ABUNDANCE AND DIVERSITY OF MACROFAUNA FROM SELECTED INTERTIDAL HABITATS OF SOUTH WEST COAST OF INDIA

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in

Marine Biology

Under the Faculty of Marine Sciences

by

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This is to certify that the thesis entitled **"Abundance and Diversity of Macrofauna from Selected Intertidal habitats of South West Coast of India"** is an authentic record of the research work carried out by Ms. Anu Pavithran V. under my supervision and guidance at the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Kochi-682016, in partial fulfillment of the requirements for Ph.D degree of Cochin University of Science and Technology and no part of this has been presented before for any degree in any university.

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Declaration

I hereby declare that the thesis entitled **"Abundance and Diversity of Macrofauna from Selected Intertidal habitats of South West Coast of India"** is an authentic record of research work done by me under the supervision of Dr. S. Bijoy Nandan, Associate Professor, School of Marine Sciences, Cochin University of Science and Technology and no part of this has been presented for any other degree or diploma earlier.

Kochi – 682016 *Anu Pavithran V.*
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In Loving Memory of My Uncle

Dedicated to,

my Ammus

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Anu Pavithran V.

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Acronyms and Abbreviations

nm	-	Nanometer
ml	-	Milliliter
m	-	Meter
^0C	-	Degree centigrade
Fig.	-	Figure
et al	-	et alli
%	-	Percentage
pp	-	Pages
Vol.	-	Volume
sp.	-	Species
Km	-	Kilometer
Long.	-	Longitude
Lat	-	Latitude
E	-	East
N	-	North
m^2	-	Square meter
mm	-	Millimeter
µm	-	Micrometer
No.	-	Number
Vs.	-	Version
m/s	-	Meter per second
Av.	-	Average
ppt	-	Parts per thousand
mg/l	-	Milligram per liter
mS/ cm	-	Millisiemen per centimeter
ppm	-	Parts per million
NTU	-	Nephelometric Turbidity Units
µmole/l	-	micro mole per liter
No./m^2	-	Number per square meter
g/m^2	-	Gram per square meter

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Chapter 1

INTRODUCTION

Contents

"Dimly I could see the intertidal creatures darting away from my feet" - (Wells, 1896).

"Ecosystem = biotope + biocoenosis; a relation complex of organisms and the conditions of the biotope they live in; used when looking at processes and interactions. Roweck (2010)

1.1 Background

In 1935, Sir Arthur Goerge Tansley pioneered the concept of ecosystem. It is the prime component of ecology. An ecosystem is described as "a spatially open unit of earth that includes all of the organisms, all along with the constituents of the abiotic environment inside its boundaries" (Likens, 1992). Ecosystems differ in their types and earth itself is an immense ecosystem. Sea, forest, river and even a small tide pool are magnificent ecosystems.

Among all other ecosystems marine ecosystems have their own status in planet. Marine ecosystems, largest among all other aquatic ecosystems, include 71% of the earth. Marine ecosystems include vast ocean and other

systems. Coastal ecosystems are part of marine ecosystems and embrace intertidal zones, estuaries and mangroves. For the better understanding of ecosystem function, the best place to be taught is intertidal zones. Spatial and temporal changes in abiotic and biotic factors can be easily seen in intertidal zones. So in scientific community intertidal zones are pulsating place to study. Globally intertidal habitats cling to some unique ecosystems, which accommodate sea grass beds, mangrove habitats, kelp beds, salt marshes and beaches. Rocky, sandy and muddy – these intertidal habitats have common environmental and ecological attributes, so they are called together as shore.

Shore ecosystems are astonishing systems that accommodate not only diverse organisms but also play a major role in material transfer from outside to inside and vice versa. These energy transfer is complex to study, but is an important link in trophic status of intertidal zone. The transition zones between aquatic and terrestrial ecosystems are familiar as vibrant or active habitats that regulate or influence movement of organisms, nutrients, material and energy within and across landscapes (Wall *et al*., 2001).

1.2 The Littoral zone – An overview

The seashore is one of the most fascinating land amid all ecosystems. Shorelines can be good home to watch the remaining evidence, as the exposed rocks observed there often hold common fossils such as ammonites, belemnites, and several species of seashells (Andrew Campbell, 2004).

The different zones of the sea shores are collectively called as intertidal zones – represents one of the most diverse ecosystems in the planet. These zones are home ground of different living beings. The assortment of these habitats is associated with tidal actions. These zones are comprised of different

ecological features and these are behind the shoreline area, comprised of dunes, marshes; the zone above the shoreline which experiences the splash of waves; the tidal zone; and the sub tidal region immediately below it.

The intertidal, sometimes called the littoral zone, is defined as the part of the seafloor that lies between the highest high and lowest low tides (Castro and Huber, 2005). Being out of water and exposed to air establishes a unique nature to this environment. 'Branch and Menge' in 2001 quoted that dwelling between low and high water tide marks, intertidal habitats fringe the world' coasts forming an almost "one dimensional bathtub ring" that ranges in vertical extent from a few cm to more than 7m. It is the only marine environment that confronts regular exposure to air or emersion. Ineluctable regular exposure of intertidal zones made the inhabitants to acquire different adaptations to cope with this condition. Air temperatures are much more variable than those in the sea (changes of 10-20^{0}C are common over a 24 hour period).

When compared to a stable ecosystem, it is highly shifting. Advantages and disadvantages of these varying environments are a continuous process and the behavior of the each shore highly depends on the degree of dynamic nature of each shore. It is varied from shore to shore. It may depend upon the substratum, physical conditions, organism's behaviour and shore morphology.

Intertidal zones having the capacity to self-adapt with the alterations of the environment but global climate changes disturbed the self-adjusting nature of these zones. Gradually these changes alter the behaviour and function of the system by interfere their physical, chemical and biological functions and interactions. So a mark or symbol of climate change can be easily gazed at in intertidal ecosystems than other systems. Global climate changing is advancing and its effects can be clearly seen in intertidal zones due to rapid accumulative

nature of intertidal zones. In this respect, it is essential to study the consequence of human impacts and environmental variability of ecosystems.

Natural changes are inevitable but man made changes are compellingly exerting to the shore for human's well being. Anthropological changes detrimentally affect the ecosystem as these ecosystems have not any options to withstand.

Tides are the elementary factor in the shores (Carefoot and Simpson, 1977, Kenchington, 1990), which are the outcome of gravitational pull of the sun and moon. The organisms (Both flora and fauna) existing in the intertidal zones experiencing the tidal movements and fluctuations, which influences the life of residents there. Generally, every 12 hours tidal cycle at any one place will be repeated. Moon moves a bit in its own orbit in the route of a day. In the point on earth it takes extra 50 minutes to become equal. So that on following days both the high and low waters emerge on average about 50 minutes later than on the day before. The most prominent feature of the tides is their twelve hourly rhythms. At new moon and full moon days the sun and the moon are almost in a straight line and their pulling effects add together on earth, so that tidal ranges will be high in spring tides. When the sun and the moon are in first and third quarters, their pulling effects cancel each other and bringing down their combined effects, so the tidal ranges will be reduced-neap tides (Castro and Huber, 2005).

The organisms in the intertidal zones are eager anticipators of each upcoming tide as they receive food, oxygen and moisture for next six hours in a semi diurnal tide. Most of the organisms wander in rising tide than low tide. So tides are unavoidable and unique factor of intertidal ecosystems.

The reflections of tidal movements are zonation of most plants and animals. The zonation is an outcome of the complex interaction of physical,

chemical and biological factors (Stephenson and Stephenson, 1972). Stephenson and Stephenson (1972) concluded on the basis of their international studies of rocky shores, that tides have not created the system of zonation, but merely modified to develop the zone.

Zonation is a very significant mark in intertidal communities among both hard (Kaiser *et al*., 2005) and soft substrates (McLachlan and Jaramillo, 1995). The distinct pattern of zonation can easily be recognized in rocky shore areas. Zonation patterns of organisms are also different in different shores depending on the variation in the shore banding pattern. In tropics banding pattern is not as clear as subtropical regions. The distribution and species occurrence of each band may vary according to physical, chemical and biological conditions that exist. Zonation patterns are best to observe the species communications and distribution pattern on rocky shores. On sandy and muddy shores, the zonation happens but it cannot be recognized easily due to the burrowing nature of most of the organisms (Raffaelli and Hawkins, 1996).

Apart from tides, waves also have much importance in intertidal habitats. The waves that mostly concern intertidal ecologists are known as gravity waves. These waves continuously keep the zone moist and wet by moisture and splash/spray of waves giving some comfort to the high tide organisms. These waves are results of wind blowing over the surface of the sea.

1.3 Types of sea shores

Generally the shores of India especially the west coast, rocky outcrops predominating with sandy nature, while in the east coast sandy nature are predominating. Coral beaches are also common in India, mainly on the east coast and Gulf of Kutch (Krishnamurthi *et al*., 1967). When advancing to the

south west coast coral beaches are completely absent and it is replaced by sandy shore with rocky outcrops. Steep beaches are mainly characteristic of the west coast of India. In the east coast sandy flats and muddy shores are common. Lagoons, deltas and marshes are common in the east coast of India.

The shores of the west coast of India, especially Kerala coasts are famous for its enchanting beauty and lustrous greenery. The coastline of Kerala is long and spreads along 590 km. Variety of shores is distinctive of Kerala coast. These may vary according to the geography and substratum. Most of the shores are of three types: rocky, sandy and muddy. Indian coast is incessantly being susceptible to effluent discharges from metropolis and industrial towns. This gives rise to massive environmental troubles directing to worsening of water quality and diminution of flora and fauna (Datta *et al*., 2010). The shores are dynamic, they are seldom static. They are undergoing erosion by the sea, or accreted by the sea or by sediments washed down from the land by rivers.

The most variable types are rocky shores. It is an amazing world to watch the diverse organisms and clear banding patterns. Crevices and pools are unique feature of rocky shores. There are several habitat types, pools, cobbles, boulders, and crevices in rocky environment. The opportunity for ample ecological niches renders the rocky shores a great diversity of animals.

Three quarters of the world's shorelines are comprised of sandy beaches (Bascom, 1980). Degree of exposure to wave action determines the sandy beach profile. Owing to capillary action, water is usually retained in the minute spaces between the grains. The ebb tide brings food and this ebbing water lubricates the grains and supplies oxygen thereby allows the animal to survive in the sand when the tide recedes. Although the surface of the sand is affected by the fall of the tide, giving rise to water loss, temperature and salinity changes, these effects

do not make any difference in deep sands, so they can exist quite well in several centimeters down (Patrick Hook, 2008). The diversity of organisms may be less when compared to rocky shores, but the larval and organism density disposal rates are high on sandy shores. Coarser sand grains cannot support many organisms as in the case of finer sand grains.

Muddy shores are made up of fine particles. These finest particles have more water retaining capacity. The muddy shores are risky places for some animals, due to frail structure and hypoxic conditions. Muddy shores are organic rich and species benefit from the organic material that flourishes well in these kinds of shores. Hence the number of species represented may be restricted in muddy shores.

1.4 The zones of the sea shore

The supra littoral zone

The supra littoral zone is the area of highest tidal limit of intertidal zone. This zone directly receives spray of waves but not immersed under it (Fig. 1).

The littoral zone

The littoral zone is the region that lies between the high tide mark and low tide marks. Organisms reside in this zone subject to intense wave action as well as constantly changing physical and chemical conditions due to the movement of tides. Survival is therefore exceptionally challenging (Fig. 2 & 3).

Infra littoral zone

This is the lowest zone in sea shores, exposed only in lowest tides. Adaptations of organisms must be stronger due to longest submersion period. The organisms in this zone cannot survive in extreme exposure to air (Fig. 2 & 3).

Figure 1. Supra littoral zone at lowest low tide (Location – Dharmadam beach)

Figure 2. Infra littoral and littoral zone at lowest low tide (Location – Dharmadam beach)

Figure 3. Supra littoral and infra littoral zones (Location – Fort Cochin beach)

1.5 Intertidal macrofaunal community

Macrofauna play an imperative function in the aquatic community, these are taking part in mineralization, promoting and integration of sediment, fluxing of oxygen into sediments and cycling of organic matter (Snelgrove, 1998, Heliskov and Holmer, 2001). They are one of the most plentiful foodstuffs for avian fauna, fishes and epibenthic invertebrates (Nybakken 1993). Macrofaunal organisms illustrate wide range of feeding style and strategies at several levels of marine food web (Fauchald and Jumars, 1979). Among the benthic animals approximately 75 % live on rocks and corals etc and 20% on sandy and muddy bottoms and only 5% are planktonic (Thorson, 1957).

Intertidal zones harbor distinct and specific organisms that are unique and special because of their quickly adaptive nature with the environment around them. The life of the animals in this zone will be tougher according to the vigorous nature and altering weather conditions. Despite these difficulties, it is still one of the foremost inhabited areas. The organisms in the intertidal zone include algae, periwinkles, barnacles, sea urchins, mussels, crabs, sea stars, sea anemones, fishes, clams, amphipods, isopods and many more.

Rocky shores take part in an imperative task in determining the species diversity through indirect influence on species abundances (Keough and Quinn, 1998; Brown and Taylor, 1999; Milazzo *et al.*, 2004). The organisms living in exposed intertidal areas must be more adaptive than sheltered areas due to intense waves and swells. According to the tidal cycle the waves recedes and advances two times a day (semidiurnal), compel a sharp gradient of physical factors. In high intertidal areas long periods of emersion are common and low intertidal areas experiencing short periods of emersion. Exposed sandy

beaches are physically dynamic benthic environment which is defined by three variables, wave energy, tide range and sand particle size (Anton McLachlan, 1996).

Organisms that live in the intertidal zone have different adaptations to cope with this condition like shell colour, shell size, hold fasts, burrowing , drying out, these features make the intertidal zone unique from all other ecosystems.

1.6 Scope of the study

Intertidal habitats are familiar as feeding grounds and nurseries to many birds and fishes. It prevents erosion of land and act as flood guard. Intertidal habitats are greatly observed as vital sites for fish, as nurseries and over-wintering sites and migration routes for anadromous and catadromous fishes (Elliott and Hemingway, 2002; McLusky and Elliott, 2004). But the intertidal habitats have been changing due to anthropological activities like fishing, beach tourism and other physical vagaries like erosion, tsunami and climatic change issues. So a continuous evaluation is necessary to understand the trophic status and diversity of these unique coastal regions, which determines the environmental status of the oceans.

Although the intertidal zones are very much accessible to the scientific community, these are not explored by them. Macrofaunal studies on beaches are very limited. Specific studies on the composition, distribution, abundance and taxonomy of fauna in the rocky, sandy or muddy shores are very limited from the south west coast of India.

In this context, the Cochin and Kannur coastal stretches, mainly the beaches are noted for its varied topography and intertidal habitat which has

been of great curiosity for researchers. Several studies are available on the biota of interstitial (Priyalakshmi, 2008; Govinadn Kutti and Nair, 1966) and selected intertidal habitats from different coastal stretches of India. But there is a very little information available on the community structure, diversity and faunal assemblages of the rocky, sandy and muddy habitats of the Kannur and Cochin coasts. Further the intertidal zone in Cochin is severely stressed as compared to the pristine habitat of Kannur region that also signifies the need to understand the region. Unfortunately, the coastal areas at the Dharmadam and Fort Cochin are largely unknown especially for its macrofauna, with not much published accounts and ecological information of beach in this area; In general, this study would provide baseline information for conservation and long term management programs of the intertidal zone on the south west coast of India. It was in this context this work is proposed.

1.7 Objectives of the Research Programme

1) To conduct qualitative and quantitative studies on the epifauna and infauna of the rocky, sandy zones of selected intertidal regions.
2) To study the hydrography and sediment characteristics of the intertidal and tide pool fauna in relation to their abundance and diversity.
3) To bring out a comparative assessment on the faunal assemblage and suggest suitable management measures.

References

Andrew Campbell, 2004. Seashores and shallow seas of Britain and Europe. Octopus publishing group Ltd., London, 320pp.

Anton McLachlan, 1996. Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. *Mar Ecol Prog Ser.,* Vol. 131: 205-217pp.

Arthur George Tansley, 1935. 'The use and abuse of vegetational terms and concepts'. *Ecology*, 16: 284-307pp.

Bascom, W., 1980. Waves and Beaches. Anchor Press/ Doubleday, New York, NY. 366 pp.

Branch, G. M. and Menge, B. A., 2001. Rocky Intertidal Communities. *Marine community ecology,* 221–251pp.

Brown, P. J. and Taylor, R.B., 1999. Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. *J. Exp. Mar. Biol. Ecol*., 235:45-53pp.

Datta, S.N., Chakraborty, S.K., Jaiswar, A.K. and Ziauddin, G., 2010. A comparative study on intertidal faunal biodiversity of selected beaches of Mumbai coast. *J Environ Biol.,* 31(6): 981-986pp.

Elliot, M. and Hemingway, K. L., 2002. Fishes in estuaries. Oxford: Blackwell Science, 636 pp.

Fauchald, K. and Jumars, P. A., 1979. The diet of worms. Study of polychaete feeding guilds. *Oceanography and Marine Biology*, An Annual Review, 17: 193 – 294pp.

Govindankutty, A. G., and Nair, N. Balakrishnan, 1966. *Preliminary observations on the interstitial fauna of the south-west coast of India. Hydrobiologia*, 28 (1); 101-112pp.

Heilskov, A. C. and Holmer, M., 2001. Effect of benthic fauna on organic matter mineralization in fish-farm sediment: importance of size and abundance. *Journal of Marine Science*, 58: 427 – 434pp.

James W. Nybakken, 1993. Marine biology: an ecological approach, Harper Collins, New York, 445pp.

Kaiser, M.J., Martin J. Attrill, Simon Jennings, David N. Thomas and David K. A. Barnes, 2005. Marine ecology: Processes, systems and impacts. Oxford University Press, 584pp.

Kenchington, R. A., 1990. Managing Marine Environmets. Taylor and Francis, New York, 248pp.

Krishnamurthy, V. and Subbaramaiah, K., 1967. The importance of Shore types in intertidal ecology of Indian marine algae. *Proc. Ind.Nat.Sci. Acad.,* Vol. 38, B, No.3 & 4.

Likens, G. E., 1992. The ecosystem approach: its use and abuse. Excellence in Ecology, book 3, Ecology Institute, Oldendorf/Luhe, Germany, 166pp.

Marco Milazzoa, Fabio Badalamentib, Giulia Ceccherelli and Renato Chemelloa, 2004. Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. *J.Exp.Mar.Biol.and Ecol*., 299, 51-62pp.

McLachlan, A. and Jaramillo, E., 1995. Zonation on sandy beaches. *Oceanography and Marine Biology: An Annual Review,* 33, 305–335pp.

McLuscky, D.S. and Elliott, M., 2004. The estuarine ecosystem: ecology, threats, and management. Oxford University Press, 214pp.

Michael J. Keough and Quinn G.P., 1998. Effects of Periodic Disturbances from Trampling on Rocky Intertidal Algal Beds. *Ecological Applications*, Vol. 8, pp. 141-161pp.

Patric Hook, 2008. A Concise Guide to the Seashore. Parrogon books Ltd., Queenstreet, 256pp.

Peter Castro and Michael E. Huber, 2005. Marine Biology. Blacklick: McGraw Hill science engineering, Ohio, USA, 468pp.

Priyalakshmi, G., 2008. Studies on the taxonomy of interstitial fauna of some prominent beaches of Kerala. *Ph.D Thesis*, Cochin University of Kerala, 327pp.

Raffaelli, D. and Hawkins, S., 1996. Intertidal Ecology. Chapman and Hall, London, 356pp.

Thomas Carefoot and Rodney D. Simpson, 1977. Seashore Ecology. St. Lucia: University of Queensland Press, Australia, 278pp.

Roweck, H., 2010. Lecture notes "Basics in Ecology". Ecology Center Kiel, Germany.

Snelgrove, P., 1998. The biodiversity of macrofaunal organism in marine sediments. *Biodiversity and Conservation*, Vol. 7, 1123-1132pp.

Stephenson, T.A. and Stephenson, A., 1972. Life Between Tide-Marks on Rocky Shores. W.H. Freeman, USA, 425 pp.

Thorson, G., 1957. Treatis on Marine Ecology and Palaeoecology. In: J.W. Hedgepeth (ed.) *Mem. Geol.Soc. Amer.*, 461-534pp.

Wall, D.H., Palmer, M.A. and Snelgrove, P.V.R., 2001. Biodiversity in critical transition zones between terrestrial, freshwater, and marine soils and sediments: processes, linkages, and management implications. *Ecosystems*, 4:418–420pp.

Wells, H.G., 1896. The Island of Doctor Moreau. The Sun dial company Garden City Publishing Company, New York.

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Chapter 2

REVIEW OF LITERATURE

Contents

2.1 General review of intertidal ecology

As far as pre history, coasts and estuaries have engrossed human populations, soon humans started exploring scientific and practical knowledge of available resources. Aristotle committed a significant part of his biological research to marine animals and he recognized a variety of species including crustaceans, echinoderms, molluscs, and fishes (342BC-322) (Raffaelli and Hawkins, 1996).

It is from the coast, that pioneers in marine ecology approached the ocean in the 19thcentury. Because of the premium access to the biological richness of the coast, research very hastily studied on the intertidal zone and the coast for several decades (Gadeau de Kerville, 1885). In the middle of the 19th century researchers were engrossed to biology and ecology of shore animals due to its easily accessible nature. Researchers were more concerned about biology and physiology of organisms. For example two researchers Jean Victor Audouin and Milne - Edwards worked on the coast of Normandy from

1826-1829 on the anatomy and physiology of crustaceans. At the end of 19thcentury different kinds of intertidal works had been conducted in different countries.

In 1890 shore organisms were taken into the laboratory and experiments were carried out and in the 1920s one of the first British books on shore ecology arrived (Flatteley and Walton, 1926) with portrayals of zonation patterns and explained surveying of shores.

The first serious study on ecology of shore was made at 1915 by Walton using more quantitative methods. The first study of whole beach ecosystem was conducted by Remane in 1933, on a sheltered beach on the coast of Germany. First qualitative effort to assess a whole beach ecosystem was done by Pearse *et al*. in 1942 and Hedgpeth in 1957.

The pioneer work on littoral organisms was conducted by Colman (1933). "Between Pacific Tides" (Ed'Ricketts *et al*., 1939) was very familiar, a pioneering study on intertidal ecology. Classic broad scale studies were commenced in 1936 by Stephenson; Ricketts and Calvin in 1939 and Stephenson and Stephenson (1949). Ecophysiology and behaviour of shore animals had been studied by Knight Jones (1953); Crisp and Southward (1958).

The vertical zonation of organisms in the marine intertidal has been first studied by (Audoin, Milne-Edwards, 1832). In 19th century onwards the zonation patterns of rocky beaches were engrossed to researchers. Quantitative studies of zonation had been first studied by Colman in 1933 and Stephenson and Stephenson in 1949. By following this, Southward and Orton in 1954 made quantitative surveys on zonation. Extending the work of zonation, Stephenson

accomplished that physical factors were the important factors that determine the upper and lower limits of intertidal communities, but biological factors outweighed in life between the tide marks. (Stephenson and Stephenson, 1949).

