cm, 60 cm respectively) for various parameters. Zone 1 was excluded as very less benthic formswereobservedandacted as a surf area duringspring tides. The detailed results of all the parametersare is given in Table 2.

Sediment composition: An average of 62.5±20.67% of silt & clay and 37.5 ±20.67% of sand) was recorded for Zone 2 and Zone 3. Zone 2 represented upper intertidal terraces covered with coastal grass and made up of loamy composition (80 ±6.32% silt & clay and 20 ±11.83% sand). Following Zone 2, Zone 3 was represented by muddy composition (45 ±11.32 % silt & clay and 55 ±11.83 % silt). No significant variation was observed at different depths with silt & clay proportion ranging between 72 to 76 % at zone 2. Silt & clay proportion ranging between 58 % and 52 % respectively at surface and 20 cm depthwhile 36 % and 34 % respectively at 40 cm and 60 cm depth at zone 3 (Figure 8).

Soil organic carbon (SOC): Average SOC recorded 0.52 ±0.06 % of zone 2 and zone 3. Average SOC recorded 0.53 ±0.04 % of all four depths and highest SOC was recorded 0.59 ±0.06 % at the depth of 40 cm in zone 2. Average SOC was recorded 0.51 ±0.07 of all four depths in zone 3 and highest SOC recorded 0.61 ±0.04 % at the depth of 60 cm (Figure 8).

Electric conductivity (EC): Average ECwas recorded 0.67±0.21 μS/cm at all four depths (surface, 20cm, 40cm, and 60cm) of zone 2 and zone 3.There was no difference found in value of EC at zone 2 and zone 3 (0.67 ±0.29 μS/cm and 0.66 ±0.11 μS/cm respectively) whiletaking average of four depths of both the zones. EC increased as depth increased in zone 2 while this trend was reversed in zone 3. The lowest ECwas recorded 0.24 ±0.09 μS/cm in the surface sediment of zone 2 while highest ECwas recorded 0.89 ±0.04 μS/cm at the depth of 40 cm of zone 2 (Figure 9).

pH: Average pH was recorded 6.85 ±0.63 for zone 2 and zone 3 atall the four depths (surface, 20cm, 40cm, and 60cm). Value of pH was decreased as depth increased in boththe zones. The highest pH was recorded 8.07 ±0.24 in the surface sample of zone 2 while lowest pH was recorded 6.12±0.10 at the depth of 60 cm of zone 2 (Figure 9).

Soil Water Content: Average water content was recorded 26.24 ±1.3% for all four depths of zone 2 and minute variation was recorded according to different depths. While in the case of zone 3, average water content was recorded 30.64 ±4.88 %for all four depths and water content % decreased as depth increased (Figure 10).

Porosity: Average porosity was recorded 0.26 ±0.01 for all four depths of zone 2 while 0.31±0.05 for all four depths of zone 3 (Figure 10).

Wet bulk density (D_{WB}): Average D_{WB} 1.58 ±0.05 g/cm^{-3}was recorded for all four depths of zone 2 and zone 3 and highest $D_{WB}$was recorded 1.67 ±0.03 g/cm^{-3} in the surface sediment sample of zone 3 (Figure 10).

Dry bulk density (D_{DB}): Average D_{DB} 1.31 ±0.03 g/cm^{-3}was recorded for all four depths of zone 2 and zone 3 and highest $D_{DB}$was recorded 1.35 ±0.02 g/cm^{-3} at the depth of 40 cm in zone 2 (Figure 10).

2.3.2 Kamboi

Sediment samples of various depths of all the zones (Zone 2 to Zone 5) were analysed. Zone 1 was excluded as it isasurf area without any benthic assemblages. The detailed results of all parameters are given in Table 3.

Sediment composition: Average 45.62 ± 21.38% silt &clay and 54.38 ±21.38% sandwas recorded as an average of all the zones (zone 2 to zone 5 - total 13 samples at different depth level). Zone 2 represented upper intertidal terraces covered with coastal grass and showed a loamy composition (sand 68% and silt & clay 32% at surface sediment). Zone 3 showed silty clay composition with 69% silt &clay and 31% sand (at surface sediment) and was important in terms of rich density of brachyurancrabspecies like *Uca annulipes* and *Ilyoplax sayajiraoi*. Zone 4 showed merely similar values of sediment composition (78% silt & Clay and 22 % sand at surface sediment) and containedsloppy terrace instead of flat terrace. Moving towards the low tidal area, zone5 represented vast flat plain with an area occupied by fine sandy composition (4 % silt & clay and 96 % sand at surface sediment) (Figure 11).

Sediment composition was analyzed up to 60 cm depths (surface, 20cm, 40cm, and 60cm) for zone 2 and zone 3 while up to 40 cm depths (surface, 20 cm and 40cm) for zone 4 and up to 20 cm depths (surface and 20 cm) for Zone 5. No significant variation was observed in proportion of silt & clay and sand (sand 68% and silt & clay 32%) at various depths of zone 2.

More or less same proportion was seen in sediment composition up to 40 cm depth at zone 3 with silt & clay proportion ranging between 61 – 69 % while at 60 cm depth silt &clayproportion was 38%. In case of zone 4 sediment composition of surfaceand 20 cm depth remained the same and dominated by silt & clay (78 % and 72 % respectively) while maximum of sand proportion (62 %) was recorded at 60 cm depth. Zone 5 was dominated with fine sand proportion with 96% sand in surface sediment anda decline was observedin proportion of sand to 64% at the depth of 20 cm (Figure 11).

***Soil organic carbon* (SOC):** AverageSOC was recorded 0.55 ±0.06 % for all four zones (zone 2 to zone 5 – total 13 samples at different depth level). Average SOC was recorded 0.58 ±0.05% for all four depths and highest SOC recorded 0.63 ±0.08% at the depth of 40 cm in zone 2. Average SOC recorded 0.57 ±0.09 %for all four depths and highest SOC was recorded 0.69 ±0.08 % at the depth of 60 cmin zone 3. Average SOC was recorded 0.54 ±0.01 % for three depths at zone 4 while 0.50 ±0.05 % for two depths at zone 5 (Figure 11).

Electric conductivity (EC): Average EC of all four zones was recorded 0.66±0.17µS/cm. In the case of zone 2, EC was ranging between 0.83 ±0.11µS/cm to 0.90 ±0.08µS/cm from sediment surface up to 40 cm while at the depth of 60 cm it was recorded 0.48 ±0.12µS/cm. EC was recorded in range of 0.58±0.11µS/cm to 0.62 ±0.07µS/cm for all the four depths in zone 3. EC was increased as the depth increased and highest value was recorded 0.89 ±0.04 µS/cm at the depth of 40 cmin zone 4. EC was recorded 0.45 ±0.07 and 0.42 ±0.04 at surface sample and depth of 20 cm respectively in zone 5 (Figure 12).

pH: Average pH was recorded 7.39 ±0.53 for all the four zones and pH increased towards lower intertidal zone while moving towards zone 5 from zone 2. The highest pH was recorded 8.07 ±0.24 in the surface sediment of zone 2 while lowest pH recorded 6.12 ±0.10 at the depth of 60 cm of zone 2.Average pH 6.71 ±0.32 was recorded for all four depths with lowest pH recorded 6.39 ±0.16 in the surface sediment of zone 2. In the case of zone 3, average pH was recorded 7.58 ±0.24 for all four depths while highest pH recorded 7.89 ±0.27 at the depth of 60 cm. pH was ranging between 0.67 ±0.17 to 0.69 ±0.12 in the various depths of zone 4. Average pH was recorded 7.97 ±0.19 with highest pH recorded 8.11 ±0.13 at the depth of 20 cm in zone 5 (Figure 12).

Soil Water Content: Average water content varied between 21.5 ±1.18 to 28.8 ±2.88 % (Table 3). Average water content was recorded 23.08 ±1.16

%for all four depths of zone 2 and value was constant with the change in depths. In the zone 3, average water content was recorded 26.23 ±1.85 % and % of water content decreased with an increase in depths. Average water content was recorded 24.92 ±1.4 % for three depths in zone 4 while 25.31 ±1.53 %for two depths in zone 5 (Figure 13).

Porosity: Average porosity was recorded 0.25 ±0.02 for various depths of four zones. Highest porosity was recorded 0.29 ±0.03 in the surface sediment sample of zone 3 while lowest porosity recorded 0.21 ±0.01 at the depth of 20 cm in zone 2 (Figure 13).

Wet bulk density (D_{WB}): General trend of increase in D_{WB} was observed from upper to lower intertidal area (zone 2 to zone 5) with the highest value of 1.91 ±0.02 g/cm^{-3} at the depth of 20 cm in zone 5 and lowest value of 1.22 ±0.07 g/cm^{-3}in the surface sediment sample of zone 2 (Figure 14).

Dry bulk density (D_{DB}): Average D_{DB} at various depths of three zones (zone 2 to zone 4) was recorded 1.30 ±0.04 g/cm^{-3}while, average D_{DB} was recorded 1.46 ±0.02 g/cm^{-3}for two samples (surface and 20 cm depth) of zone 5and negligible difference was found with respect to various depths (Figure 14).