In 1964, Lewis revised the theory of zonation. He segregated the shore into three biologically defined zones and they are technically named the littoral fringe, the eulittoral zone, and the sublittoral zone. Numerous investigations have been conducted based on the pattern of zonation of intertidal organisms recently, Wormser in 2012 conducted zonation study of two gastropods (*Nerita* and *Morula* sp.). Waller in 2013 studied zonation in cryptic Antarctic intertidal macrofaunal community. Castilla in 2014 conducted studies based on rocky intertidal zonation pattern in Chile. Tamar Guy Haim, in 2015 studied different settlement strategies of zonation of Barnacles in Eastern Mediterranean.

Zonation is not only an intertidal phenomenon. In general a forecast of zonation scheme of sandy shores may perhaps tricky due to elevated inconsistency of intertidal zones in time and space (Dexter, 1984; McLachlan and Jaramillo, 1995; Giere, 1993; Brazerio and Defeo, 1996; Brown and McLachlan, 1990). General patterns were assessed by McLachlan and Jaramillo, 1995; Defeo and McLachlan, 2005) and observed that sandy beach zonation is normally considered to be structured by environmental factors.

There was a hastened interest in intertidal ecology of Australian beaches during 1880-1950. Hedley (1915) described the ecology of the Sydney beaches and this was the first effort to converse the ecology of one area. Johnston (1917) during the same time was working on the ecology of Caloundra in Queensland.

In 1943 Pope instituted a survey of the animal communities in Long beach. Dakin *et al*. (1948) well thought out the salient ecological features of the coast of New South Wales and the basic zonation. Edmonds (1948) has described the distribution of animal species in Kangaroo island of South Australia.

Sandy beach macrofaunal patterns and ecological importance has been well observed by many researchers, Jaramillo and McLachlan, 1993; Jaramillo *et al*., 1993; Trevallion *et al*., 1970; Ansell *et al*., 1972; Leber, 1982; McLachlan, 1977; Dye *et al*., 1981; Defeo *et al*.,1992; Rafaelli *et al*., 1991; Bamber, 1993 etc. Studies on soft shores had been conducted by Dahl (1952) and Dakin (1953).

Short and Wright in 1983 classified sandy beaches into different types. Dissipative beaches characterize the elevated energy end of the beach variety. Hughes and Cowell (1987), Bauer and Allen (1995) studied that reflective beaches are relatively steep and sediment size that will be coarsest sand at the base of the swash zone. In 1999, Short concluded that the reflective beaches are lower energy beaches. He also mentioned about intermediate beaches, represent an alteration from dissipative to reflective beach. In 1993 Jaramillo *et al.* found that on dissipative beaches a wide range of species occurs, but in reflective beaches, species may be less. He concluded that intertidal zones will be devoid of intertidal macrofauna and only supra littoral forms present. Sandy shores are an interesting subject to researchers in recent time also. Brazeiro in 1999 studied the community patterns in sandy beach in Chile and Ledesma *et al.* in 2001 studied the species area relationship of sandy beaches in England. McLachlan conducted so many studies in sandy beaches. In 2006, McLachlan and Brown studied the ecology of sandy shores and in 2007 McLachlan and

Dorvlo conducted global pattern of macrobenthos in sandy beaches. Zonation of sandy tropical beaches by using *Dottilla* sp. were conducted by Allen *et al.* in 2010 and Cisneros in 2011 studied sandy beach community structure and complex dynamic pattern of abiotic factors. Schalacher *et al.* (2007) studied sandy beach community patterns and Brown *et al.* (2002) studied sandy shore ecosystem and threats. Defeo and McLachlan (2005) studied patterns and regulatory mechanisms in sandy beach macrofauna. Benazza *et al.* in 2015 studied fish and macro crustacean on sandy beach. Milker *et al.* in 2015 studied intertidal foraminifera in marsh area, USA.

Rocky shores have pull towards the attention for many years for the majority part due to the ease of access of the habitat and wide variety of animals. Connell (1972) has evaluated many of the traits of these kind of shores for ecological research. The ecology of plants and animals in intertidal rocky shores has been a topic of interest world wide. The major works on intertidal flora has been done by many researchers (Colman, 1933; Fischer-Piette, 1936). The rocky intertidal work extended by pioneer ecologists like Colman (1933), Stephenson (1936) and Doty (1946).

In rocky shores some evidences recommends that diversity patterns can depend strongly on micro habitat such as cracks and crevices (Hixon and Menge, 1991). The population residing the rocky intertidal have been considered as open due to larval transport and recruitment from separate population (Underwood and Fairweather, 1989, Menge, 1991, Small and Gosling, 2001). The inconsistency found in populations inhabiting the rocky intertidal may be due to different abiotic factors such as tidal regime, temperature, changes in sea level, storms, wave action and fisheries. (Pulliam, 2000). Gimenez in 2011 evaluated the community structure of macrobenthic

community of rocky beaches of Uruguay. They concluded that the positions of the estuarine frontal zones are important to explain the community structure of that area. Fenberg *et al.,* 2014 studied biogeographic structure of Pacific rocky intertidal and Thorner *et al.,* 2014 studied turf forming algae of pacific rocky intertidal. Garcia *et al.,* 2013 studied the human visitation and affects of California rocky intertidal. Menge *et al.,* 2013 studied the rocky shore ecosystem in Pacific coast. The most essential ecological phenomenon the 'keystone predation', were studied by Paine, 1974; Estes and Duggins 1995).

2.2 A brief review on intertidal macrofauna

Macrofauna play an important role in the aquatic community, these are taking part in mineralization, promoting and incorporation of sediment, fluxing of oxygen into sediments, cycling of organic matter (Snelgrove, 1998, Heliskov and Holmer, 2001). Macrofauna are one of the most plentiful food items for birds, fishes and epibenthic invertebrates (Nybakken, 1993).

Sandy beaches are very dynamic environments. Wave, wind action, grain size and tide amplitude are the most imperative factors that influence their physical characterization (Nybakken, 1993). In 1935 New Combe performed studies on certain environmental factors of a sand beach in the St. Andrew region, New Brunswick based on the intertidal communities.

The intertidal macrofaunal studies have been of great interest to the researchers during the mid of the 20th century, Emrys Watking had studied the macrofauna of intertidal sand of Kames Bay in 1942. Robert W Pennak in 1943 detected a new order of crustacean from intertidal beaches in Massachusetts and Connecticut. In 1960 Qualye had studied the intertidal bivalves of British Columbia. In 1965 Glynn and Peterwilliams had conducted

studies on community composition structure and inter relationships in marine intertidal *Endocladia muricata –Balanus glandula* association in Monterey Bay. In European waters, Elmhirst (1931), Stephen (1929) Colman and Segrove (1955), Pirrie *et al.* (1932) studied the fauna of the sandy beaches.

Between 1920s and 1980s shore studies were at its peak. In 1954 Southward and Orton, Crisp and Southward (1958) had conducted quantitative surveys on zonation. In 1983, two researchers McLachlan and Brown have studied about the patchiness of sandy beach macrofauna. In continuation Thrush, 1991, Morrisey *et al.,* 1992 and James *et al.,* 1995 have studied on the distribution pattern and abundance of organisms including soft sediment macrofaunal patchiness.

Studies in different parts of the world explored sandy beach macrofaunal organisms and their retorts in different physical factors, wave energy and sediment composition (Travellion *et al*., 1970; Eleftheriou and Nicholson, 1975). The summary of many research works revealed that sandy beach macrofaunal communities are directed by physical conditions of the shore (Jaramillo *et al.,* 1993). The studies of Lastra *et al.* (2006), Rodil *et al*. (2007) and Cisneros *et al.* (2011) have verified that the macrofaunal community is not only prearranged by physical factors, other factors such as inorganic nutrients, ease of accessibility of food are also imperative. The general features of the intertidal and sub tidal macrobentic fauna of western and northern gulf are well documented by Jones (1986) and Jones and Richmond (1992).

Branch in 1981 have distinguished the common sandy beach macrofauna of the west, south and east coast of Africa. The high shore organisms are described as air breathing scavengers by Branch (1981) and also pointed out

that both sand mussel, *Donax* and the sea louse, *Emerita*, travel up shore with the promising tide and then follow descending tide.

Macrofauna goes well with the physical arrangement of sandy beaches and the merged effects of wave energy, sand particle size, and beach slope was projected as the main phase vital to the macrofauna group (Jaramillo, 1994). The tropical structure of macrobenthic community on the Portuguese coast was investigated by Boaventura *et al.* in 2002. The significant role of macrofauna for the recognition of long term environmental consequences has been documented in many studies (Rogers and Greenway, 2005).

Changes in the abundance of macro invertebrate species have been documented from the rocky intertidal community between surveys in 1993-96. The major driving forces in the community ecology of rocky intertidal are species inter relationships and environmental stress (Menge and Southerland, 1987, Menge *et al.,* 1999, 2002, and Helmuth, 2002). In 2002 Somero have observed that rocky intertidal communities are also prejudiced by physiological adaptation of organisms uncovered to vigorous environment.

In 2005 Bortone studied about intertidal polychaetes and observed that the *Scolelepis (Scolelepis) squamata* species have salinity range of 17-35ppt. Rizzo and Amaral in 2001 also found the same observation that these species can tolerate oscillations of salinity.

2.3 A focus on intertidal faunal studies; Indian scenario

In India the pioneering work on benthos was done by Annandale, 1907, works of Ansari, Harkantra, Nair and Parulekar, 1977, from Bay of Bengal. In India Seshappa (1953), Kurian (1953 performed comprehensive works on the bottom fauna of Madras, Malabar and Travancore coasts.

In 1970, K.P. Philip had done preliminary observations on the intertidal macrofauna of the sandy beaches of Cochin. In 1970 Gopalakrishnan made some observations on the shore ecology of Okha coast. Some aspects of biological and ecological studies of certain abundant forms in the sandy beaches were studied by Alagarswami (1966) and Alikunhi (1944).

Subramanyam *et al.* in 1952 studied the faunal composition of intertidal ecosystem around Mumbai but it has been disturbed and imbalanced due to ever mounting anthropogenic discharges from the city (Govindan and Desai, 1980). In 1983, Nandi and Choudary conducted intertidal studies in Sundarban Delta. Zonation studies in intertidal zones are very less in India. An attempt was made to study the zonation of intertidal organisms concerning environmental factors at four rocky shores and two sandy shores on Anjidiv islands (south west coast of India) by Arun Parulekar in 1972.

Along the Indian coast very diminutive work has been done on the macro and microfauna of sandy beaches, the only noteworthy works being that by Ganapathi and Chandrashekhara Rao in 1962 , MacIntyre (1968), and Govindan Kutty and Nair (1966). During 1960- 80 there was an accelerated interest in intertidal studies. The crustacean studies, mainly Amphipoda, diverse group of crustaceans from Indian coast were documented by Tambe and Deshpande in 1964 and Rabindranath (1969) and Sivaprakasham in 1968. In 1978, Murthy Bhattacharya and Radia have studied ecological studies on the intertidal algae at Okha. Intertidal echinoderm along Indian coast had studied in detail by James in 1982.

Most studies have been conducted on the west coast of India compared to the east coast. On the other hand intertidal meiofaunal studies have been

alert along east coast. In 1981, Parulekhar studied the intertidal fauna of Malvan, west coast of India. Several other ecologists also carried out studies on different kind of fauna in Malvan. Molluscs of Malvan have been observed by Joshi in 1969, pearl oysters by Ranade in 1977.

Comprehensive studies have been done on intertidal faunal, physical and climatic interactions during 2000-2014. In 2001 Quadros conducted a study of intertidal fauna of Thane creek, Mumbai. Impact of turbidity on macrofauna at Madhuva and Veraval coast (West coast of India) have been studied in detail by several researchers in 2003 (Ragunathan, Tewari, Joshi, Saravan kumar, Trivedi and Yasmin Khanubhaty). In 2005 Misra and Kundu conducted studies on gastropods along Indian coast and documented that the gastropods are occupant of rocky shores at the intertidal level. Sathish Patel and Bhavani Singh conducted studies on animal - sediment relationship of the crustaceans and polychaetes in the intertidal zone around Mandvi, Gulf of Kutch in 2009. Studies on anthropogenically affected areas were also gained attraction and several studies were also conducted on this topic due to the increased disturbances by humans on intertidal zones. Among this an important study has been conducted by Quadros, Soniya Sukumaran and Athalye in 2008 on impact of the changing ecology on intertidal crustaceans and polychaetes in antropogenically strained tropical creek in India. In 2010 status of population ecology, diversity and water quality of a highly industrialized shore of north western coast of India have been studied by Vaghela, Bhadja, Ramolia, Patel and Kundu.

In 2012 researchers expressed interest in diversity studies as it is the most important factor in the intertidal zone. Bharath singh Gohil and Rahul Kundu (2012) studied the diversity of the intertidal macrofauna at rocky

shores of west coast of Gujarat. At the same time (2012) Loganathan Palanikumar, Madasamy Rajee and Arumugam Kuruppusami Kumara guru conducted studies on intertidal rocky coastline of Puthumadam, Gulf of Mannar. Vakani *et al.* in 2014 studied variation of population ecology of limpets on rocky shore of Saurashtra coast. Gohil *et al.,* 2013 studied ecological status of *Cerethium* at Dwaraka coast.

References

Alagarswami, K., 1966. Studies on some aspects of biology of the Wedge clam *Donax faba Gmelin* from Mandapam coast in the Gulf of Mannar. *J,Mar.Biol.Ass.India*., 8; 56-75pp.

Alikunhi, K.H., 1944. The zone distribution of the mole crab (*Emerita Asiatica*) on the Madras coast. *J.Bom.Nat.His.Soc*., 45; 94-96pp.

Allen, C.J., Paterson, G.L.J., Hawkins, L.E., Hauton, C., Clark, P.F. and Aryuthaka, C., 2010. Zonation on tropical sandy beaches: a case study using *Dotilla intermedia*. *Marine Ecology Progress Series,* 408, 97–107pp.

Annandale, N., 1907. The fauna of brackish ponds at Port Canning, Lower Bengal *I. Rec. Ind. Mus*. (Calcutta), 1: 35-43pp.

Ansari Z. A., Harkantra S. N., Nair S. A., and Parulekar A. H., 1977. Benthos of the Bay of Bengal: A preliminary account. *Mahasagar Bulletin of the National Institute of Oceanography*, 10: 55–60pp.

Ansell, A.D, *et al*., 1972. The ecology of two sandy beaches in the south-west India; Seasonal changes in physical and chemical factors, and in the macrofauna. *Marine Biology*, 17; 35-62pp.

Anthony Garcia, Jayson R. Smith, 2013. Factors influencing human visitation of southern California rocky intertidal ecosystems. *Ocean & Coastal Management,* 73; 44-53pp.

Arun Parulekhar, 1972. Studies on intertidal ecology of Anjidiv island, *Proc. Indian Nat.Sci.Acad.*, 39; 611-631pp.

Audoin, V. and Milne Edwards, 1832. Recherches pour server aI' histoire naturelle du littoral de la France. V-1.

Bamber, R.N., 1993. Changes in infauna of a sandy beach. *J.Exp.Mar.Biol.Ecol.*, 172; 93-107pp.

Bauer, B.O. and Allen, J., 1995. "Beach steps: an evolutionary perspective," *Marine Geology,* 123; 143-166pp.

Benazza, A and others, 2015. Environmental control on fish and macrocrustacean spring community-structure, on an intertidal sandy beach. *Plos One*, 24; 10pp.

Bharat singh Gohil and Rahul Kundu, 2013. Ecological status of *cerethium caeruleum* at Dwarka coast, Gujarat (India). IJMS, 42; 481-486pp.

Bharathsingh Gohil.,Rahul Kundu., 2012. Diversity of the intertidal macrofauna at west coast of Gujarat,India, *Life science Leaflets*, 12: 135-145pp.

Boaventura, D., Re, P., Cancela da Fonseca, L., Hawkins, S.J., 2002. Intertidal rocky shore communities of the continental Portuguese coast: analysis of distribution patterns. *Marine Ecology* 23, 69-90pp.

Bortone S.A., 2005. Estuarine indicators, CRC press, 290pp.

Branch, G.M., 1981. The biology of limpets: physical factors. Energy flow and ecological interactions. *Oceanogr. Mar. Biol. Annu. Rev.*, 19; 235-380pp.

Brazeiro, A., 1999. Community patterns in sandy beaches of Chile: richness, composition, distribution and abundance of species. *Rev Chil Hist Nat,* 72:99–111pp.

Brazeiro, A., Defeo, O., 1996. Macrofauna zonation in microtidal sandy beaches: is it possible to identify patterns in such variable environments*? Estuar Coast Shelf Sci,* 42:523–536pp.

Brown, A. C., and McLachlan, A., 1990. 'Ecology of Sandy Shores'. Elsevier: Amsterdam, 328 pp.

Brown, A.C., 1983. The ecophysiology of beach animals - a partial review. In: (eds. A. McLachlan & T. Erasmus) Sandy beaches as ecosystems. The Hague, The Netherlands: Junk, 575-605pp.

Brown, B.K., Clarke, K., Warwick, R., 2002. Serial patterns of biodiversity change in coral across shallow reef flats in Ko Phuket, Thailand due to the effects of local (sedimentation) and regional (climatic) perturbations. *Marine Biology*, 141(1); 21-29pp.

Castilla, J.C., Manriques, P.H., Delgado, A., Ortiz, V, Jara, M.E., Varas, M., 2014. Rocky Intertidal Zonation Pattern in Antofagasta, Chile: Invasive Species and Shellfish Gathering. *PLOS one*, 9(11).

Catherine L. Waller, 2013. Zonation in a cryptic Antarctic intertidal macrofaunal community. *Antarctic Science,* 25(1), 62–68pp.

Cisneros, K.O., Smit, A.J., Laudien, J., Schoeman, D.S., 2011. Complex, dynamic combination of physical, chemical and nutritional variables controls spatio-temporal variation of sandy beach community structure. *PLoS ONE,* 6; 237-244pp.

Colman, J.S. and Segrove, F., 1955. The fauna living in Stoupe beck sand, Robinhoods Bay. *J.Anim.Eco*., 24; 426-444pp.

Colman, J.S., 1933. The nature of the intertidal zonation of plants and animals. *J. Mar. Biol. Assoc. UK* 18, 435–476pp.

Connell, J.H., 1972. Community interactions on marine rocky intertidal shores. *Annual Review of Ecology and Systematics,* 3: 169-192pp.

Crisp, D.J., and Southward, A.J., 1958. The distribution of intertidal organisms along the coast of the English Channel. *J.Mar.Biol.Ass.UK*., 37; 315-328pp.

Dahl, E., 1952. Some aspects of the ecology and zonation of the fauna on sandy beaches, *Oikos*, 4: 1-27pp.

Dakin, W.J., 1953. Australian sea shores. Angus & Robertson, Sydney.

Dakin. W. J., Bennett, L. and Pope, E.C., 1948. Some aspects of the ecology of the intertidal zone of the N.S,W. coast. *Austr. J. Sci. Res*., 176-231pp.

David Raffaeli and Hawkins, S.J., 1996. Intertidal ecology. Springer, 356pp.

Defeo, O., Jaramillo, E., Lyonnet, A., 1992. Community structure and intertidal zonation of the macroinfauna on the Atlantic Coast of Uruguay. *J Coast Res* 8:830-83pp.

Defeo, O., McLachlan, A., 2005. Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multiscale analysis. *Mar Ecol Prog Ser*,295:1–20pp.

Dexter, D. M., 1984. Temporal and spatial variability in the community structure of the fauna of four sandy beaches in south-east New South Wales. *Australian Journal of Marine and Freshwater Research,* 35; 663–672pp.

Doty. M. S., 1946. Critical tide factors that are correlated with the vertical distribution of marine algae and other organisms along the Pacific coast. *Ecology,* 27: 315-328pp.

Dye, A.H., McLachlan, A., Wooldndge, T., 1981. The ecology of sand beaches in Natal. *S Afr J Zool.,* 16; 200-209.

Ed'Ricketts and Jack calvin, 1939. Beween Pacific Tides. Stansford University press.

Edmonds, S. J., 1948. The commoner species of animals and their distribution on an intertidal platform at Pennington Bay. *Kangaroo Is., S. Australia.,* 72; 167-177pp.

Eleftheriou, A. and Nicholson, M.D., 1975. The effects of exposure on beach fauna. *Cahiers de Biologie Marine (suppl),* 16(5), 695-710pp.

Elmhirst, 1931. Studies in the Scottish marine fauna; The crustacean of the sandy and muddy areas of the tidal zone. *Proc.R.Soc.Edinb*., 51; 169-175pp.

Emrys Watking, 1942. The Macrofauna of the Intertidal Sand of Kames Bay, Millport, Buteshire. *Royal Soc.Edinb*. V-60.

Estes, J.A and Duggins, D.O., 1995. Sea otters and kelp forest in Alaska: generality and variation in a community ecological paradigm, *Ecol.Monogr*., 65.

Fenberg, P.B., Posbic, K., Hellberg, M.E., 2014**.** Historical and recent processes shaping the geographic range of a rocky intertidal gastropod: phylogeography, ecology, and habitat availability. *Eco.Evol*., 4(16); 3244-3255pp.

Fischer-Piette, E., 1936. Etudes sur la biogeographie intercotidale des deux rives de la Manche. *J. Linn. Soc.Lond*., 40; 181–272pp.

Flatteley, Walton, 1926. The biology of the sea-shore. Macmilan, London: 336pp

Gadeau de Kerville, H., 1885. Note sur les crustacés schizopodes de l'estuaire de la Seine suivie de la description d'une espèce nouvelle de mysis Mysis kervillei (Original not obtained).

Ganapati and Chandrasekara Rao, 1962. Ecology of interstitial fauna inhabiting the sandy beaches of Waltair coast. *J.Mar.Biol.Asso.India.,* 4; 44-57pp.

Giere, O., 1993. Meiobenthology. The Microscopic Fauna in Aquatic Sediments. Berlin-Heidelberg.

Giménez L, 2011. Exploring mechanisms linking temperature increase and larval phenology: the importance of variance effects. *J. Exp Mar Biol Ecol*., 400pp.

Glynn and Peterwilliams, 1965. *Musculis pygmaeus* sp. nov., a minute mytilid from the high intertidal zone at Monterey Bay, California (Mollusca: Pelecypoda). Veliger, 7; 121-128pp.

Gopalakrishnan, P., 1970. Some observations on the Shore Ecology of Okha Coast. *J. Mar. bio.Ass. India* 12: 15-34pp.

Govindan Kutti, A.G. and Balakrishnan Nair, N., 1966. Preliminary observations on the interstitial fauna of south west coast of India. *Hydrobiologia*, 28; 101-122pp.

Govindan, K. and Desai, B.N., 1980. Mahim bay, a polluted environment of Bombay. *J. Ind. Fish. Ass*., 10&11, 5-10pp .

Hedgpeth, J. W. 1957. Sandy beaches, Treatise on marine ecology and paleoecology, v. 1. *Geol. Sot. Am. Mem*. 67; 587-608pp.

Hedley, C., 1915. An Ecological Skech of the Sydney beach. *Proc. Roy.Soc.N.S.W*., 49; 15-77pp.

Heilskov, A. C. and Holmer, M., 2001. Effect of benthic fauna on organic matter mineralization in fish-farm sediment: importance of size and abundance. *Journal of Marine Science*, 58: 427 – 434pp.

Helmuth, B. , 2002. How do we measure the environment? Linking intertidal thermal physiology and ecology through biophysics. *Int. Comp. Biol.,* 42: 837-845pp.

Hixon, M.A. and Menge, B.A., 1991. Species diversity – prey refuges modify the interactive effects of predation and completion. *Ther. Pop.Biol*., 39 ; 178-200pp.

Hughes, M.G. and Cowell, P.J., 1987, "Adjustment of reflective beaches to waves". *Journal of Coastal Research*, 3; 153–167pp.

James, D. B., 1982. Ecology of intertidal echinoderms of the Indian Seas. *Journal of the Marine Biological Association of India*, 24; 124-129pp.

James, R.J., Lincoln Smith, M.P., Fairweather, P.G., 1995. Sieve mesh-size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. *Mar Ecol Prog Ser* 118:187–198pp.

Jaramillo, E., 1994. Patterns of species richness in sandy beaches of South America. *South African Journal of Zoology*, 29; 227-234pp.

Jaramillo, E., and McLachlan, A., 1993. Community and population responses of the macroinfauna to physical factors over a range of exposed sandy beaches in south-central Chile. *Estuarine and Coastal Shelf Science,* 37, 615–24pp.

Jaramillo, E., McLachlan, A. and Coetzee, P., 1993. Intertidal zonation patterns of macrofauna over a range of exposed sandy beaches in south-central Chile. *Mar. Ecol. Prog. Ser*., 101: 105-118pp.

Jean-Victor Audouin and Henri-Milne Edwards, 1826-1829. Bulletin de l'Institut Océanographique de Monaco, No. Spécial 2 (Congrès International d'Histoire de l'Océanographie 1): 417-437pp.

Johnston, T. R., 1917. Ecological notes on the littoral fauna and flora of Caloundra, Queesland, *Queensland Nat*., 2; 53-63pp.

Jones, D. A. and Richmond, M. D., 1992. Intertidal and subtidal marine habitat surveys. In: Establishment of a marine habital and wildlife sanctuary for Gulf region. Final report for phase I: 134-161pp.

Jones, D. A., 1986. A Field Guide to the seashore of Kuwait and the Arabian Gulf. Kuwait University Press, Kuwait, 192 pp.

Joshi, M.C., 1969. The marine mollusc of the Konkan coast. *Journal of the Shivaji University*, 2; 47-54pp.

Knight Jones, E.W., 1953. Laboratory studies on gregariousness during settling in *Balanus balanoides* and other barncacles. *J.Exp.Mar.Biol.Ecol*., 30; 584-598pp.

Kurian C. V., 1953. A preliminary survey of the bottom fauna and bottom deposits of the Travancore coast within the 15-fathom line. *Proceedings of the National Institute of Sciences of India*, 19: 746– 775pp.

Lastra, M., de la Huz, R., Sanchez Mata, A. G., Rodil, I. F., Aerts, K., Beloso, S., López ,J., 2006. Ecology of exposed sandy beaches in northern Spain:

environmental factors controlling macrofauna communities. *J. Sea Res*., 55 (2), 128–140pp.

Leber, K. M.,1982. Seasonality of macroinvertebrates on a temperate, high wave energy sandy beach. *Bulletin of Marine Science*, 32; 86-98pp.

Ledesma, M.E., and O'Connor, N.J. 2001. Habitat and diet of the non-native crab *Hemigrapsus sanguineus* in south eastern New England. North eastern Naturalist 8:63–78pp.

Lewis, J.R., 1964. The ecology of rocky shores. English University press, London, 300pp.

Loganathan Palanikumar, Madasamy Rajee and Arumugam Kuppusamy Kumaraguru, 2012. Population of *Modiolus* sp. in the Intertidal Rocky Coastline of Pudhumadam, Gulf of Mannar. *J. BIOL. ENVIRON. SCI*., 6 (16), 55-58pp.

McIntyre, A.D., 1968. The meiofauna and macrofauna of some tropical beaches. *J.Zool.Lon*., 156, 377-392pp.

McLachlan, A., 1977. Composition, distribution, abundance and biomass of the macrofauna and meiofauna of four sandy beaches. *Zoologica Africana* 12**;** 279–306pp.

McLachlan, A., 1983. Sandy beach ecology: a review. In *Sandy beaches as Ecosystems*. In: McLachlan, A. and Erasmus, T. (Eds.). The Hague, Junk. 321-380pp.

McLachlan, A., Brown, A., 2006. The Ecology of Sandy Shores. Elsevier, Amsterdam, 373 pp.

McLachlan, A., Dorvlo, A., 2005. Global patterns in sandy beach macrobenthic communities. *Journal of Coastal Research*, 21; 674-687pp.

McLachlan, A., Jaramillo, E., 1995. Zonation on sandy beaches. *Oceanogr Mar Biol Annu Rev,* 33:305–335pp.

Menge, B. A., Daley, B. A., Lubchenco, J., Sanford, E., Dahlhoff, E., Halpin, P. M., Hudson, G. and Burnaford, J. L., 1999. *Ecol. Monogr*., 69, 297–330pp.

Menge, B. A., Sanford, E., Daley, B. A., Freidenburg, T. L., Hudson, G. and Lubchenco, J. 2002. *Ecol. Res*., 17, 1–16pp.

Menge, B.A. and Menge, D.L., 2013. Dynamics of coastal meta ecosystems; the intermittent upwelling hypothesis and a test in rocky intertidal region. *Ecol.Monogr.*, 83; 283-310pp.

Menge, B.A., 1991. Generalizing from experiments: is predation strong or weak in the New England rocky intertidal? *Oecologia,* 88, 1–8pp.

Menge, B.A., and Sutherland, J.P., 1987. Community regulation: Variation in disturbance, competition and predation in relation to environmental stress and recruitment. *Am. Nat*. 130: 730-757pp.

Milker, Y and others, 2015. Annual and seasonal distribution of intertidal foraminifera and stable carbon isotope geochemistry, Bandon marsh, Oregon, USA. *Journal of Foraminiferal Research*, 45; 146–166pp.

Misra, S and Kundu, R., 2005. Seasonal variations in population dynamics of key intertidal molluscs at two contrasting locations. *Aquatic Ecology*, 39; 315-324pp.

Morrisey, D.J., Underwood, A.J., Howitt, L., Stark, J.S., 1992. Temporal variation in soft-sediment benthos. *J Exp Mar Biol Ecol,* 164:233–245pp.

Murthy, M. S. and Radia, P., 1978. Eco-biochemical studies on some economical important intertidal algae from Port Okha (India). *Botanica Marina,* 24: 417-422pp.

Nandi, S. & A. Choudhury, 1983. Quantitative studies on the benthic macrofauna of Sagar Island, intertidal zones, Sunderbans, India. Mahasagar-*Bull. Nat. Inst.Oceanogr*., 16: 409-414pp.

New Combe, C.L., 1935. A study of the community relationship of the sea mussel, *Mytilus edulis. Ecology,* 16; 23-243pp.

Nybakken, J. W., 1993. Marine Biology: an ecological approach. Harper Collins College. New York. 445pp.

Paine, R.T. 1974. Intertidal community structure. *Oecologia,* 29; 93-120pp.

Parulekar A. H., 1981. Marine fauna of Malvan, Central West Coast of India. *Mahasagar Bulletein of National Institute of Oceanography*. 14(1): 33-44pp.

Patel, S.J. and Desai B. G., 2009. Animal-Sediment Relationship of the Crustaceans and Polychaetes in the intertidal zone around Mandvi, Gulf of Kachchh, Western India. *Jour. Geol. Soc. Ind.,* 74; 233-259pp.

Pearse, A. S., Humm, M. J., Wharton, G. W.,1942. Ecology of sand beaches at Beaufort, N. C. *Ecol. Monogr* 12: 135-190pp.

Pennak, R.W., Ecology of microscopic metazoan inhabiting the sandy beaches of some Wisconsin Lakes. *Ecol.Monogr.,* 10; 537-615pp.

Philip K. P., 1970. The intertidal fauna of the sandy beaches of Cochin, *Proc.Indian natn.Sci.Acad*. 38(B): 317-328pp.

Pirrie, M.E., Bruce, J.R. and Moore, H.B., 1932. A quantititative study of sandy beach at Fort Erin. *J.mar.Ass.UK*., 18; 279-286pp.

Pope, E. C., 1943, Animal and plant communities of the coastal rock platform at Long reef, N.S.W. *Proc. Linn. Soc. N.S. W*, 68; 221-254pp.

Pulliam, R., 2000. On the relationship between niche and distribution. *Ecol. Lett*., 3, 349–361pp.

Quadros, G., Sukumaran, S., Athalye, P., 2008. Impact of the changing ecology on intertidal polychaetes in an anthropogenically stressed tropical creek, India. *Aquatic Ecology*, 43; 977-985pp.

Quadros, Goldin I, 2001. Study of Intertidal Fauna of Thane Creek, PhD Thesis, Mumbai University.

Qualye, D.B., 1960., The intertidal bivalves of British Columbia. McDiarmid, Victoria, 104pp.

Rabindranath, P., 1969. Taxonomic study of Amphipoda. Ph.D thesis, University of Kerala, 443pp.

Raffaelli, D., J., Limia, S. Hull, and S. Pont, 1991. Interactions between the amphipod *Corophium volutator* and macroalgal mats on estuarine mudflats. *J. Mar. Biol. Ass. U.K.* 71: 899–908pp.

Raghunathan, C., Tewari, A., Joshi, H.V., Sravan Kumar, V.G., Trivedi, R.H. and Yasmin Khambhati, 2003. Impact of turbidity on Intertidal macrofauna at Gopnath, Madhuva and Veraval coasts (west coast of India). *Indian Journal of Marine Sciences,* 32(3): 214-221pp.

Ranade, M.R., 1977. Occurrence of Pearl Oysters in Ratnagiri district. *Journal of Bomabay Natural History society,* 74; 553pp.

Remane, A., 1933. Verteilung und Organisation der benthonischen Vdkrofauna der Kieler 3ucht. Wiss. l,'ieereslli1ters (Abt. Kiel), 21: 161-221pp.

Rizzo A.E., Cecilia A., and Amaral Z., 2001. Environmental variables and intertidal beach annelids of Sao Sebastiao channel (State of Sao Paulo, Brazil), *Revista Brasileira de Biologic*a, 49: 3-4pp.

Rodil, I. F., Lastra, M., Sanchez Mata, A. G., 2006, Community structure and intertidal zonation of the macroinfauna in intermediate sandy beaches in temperate latitudes: north coast of Spain. *Estuar. Coast. Shelf Sci.,* 67 (1–2), 267–279pp.

Rogers, S.I., Greenaway, B., 2005. A UK perspective on the development of marine ecosystem indicators. *Marine Pollution Bulletin*, 50, 9–19pp.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., Defeo, O., 2007. Sandy beaches at the brink. Diversity and Distributions, 13; 556–560pp.

Sheshappa, G., 1953. Observations on the physical and biological features of the inshore sea bottom along the Malabar Coast. *Proc.natn.Inst.Sci.India*, 19; 257-279pp.

Short, A.D., 1999. Handbook of Beach and Shore Morphodynamics.Wiley and Sons, London, 392 pp.

Short, A.D.,, Wrigh,t L.D., 1983. Physical variability of sandy beaches. In: McLachlan A, Erasmus T (eds) Sandy beaches as ecosystems. W Junk, The Hague, 133–144pp.

Sivaprakasam, T.E., 1968. Amphipoda from the east coast of India. *J.Mar.Biol.Ass. India*., 8; 82-122pp.

Small, M.P. and Gosling, E.M., 2001. Population genetics of a snail species complex in the British Isles: *Littorina saxatilis* (Olivi), *L. neglecta* Bean and *L. tenebrosa* (Montagu), using SSCP analysis of Cytochrome-B gene fragments. *Journal of Molluscan Studies*, 67: 69–80pp.

Snelgrove, P.V.R., 1998. The biodiversity of macrofaunal organisms in marine sediments. *Biod Cons,* 7:1123–1132pp.

Somero, G. N., 2002. Thermal physiology and vertical zonation of intertidal animals: optima, limits, and costs of living. *Integr. Comp. Biol.,* 42:780–789pp.

Southward, A.J., and Orton, J.H., 1954. The effects of wave action on the distribution and numbers of the commoner plants and animals living on the Plymouth breakwater. *J.Mar.biol.Ass.UK*., 33; 1-19pp.

Stephen, S.C., 1929. A study on the Scottish marine fauna. The fauna of the sandy and muddy areas of the tidal zone. *Trans.R.Soc.Edinb.,* 59; 291-306pp.

Stephenson, T.A. and Stephenson, A., 1949. The universal features of zonation between tide marks on rocky coasts. *Journal of Ecology*, 38: 289-305pp.

Stephenson, T.A., 1936. The marine ecology of the South African coast, with special reference to the habits of limpets. *Proceedings of the Linnean Society of London*, 148: 74-79pp.

Subramanyam, T.V., Karandikar, K.R. and Murthi, N.N., 1952. Marine gastropods of Bombay. Part II. *J. Univ. Bombay*, 21; 21-34pp.

Tamar Guy-Haim, Gil Rilov, Yair Achituv, 2015. Different settlement strategies explain intertidal zonation of barnacles in the Eastern Mediterranean. *Journal of Experimental Marine Biology and Ecology,* 463; 125–134pp.

Tambe, V.B. and Desh Pande, K.K.B., 1964. Amphipods of Bombay shores. *J.Uni.Bomb.Nat.His.Soc*., 31; 113-117pp.

Thorner, J., Kumar, L., Smith, S.D.A., 2014. Impacts of Climate-Change-Driven Sea Level Rise on Intertidal Rocky Reef Habitats Will Be Variable and Site Specific. *PLoS ONE*, 9(1).

Thrush, S. F., 1991. Spatial patterns in soft-bottom communities. *TREE*, 6(3):75–79pp.

Trevallion, A., Ansell, A. D., Sivadas, P., Narayanan, B., 1970. A preliminary account of two sandy beaches in South West India. *Mar.Biol*.6, 268-279pp.

Underwood, A.J., Fairweather, P.G., 1989. Supply-side ecology and benthic marine assemblages. *TREE* 4, 16–20pp.

Vaghela, A., Bhadja, P.,Ramoliya, J.,Patel, N. and Kundu, R., 2010. Seasonal variations in water quality, diversity and population ecology of intertidal macrofauna at an industrially influenced coast. *Water Science and Technology*, 6; 1505-1514pp.

Vakani, B., Poriya, P., Kundu, R., 2014. Spatio- temporal variations in population ecology of limpets in rocky intertidal shore of south Saurashtra coast, Gujarath, India.*The Ecosan*, 8; 71-75pp.

Walton, C.L., 1915. The distribution of some littoral Trochidae and Littorinidae in Cardigan Bay. *J.Mar.Biol.Ass.India* .UK. 10, 114pp.

Wormser, R.V., 2012. Intertidal zonation of two gastropods *Nerita plicata* and *Morula granulate,* Moorea, French Polynasia. Student research papers, eScholarship, California, 1-11pp.

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Chapter 3

MATERIALS AND METHODS

Contents

3.1 Introduction

Beaches have been heave towards common man due to its enchanting beauty and recreational activities since many years. Tourism is a major activity of common man in beaches. But on scientific point of view beaches are not only for recreational purposes but those are wonderful ecosystems that are very much available and interested to the scientific community. Beaches are plenteous with oxygen, food and nutrients. The beaches let in energy from the sea; beaches are a very momentous dissipater of wave energy (Connell, 1972).

The study of abundance of life in each ecosystem is a cognizance to everyone that how an ecosystem is functioning. Nowadays ecosystems are facing more natural and human made destructions. Beach erosion causes threat to the ecosystem by destroying the habitat. Though the intertidal areas are

nesting and breeding zones of many organisms, they deserve enough protection of their ecosystems. But the common man disregards the above fact as they value only the aesthetic beauty of beaches.

Since the intertidal zones are ecologically important systems, there should be a measure or solution to protect it and for doing it there must be awareness about community structure of the zone. Biodiversity and distributional patterns of littoral marine organisms gives qualitative and quantitative understanding of that area. This research work is focused on assaying the quantitative study of diversity on a comparative scale and abundance of selected intertidal habitats of Kerala coast.

3.2 Study Area

Two beaches were selected by site survey for the study; Fort Cochin beach (Cochin, Kerala) and Dharmadam Beach (Kannur, Kerala). Dharmadam beach is located 17km from Kannur. It is an unpolluted and unaltered beach whereas Fort Cochin beach is highly under anthropogenic stress by industrial, agriculture and animal wastes, and also fishing and oil seepage and spilling etc. Fishing operations, mainly Chinese dip net operations are main attractions on this beach. On the contrary, these operations and tourist activities give tremendous challenge to the intertidal zone of Fort Cochin beach. Due to increasing tourism activities the intertidal zone of the beach is dumped with plastic wastes. Fort Cochin area is located 12km away from the main Cochin city.

Fort Cochin beach (sampling site 1) (Long.76^0 15’ 27”E, Lat.9^0 57’58”N) is an open beach with continuous surf action (Fig. 4, 5, 6 and 7). It is situated close to the barmouth (0.25km south). It has an extensive berm but the beach is gently sloping. The Fort Cochin beach has fairly coarse sand, 10-12m

of beach from high to low is exposed during low tide and the time frequency of a wave is 6-9 seconds. Sea erosion is severe during South West monsoon. Field sampling stations 1&2 were fixed at this site at 500m distance. Fort Cochin beach is fed by river discharge from Cochin backwater, an arm of Vembanad backwater system.

Station 1 & 2 of Fort Cochin beach

Steeper sandy profile is existing in station 1 as compared to station 2. Coarse sand and tetrapods are seen in the shoreline area to prevent flooding (Fig. 5 & 6). Station 1 is affected with plastic waste accumulation. Station 2 of Fort Cochin beach is characterized by frequent operations of Chinese dip nets and is filled with animal waste (Fig. 7).

Dharmadam beach (Long. 75^0 27' 23"E, Lat. 11^0 46'35"N) is also an exposed beach with mixed type of sediment composition; rocky and sandy (Fig. 4, 8, 9 & 10). It is a long (1.5km) clean beach. The characteristics of beach sand are fine with darker colour adhering with scattered laterite rock formations. About, 15-30m of beach from high to low tide is exposed at low tide and the time of frequency of wave is 6-8 seconds. It has connections with Anjarakkandy River. Besides precipitation, Dharmadam beach has fresh water influx through this river mouth. The arms of the river come from two sides of the beaches; north and south, the northern arm of the river is called Dharmadam River. The beach experiences continuous wave action and the area where the rock formation is found, the more intense is the wave action.

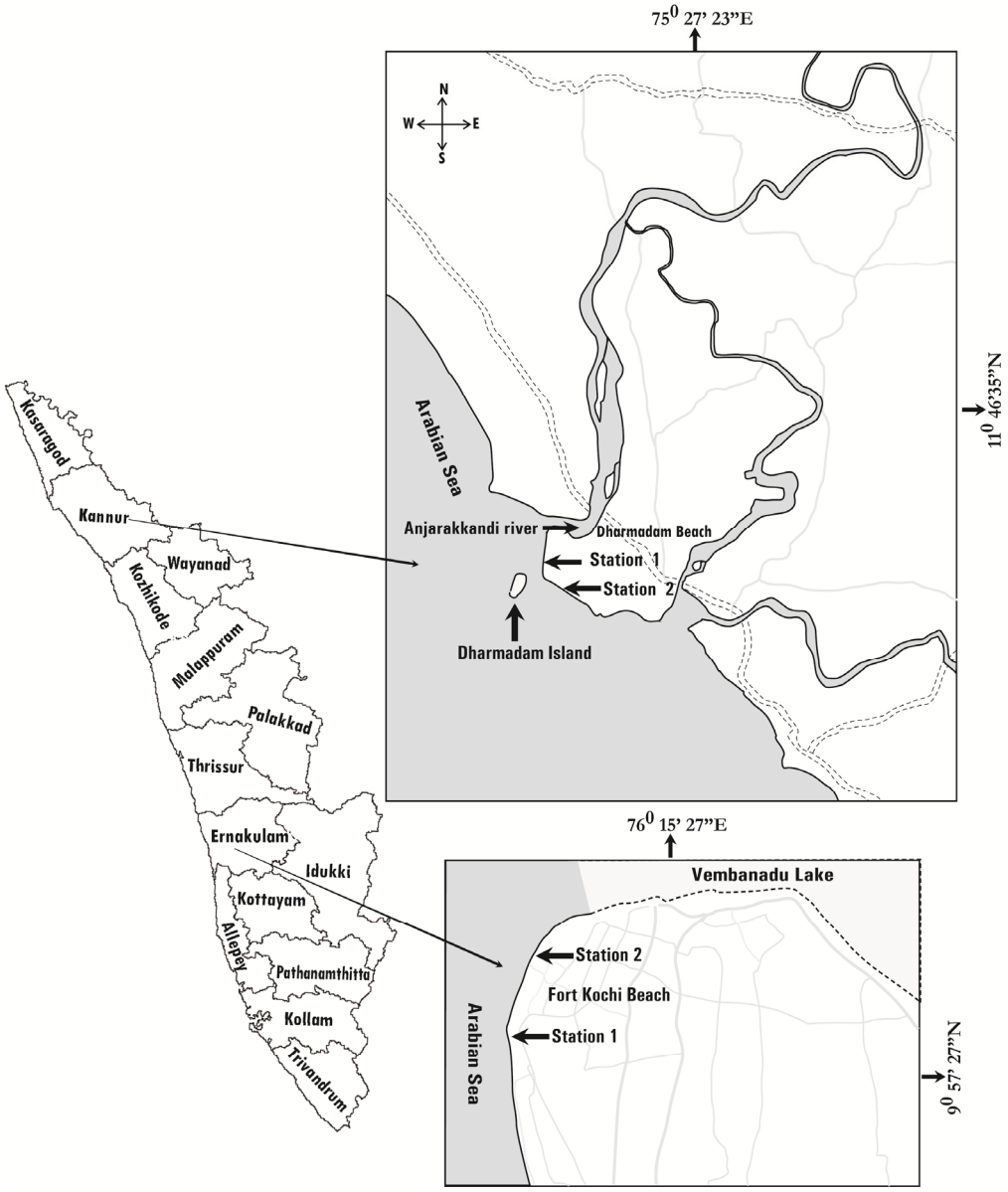

Figure 4 Map showing Study area

Station 1& 2

Two sampling stations are situated in this beach at a distance of 500m apart. Stations 1 and 2 are pristine natured and station 2 holds laterite rock formations (Fig. 9). Station 1 is purely sandy in nature (Fig. 8). Fishing operation is observed in minimum level. Opposite to these stations, a small green island called Dharmadam Island is situated, which is also ecologically important area due to the lush of mangrove vegetation (Fig. 10).