3. DISCUSSION

Estuaries are transitional zones in which the chemical composition varies from that of freshwater to marine. Salinity isa key determinant in the distribution of estuarine flora and fauna, especially for benthic invertebrate communities (Engle et al. 1994; Weisberg et al. 1997; Pandya, 2011; Pandya and Vachhrajani, 2012; Varadharajan, 2013).Salinity was recorded 31^{+} ppt at Kamboi suggest that Kamboi comprises marine water during both the tides (High tide and low tide) and being the mouth of estuary it contain marine environment. Salinity recorded 31.31 ±0.89 ppt during high tide and 28.67

±1.02ppt during low tide suggest mixing of fresh water during low tide at Nahar. In the case of Sarod salinity was recorded near 27 ppt during both the tides suggest the fresh water mixing during high tide also and this may be due to effluent release channel while very low salinity during both the tides at Dabka suggests it is mid estuarine site with very high fresh water intrusions. Total solids followed the same trend as Salinity and confirmed that Kamboi is marine sites where as Nahar and Sarod received the minute effect of fresh water mixing during low tide and Dabka contained minimum impact of tides. High value of Acidity and Alkalinity at Sarod and Nahar reflects the effect of effluent release at Sarod. Total hardness, Ca hardness and Chloride again showing the effect of marine water intrusions and recorded high during high tide. Phosphate is recorded very low at all sites during both the sites showing the low nutrient distribution along the estuarine area. Linear correlation between different Physico-chemical parameters suggests that Ca Hardness corretats with Phosphate and alkalinity (Table 4).

Results of Cluster analysis showed that Dabka during both the tides had total different Physico-chemical condition than other sites. During both the tides Kamboi showing the similar conditions and hence it is very close. High tide conditions of Nahar showing nearly similar condition with Kamboi where as low tide condition of Nahar have similarity with low tide Sarod. Sarod High tide conditions have similarities with low tide conditions of Nahar and Sarod. Being the immediate downstream site of Sarod, effluent release site, Nahar reflecting the similar condition during low tide where as during high tide marine water intrusion dilute the effluent impact and Nahar reflects the marine environment conditions like Kamboi (Figure 15). When we analyse the results to K-means cluster by giving them 3 group options, Dabka fits in 3rd group with both the tides condition. High tide and low tide condition of Kamboi with high tide condition of Nahar makes 2nd group while low tide and high tide conditions of Sarod with low tide conditions of Nahar occupied 1st group (Table 5). So, we can observe that though Sarod and Kamboi have marine environment their Physico-chemical condition is difference and this may be due to effluent channel which is release at Sarod. Hence, we have taken these two sites for detailed studies.

Since Estuaries are usually regions of low topographic gradients and active sedimentology, most of the bottom materials are unconsolidated muds and sands in various combinations and one of the muddy bottoms of estuary is its tendency to retain the water of higher salinity as the tide recedes (Emery and Stevenson, 1957). Soil quality is usually considered to have main aspects: Physical, chemical and biological. Physical quality of soil has big effect on chemical and biological process in the soil and therefore it plays a central role in studies of soil quality (Dexter, 2004). Mass physical sediment properties play an important role in sediment stability, benthic ecology, microbiology and biogeochemistry. The objective of measuring sediment composition is to detect and describe spatial and temporal changes of the benthic habitat. Sediment composition information may explain the temporal and spatial variability in biological assemblages related to an organism's ability to build tubes, capture food, and escape predation. Sarod intertidal area comprises three different zones perpendicular to seashore. Zone 2 contains loamy composition with high silt-clay % while zone 3 contains muddy composition with more or less equally silt-clay & sand % and hence both the zone has different microhabitat. In the similar case Kamboi intertidal area comprises five zones with different silt-clay & sand ratio and provides five different microhabitat or mosaic of microhabitat perpendicular to seashore. In linear regression of silt-clay %(mud content %) and water content %, we can observed that positive relation between both parameters (r=0.27), peak of water content % found at 58 % of silt-clay (Figure 16). As silt-clay % (mud content %) increases Dry bulk density (DBD) decreases (Flemming and Delafontaine, 2000) hence with the increase of water content %, Dry bulk density decreases.

In linear regression with water content % and DBD, we found negative correlation (r = -0.22). So we found similar results as discussed by Flemming and Delafontaine (2000) in review paper on mass physical properties (Figure

17). Water content % is always found in linear relationship with porosity as they both are reciprocal to each other. Soil carbon content % recorded low in all the zones of both the sites and highest recorded in sample where 69% silt-clay ratio, its again the confirmation with results of Flemming and Delafontaine (2000) who stated that at 60 % mud contents highest soil organic matter found. Linear correlation suggest that EC shows strong positive correlation with organic carbon content and water content and pH shows strong correlation with water content.

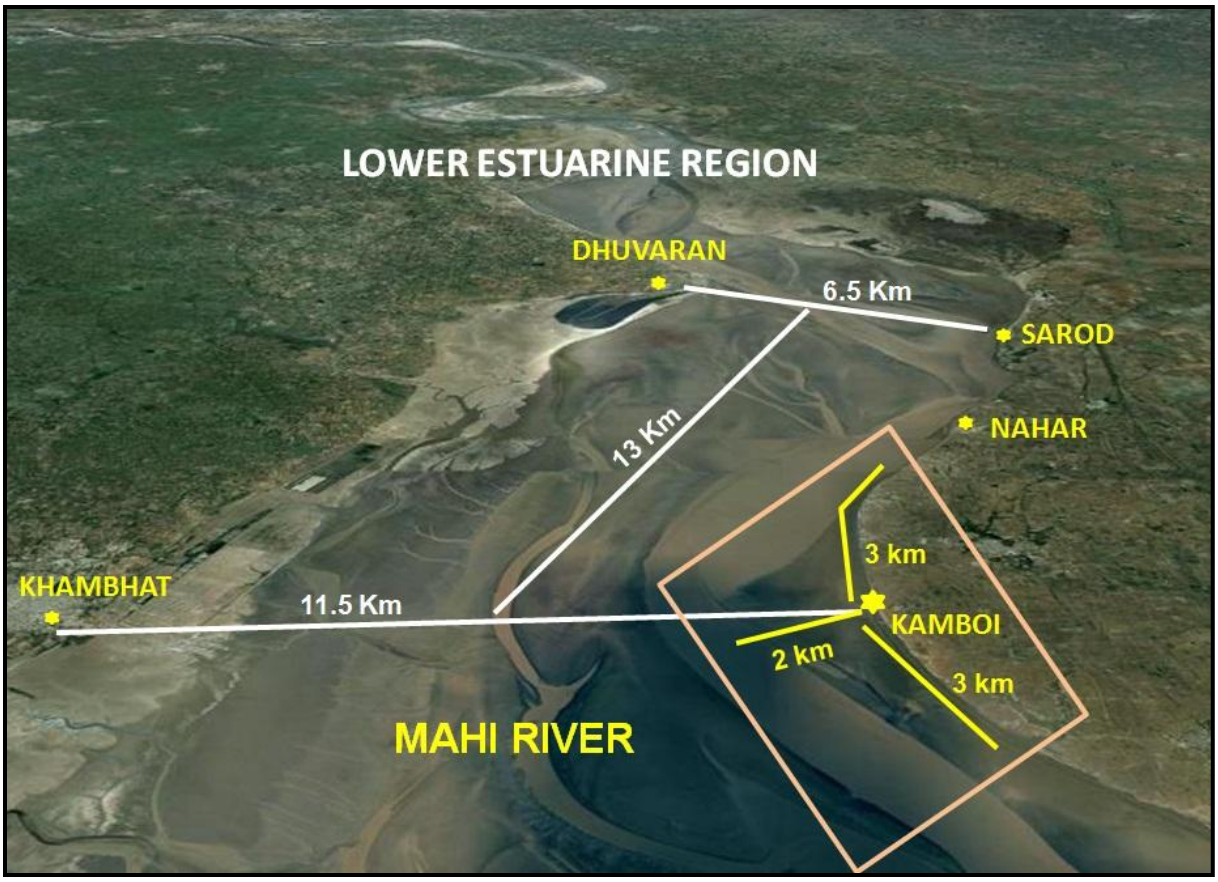


Figure 1. The Lower Estuarine area of Mahi River between Sarod and Kamboi

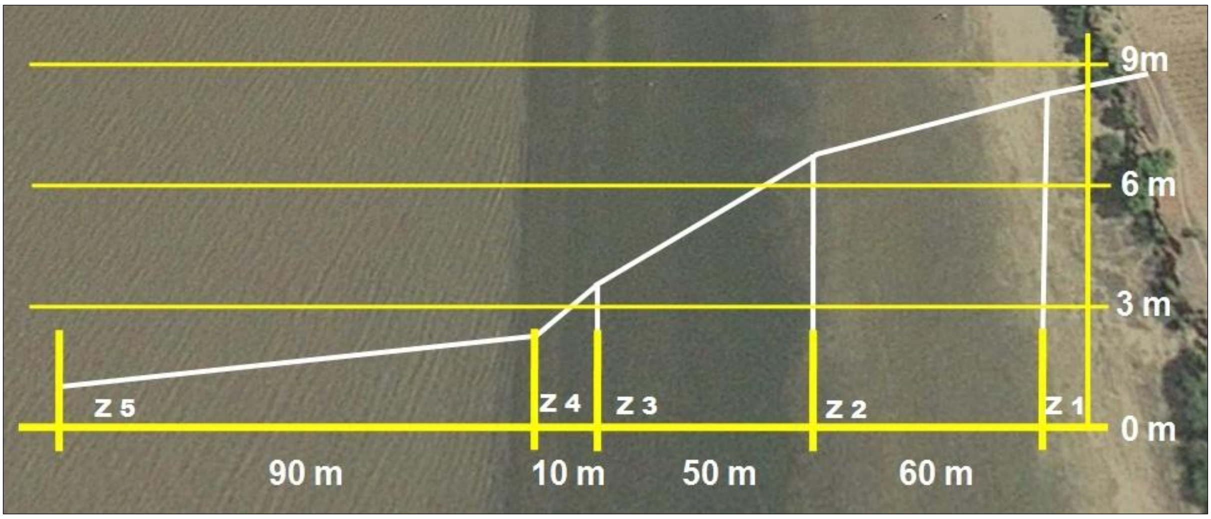


Figure 2. Beach profile and slope (cross sectional view) from the upper surf zone (Z1) to the lower intertidal area (Z5) up to 200 m at Kamboi.

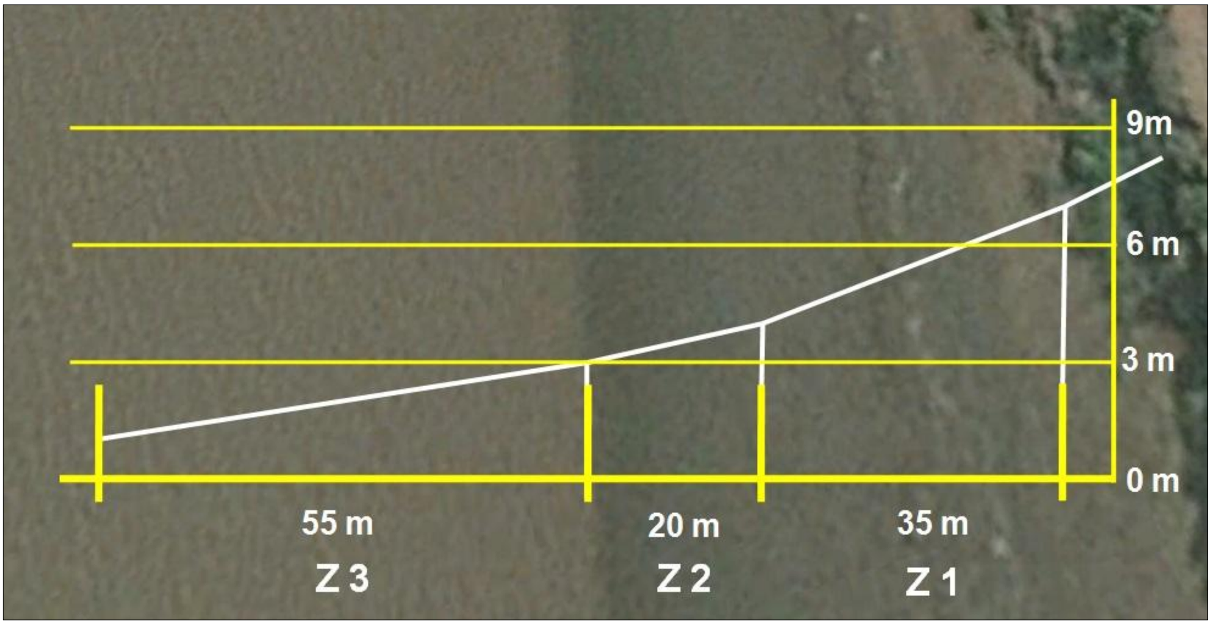


Figure 3. Beach profile and slope (cross sectional view) from the upper surf zone (Z1) to the lower intertidal area (Z3) up to 110 m at Sarod.

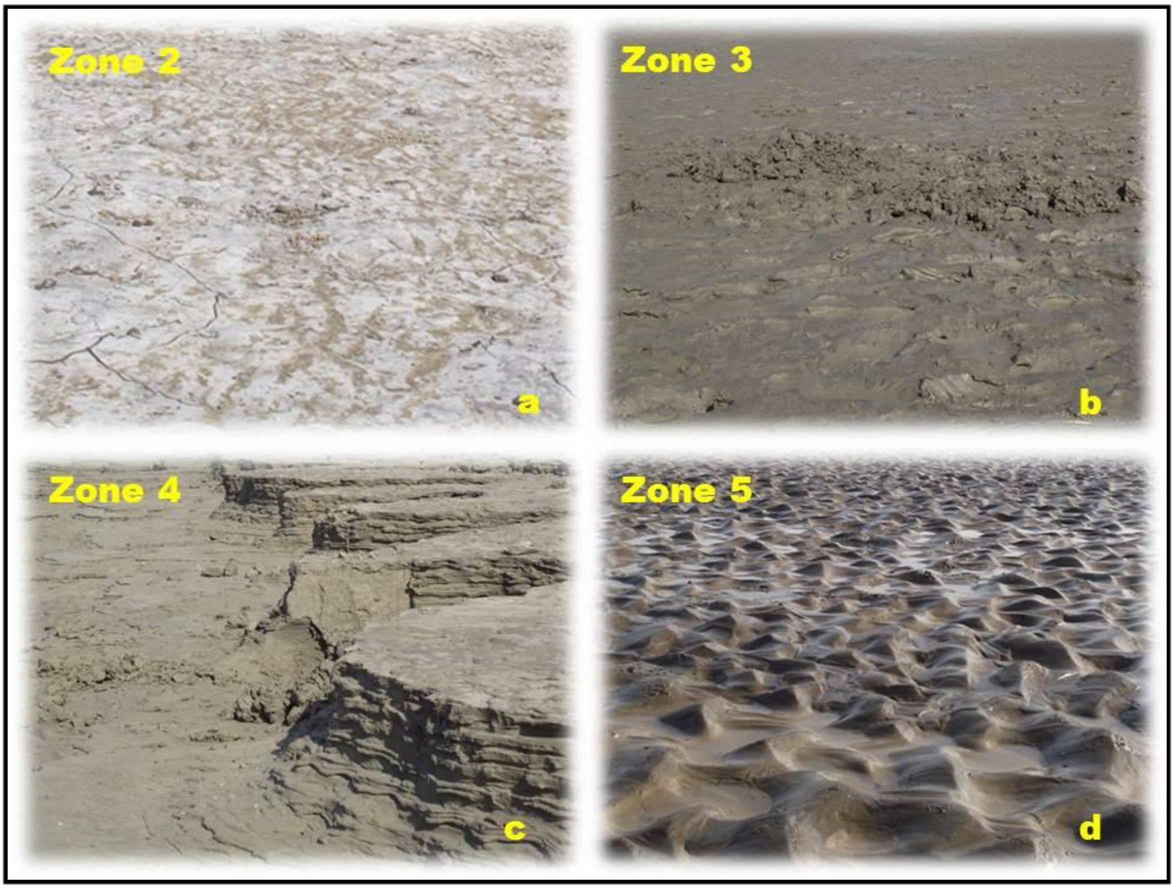


Figure 4. Different Sediment types of intertidal area at Kamboi.

(a) Zone 2 (b) Zone 3 (c) Zone 4 and (d) Zone 5

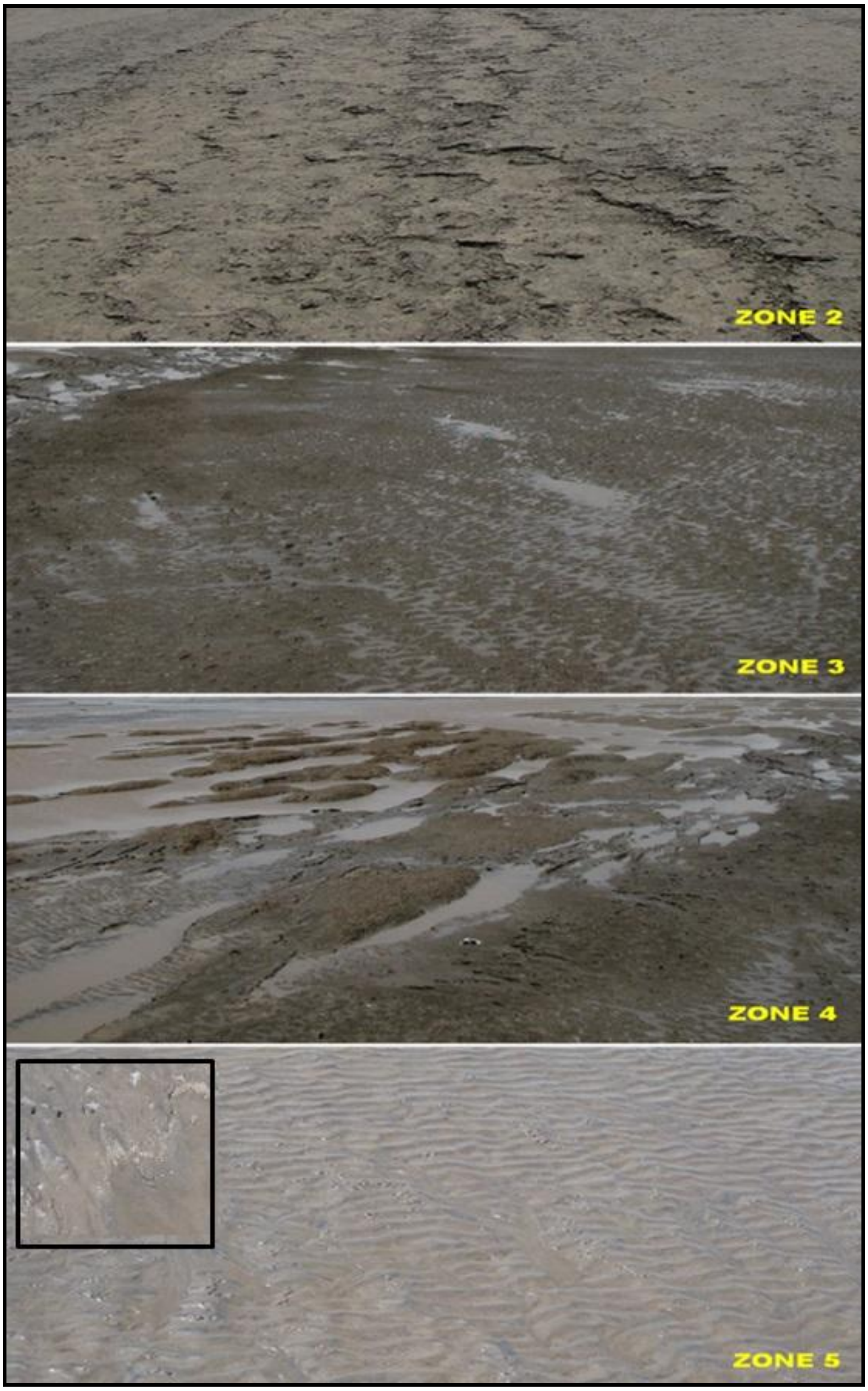


Figure 5. Water inundation in different zones during low tide

Table 1. Result of water quality analysis of lower estuarine are of Mahi estuary.