Both Fort Cochin and Dharmadam have certain dissimilarity in their beach profiles. The Fort Cochin beach is a narrow beach and much steeper than Dharmadam beach, whereas Dharmadam beach is wide, long and not steep when compared to Fort Cochin beach. According to the differences in their morphological characteristics the diversity and population of the beaches also have different identity.

Fort Cochin beach Station 1 (Long.76^0 15' 27"E, Lat.9^0 57'58"N)

Figure 5 **Figure 6**

(Station 1- Continous exposed sandy beach with gentle steeper profile).

Fort Cochin beach Station 2(Long.76^0 15' 27"E, Lat.9^0 57'58"N)

Figure 7

(Station 2 – Chinese dip nets are common and hotspot of tourism)

Dharmadam beach Station 1 (Long. 75^0 27' 23"E, Lat. 11^0 46'35"N)

Figure 8

(Station 1 - Continous exposed beach with flat profile and clean beach with lesser anthropogenic pressure)

Dharmadam beach Station 2 (Long. 75^0 27' 23"E, Lat. 11^0 46'35"N)

Figure 9 **Figure 10**

(Station 2 – Main attraction of tourists due to the presence of enthralling green island and scatterd laterite rocks)

3.3 Methodology

Eighteen months of continuous monthly sampling and collections were done from August 2009 to January 2011 during low tide. Predicted tide tables were used for understanding low tide period. Rainfall data was obtained from India Meteorological Department (IMD). Long shore currents were measured by releasing a plastic bottle top to the water and determined the time for it to travel one meter. Three consecutive readings were taken (Gillian Cambers *et al.,* 2005). Frequency of waves and angle of approach of waves (Giavolaa *et al.,* 1996) have been measured by visual observation. Visual observations are used for preliminary estimates of wave angle.

Quantitative sampling methods were used for sampling process. For getting accurate samples, transects were taken and lined across the width of the beach. Generally 10 - 30m (10- 12m in Fort Cochin and 15-30m in Dharmadam beach) transect were taken at both the beaches. In Fort Cochin beach the exposed area of the beach at low tide time was 10 -12m, that in

Dharmadam it was 15 - 30m. Along this transect quadrate of 25x 25 cm ($0.625m^2$) were placed at regular intervals by using stratified random sampling method (quadrate is a small, square or rectangular frame used to measure the relative abundance of organism in an area) (Holme and Mclntyre,1984, Eleftherious and Anastarious, 2005). In beaches, for quantitative study quadrate sampling is the best method to collect macrofauna. Four quadrates were placed along transect in each station. Sediments upto 15cm within the quadrate were sampled and sieved through the 0.5mm mesh sieve (500µm). The organisms obtained after sieving were transferred to a plastic bottle and preserved in 5% formalin with filtered sea water. The preserved specimens were stained with 1% Rose Bengal (Pfannkuche and Thiel, 1988) for further identification. The stain imparts brighter colour to the organism which helped in sorting the organism more easily from the sediments. In rocky beaches the quadrates were kept on rocks and the organisms within the quadrates were counted and collected. Organisms were identified upto the possible genus and species levels. Some species that are difficult to identify (due to damage) were identified up to genus level. For unsure species in identification, the lowest dependable taxonomic level was given.

Biomass was calculated for the faunal groups, polychaetes, amphipods, molluscs (without shell), other crustaceans, tanaids and others were calculated separately. It was estimated based on wet weight method by using high precision electronic balance. Percentage abundance of organisms in group wise was also calculated by using the formula

$$\%\ \text{abundance} = \frac{\text{Number of organisms}}{\text{Total number of organisms}} \times 100$$

The epifauna of the rocky areas of beaches were collected by hand picking and also by using chisels (Stephenson and Stephenson, 1972). For quantitative measurements quadrates were placed on rocky surface and the organisms within the quadrates were collected and preserved. Percentage cover of epifauna was also done (Stephenson and Stephenson, 1972).

$$\text{Relative percentage abundance (\%)} = \frac{\text{Species occurrence (within the quadrate)}}{\text{Total species occurrence (within the quadrate)}} \times 100$$

Visual observations of organisms like birds and other animals of the beaches were also done.

3.4 Hydrography

Water quality parameters from both the beaches were collected on display of environmental variables that can be influential to the macrofauna residing there. Both interstitial and sea water were analysed. Sea water was collected to analyse the water quality as interstitial water showed minimal variations. Temperature of water samples was measured by using centigrade thermometer (range = 0-50^{0}C $\pm$0.1^{0}C). pH by Systronics pH meter (No.335, accuracy $\pm$ 0.01). Salinity, turbidity and total dissolved solids were measured with Systronics water analyser (Model no.317) and conductivity was measured by conductivity meter (Model no.318). For measuring salinity Mohr-Knudson method was also used (Strickland and Parsons, 1972). Standard silver nitrate and potassium chromate were used with 10ml sample. Carbon dioxide was measured by using titrimetric method (APHA, 2005). Standard sodium hydroxide, sulphuric acid (H_2SO_4) and phenolphthalein indicator were used with 10ml sample. Inorganic nutrients were also estimated. Phosphate was measured by ascorbic acid method and absorbance was measured at 880nm

(Grasshoff *et al*., 1983). Silicate was measured by using ammonium molybdate spectrophotometric method and absorbance was measured at 810nm (Grasshoff *et al.,* 1983). Nitrate was measured by using resorcinol method and absorbance was measured at 505nm (Jia Zhong chalres, 2003) and nitrite by using sulphanilamide solution and N-(1-Naphthyl) ehthylene diamine dihydrochloride and absorbance measured at 543nm (Grasshoff *et al*., 1983). Dissolved oxygen (DO) was estimated by Winkler's Method (Grasshoff *et al.,* 1983). Winkler A and B were used to fix the samples and standard sodium thiosulphate was used to titrate against the sample (25ml). Starch solution was used as indicator. Tide levels were observed by predicted tide tables (Tide tables of 2009-11 were collected from Cochin port trust).

3.5 Sediment analysis

A 25x25cm quadrate was used to sample the intertidal macrofauna. Sediment parameters from low to high tide were checked during the study. It showed minimal variation (below 1). So average from high to low tide was taken for each parameter. For the analysis of sediment, the parameters, temperature, pH, conductivity, organic carbon, particle size and moisture content of sediment were taken and measured. Sediment temperature was measured using a degree centigrade thermometer (Range – 0-50^{0}C, accuracy – 0.1^{0}C). Sediment pH (Accuracy - $\pm$0.01) and sediment conductivity were measured using Systronics Analyser (Model no.321). Organic carbon by using wet oxidation method (Walkley and Black, 1934, Jackson, 1973). The organic carbon is then converted into organic matter by conversion factor of 1.724 (Wiseman & Bennette, 1960). Moisture content was estimated using conventional oven method (Jackson, 1973). Particle size was measured using particle size analyser (Sympatech, Germany). Laser diffraction is the main principle used

in particle sizing technique for materials sorting from hundreds of nanometers up to several millimeters in size.

3.6 Statistical analysis

Arrays of statistical analysis were done for the better explanation of sample data. For this, software programs like SPSS Vs.16.0 (Statistical Programme for Social Sciences version 16.0) and PRIMER Vs. 6.1.8 (Plymouth Routines in Multivariate Ecological Research, version 6.1.8) were employed. ORIGIN 7 software was also employed to plot ternary diagrams to observe the distribution of sediment particles. Univariate and multivariate of data were done based on this. The univariate analysis like species diversity, species richness, species evenness and species dominance and Caswell neutral modal were analysed. Multivariate analysis done were cluster analysis with SIMPROF (Similarity Profile), MDS (Non-metric Multidimensional Scaling), bubble plots, BEST analysis (BIO - ENV + BV - STEP), PCA (Principal Component Analysis), draftsman plot, ANOSIM (Analysis of Similarity), SIMPER (Similarity Percentage), ABC curve (Abundance Biomass Curve) and geometric class plot (Clarke and Gorley, 2006).

Univariate and multivariate analysis are equally important to know the profile of sample data. Univariate analysis like species diversity indices were computed to know the community structure of intertidal macrofauna from both the beaches. Diversity index provides good measure of the community composition along with its survival strategy.

Multivariate analysis is used to analyze two or more statistical variable at a time to identify patterns and relationships. By using PRIMER multivariate analyses like similarity indices such as cluster analysis with SIMPROF, MDS,

Draftsman plot were done. BEST analysis, PCA, ANOSIM, SIMPER, ABC curve were also attempted.

3.7 Univariate Analysis

3.7.1 Diversity indices

1. Shannon-Weiner index (H') (species diversity)

For measuring species diversity Shannon- Weiner index was used (Shannon, 1949) by the formula

H' = -∑S Pi log 2 Pi.....
i = 1

In ecology, P_i is often the proportion of individuals forming the *i*th species in the dataset.

2. Margalef richness index (d)

It is used to analyze the species richness of the community based on Margalef (1958) formula. It is also the measure of total number of species in a given number of individuals.

d= (S – 1) / In N
S = number of individuals of one species
N = total number of all individuals in the sample
In = logarithm to base e

3. Pielou's index (j')

Species evenness refers to how close in numbers each species in an environment (Pielou, 1975). Pielou's evenness index is expressed as

j'= H'/ ln (S)

j' : Pielou eveness index

H': Shannon index

S: number of classes

4. Simpson's dominance index (Lamda')

The dominance of species was measured by Simpson's index (Simpson, 1949).

$\lambda = \sum Pi^2$

Pi = ni /N

N = total number of individuals, ni = number of individuals of i, i2 etc.

CASWELL neutral model (V statistics): it is comparison of Shannon diversity (H') with expected diversity conditional on the observed number of species S and inviduals N under some model rules for the community which are 'ecologically neutral'. V (N.D.) is calculated by subtracting E [H'] from H' and dividing by the standard error of H'.

3.8 Multivariate analysis

Cluster analysis: It is used to find out the similarity trend between variables. Hierarchical clustering methods are commonly used. The output of this is a dendrogram of two axis (Bray and Curtis, 1957). Bray - Curtis coefficient of similarity with SIMPROF (similarity profile) was used. SIMPROF test was used to find out the similarity significance between cluster groups (indicated in redline). The coefficient was calculated by using the formula,

$$S_{17} = 100\left(1 - \frac{\sum_i |y_{i1} - y_{i2}|}{\sum_i y_{i1} + \sum_i y_{i2}}\right) \equiv 100.\frac{\sum_i \min\{y_{i1}, y_{i2}\}}{(\sum_i y_{i1} + \sum_i y_{i2})/2}.$$

Here y_{il} is the count for the ith species from sample 1.

MDS (Non-metric multidimensional scaling): The ordination plot of samples was performed by non-metric Multi-dimensional scaling (MDS) using Euclidean distance as a distance measure to explore trends between samples. Its main purpose is to plot the samples in two dimensional scales. The samples that are familiar in community or environmental variables will be close together (Clarke and Gorley, 2006)

Bubble plots: The abundance of single species over the area can be best seen in bubble plots. The bubbles will be superimposed and the relative size of the bubbles is related to abundance of species in that area.

Draftsman plot: Draftsman scatter plot were done to find out interaction between organisms. Pair wise interaction can be observed in Draftsman plot.

The BEST analysis (BIO-ENV + BV- STEP): This gives the 'best' match between the multivariate among-sample patterns of a community associated environmental variables with those assemblage (Clarke and Gorley, 2006). BIO-ENV and BVSTEP procedure of PRIMER Vs 5 combined together for better result.

PCA (Principal Component Analysis): This is an ordination in which samples are regarded as points in the high dimensional variable space and are projected onto a best – matching plane. The function of the new axes is to detain much variability as possible (Clarke and Gorley, 2006).

ANOSIM (Analysis of Similarity): Analysis of similarity is used to measure the dissimilarity matrix rather than raw data (Clarke, 1993). R value ranges from -1 to +1.

SIMPER (Similarity Percentage): This calculates the average Bray-Curtis dissimilarities between all pairs of samples and also similarities among samples from a group and into percentage contributions from each species.

Abundance Biomass Curve (ABC curve): It plots both abundance and biomass curves to determine the disturbances in community.

Geometric class plot: geometric class plot were done to observe species abundance distribution. Different abundance classes are described in geometric plots. Plots gives the proportion of total species represented by 1 individual in the sample (geometric class 1), 2-3 individuals is considered as geometric class 2, 4-7 individuals as geometric class 3, 8-15 individuals as geometric class 4, etc. Higher abundance classes reveals unhealthy ecosystem (Clarke and Gorley, 2006).

3.9 Biotic indices

3.9.1 AMBI (AZTI's Marine Biotic Index)

To get the ecological quality status of (EcoQS) benthic environment, biotic indices like AMBI (AZTI's Marine Biotic Index) and BOPA index (Benthic Opportunistic Polychaete Amphipod ratio) were performed for the assessment of benthic invertebrates. AMBI (Borja *et al*., 2000; Muxika *et al.,* 2005) is using different soft bottom macrofauna for benthic quality assessment and classified them into 5 groups.

- Group 1 - Sensitive species, present only in uncontaminated condition.
- Group 2 - Organisms unresponsive to organic enrichment with low densities.

- Group 3- Tolerant species, may occur in normal conditions and proliferated when organic enrichment occurs.
- Group 4- Second order opportunist species with small size
- Group 5- First order opportunist species.

According to Muxika *et al.,* 2005, biotic coefficient value of AMBI from 0 - 1.2 is normal community, undisturbed site and high ecological status.

1.2-3.3 - Unbalanced community, slightly disturbed site, Good ecological status.

3.3- 4.3- Transitional to pollution, moderately disturbed site, moderate ecological status

4.3 - 5 - Polluted community, poor status

5 - 5.5 - Transitional to heavy pollution, heavily disturbed site,

5.5-6.0- Heavy polluted, bad status

6.0 -7.0- Azoic, extremely disturbed.

AMBI was calculated by using the formula,

$$\text{AMBI} = \frac{[(0 \times \%\text{EGI}) + (1.5 \times \%\text{EGII}) + (3 \times \%\text{EGIII}) + (4.5 \times \%\text{EGIV}) + (6 \times \%\text{EGV})}{100}$$

EG I- the disturbance-sensitive species, EG II – disturbance - indifferent species, EG III- disturbance - tolerant species, EG IV- second-order opportunistic species and EG V – first - order opportunistic species.

3.9.2 BOPA index (Benthic Opportunistic Polychaete Amphipod ratio)

BOPA index is based on the opportunistic polychaete and amphipod rtaio (Except the genus *Jassa*) (Gesteira and Dauvin, 2000).

BOPA index was calculated by using the formula,

BOPA = log [(fp / fa + 1) + 1], where fp = frequency of opportunistic polychaetes and fa = frequency of amphipods except the genus *Jassa.*

Classification- BOPA index value 0.00 - 0.04 - High ecological status, 0.04 - 0.13 - good ecological status, 0.13 - 0.19 - moderate ecological status, 0.19 - 0.26 - poor ecological status, 0.26 - 0.30 - bad ecological status.

SPSS Vs.16.0 was used to find out 3 way ANOVA, standard deviation, correlation etc. Pearson's correlation shows the linear relationship between two sets of data. Pearson correlation coefficient is the measure of the strength of the association between the two variables.

References

APHA, 2005. Standard method for the examination of water and waste water. APHA, Washington, USA, 1368pp.

Borja, A., Franco, J. and Perez, V., 2000. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos within European Estuarine and Coastal Environments. *Mar. Pol. Bull.,* Vol.40, 1100-1114pp.

Bray, J.R. and Curtis, J.J., 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecology monograph,* 27: 325-349pp.

Clarke, K.R. and Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth, 189pp.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. *Aust J Ecol*., 18:117–143pp.

Connell, J. H., 1972. Community interactions on marine rocky intertidal shores. *Ann. Rev. Ecol. Syst*. 3: 169-192pp.

Eleftheriou, A. and McIntyre, A.D., 2005. Methods for the study of marine benthos. Blackwell Science, 418pp.

Giavolaa , P., Tabordab, R., Ferreiraa, O., Alveirinho Diasa, J., 1996. Longshore Sand Transport: A Comparison between Field Observations and Predictions of Numerical Models and Implications for Coastal Erosion Studies. Partnership in Coastal Zone Management, Samara Publishing Limited, Cardigan, 185-193pp.

Gillian Cambers and Fathimath Ghina, 2005. Introduction to sand watch, an educational tool for sustainable development. UNESCO, France.

Gomez Gesteira, L., and Dauvin, J. C., 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin*, 40: 1017– 1027pp.

Grasshoff, K., Manfred, E.M., Kremling, K. and Almgren, T., 1983. Methods of seawater analysis. Verlag Chemie, 419 pp.

Holme, N. A. and McIntyre, A. D., 1984. Methods for the study of marine benthos. Blackwell Scientific publications, 16; 339pp.

Jackson, R.D., 1973. Diurnal Changes in soil water content during drying, A R.R. Bruce *et al.* (Editors) Field soil water regime. *Soil Sci. Soc. Amer. Proc.*, 37- 55pp.

Margalef, R., 1958. Information theory in Ecology. *General systems*, 3: 36-71pp.

Muxikaa, I., Borja A., Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. *Ecological indicators*, 5: 19-31pp.

Pfannkuche, O. and Thiel, H., 1988. Sample processing. In: Introduction to the study of meiofauna. Smithsonian Institution press, London, 488 pp.

Pielou, E.C., 1975. A general book on ecological diversity, Entropy based diversity measures (Models for distribution of species). *Ecological diversity*, Newyork: Wiley.

Shannon, C.E., 1949. The mathematical theory of communication. Univ.of Illinoise press, Urvana.

Simpson, E.H., 1949. Measurement of Diversity. *Nature,* 163:688pp.

Stephenson, T.A. and Stephenson, A., 1972. Life Between Tide-Marks on Rocky Shores. W.H. Freeman, USA, 4005A0057QW111`25 pp.

Strickland, J. D. H. and T. R. Parsons, 1972. A practical handbook of seawater analysis. *Bull. Fish. Res. Bd. Can*., 2nd Edn.., vol. 167; 310pp.

Walkley, A. and Black I. A., 1934. Method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil. Sci*., 37: 29-37pp.

Wiseman, J.D.H. and Bennette, H.E., 1960. Distribution of organic matter and nitrogen in the sediments from Arabian sea. John Murray Expedition, 3: 221pp.

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Chapter 4

HYDROGRAPHY

Contents

4.1 Introduction

In an open ecosystem, for the well being of organisms residing there, hydrological and sediment parameters are important factors. Hydrological parameters are essential for proper functioning of organisms. A favorable range of abiotic factors are vital for the growth and function of organisms. According to the optimum range, organisms prefer different habitat within the zone.

Physical and chemical properties of water and biota living there have immense influence. For understanding the dynamics of water body, the physico-chemical study is crucial (Unanam and Akpan, 2006). Water quality plays a major role in the welfare of organisms residing in the intertidal zone. Intertidal water quality has been deteriorating day by day. Discharges from metropolis and industries continuously threaten coastal biota and the ambient water quality of the area. This immensely affects the flora and fauna residing there. Anthropogenic disturbances also affect the water quality and organisms

of that area. Studies have shown that anthropogenic activities may affect the growth rate, recruitment and transience (Tablado *et al*., 1994; Johnston and Keough, 2002).

The main factor that seems to control "life" on exposed sandy beaches is the wave action, which is strongly associated to sediment grain size and beach morphology (McLachlan *et al.,* 1993; McLachlan, 1990; McLachlan and Jaramillo, 1995; Jaramillo *et al.,* 1993; McLachlan, 1996). The most relevant physical factors in these habitats are waves, sediments (size, porosity and permeability), geomorphology, tidal regime and wind (Brown and McLachlan, 1990). Sandy beach macrofaunal communities are proscribed by physical environment (McLachlan *et al.,* 1993). Across-the-broad environmental variations that are happening and expected to take place, the effects of environmental factors on marine species and exchanges is critical (Studer and Poulin, 2012). In 2013 Anxo Conde, Novais and Domínguez conducted a study on how the environmental conditions shape intertidal macrofauna of estuarine saline boundary.

The physical and chemical factors that were taken into consideration for the study were tide levels, rainfall, long shore current, temperature, pH, salinity, dissolved oxygen, carbon dioxide, conductivity, turbidity, TDS (Total Dissolved Salts) and nutrients like phosphate, silicate, nitrate and nitrite. Several studies have been conducted based on the relationship with environmental parameters.

Temperature has renowned as a key factor leading species distribution (Isaac, 1938; Stephenson, 1944; Lewis, 1964) and method for that was studied by Southward (1955, 1958), Crisp (1957) and Lewis (1964) (McQuaid and Branch, 1984). Equally the extent of wave action may have imperative outcome

on the community (Kingsbury, 1962; Dayton, 1971; Hallfors *et al.,* 1975). Steele (1983) reported that temperature has considered as the most critical factor seminal to the ecological boundaries of marine species allocation. Jensen and Muller-Parker (1994) indicated that temperature may be the most key factor influencing the increased allocation of an intertidal organism.

Salinity is among the most important environmental factor that put forth various effects on the liveliness of marine organisms (Arash Javanshir, 2013). The influence of salinity has been studied during 1960s. In 1967 Ralph Johnson studied about the salinity of interstitial waters in a sandy beach. Rocky tide pools are much more prone to salinity fluctuations. Effects of salinity on tide pools have been studied by Leanna O'Grady in 2002. These pools can be demanding to the organisms owing to vacillations in environmental factors like temperature, salinity, pH (Dando and Burchett, 1996). Evaporation in tide pools can rise up salinity values above usual points (Adam, 1990; Wheatly, 1988; Brierley and Kingsford, 2009). Salinity is regarded as the essential environmental factors in marine ecosystems, affecting small and broad-scale biotic swaps (Berger and Kharazova, 1997; Ingole and Parulekar, 1998). Salinity can influence the distribution, physiology and reproduction of intertidal species (Crain *et al*., 2004; Kneib, 1984), (Hylleberg, 1975; Pequeux, 1995; Shock *et al.,* 2009) (Deschaseaux *et al.,* 2010),.

Mounting levels of atmospheric carbon dioxide are swiftly acidifying the world's oceans than normal interactions; such chemical alteration to the oceans could have major ramification for marine existence, especially to those organisms that depend on the process of calcification for put up their frameworks (Riebesell *et al*., 2000; Orr *et al*., 2005). Environmental conditions varying with global climate change and oceans will turn into more acidic as interaction

of rising amounts of atmospheric CO_2 with oceanic water (Alenius and Munguia, 2012). They have deliberated the outcome of pH unevenness on an intertidal isopod, *Paradella dianae.* They have studied the influence of seawater acidification on early growth of intertidal sea urchin, *Paracentrotus lividus.* Water conductivity was used to verify the amount of suspended solids in water that could be an indicator for pollution.

Dissolved oxygen (DO) is the amount of oxygen, usually determined in milligrams or milliliters, which dissolved in one liters of water. Oxygen levels are highest in surface waters, particularly coastal waters due to constant atmospheric interaction and turbulence. Marine and estuarine surface waters easily permit oxygen fortification through atmospheric interaction, and adequate light can penetrate surface waters, permit the oxygen-releasing processes of photosynthesis to take place (Davis, 1975). Ueda *et al.* in 2000 conducted experiments on impact of oxygen scarce water on macrobenthic fauna of intertidal flats in Kitakyushu, Japan. A very slight oxygenated stratum is common on the sediment surface of aquatic ecosystems (Revsbech *et al.,* 1980; Andersen and Helder, 1987; Silverberg *et al.,* 1987, Lindeboom *et al.,* 1984; Baillie, 1986). Brotas *et al.* (1990) studied about the oxygen profiles in intertidal sediment bottom of Ria Formosa (S. Portugal).

Turbidity is a measure of water clarity. Soil erosion and sedimentation are the main reason of turbid conditions. Turbidity has become threats to the environment in many coastal areas. High turbidity in natural sea waters may affect the species composition and community structure of an ecosystem. The outcome of some of the turbidity related parameters like total suspended solids have been reported from the Madhuva and Veraval coast (Norris *et al.,* 1982; Gideiri, 1984; and Parulekhar *et al.,* 1986). Turbidity is an important limiting

factor of benthic primary production and nutrient accumulation on estuarine intertidal sand flats (Pratt *et al.,* 2013).

Phytoplankton primary production in coastal areas is contingent upon the nutrient supply, in which benthic renaissance be capable of characterize an significant contribution (Boynton *et al.,* 1980; Nixon, 1981; Callender and Hammond, 1982; Hopkinson, 1987). Nutrient fluxes at the sediment-water interface can definitely persuade or order the nutrients of the water column as the sediment can act as a supply of inorganic nitrogen, phosphorus and silica during different biogeochemical methods (Nixon *et al.,* 1976; Billen, 1978; Peterson, 1979; Kemp *et al.,* 1990).

4.2 Results

4.2.1 Tide levels

Tides are ascend and descend of sea levels prompted by the joint effects of the gravitational forces applied by the moon and the sun and the rotation of the earth. Some coast lines experience two nearly equal high tides and two low tides each day, called a semi diurnal tide.

The selected study areas, Fort Cochin and Dharmadam experience a semi diurnal tide. Tides are important physical factor in shaping the distribution of organisms. Semi-diurnal progress of tidal water alters biotic and abiotic environments in intertidal sediments over short time intervals (Alongi, 1998). Tide height during the time of sampling varied from 0.12 - 0.73m (Avg. value - 0.36m) at Fort Cochin beach (Fig. 11) and 0.01 - 0.64m (Avg. value - 0.28m) at Dharmadam beach (Fig. 12). The highest tidal height was observed in August, 2009 and lowest was in May, 2010 in Dharmadam beach. In Fort Cochin beach the highest tide height was observed in November, 2009 and lowest was in September, 2010. The highest tidal height experienced during the sampling period

(August, 2009- January, 2011) according to predicted tide table was 1.3m. The low tide height experienced during the monthly sampling is depicted below.

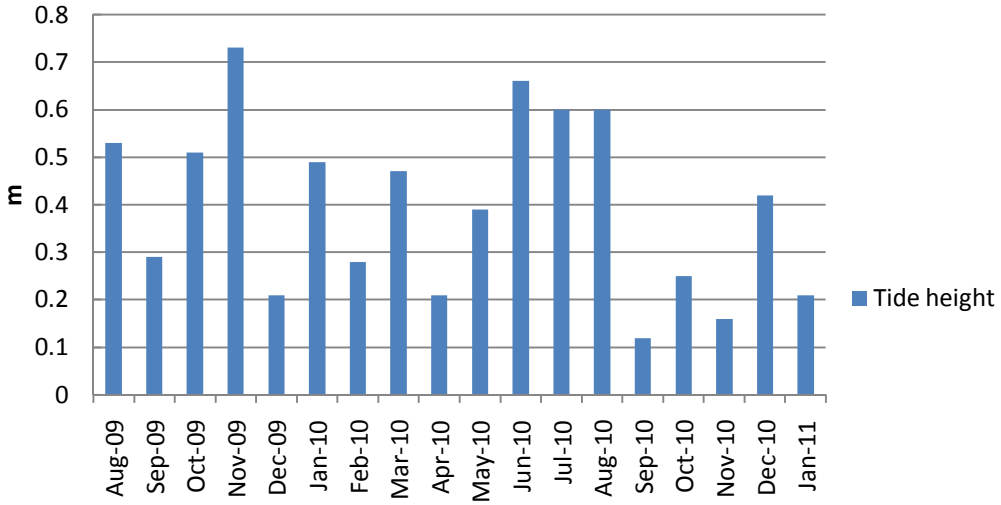

Figure 11 Monthly variations in tidal height in Fort Cochin beach during 2009-2011.

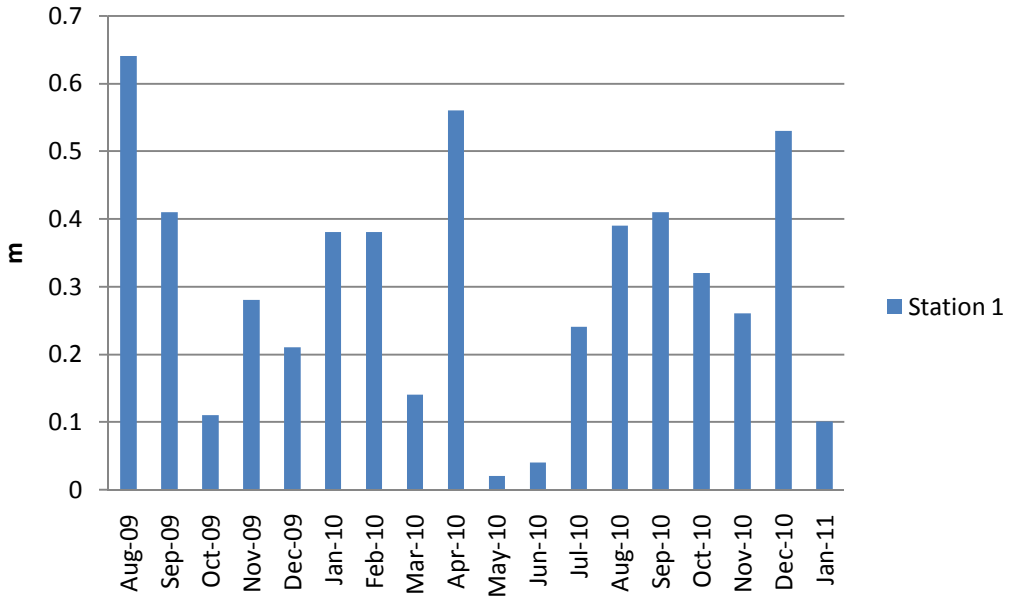

Figure 12 Monthly variations in tidal height in Dharmadam beach during 2009-2011.

4.2.2 Long shore currents

A long shore current is an ocean current that advances parallel to the shore. It is mainly due to large swells impending into the shoreline at an angle and asserting water down the length of the beach in one direction. Uncovered breaking surf beaches experience long shore currents. At Fort Cochin and Dharmadam beach the speed of long shore current were measured and the average was considered. The seasonal average of long shore current was measured. The speed of Long shore current at Fort Cochin beach was 0.025 - 0.038m/s. In Fort Cochin beach post monsoon season (2010) showed highest long shore current speed (0.038m/s) and lowest was in monsoon, 2009 (0.025m/s). In Dharmadam beach the speed of long shore current was 0.023 – 0.034m/s. Highest was observed in post monsoon season, 2010 (0.034m/s) and lowest was in monsoon, 2009 (0.023m/s)

4.2.3 Temperature

Water temperature is the most important physical parameter that plays a prominent role in intertidal zone. Significance of water temperature is massive as it controls different abiotic characteristics of an aquatic ecosystem (Hutchinson, 1957; Singh and Mathur, 2005; Ramachandra and Solanki, 2007). Water temperature is very crucial and it may fluctuate as the time and season changes in an intertidal area. Intertidal organisms must cope with a large range of temperatures to avoid temperature vacillations. They have acquired special adaptations by crawling around and hiding in cool and shelters at crevices and burrows. Among some organisms in the intertidal area temperature establishes the zonation and migration towards upper and lower level of beach.

On rocky beaches tide pools are common and the distribution of organisms residing in the tide pools are temperature controlled. Among the important physical parameters temperature plays a crucial role in the distribution and zonation of organisms habituated on the rock surfaces.

4.2.4 Atmospheric temperature and rainfall

During the sampling period the atmospheric temperature values varied from 25 - 33^{0}C. During monsoon period the atmospheric temperature value was found to be less (25-29^{0}C) and during pre monsoon periods it was found to be high (27-33^{0}C). The rainfall in Kannur district was 0 - 1456.6mm in 2009 (Fig. 13) and 0 - 959 mm in 2010 (Fig.14). In Ernakulum it ranged from 0 - 838mm in 2009 (Fig. 15) and 0 - 849.9mm in 2010 (Fig. 16). July month showed highest downpour in Kannur district but in Ernakulam district it was in June, 2010.

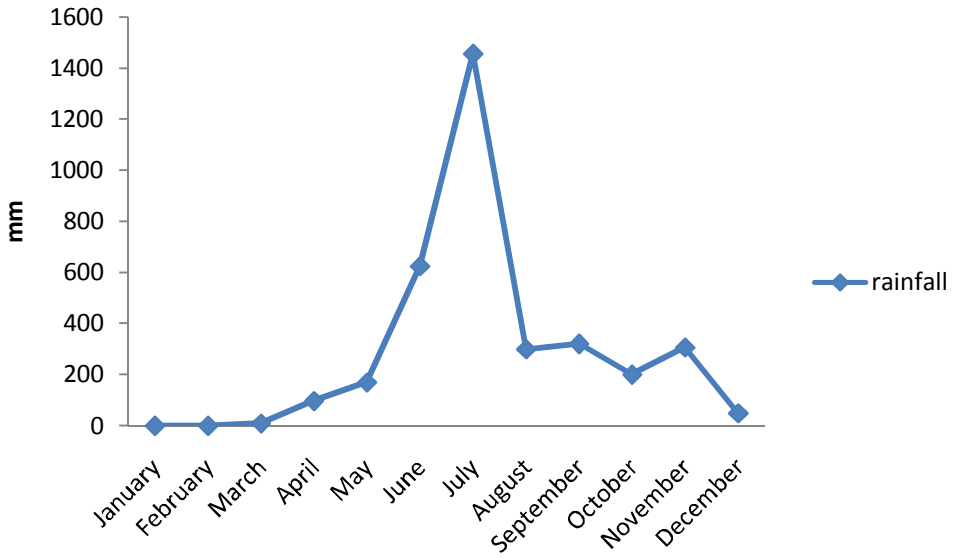

Figure 13 Average monthly rainfall (mm) in Kannur district of Kerala during 2009

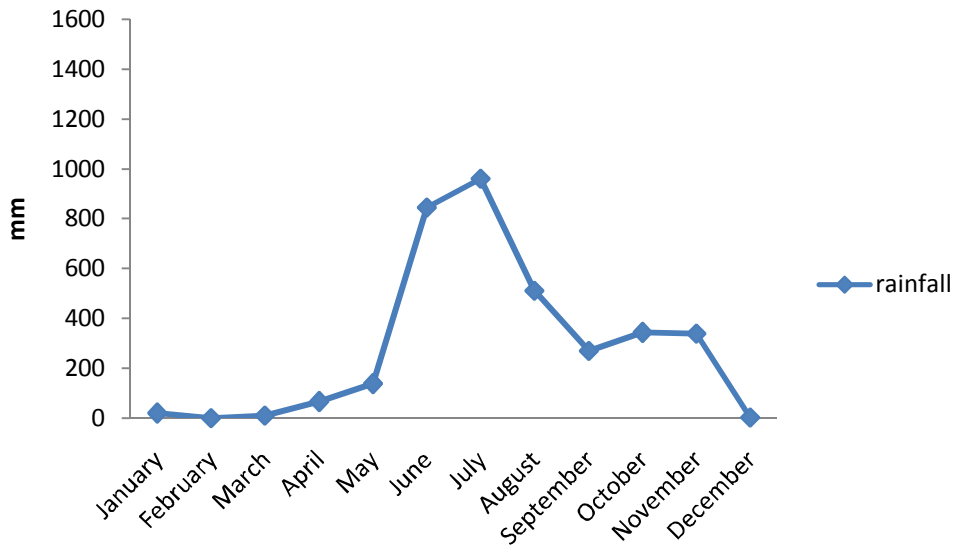

Figure 14 Average monthly rainfall (mm) in Kannur district of Kerala during 2010

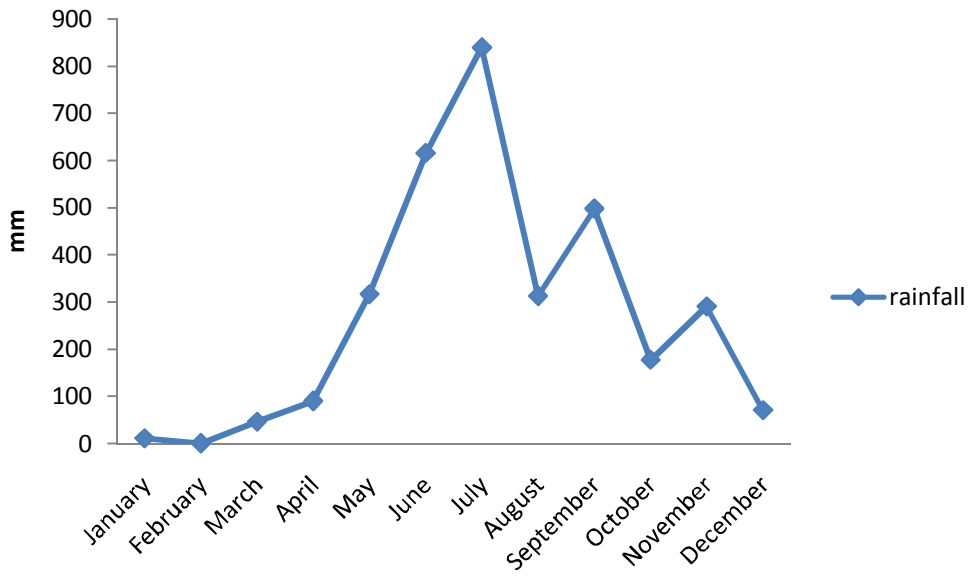

Figure 15 Average monthly rainfall (mm) in Ernakulam district of Kerala during 2009

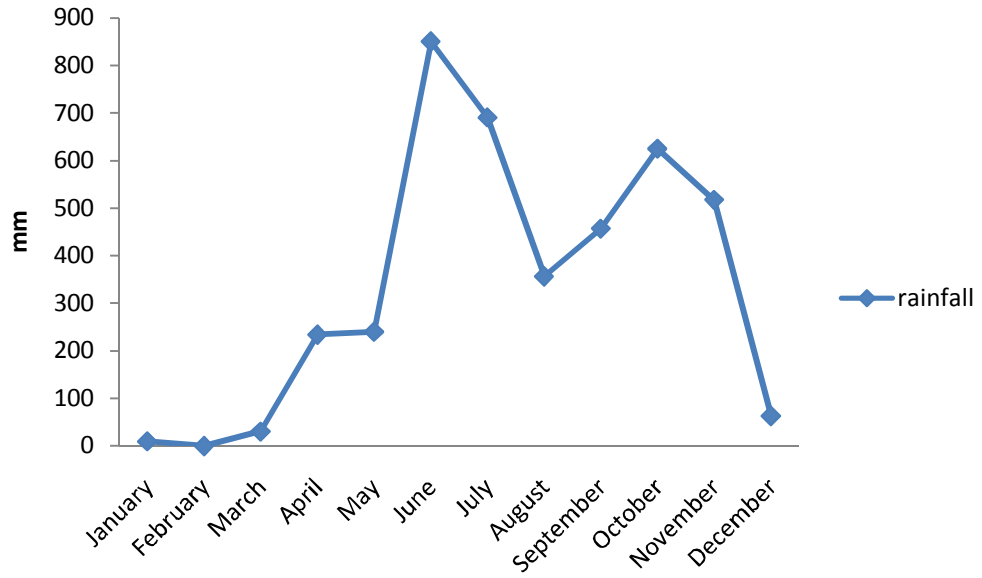

Figure 16 Average monthly rainfall (mm) in Ernakulam district of Kerala during 2010

4.2.4.1 Temperature variations at Fort Cochin beach

At station 1 of the Fort Cochin beach the surface water temperature ranged from 27-32^{0}C (Av. – 29.89^{0}C) during the sampling (Fig. 17). The lowest value of temperature was observed in September (2009). Highest value was observed in October, 2009 and April, 2010. Seasonally, pre monsoon season (2010) showed highest average temperature (32^{0}C$\pm$1.7) (Fig. 18). At station 2 the temperature ranged from 20-33^{0}C (Av.-29) during sampling period (Fig. 17). At station 2 of Fort Cochin beach the lowest value was observed in September (2009). When compared to both stations the lowest value (20^{0}C) was observed in station 2. Highest value was also observed at station 2 (33^{0}C) in April (2010). At Station 2 also seasonal average temperature values were highest in pre monsoon (2010) that was 31.3^{0}C$\pm$2.2 (Fig. 18). Both the stations showed almost similar profile in temperature values except in September,

2009. Temperature values showed fluctuations based on seasonal variations, the climatic conditions, and tidal heights. ANOVA of water temperature in four stations showed overall significance but the variation between station and months were not significant (R^2=.681) (p= 0.733 $p > 0.05$) (Table 1). Highest mean was observed in station 1 (29.8^{0}C $\pm$1.7) (Table 6).

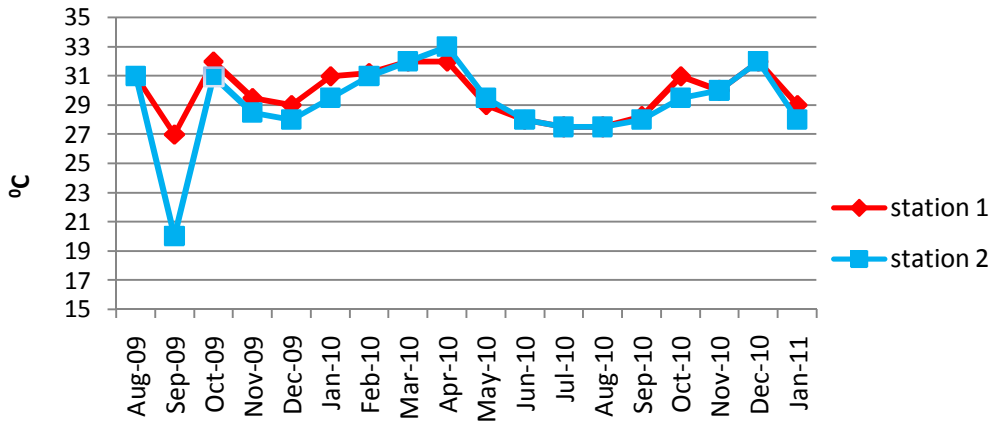

Figure 17 Monthly variations of water temperature in Fort Cochin beach during 2009-2011.

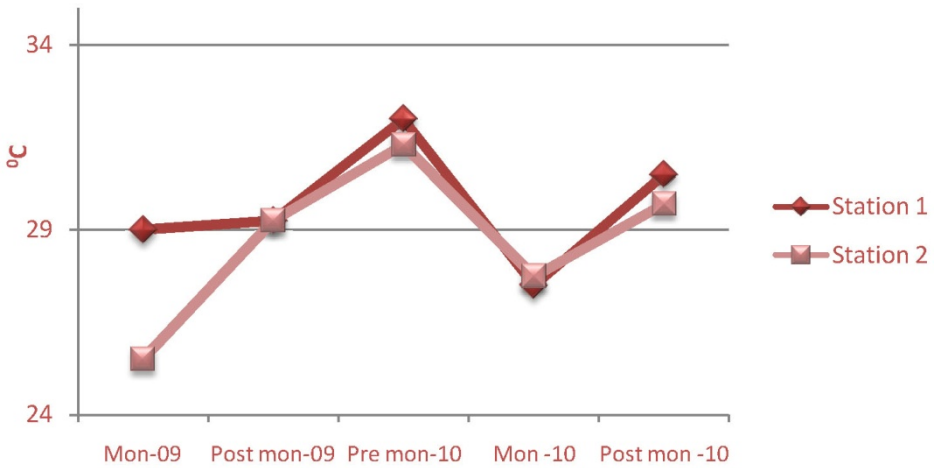

Figure 18 Seasonal variations of water temperature in Fort Cochin beach during 2009-2011 (Mon- monsoon, Post mon – Post monsoon, Pre mon – Pre monsoon)

4.2.4.2 Temperature variations at Dharmadam beach

On Dharmadam beach at station 1 the variation of temperature was pronounced. The value of temperature ranged from 25 - 34^{0}C (Av. – 29.13^{0}C) (Fig. 19). The highest value of temperature has been observed at station 1 (34^{0}C) during March, 2010 and lowest value was also observed at station 1 (25^0 C) during August, 2009. At station 2 the temperature ranged from 25.5 - 32^{0}C (Av. – 29.3^{0}C) during sampling period (Fig. 19). The lowest temperature (25.5^{0}C) was recorded in July, 2010 and the highest temperature in April, 2010 (32^{0}C). Seasonal average values showed that in both stations during pre monsoon the temperature was high, 32^{0}C$\pm$2.2 and 31^{0}C$\pm$ 1.6 in station 1 and 2 respectively (Fig. 20). Highest mean was observed in both stations (29.3^{0}C, $\pm$2.4, 1.9 respectively) (Table 6).