	Dabka		Sarod		Nahar		Kamboi	
	HT	**LT**	**HT**	**LT**	**HT**	**LT**	**HT**	**LT**
Acidity	8.33 ±2.89	6.67 ±2.89	125 ±18.03	36.67 ±10.41	70 ±22.91	31.67 ±7.64	13.33 ±5.77	8.33 ±2.87
Alkalinity	340 ±43.59	270 ±55.68	366.67 ±55.08	523.33 ±51.32	225.67 ±15.28	410 ±36.06	250 ±17.32	280 ±26.06
Total Hardness	233.33 ±20.82	686.67 ±70.24	2886.67 ±295.69	2726.67 ±220.08	3426.67 ±257.94	3080 ±322.34	3096.67 ±345.59	2793.33 ±148.44
Ca Hardness	150 ±52.92	180 ±36.06	250 ±40	290 ±36.06	256.67 ±25.17	253.33 ±35.12	350 ±26.46	223.33 ±15.28
Chloride	7273.33 ±1310.10	2363.33 ±217.33	15009 ±385.96	13520 ±594.31	16133.33 ±450.04	14076.67 ±763.76	15880 ±563.54	15405 ±742.77
Phosphate	0.67 ±0.33	0.83 ±0.47	0.37 ±0.28	1.28 ±0.30	0.47 ±0.19	1.02 ±0.39	0.37 ±0.23	0.51 ±0.19
Total Solids	4135.33 ±807.71	3676.33 ±971.72	27208.7 ±985.21	25632.7 ±998.50	28623.33 ±552.00	25722 ±1898.97	29479.3 ±1035.7	29196 ±545.98
Salinity	4.72 ±3.21	3.77 ±1	27.81 ±0.62	27.68 ±1.17	31.31 ±0.89	28.67 ±1.02	31.48 ±1.39	32.18 ±0.67

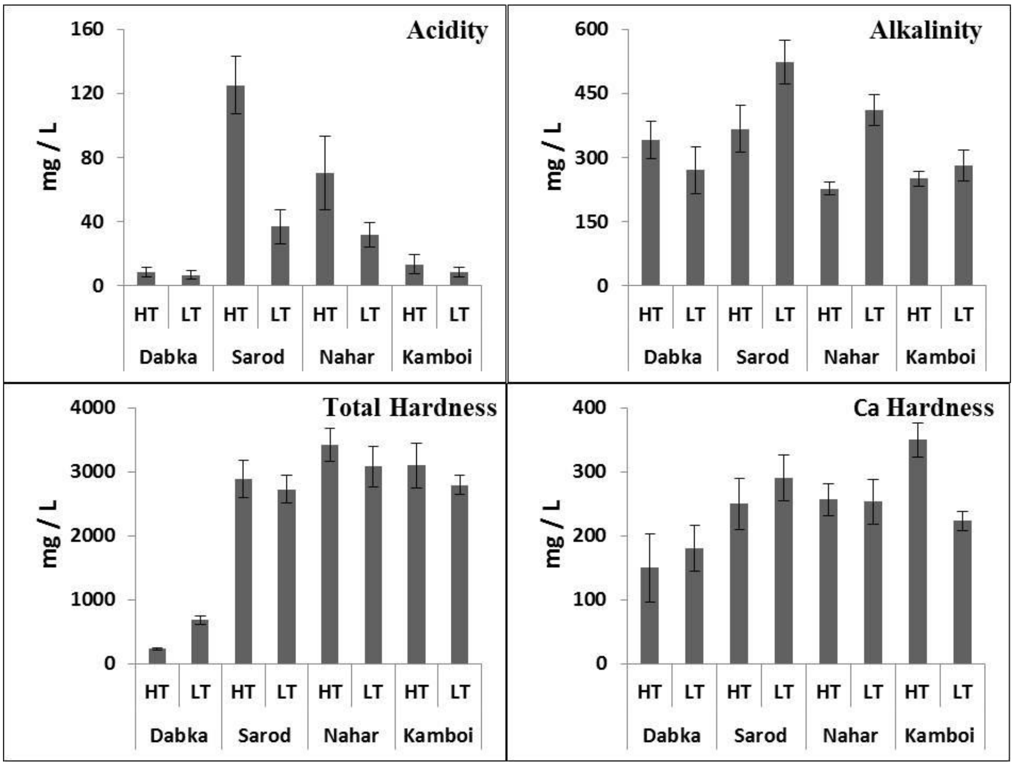


Figure 6. Acidity, Alkalinity, Total Hardness and Ca Hardness of lower estuarine water sample

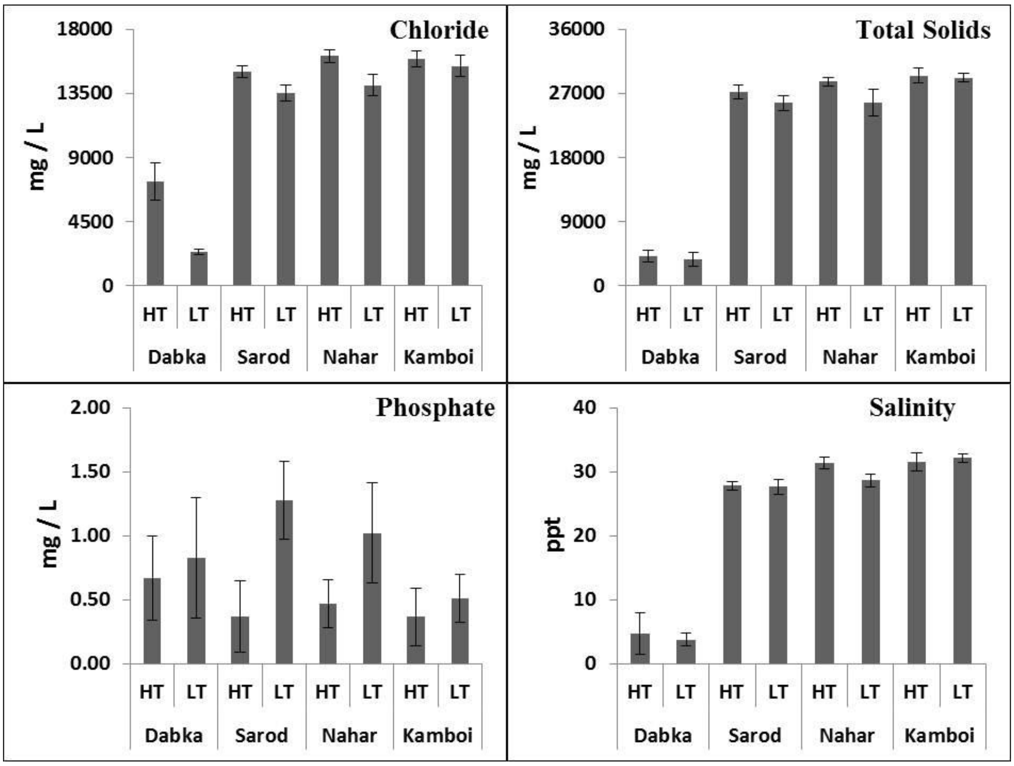
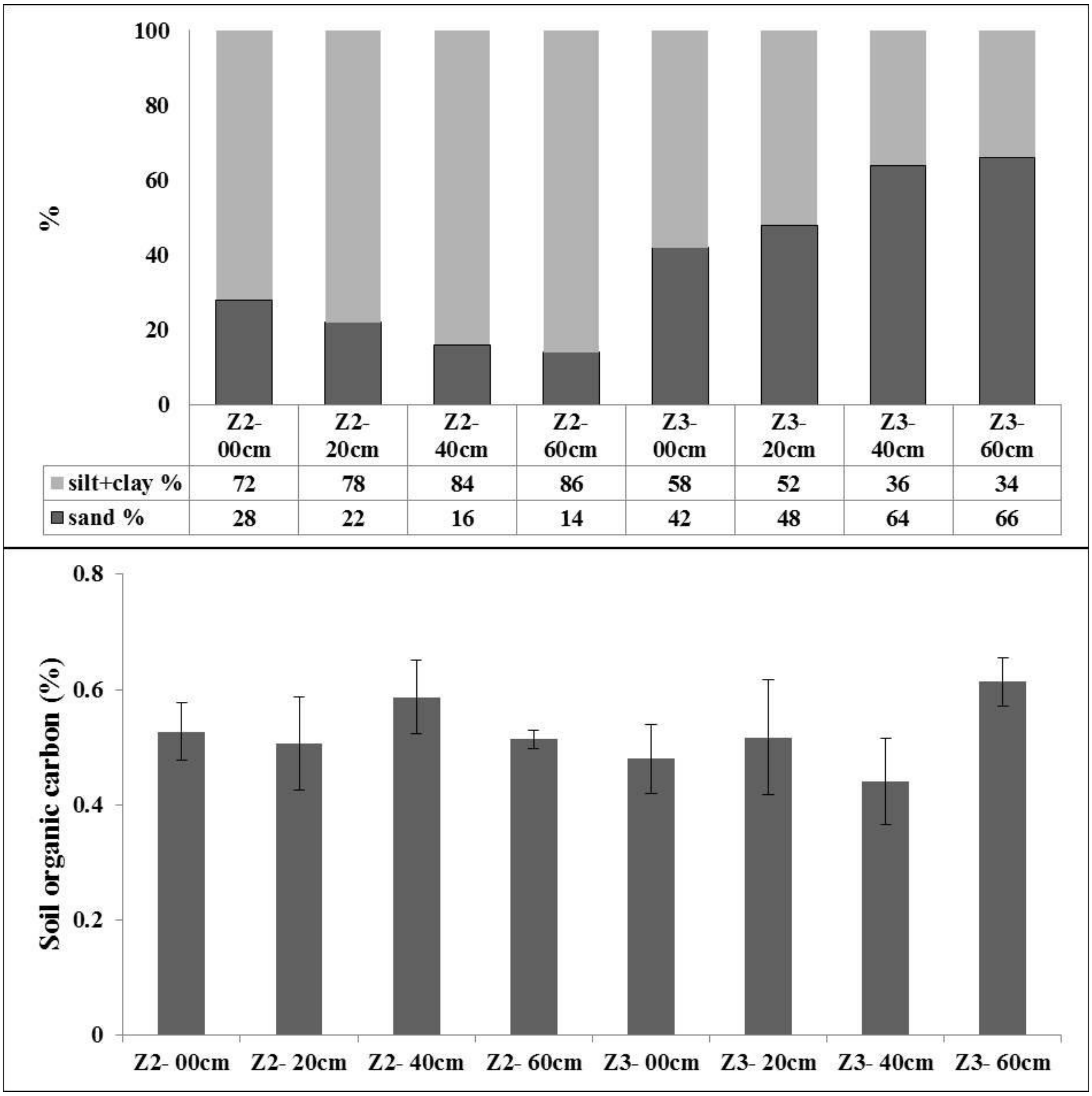