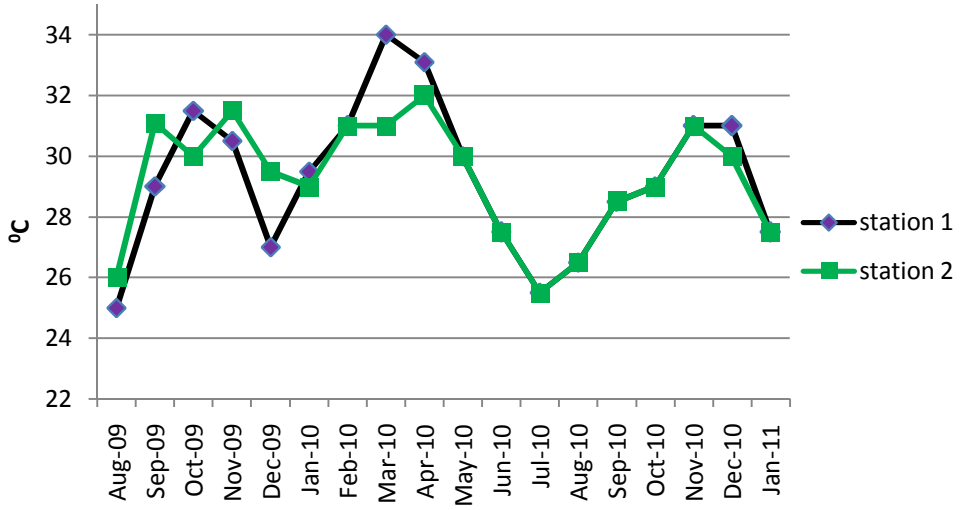

Figure 19 Monthly variations of temperature in Dharmadam beach during 2009-2011

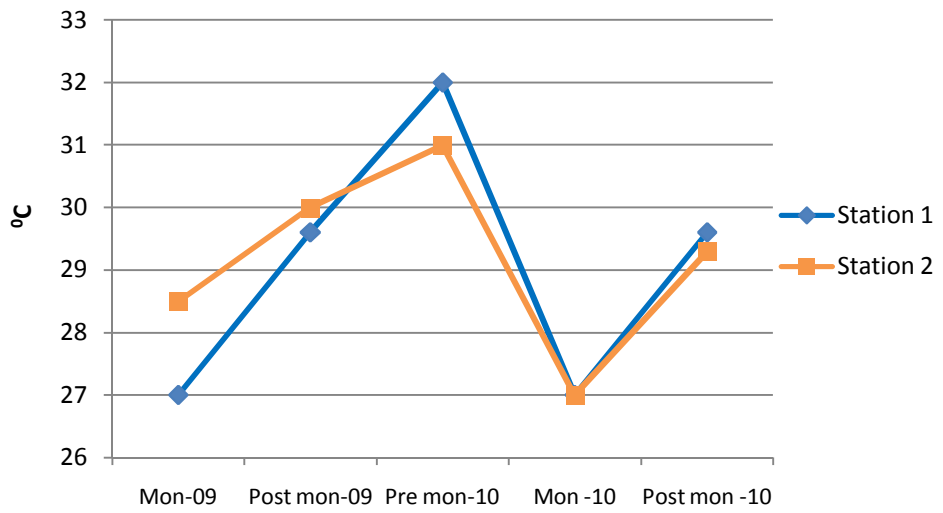

Figure 20 Seasonal variations of temperature in Dharmadam beach during 2009-2011

Table 1. ANOVA of water temperature in Fort Cochin and Dharmadam beach during 2009 - 2011.

Source	df	Mean Square	F
Corrected Model	26	9.722	3.699
Station	3	1.128	0.429
Month	17	5.033	1.915
Station* Month	6	1.227	0.467
Error	45	2.628	
Total	72		

R^2= .681

4.2.5 pH

Chemically speaking pH is a measure of the acidity or basic nature of an aqueous solution. By definition it is negative logarithm of hydrogen ion concentration in a solution. pH is a necessary chemical factor for marine life. pH can determine the survival rate and reproductive success of a marine organism, particularly shelled organisms. An adequate pH level is important

for the shelled organisms in intertidal areas, like mussels, clams, gastropods etc. pH plays an important role in intertidal areas. Since the intertidal environment is undergoing daily fluctuations, like many other physical and chemical parameters pH also shows variations (Ceballos *et al.,* 2013). Both elevation and lowering of pH is detrimental to the organism. Lowering of pH beyond limits may lead to threat for the organisms to produce their outer shells. It will impact on the survival of intertidal communities.

The whole marine system is affected by climate change. Intertidal areas are also prone to climate change. This will affect the organism with the changing pH and CO_2. Acidification of oceans increases owing to global warming and climate change, it lowers the pH of water as the CO_2 has been more absorbed by ocean. Upwelling, photosynthesis, respiration, and pollution also affect the pH concentration.

4.2.5.1 Variations of pH at Fort Cochin beach

pH showed acidic to alkaline nature in station 1. At station 1 of Fort Cochin beach pH values ranged from 6.57 - 8.25 (Av. – 7.5) during sampling period (Fig. 21). The highest pH value was observed in September, 2009 and the lowest was observed in December, 2009. At station 2 of Fort Cochin beach the pH values ranged from 6.59 - 8.22 (Av.7.4) (Fig. 21). Highest was observed in October, 2009 and lowest in December, 2009. Seasonal values of pH showed that during monsoon season (2009) the values were high (8.1$\pm$0.35) and during post monsoon (2010) season the values were low (7.3). In station 2 during monsoon season (2009) pH values were high (7.95$\pm$0.32) and during monsoon season of 2010, pH values were found to be low (7.29) (Fig. 22). ANOVA showed overall significance (R^2 = 0.998) (Table 2) and also significant variation at 1% level

between station and month in both the beaches (F= 0.447) (p = 0.001 p< 0.05). The highest mean value was measured at both the stations were (7.55±0.44) (Table 6).

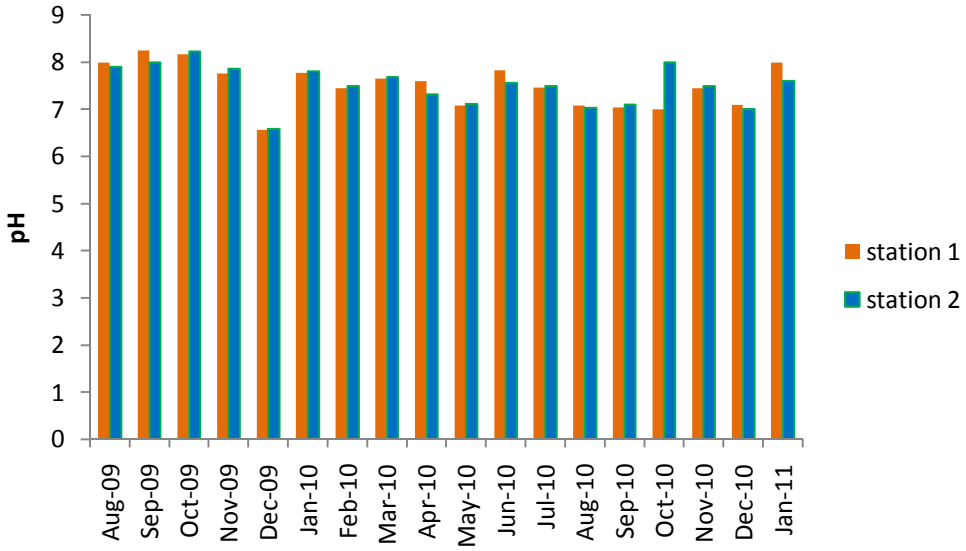

Figure 21 Monthly variations of water pH in Fort Cochin beach during 2009-2011.

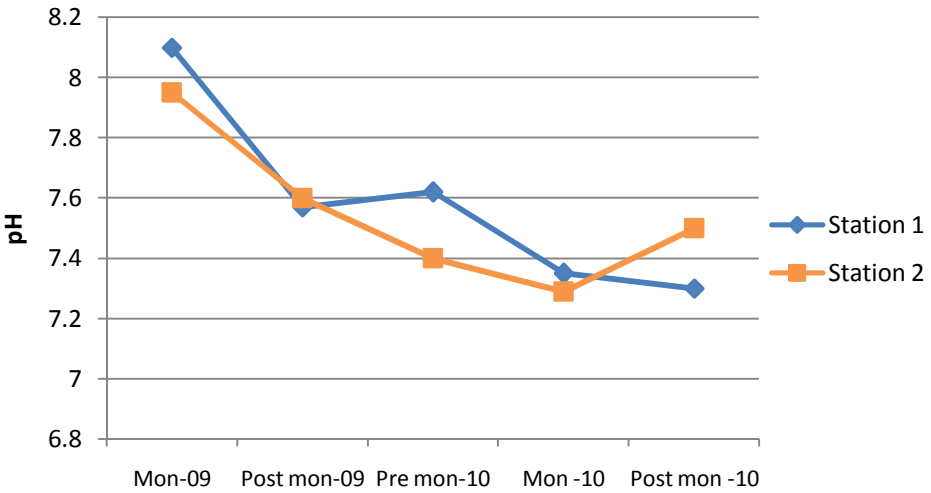

Figure 22 Seasonal variations of water pH in Fort Cochin beach during 2009-2011.

4.2.5.2 Variations of pH at Dharmadam beach

In Dharmadam beach the pH value ranged from 7- 8.32 (Av. - 7.8) at station1 and 6.48-8.31 (Av.-7.7) at station 2 during the sampling period (Fig. 23). When compared to station 1, station 2 showed lowest pH level (6.48) in August, 2010. At station 1 the highest pH value (8.32) was observed in July, 2010 and the lowest value (7) in December 2010. At station 2 of Dharmadam beach the highest value (8.31) was observed in July 2010 (Fig. 23). Seasonally high pH value was observed in monsoon season (2009), it was 7.9± 0.17 and 8.05± 0.9 at station 1 and 2 respectively and the mean value was same in both stations (7.7 ± 0.32) (Fig. 24) Table (6).

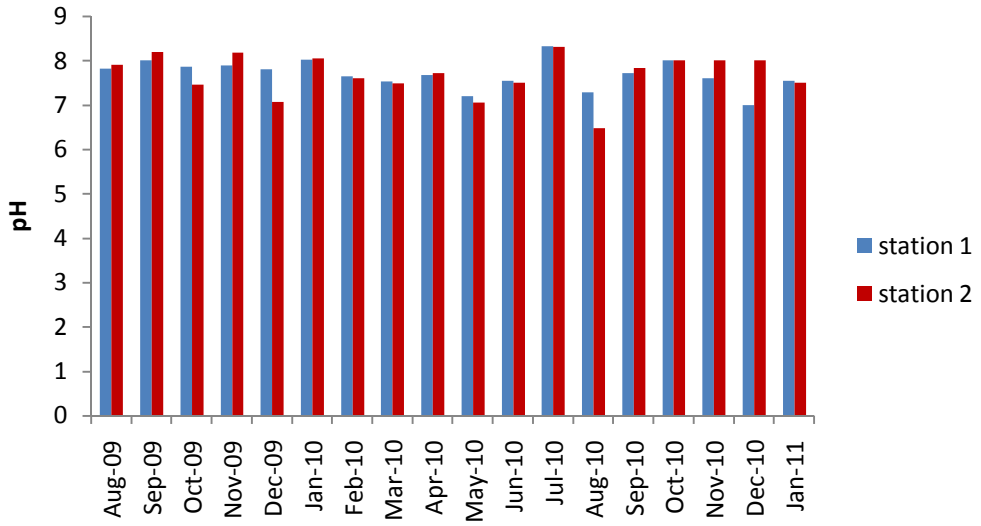

Figure 23 Monthly variations of water pH in Dharmadam beach during 2009-2011.

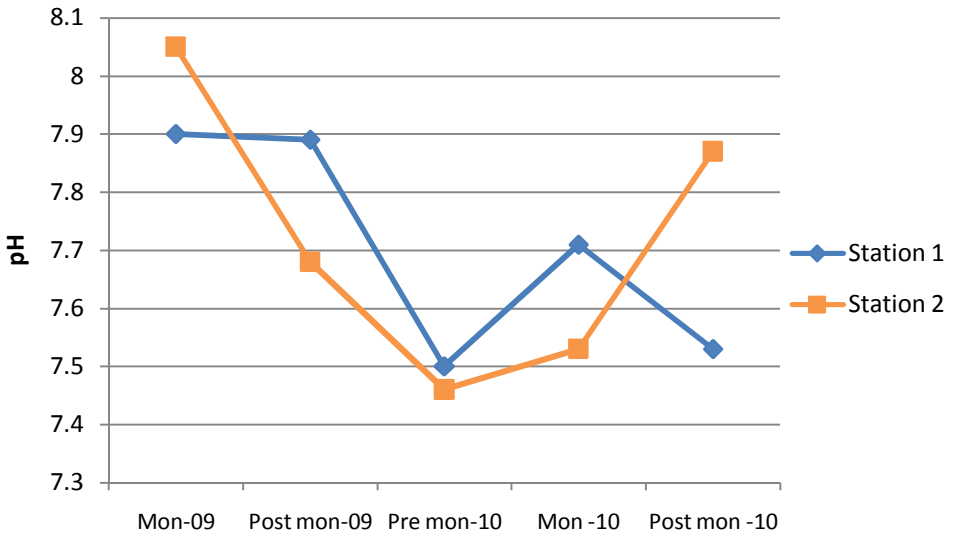

Figure 24 Seasonal variations of water pH in Dharmadam beach during 2009-2011.

Table 2 ANOVA of water pH in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Model	21	177.886	1.0813
Month	17	.487	2.960
Station	3	.204	1.238
Station*Month	45	0.109	0.447**
Error	51	.164	
Total	72		

$R^2 = 0.998$

4.2.6 Salinity

Salinity is among the most imperative environmental factor and wields various effects on the vitality of marine organisms (Arash Javanshir, 2013). Intertidal environment often subjected to sudden fluctuations in salinity distressing the distribution and abundance of organisms. Being unstable

salinity regime organisms with effective adaptations to fluctuating salinity can live in such habitats. The decreasing or increasing trend of salinity aids the deteriorating effect on the growth rate of organisms. Fresh water influx from adjacent rivers also affects salinity of the area. On rocky beaches tide pools are more inclined to salinity variations. High salinity will be reached during summer due to evaporation. During winter, in subtropical areas frozen state will be grasped and thus lowering of salinity. Intertidal organisms are much more modified to variations in salinity, but high variation can cause unfavorable effects.

4.2.6.1 Variations in salinity at Fort Cochin beach

Salinity showed wide variations during entire study. Since it has been affected by several factors, both stations showed salinity fluctuations during seasons and months. At station 1 salinity value was observed to vary from 7.8 - 30.8ppt (Av. – 20.01ppt) during sampling period. At station 2 it ranged from 5.68 - 31ppt (Av. - 19.6ppt). In station 1 highest was observed in February, 2010 (30.8ppt). At station 2 highest value of salinity was observed in January, 2010 (31ppt) and the lowest was in September, 2009 at station 1 and in November, 2009 in station 2 (Fig.25). The average seasonal values showed that during post monsoon season (2010) the values were high (21.75ppt$\pm$6.7) and during monsoon season (2009) whereas it was low (13.1ppt) in station 1. At station 2 during monsoon season (2009) the value was 20.6ppt $\pm$2.2 and in post monsoon season (2009), it was lower (15.18ppt) when compared to other seasons (Fig.26). There is no significance that was observed in ANOVA, between station and month but overall significance was evident (R^2 = 0.662) (p= 0.326 p> 0.05) (Table 3). The mean value showed it's highest at station 1 in Fort Cochin (19.9 ppt, SD = 7.9) (Table 6).

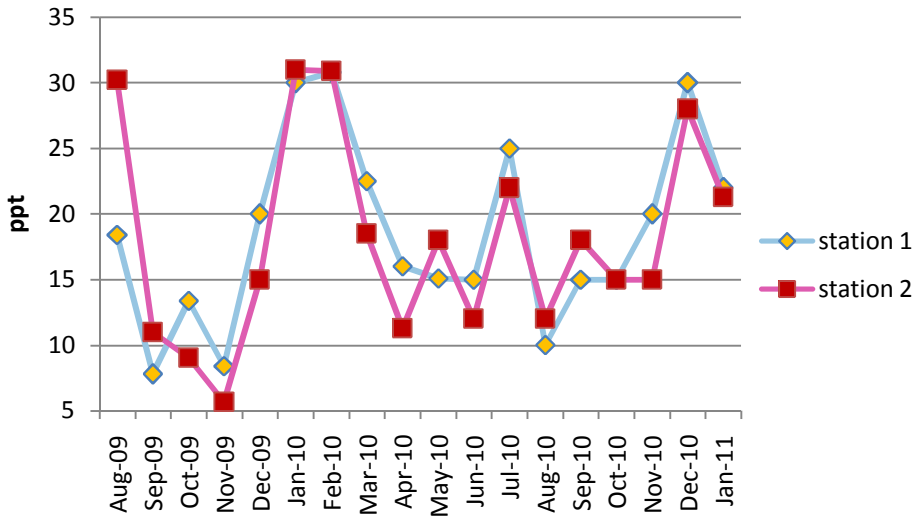

Figure 25 Monthly variation of salinity in Fort Cochin beach during 2009-2011.

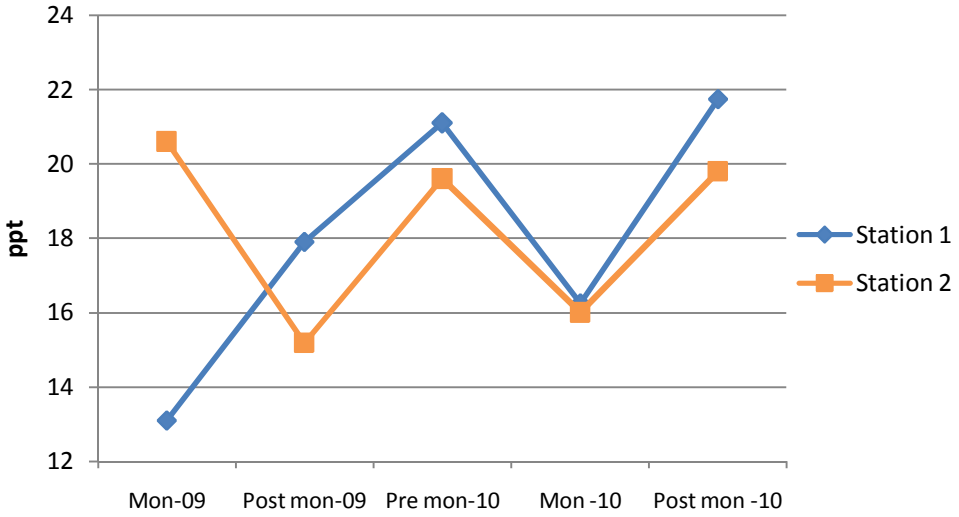

Figure 26 Seasonal variations of salinity in Fort Cochin beach during 2009-2011

4.2.6.2 Variation in salinity at Dharmadam beach

At station 1, salinity ranged from 10.8 - 33ppt (Av. - 22.5ppt) during the sampling period. The highest salinity was found in April, 2010 and lowest was in March 2010 (Fig.27). The average seasonal value was higher in post monsoon season, 2009) (23.9ppt±1.3) and lowest was in monsoon, 2010 (20.45ppt) (Fig. 28). At station 2 it ranged from 8.95 - 30.7ppt (Av. – 23.5ppt) during the sampling period. The highest (30.7ppt) was observed in September, 2010 and lowest (8.95ppt) in October, 2009 (Fig.27). Seasonally salinity showed its highest in monsoon (2009) (26.9ppt±2.97) and lowest was in post monsoon season, 2009 (18.3ppt) (Fig. 28) In Dharmadam beach mean value showed highest at station 2 (23.1ppt ±7.4) (Table 6).

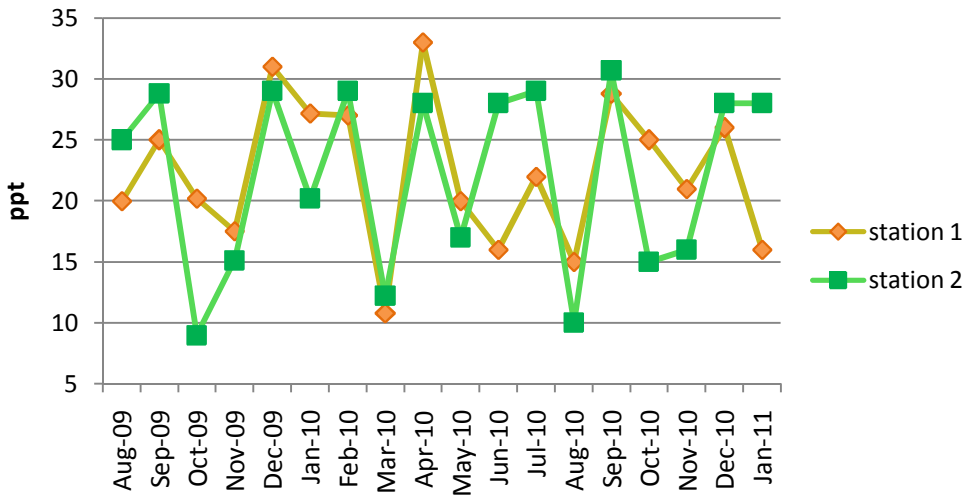

Figure 27 Monthly variations of salinity in Dharmadam beach during 2009-2011.