Figure 7. Chloride, Phosphate, Total solids and salinity of lower estuarine water sample

Table 2. Results of Sediment analysis of Zone 2 and Zone 3 at Sarod.

Zone	Depth	EC(μS/cm)	Ph	Organic Carbon (%)	Water Content (%)	Porosity	Wet bulk density (g cm^{-3})	Dry bulk density (g cm^{-3})
Zone-2	Surface	0.24 ±0.09	8.07 ±0.24	0.53 ±0.05	24.48 ±0.54	0.24 ±0.01	1.55 ±0.04	1.30 ±0.04
	0 cm	0.76 ±0.12	7.08 ±0.35	0.51 ±0.08	27.4 ±1.30	0.27 ±0.01	1.59 ±0.09	1.29 ±0.05
	20 cm	0.89 ±0.04	6.46 ±0.15	0.59 ±0.06	27.04 ±0.86	0.27 ±0.01	1.57 ±0.02	1.35 ±0.02
	40 cm	0.79 ±0.08	6.12 ±0.1	0.51 ±0.02	26.05 ±3.1	0.26 ±0.03	1.57 ±0.10	1.30 ±0.01
Zone-3	Surface	0.79 ±0.06	7.34 ±0.15	0.48 ±0.06	35.34 ±2.9	0.35 ±0.03	1.67 ±0.03	1.31 ±0.06
	0 cm	0.71 ±0.09	6.44 ±0.29	0.52 ±0.1	32.12 ±3.68	0.32 ±0.04	1.63 ±0.101.	1.27 ±0.01
	20 cm	0.65 ±0.07	6.83 ±0.19	0.44 ±0.08	31.27 ±1.18	0.31 ±0.01	1.52 ±0.06	1.30 ±0.04
	40 cm	0.5 ±0.07	6.48 ±0.21	0.61 ±0.04	23.81 ±1.88	0.24 ±0.02	1.54 ±0.01	1.34 ±0.09



	Z2- 00cm	Z2- 20cm	Z2- 40cm	Z2- 60cm	Z3- 00cm	Z3- 20cm	Z3- 40cm	Z3- 60cm
silt+clay %	72	78	84	86	58	52	36	34
sand %	28	22	16	14	42	48	64	66

Figure 8. Sand & silt-clay % and Soil organic carbon (%) in Z2 and Z3 at Sarod

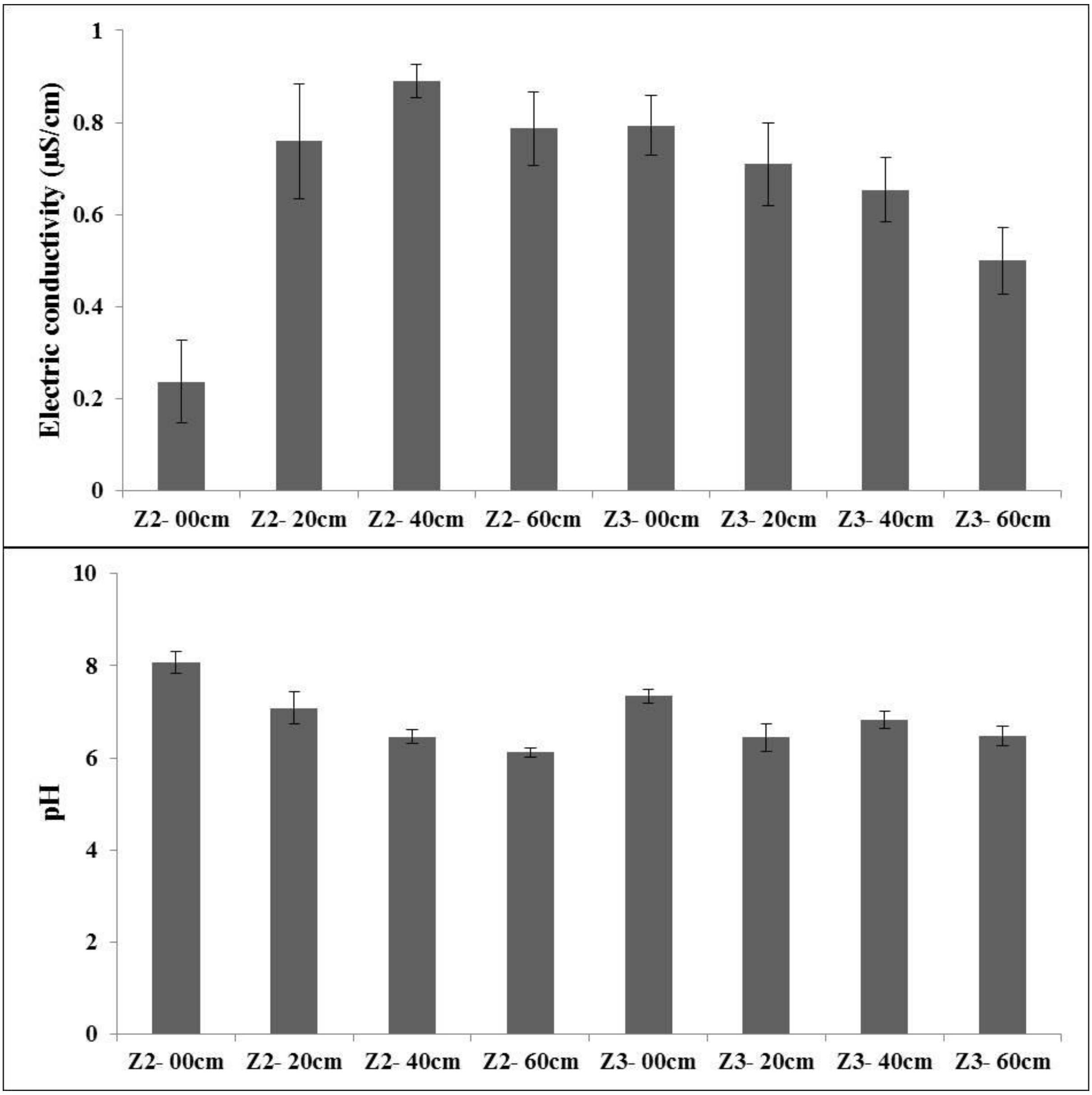


Figure 9. Electric conductivity (µS/cm) and pH in Z2 and Z3 at Sarod

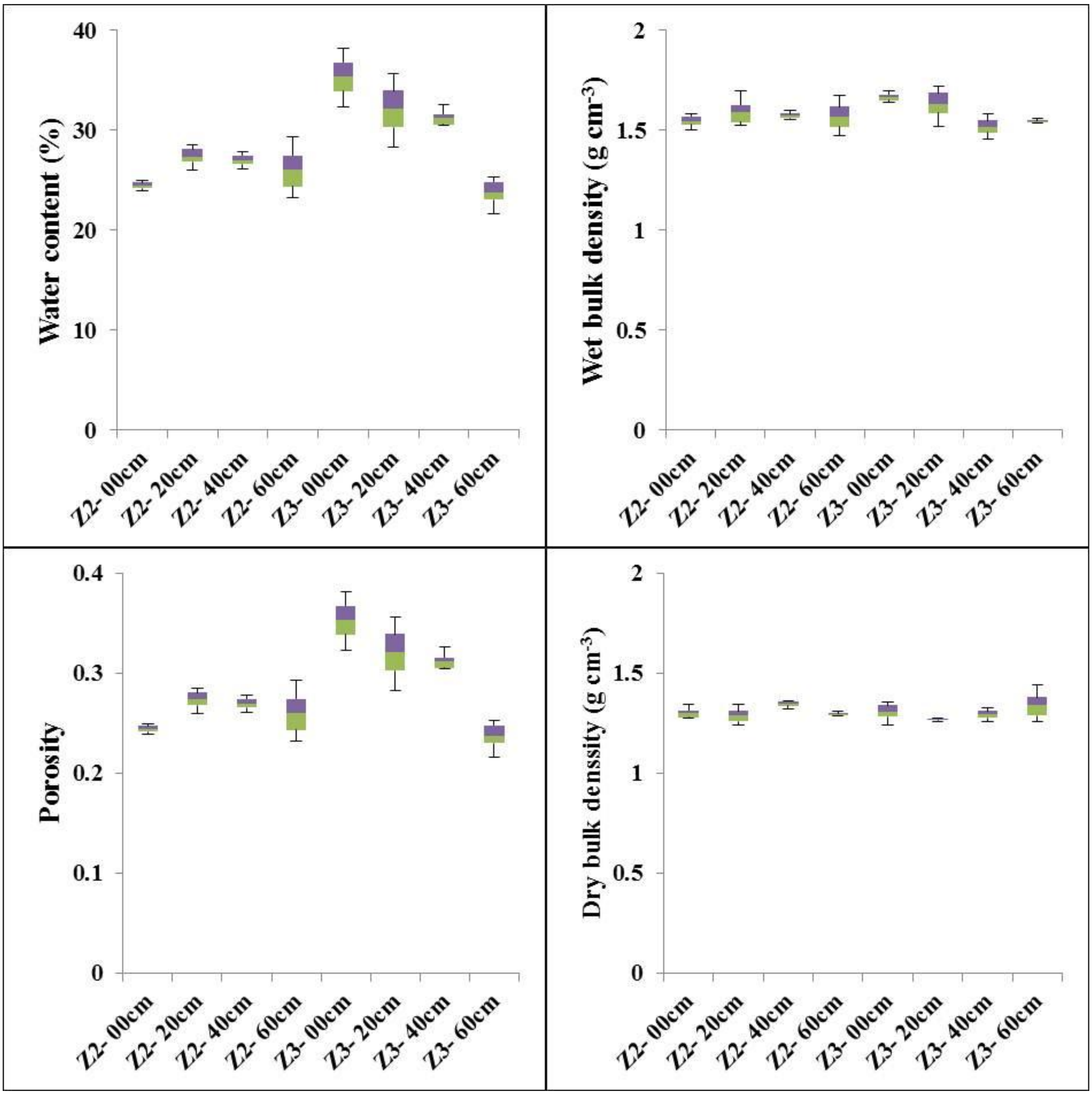


Figure 10. Water content (%), Porosity, Wet bulk density (g/cm^{-3}) and Dry Bulk density (g/cm^{-3}) in Z2 and Z3 at Sarod

Table 3. Results of Sediment analysis of Zone 2 and Zone 3 at Sarod.

Zone	Depth	EC(µS/cm)	Ph	Organic Carbon (%)	Water Content (%)	Porosity	Wet bulk density (g cm^{-3})	Dry bulk density (g cm^{-3})
Zone -2	Surface	0.83 ±0.11	6.39 ±0.16	0.57 ±0.09	23.39±1.11	0.23 ±0.01	1.22 ±0.07	1.32 ±0.09
	0 cm	0.88 ±0.07	7.1 ±0.13	0.53 ±0.09	21.47±1.18	0.21 ±0.02	1.22 ±0.03	1.39 ±0.06
	20 cm	0.90 ±0.08	6.52 ±0.22	0.63 ±0.08	23.21±2.87	0.23 ±0.03	1.23 ±0.04	1.29 ±0.03
	40 cm	0.48 ±0.12	6.83 ±0.35	0.61 ±0.08	24.23±1.01	0.24 ±0.01	1.33 ±0.05	1.22 ±0.04
Zone -3	Surface	0.6 ±0.06	7.5 ±0.27	0.69 ±0.08	28.79±2.88	0.29 ±0.03	1.55 ±0.19	1.26 ±0.05
	0 cm	0.58 ±0.11	7.6 ±0.05	0.57 ±0.09	26.29±1.91	0.26 ±0.02	1.61 ±0.14	1.32 ±0.07
	20 cm	0.62 ±0.07	7.32 ±0.17	0.46 ±0.07	24.53±1.80	0.25 ±0.02	1.62 ±0.05	1.28 ±0.07
	40 cm	0.61 ±0.06	7.89 ±0.27	0.55 ±0.12	25.32±1.98	0.25 ±0.02	1.66 ±0.07	1.33 ±0.09
Zone -4	Surface	0.53 ±0.04	7.69 ±0.12	0.53 ±0.07	24.41±2.00	0.24 ±0.02	1.71 ±0.06	1.31 ±0.08
	0 cm	0.75 ±0.10	7.66 ±0.19	0.54 ±0.11	26.49±2.07	0.26 ±0.02	1.66 ±0.04	1.27 ±0.05
	20 cm	0.89 ±0.04	7.66 ±0.17	0.55 ±0.12	23.86±3.36	0.24 ±0.03	1.67 ±0.06	1.29 ±0.08
Zone -5	Surface	0.45 ±0.07	7.84 ±0.11	0.46 ±0.09	24.23±1.82	0.24 ±0.02	1.86 ±0.05	1.47 ±0.05
	0 cm	0.42 ±0.04	8.11 ±0.13	0.53 ±0.10	26.39±1.84	0.26 ±0.02	1.91 ±0.02	1.44 ±0.05