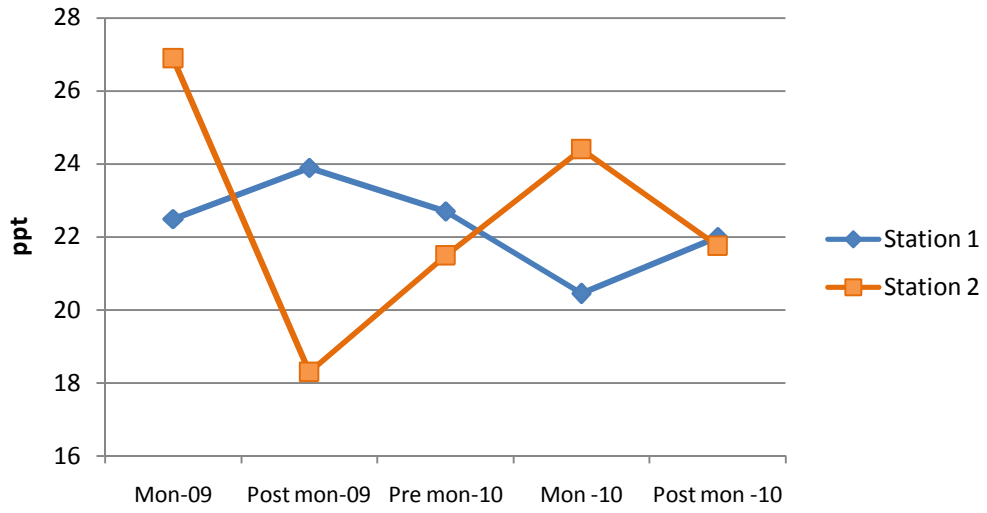

Figure 28 Seasonal variations of salinity in Dharmadam beach during 2009-2011

Table 3 ANOVA of water salinity in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	104.458	3.386
Station	3	56.393	1.828
Month	17	147.161	4.770
Station * Month	6	36.913	1.196
Error	45	30.851	
Total	72		

$R^2 = 0.662$

Table 4 Temperature, pH and salinity of interstitial water in Fort Cochin beach during 2009-2011

Parameter	Temperature (^{0}C)			pH			Salinity (ppt)		
Tide zones	Low	Mid	High	Low	Mid	High	Low	Mid	High
Station 1	27-28.5	27.5- 32	28- 32.4	6.5-7.5	7-7.2	7-7.8	12-29	15-32	10-32
Station 2	21.1-29	23-30	23-33.3	6.2-7.6	6-7.5	6.8-8	8-29	9.7- 31	10-31

Table 5 Temperature, pH and salinity of interstitial water in Dharmadam beach during 2009-2011

Parameter	Temperature (^{0}C)			pH			Salinity (ppt)		
Tide zones	Low	Mid	High	Low	Mid	High	Low	Mid	High
Station 1	25.4-29	27-34	26-34	7-7-9	7.5-8	7.7-8.1	12-30	15-34.1	20-31
Station 2	26.2-29	26-32	27-32	7.9-8	7-8.2	7.2-8.2	11.5-29	16-31	18-32.1

Table 6 Mean and standard deviation of temperature, pH and salinity in Fort Cochin and Dharmadam beach during 2009-2011

Stations		Temperature	pH	Salinity
1	Mean	29.8944	7.5517	19.9678
	Std. Deviation	1.77680	.44628	7.93702
2	Mean	29.1667	7.4594	19.7183
	Std. Deviation	2.86972	.42412	8.67049
3	Mean	29.3111	7.7728	22.7500
	Std. Deviation	2.48901	.32022	6.15049
4	Mean	29.3111	7.6878	23.1083
	Std. Deviation	1.97660	.49650	7.43209

(Station 1 & 2 – Fort Cochin beach, Station 3 & 4 – Dharmadam beach)

4.2.7 Dissolved Oxygen

Dissolved oxygen can be the critical source which offers information about the biological, biochemical and inorganic chemical reactions taking place in aquatic environment. Dissolved oxygen is the most fundamental parameter in water. Mixing of free oxygen from the atmosphere to water and photosynthesis are the major source of oxygen in the intertidal area. It is a good indicator of water quality. In littoral zone 4 -6mg/l diurnal fluctuations could be seen. Below 2mg/l has been considered as risky to the surviving organisms in the habitat. During photosynthesis aquatic macrophytes and algae strikingly advance the oxygen level and at night devour oxygen during respiration. This mechanism manages the oxygen level in the littoral area. Increase of temperature and pressure affects the amount of oxygen. When the temperature and pressure increase oxygen level decreases. Cold water can hold more oxygen than warm water.

4.2.7.1 Variations of dissolved oxygen at Fort Cochin beach

At station 1, dissolved oxygen (DO) showed variations at different months. At station 1 the value of DO ranged from 3.06 - 8.8mg/l (Av. – 6.77mg/l) during sampling period. The lowest concentration (3.06mg/l) was observed in September and October, 2009 and highest (8.8mg/l) was observed in November, 2009 and September, 2010 at station 1 (Fig. 29). At station 2 it ranged from 3.2-9.7mg/l (Av. – 6.8mg/l). At station 2 highest value (9.7mg/l) was observed in December, 2010 and lowest value (3.2mg/l) was observed in April 2010 (Fig. 29). Seasonally post monsoon season (2010) showed highest DO value (7.37mg/l±1.2) in station 1 and in station 2 also post monsoon season (2010) showed highest value (7.72mg/l±0.83). Lowest was observed in monsoon (2009) season in station 1, it was 4.03mg/l and station 2 showed lowest seasonal value in pre monsoon season (5.4mg/l) (Fig. 30). ANOVA value showed significant $p = 0.03$ ($p < 0.05$) and showed significance at 5% level between station and month in both the beaches (Table 7). The highest mean value was showed in station 1, it was 6.66 mg/l ±1.7) (Table 8).

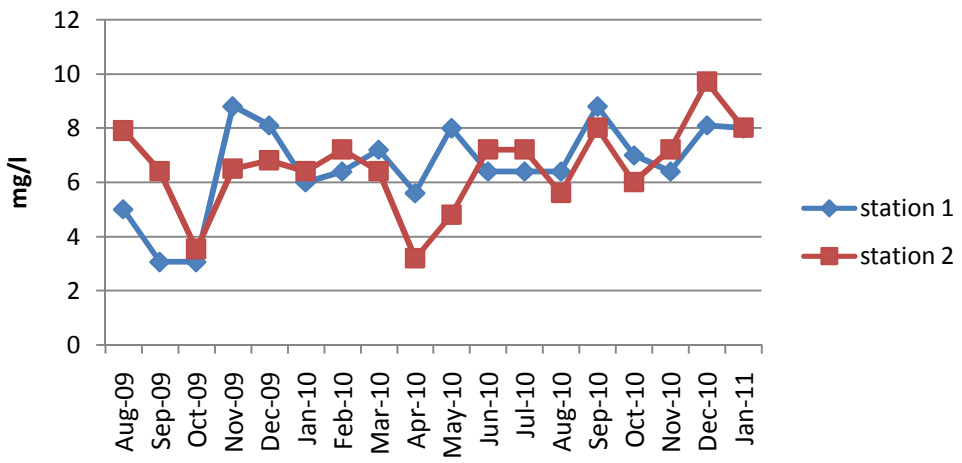

Figure 29 Monthly variations of dissolved oxygen in Fort Cochin beach during 2009-2011.

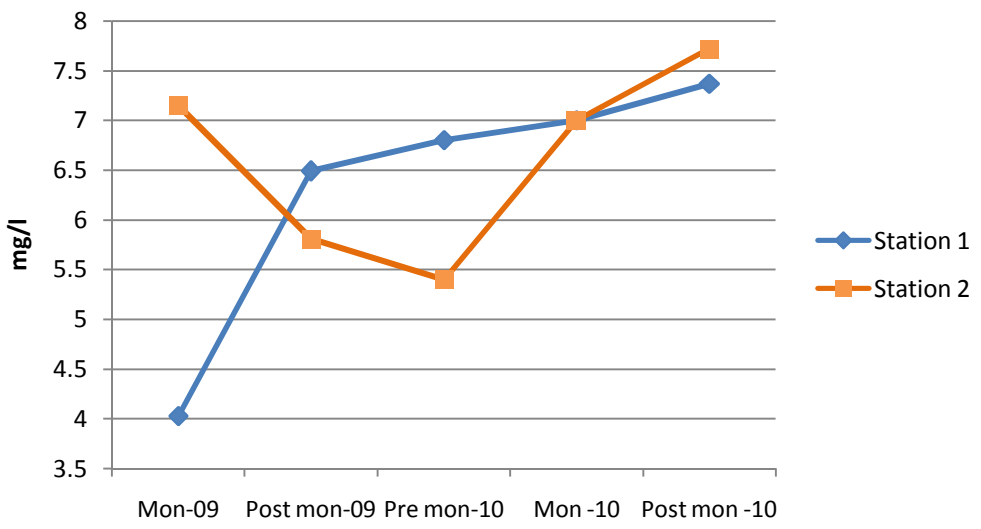

Figure 30 Seasonal variations of dissolved oxygen in Fort Cochin beach during 2009-2011.

4.2.7.2 Variations of dissolved oxygen at Dharmadam beach

At station 1 of Dharmadam beach the value of DO ranged from 2.5 - 10.4mg/l (Av. – 7.44mg/l). The highest value (10.4mg/l) was observed in May, 2010 and the lowest (2.5mg/l) was observed in August 2009. At station 2 the DO values ranged from 3.2-12mg/l (Av. – 7.15mg/l). The highest (12mg/l) was observed in May 2010 and the lowest (3.2mg/l) was in August and October, 2009 (Fig. 31). Seasonally the highest value was observed in pre monsoon season, 2010 (8.87mg/l±1.6) and lowest was in monsoon season, 2009 (4.95mg/l). At station 2 the highest value was in pre monsoon month (2010) as in the case of station 1 (9.15mg/l±2.18) and the lowest value was in monsoon season, 2009 (3.35mg/l) (Fig.32). In Dharmadam beach the highest mean value was showed in station 1 (7.68mg/l ±2.3) (Table 8).

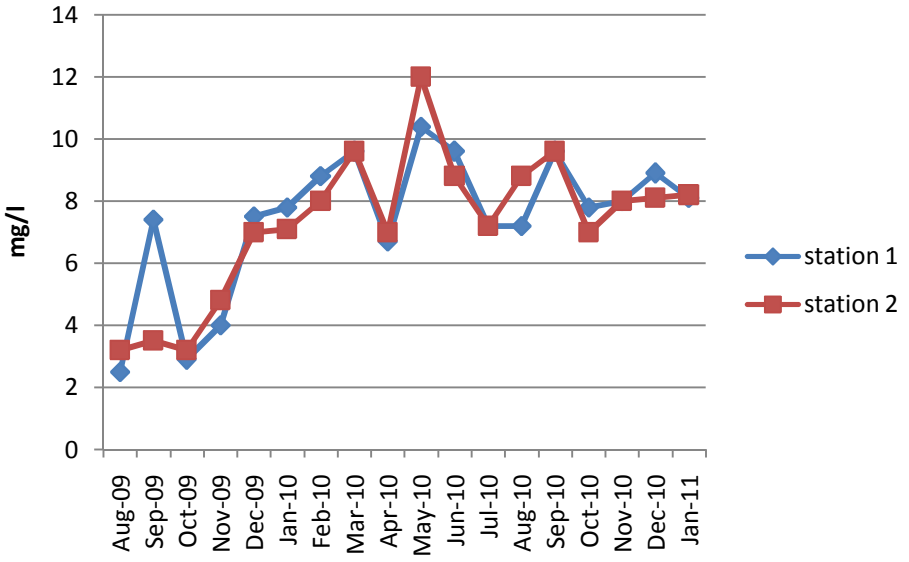

Figure 31 Monthly variations of dissolved oxygen in Dharmadam beach during 2009-2011.

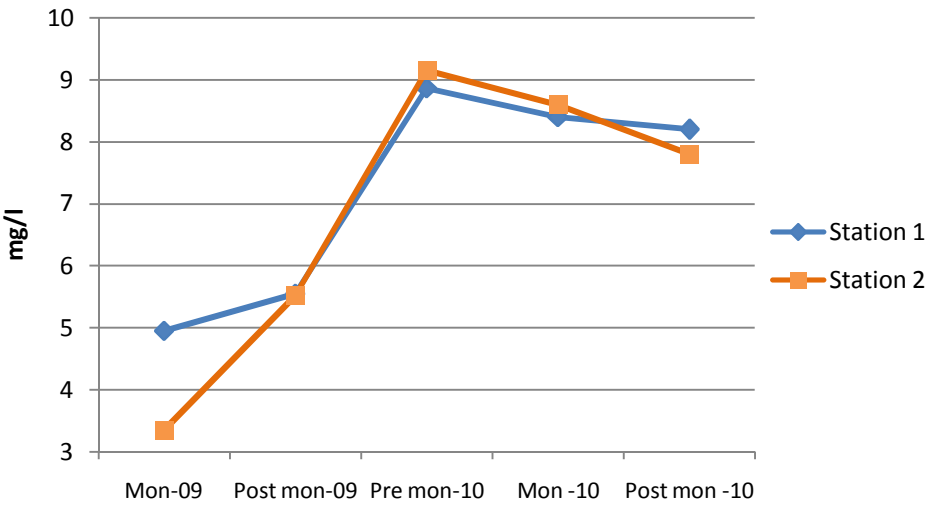

Figure 32 Seasonal variations of dissolved oxygen in Dharmadam beach during 2009-2011.

Table 7 ANOVA of dissolved oxygen in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	8.674	4.858
Station	3	8.738	4.894
Month	17	11.682	6.543
Station * Month	6	4.641	2.600*
Error	45	1.785	
Total	72		

R^2= .737

Table 8 Mean and standard deviation of dissolved oxygen in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	6.6622	1.71144
2	6.5967	1.57971
3	7.6889	2.37162
4	7.4778	2.44024

4.2.8 Carbon Dioxide

Since coastal ocean along the continental margin is responsible for 15-30% of primary production, it is considered as the important environment for CO_2 uptake (Gattuso *et al*., 1999). As the intertidal zones are more turbulent, the absorption shall be more pronounced compared to open coastal system (Dileep Kumar *et al.*, 1992). The atmospheric CO_2 fixed in the intertidal ecosystem mainly by littoral vegetation as dissolved organic matter. The fixed CO_2 is released by respiration and decomposition of dead organic matter. When CO_2 become more in the system, pH drops and it is inauspicious for the organisms residing in the littoral zone.

4.2.8.1 Variations of CO_2 at Fort Cochin beach

At station 1 of Fort Cochin beach the CO_2 values ranged from 0 - 16mg/l (Av.-5.75mg/l) and the highest value (16mg/l) was observed in February 2010 and it was non detectable in October 2009 (Fig. 33). Seasonally monsoon season (2009) showed highest value (8mg/l±2.2) and lowest was in post monsoon season (2009), it was 2mg/l (Fig. 34). At station 2 it ranged from 0 - 18mg/l (Av. – 5.41mg/l) during sampling period. Highest value (18mg/l) was observed in February 2010 and lowest nil value was in November and December 2009 (Fig. 33). At station 2 seasonal studies showed that during pre monsoon season (2010) the value was high (9.25mg/l±1.99). In post monsoon season (2009) the value was low (4.5mg/l) (Fig. 34). ANOVA showed no significance between station and month in both the beaches but overall significance was observed (R^2 =.625) (Table 9). Highest mean value was observed in station 2 (6.5mg/l ±5.5) (Table 10).

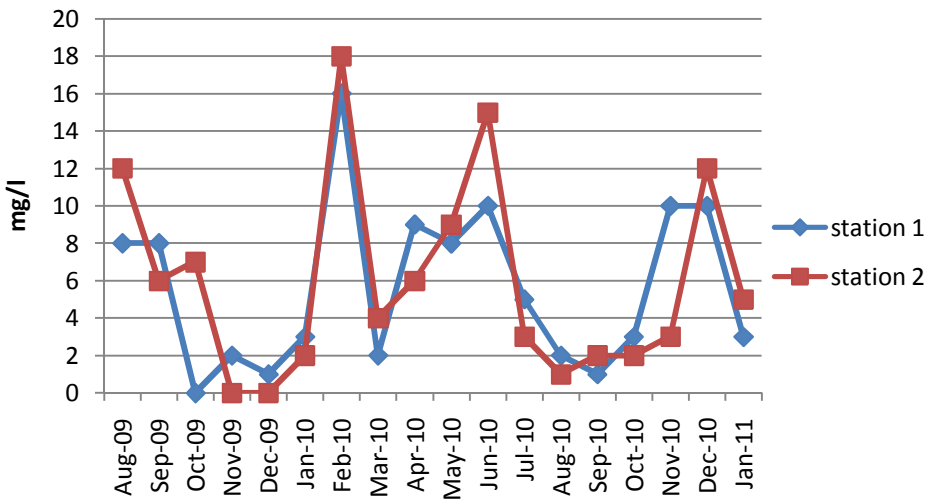

Figure 33 Monthly variations of carbon dioxide in Fort Cochin beach during 2009-2011.

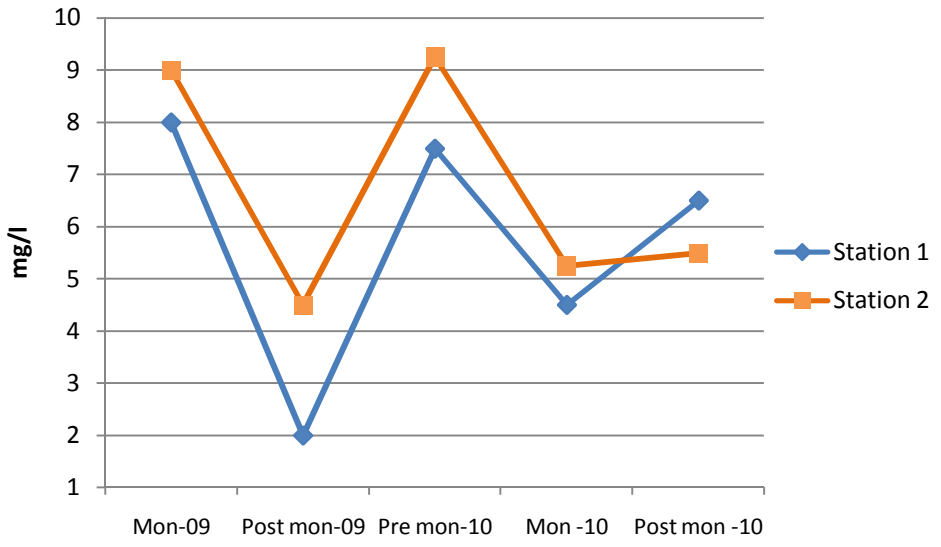

Figure 34 Seasonal variations of carbon dioxide in Fort Cochin beach during 2009-2011.

4.2.8.2 Variation of CO_2 at Dharmadam beach

At station 1 the CO_2 ranged from 0 - 20mg/l (Av. – 4.75mg/l). Highest value (20mg/l) was observed in August 2009 and absence of carbon dioxide was observed in March 2010 (Fig.35). Seasonally station 1 showed highest value in monsoon (2009) season (14mg/l$\pm$3.9) and lowest value was in monsoon, 2010 and it was 3.25mg/l (Fig.36). At station 2 the CO_2 values ranged from 0 - 12mg/l (Av. – 3.75mg/l) during sampling period (Fig. 36). In station 2 the highest value (12mg/l) was observed in June and January, 2011. Zero value was observed in March, 2010 (Fig. 35). Average seasonal highest value was observed in post monsoon season in 2009 (11.75mg/l$\pm$3.12) and the lowest value was in pre monsoon season (2010), it was 3.6mg/l (Fig. 36). The highest mean was observed in station 1 (4.8mg/l $\pm$4.9) (Table 10).

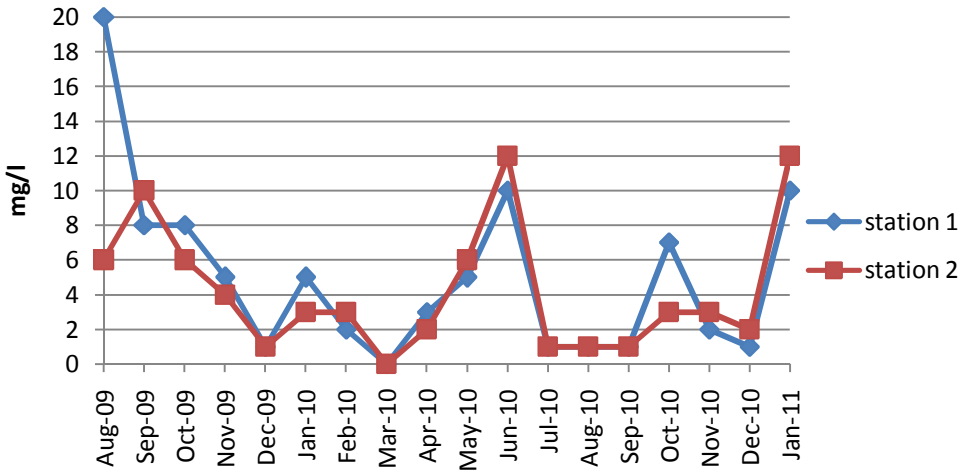

Figure 35 Monthly variations of carbon dioxide in Dharmadam beach during 2009-2011.

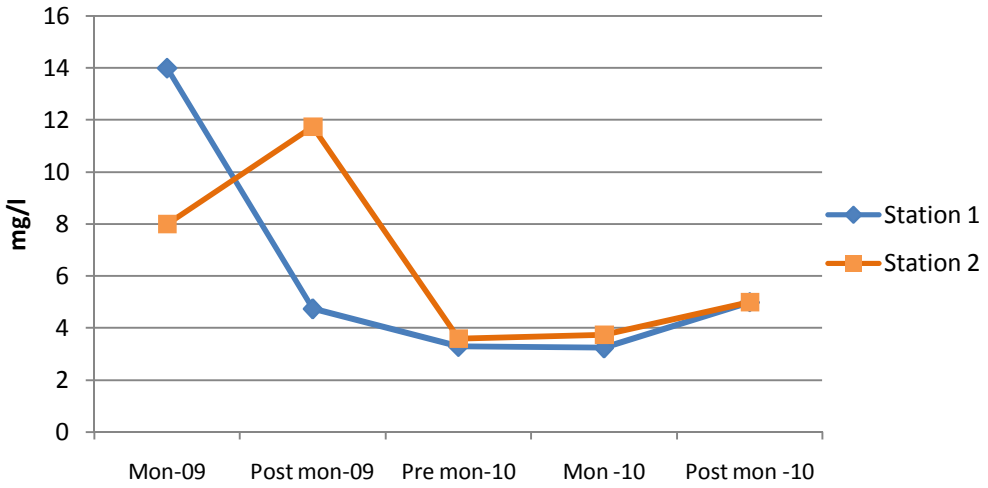

Figure 36 Seasonal variations of carbon dioxide in Dharmadam beach during 2009-2011.

Table 9 ANOVA of carbon dioxide in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	40.012	2.890
Station	3	32.356	2.337
Month	17	55.674	4.021
Station * Month	6	19.783	1.429
Error	45	13.845	
Total	72		

R^2 = .625

Table 10 Mean and standard deviation of carbon dioxide in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	5.9444	4.94050
2	6.5556	5.58593
3	4.8889	4.96919
4	4.2222	3.75038

4.2.9 Conductivity

It is a measure of the capacity of water to conduct an electric current. It is used to verify salinity and is proportional to the concentrations of total dissolved solids. It has confirmed to be beneficial in determining the range of influence of runoff and effluent discharge in aquatic ecosystem. Its measurement is shaped by temperature, ion mobility and electric charge on each ion (Chapman, 1992).

4.2.9.1 Variations of conductivity at Fort Cochin beach

In Fort Cochin beach conductivity values ranged from 8.6 - 63.4mS/cm (Av. - 28.57mS/cm) during the sampling period. The highest value (63.4mS/cm)

was observed in June, 2010 at station 1 and lowest value in September, 2009 (8.6 mS/cm) (Fig. 37). Seasonally conductivity was high in monsoon season, 2010 (38.3mS/cm±5.16) and the lowest value was in post monsoon season, 2010 (21.75mS/cm) (Fig. 38). At station 2 the conductivity values ranged from 3.21 - 53.9mS/cm (Avg. – 24.9mS/cm) during the sampling period. At station 2, in same month (June 2010) as in the case of station 1, the peak conductivity value was observed (53.9mS/cm) and the lowest value was in August, 2010 (3.21mS/cm) (Fig. 37). Seasonally the conductivity value was high in monsoon season, 2010 (31.4mS/cm±6.6) and the lowest was in monsoon season, 2009 (13.8mS/cm) (Fig. 38). Highest mean was observed in station 1 (29.8mS/cm ±15.7) (Table 12) No significant variation between station and month (p = 0.09, p > 0.05) were observed in ANOVA.