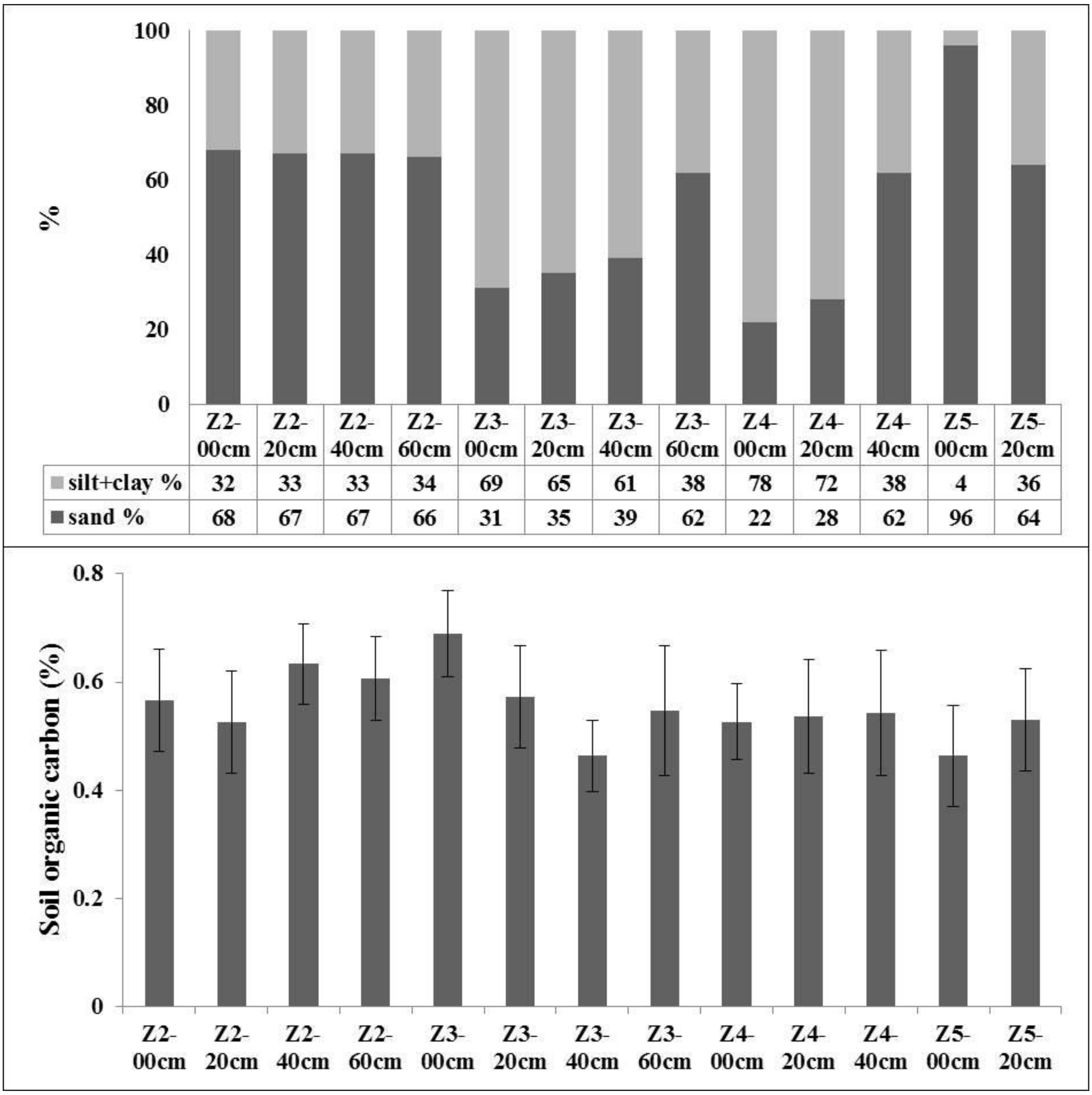


Figure 11. Sand & silt-clay % and Soil organic carbon (%) in Z2 to Z5 at Kamboi

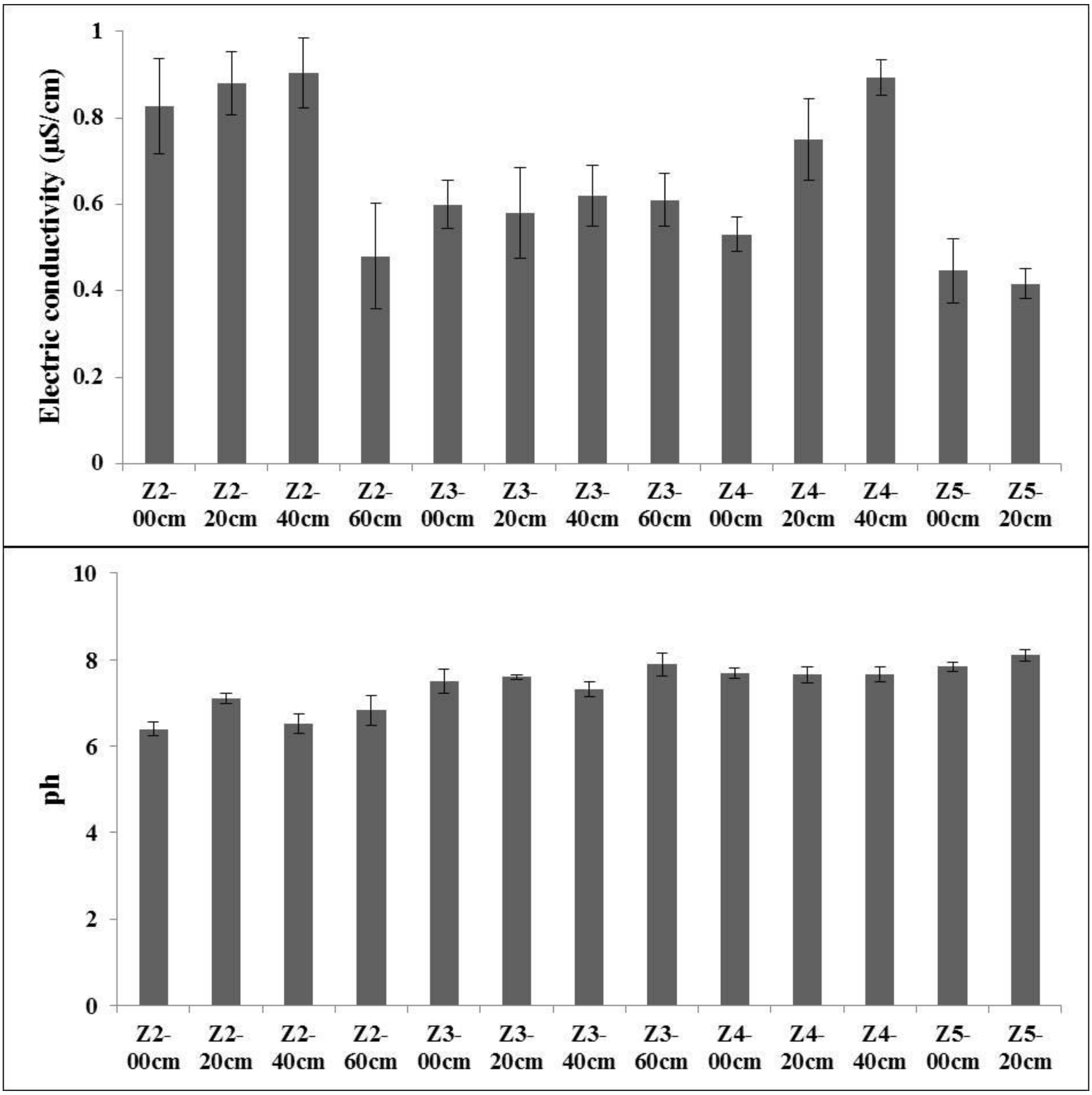


Figure12. Electric conductivity and pH in Z2 to Z5 at Kamboi

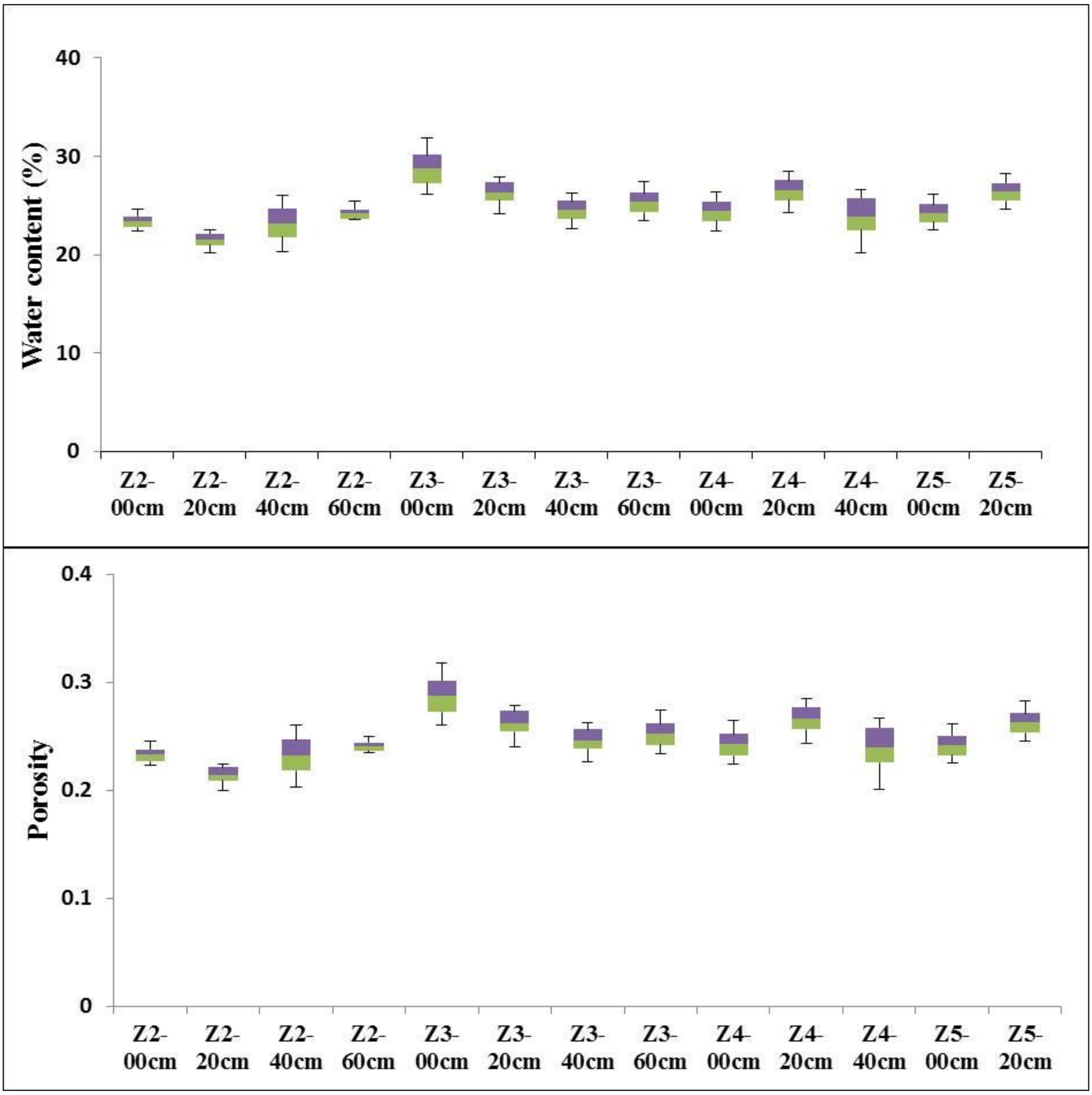


Figure 13. Water content and Porosity in Z2 to Z5 at Kamboi

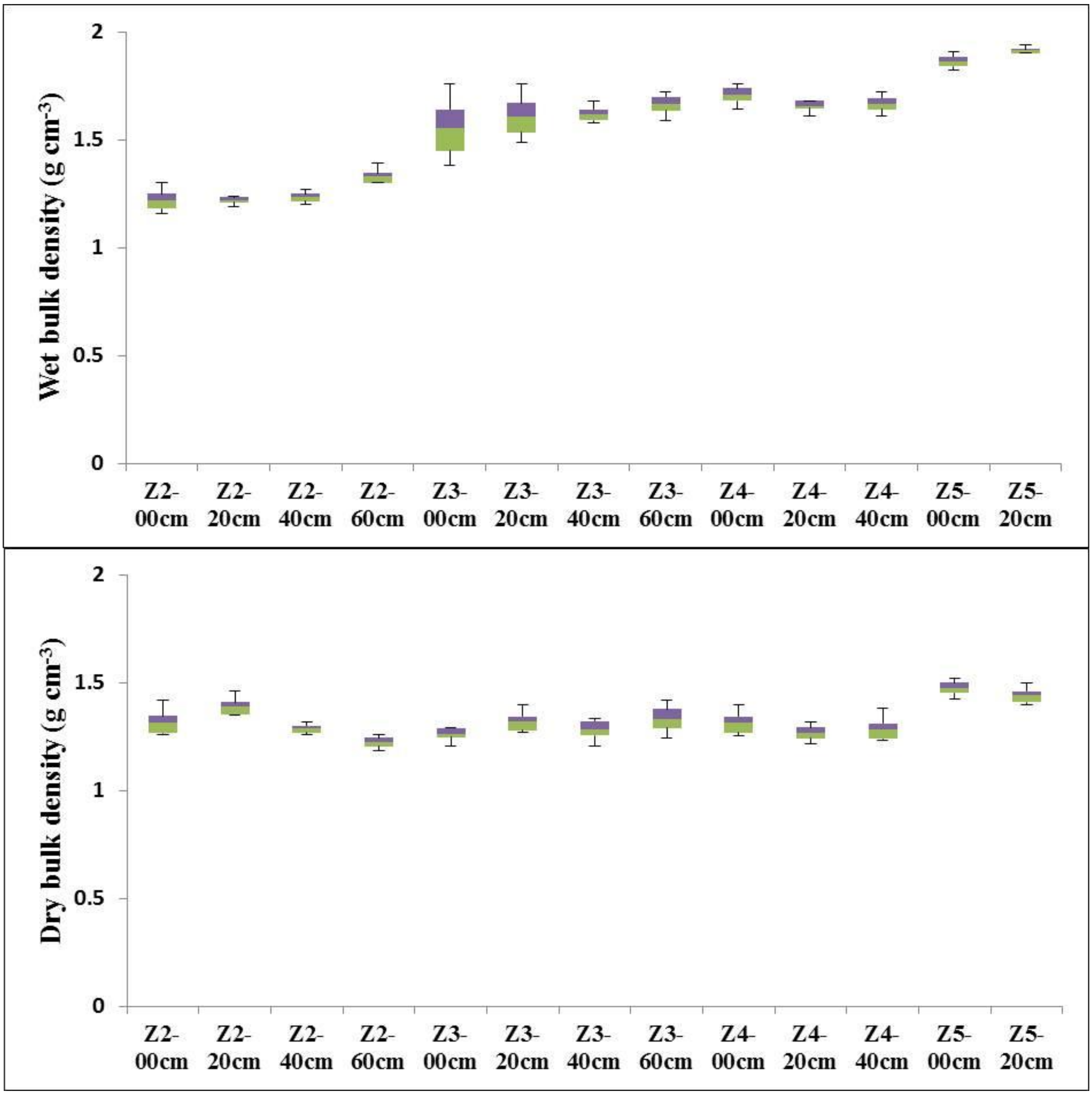


Figure 14. Wet bulk density and dry bulk density in Z2 to Z5 at Kamboi

Table 4. Showing the linear correlation between different Physico-chemical parameters

	Acidity	Alkalinity	Total Hardness	Ca Hardness	Chloride	Phosphate	Total solids	Salinity
Acidity	0	0.547	0.121	0.145	0.392	0.463	0.392	0.569
Alkalinity		0	0.284	0.899	0.284	0.113	0.284	0.378
Total Hardness			0	0.0588	0.044	0.183	0.044	0.059
Ca Hardness				0	0.131	0.704	0.131	0.208
Chloride					0	0.071	0.008	0.012
Phosphate						0	0.070	0.194
Total solids							0	0.012
Salinity								0

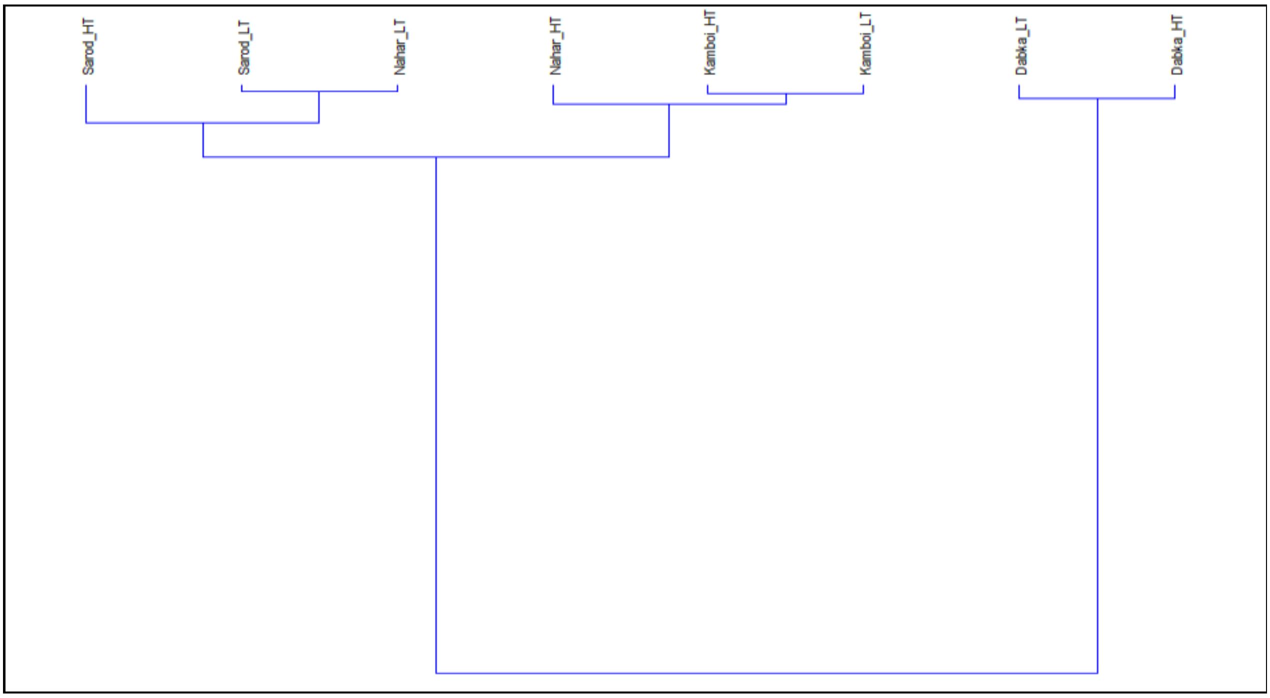


Figure 15 Cluster analysis of study sites on the basis of Physico-Chemical conditions.

Table 5. Showing the result of K-means cluster

Sites	Group
Dabka_HT	3
Dabka_LT	3
Sarod_HT	1
Sarod_LT	1
Nahar_HT	2
Nahar_LT	1
Kamboi_HT	2
Kamboi_LT	2

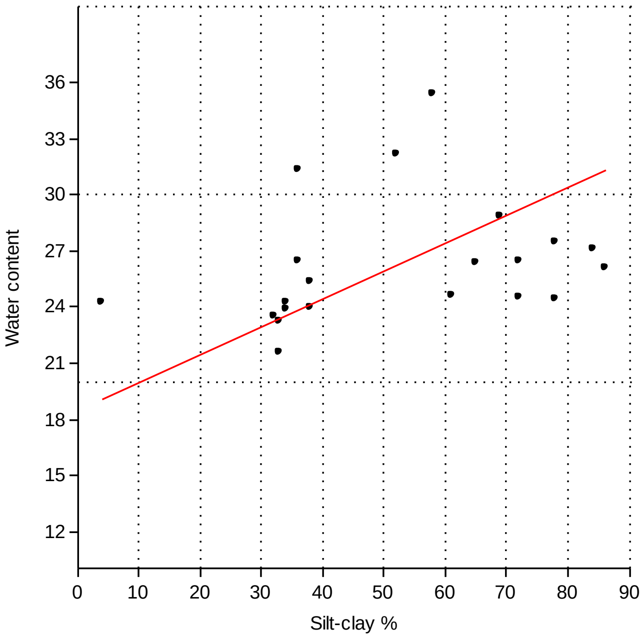


Figure 16. Linear regression between silt-clay % and water content % (r=0.27, slope a=0.15, intercept b=18.405)

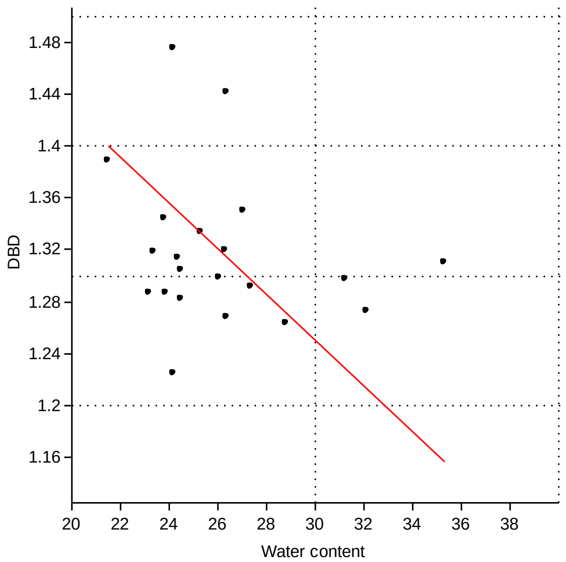


Figure 17. Linear regression between water content % and Dry bulk density (g cm^{-3}) (r=-0.22, slope a=-0.018, intercept b=1.776)