4.2.9.2 Variations of conductivity at Dharmadam beach

At station 1 the highest conductivity value range was 13.8 - 47mS/cm (Av.31.43mS/cm) during the sampling period. In this beach at station 1 the conductivity showed its highest value in December, 2009 (47 mS/cm). Lowest was observed in August, 2010 (13.8mS/cm) (Fig. 39). Seasonally in station 1 the conductivity was high in post monsoon season, 2009 (37.8mS/cm±3.9). The lowest was in monsoon season, 2010 (24.9mS/cm) (Fig. 40). At station 2 the range of conductivity values was 9.35 - 47.4mS/cm (Av.27.78mS/cm). At station 2 it was observed to be highest in February, 2010 (47.4mS/cm). Lowest was observed in May 2010, the value was 9.35mS/cm (Fig. 39). Seasonally the highest value was observed in monsoon season, 2009 (36.3mS/cm±5.16). The lowest was in monsoon season, 2010 (19.5mS/cm) (Fig. 40). Highest mean was observed in station 1 (31.5mS/cm ± 11.1) (Table 12).

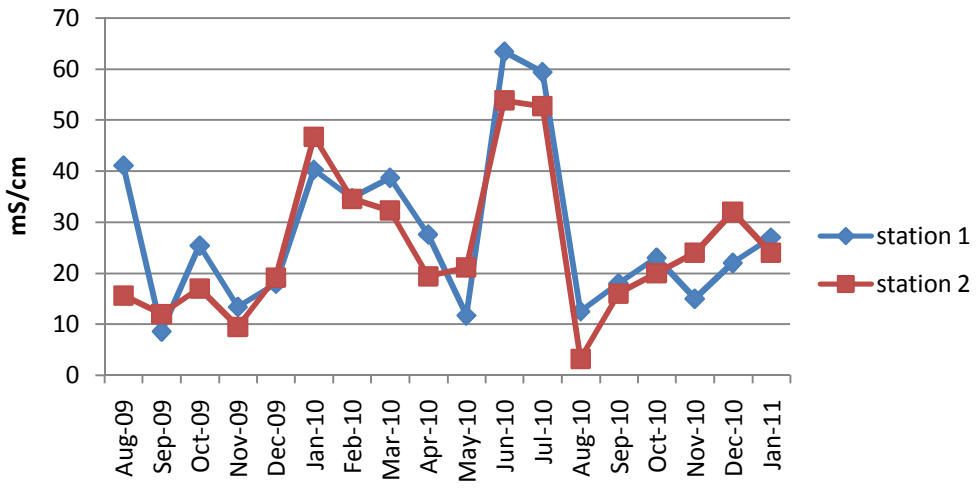

Figure 37 Monthly variations of conductivity in Fort Cochin beach during 2009-2011.

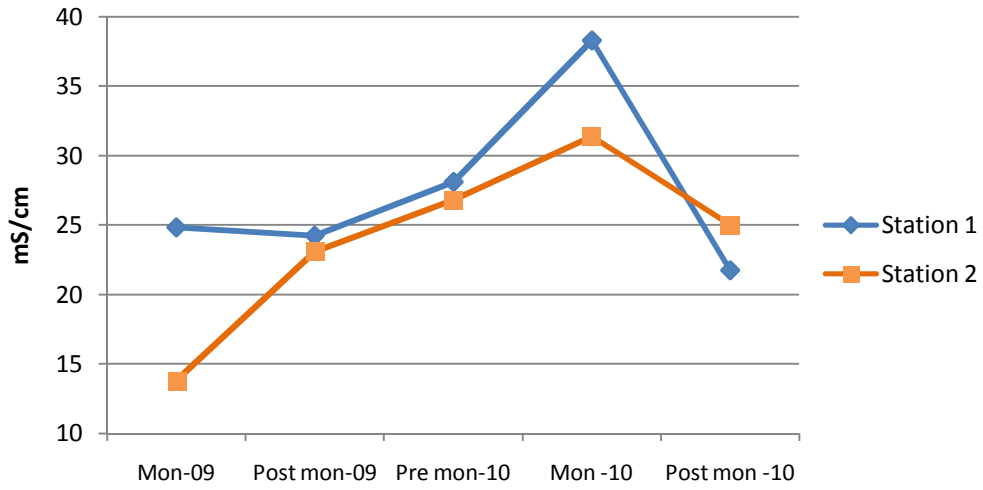

Figure 38 Seasonal variations of conductivity in Fort Cochin beach during 2009-2011.

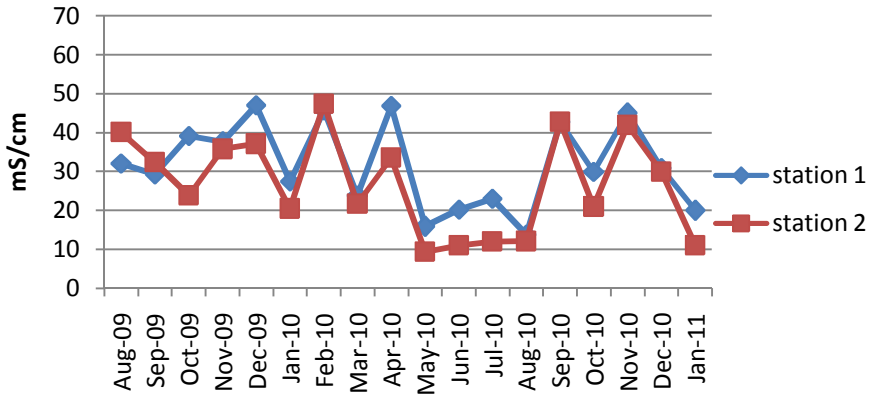

Figure 39 Monthly variations of conductivity in Dharmadam beach during 2009-2011.

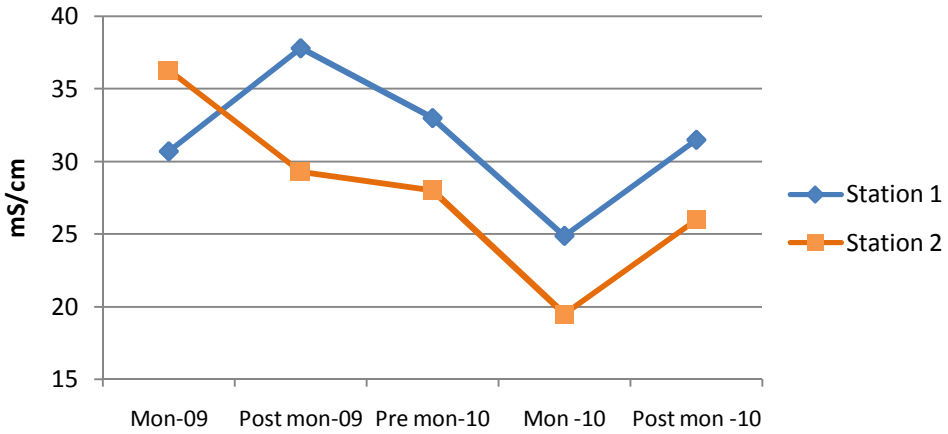

Figure 40 Seasonal variations of conductivity in Dharmadam beach during 2009-2011.

Table 11 ANOVA of conductivity in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	206.274	1.163
Station	3	78.642	.443
Month	17	312.649	1.762
Station * Month	6	62.268	.351
Error	45	177.414	
Total	72		

R^2= .402

Table 12 Mean and standard deviation of conductivity of Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	29.8000	15.70568
2	27.1817	15.17564
3	31.5833	11.10004
4	27.1361	13.03935

4.2.10 Total Dissolved Solids.

4.2.10.1 Variation of TDS at Fort Cochin beach

In station 1 of Fort Cochin beach the TDS value ranged from 4.88 - 39.88g/l (Av. – 15.32g/l) during the sampling period. At station 1 TDS showed highest value at July, 2010 (39.8g/l) and lowest was observed in September, 2009 (4.88g/l) (Fig. 41). Seasonally the TDS showed its peak value in monsoon season, 2010 (23.5g/l±4.57) and the lowest was in monsoon season, 2009 (10.44g/l) (Fig.42). The range of TDS at station 2 was 1.77 - 32.6g/l (Av. – 14.5g/l) during the sampling period. At station 2 the highest was observed in July, 2010 (32.6g/l) and lowest was in August, 2010 (1.77g/l) (Fig. 41). In station 2, monsoon season (2010) showed highest value (19.5g/l±2.66) and the lowest was in post monsoon season, 2009, it was 12.12g/l (Fig. 42). ANOVA value showed overall significance (R^2 = .573) but no significance between station and month with TDS in both the beaches were observed (p = 0.974 p> 0.05) (Table 13). Highest mean was observed in station 1 (16.1g/l ±10.1) (Table 14).

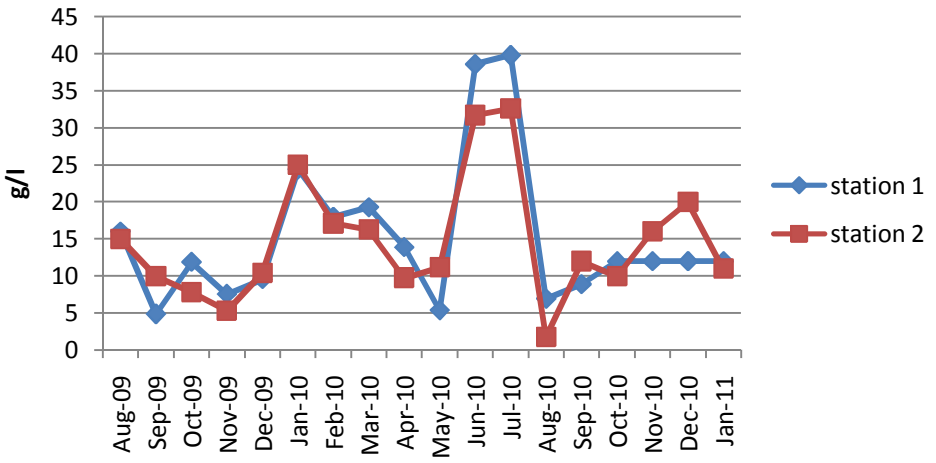

Figure 41 Monthly variations of TDS at Fort Cochin beach during 2009-2011.

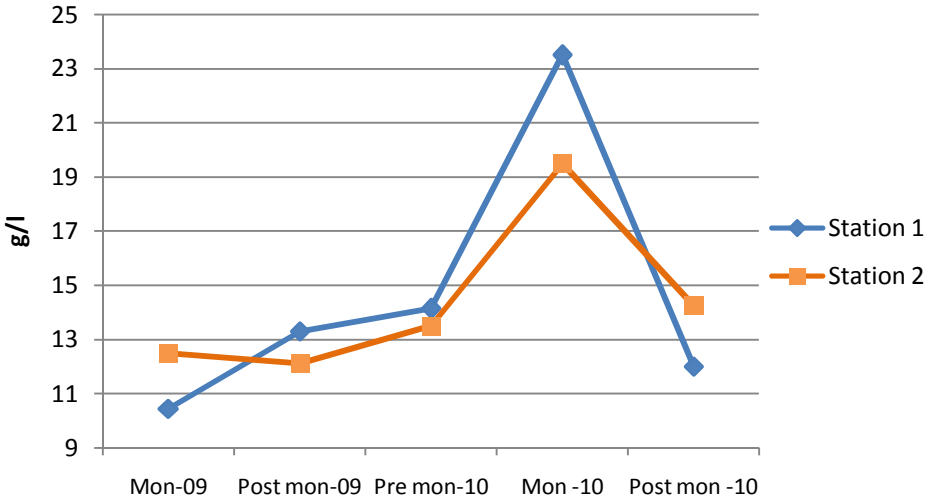

Figure 42 Seasonal variations of TDS in Fort Cochin beach during 2009-2011.

4.2.10.2 Variations of TDS in Dharmadam beach

In station 1 the TDS value ranged from 7.84 - 25.9g/l (Av. – 17.76g/l) during sampling period. At station 1 the highest value was observed in December, 2009 (25.9g/l) and lowest was observed in August, 2010 (7.84g/l) (Fig.43). Seasonally the highest value was shown in post monsoon season, 2009, it was 19.5g/l±2.91. The lowest was observed in monsoon season, 2009 (16.8g/l) (Fig. 44). At station 2 the range of TDS values was 4.97 - 25.7g/l (Av. – 16.86g/l). In station 2 the highest value was showed in December, 2009 (25.7g/l) and the lowest was in May, 2010 (4.97g/l) (Fig.43). In station 2 the seasonal average showed low value during pre monsoon season, 2010 (14.9g/l+1.7) and in monsoon season, 2009 the value was high (19.8g/l) (Fig. 44). Highest mean was observed in station 1 (18.1g/l ± 5.2) (Table 14).

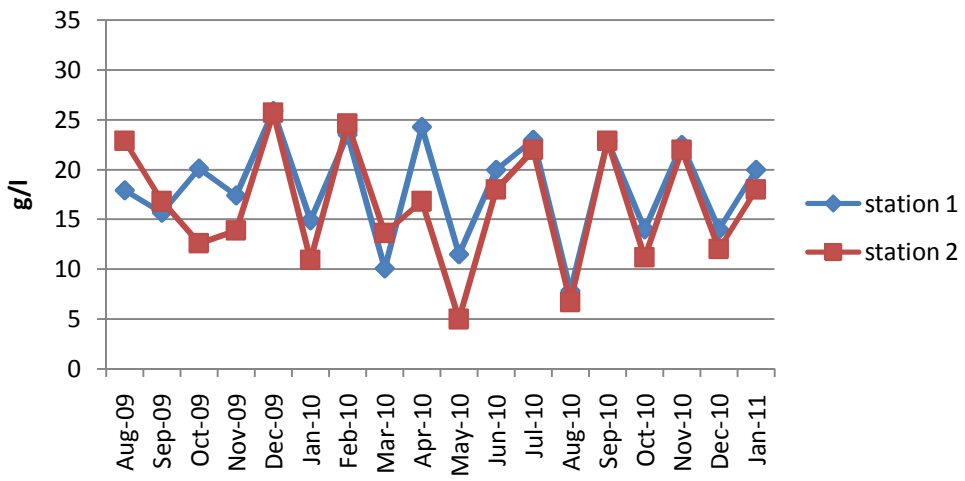

Figure 43 Monthly variations of TDS in Dharmadam beach during 2009-2011.

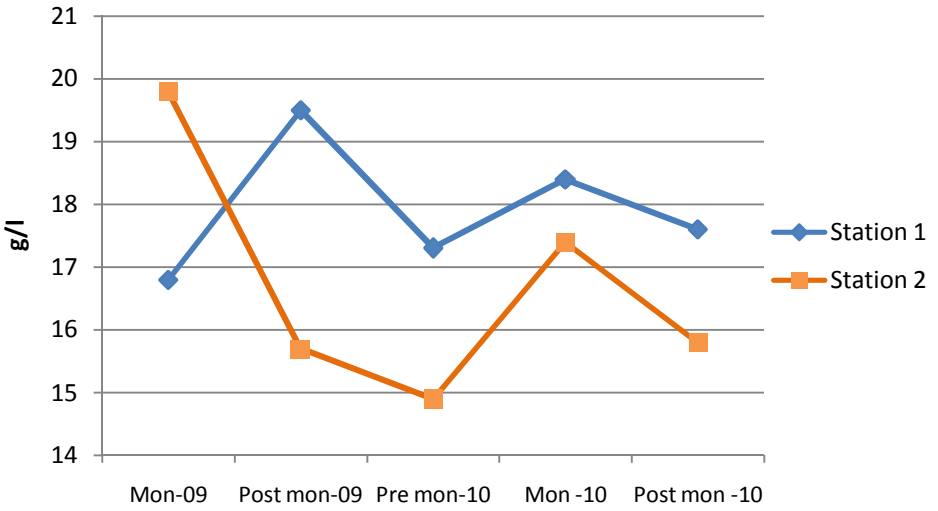

Figure 44 Seasonal variations of TDS in Dharmadam beach during 2009-2011.

Table 13 ANOVA of total dissolved solids in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	93.300	2.320
Station	3	20.620	.513
Month	17	147.253	3.662
Station * Month	6	8.196	.204
Error	45	40.216	
Total	72		

R^2= .573

Table 14 Mean and standard deviation of total dissolved solids in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	16.1739	10.18895
2	15.4956	8.58712
3	18.1133	5.27867
4	16.4644	6.30940

4.2.11 Turbidity

4.2.11.1 Variation of turbidity at Fort Cochin beach

At station 1 the turbidity values ranged from 8.7 - 46NTU (Av. – 19.27NTU) during the sampling period. At station 1 the peak was observed in September, 2009 (46NTU) and lowest was in December, 2009 (8.7NTU) (Fig. 45). Seasonally monsoon season, 2009 showed high value (33NTU+5.54) and the lowest was in pre monsoon season, 2010 (18NTU) (Fig. 46). At station 2 turbidity values ranged from 3.3-35NTU (Av. – 19.48NTU) during sampling period. The peak was observed in August, 2009 (35NTU) and lowest was in August, 2010 (3.3NTU) (Fig. 45). Monsoon season, 2009 showed highest value (33.5NTU±5.75) seasonally and lowest was in monsoon season, 2010 (17.3NTU) (Fig. 46). Highest mean was observed in station 1 (20.9NTU ±9.1) (Table 16) No significant variation ($p = 0.08$ $p > 0.05$) was observed in ANOVA

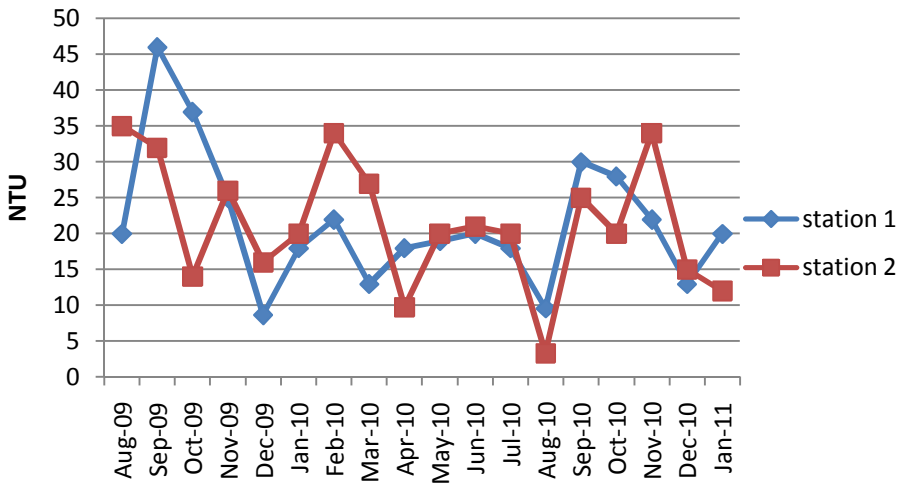

Figure 45 Monthly variations of turbidity in Fort Cochin beach during 2009-2011.

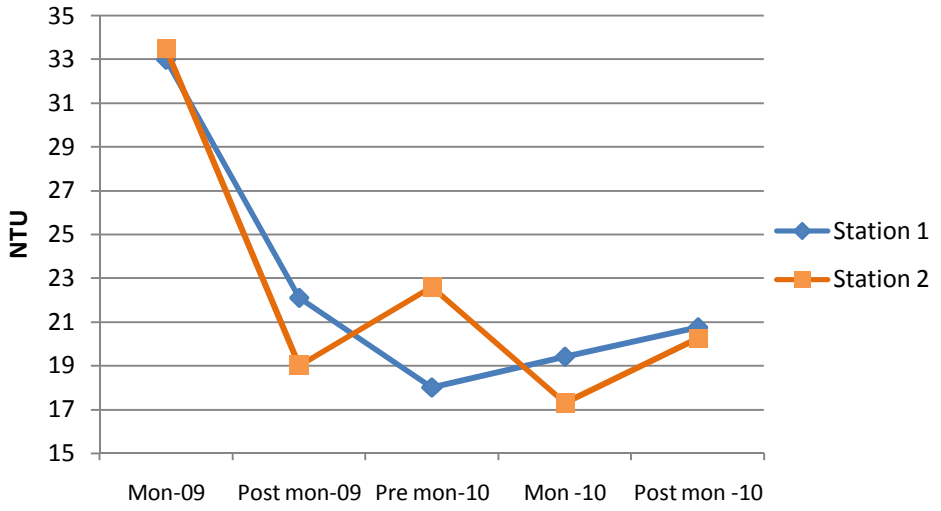

Figure 46 Seasonal variations of turbidity in Fort Cochin beach during 2009-2011.

4.2.11.2 Variation of turbidity at Dharmadam beach

At station 1 the turbidity values ranged from 3.7 – 26.2NTU (Av. – 13.8NTU) during sampling period. At station 1 the peak was shown in August, 2009 (26NTU) and lowest was in February, 2010 (3.7NTU) (Fig. 47). Monsoon season, 2009 showed highest value (17.65NTU+1.8) and lowest (10.42NTU) was in pre monsoon season, 2010 seasonally at station 1 (Fig. 48). The range of turbidity at station 2 during sampling period was 7.1 - 53.6NTU (Av. – 18.2NTU). At station 2 the peak was observed in August, 2009 (53.6 NTU) and lowest was in September, 2009 (7.1 NTU) (Fig. 47). Seasonally monsoon season (2009) showed highest value (30.35NTU±6.9) in station 2 and lowest was in post monsoon season (2009), it was 11.67NTU (Fig. 48). Highest mean was observed in station 2 (15.9NTU ± 11.1) (Table 16).

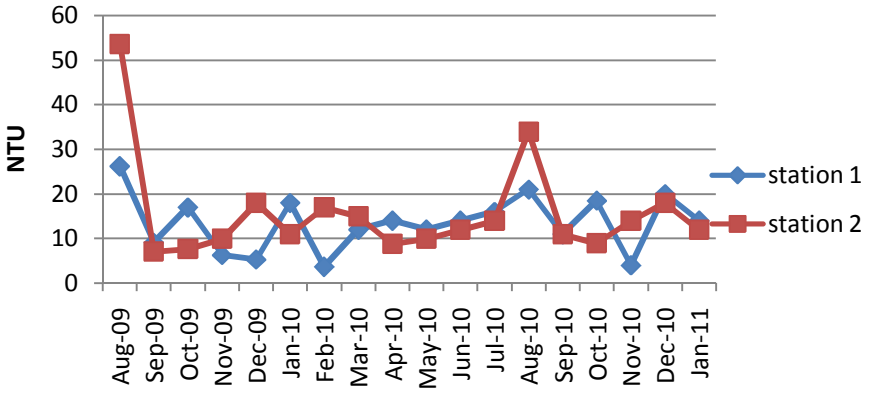

Figure 47 Monthly variations of turbidity in Dharmadam beach during 2009-2011.

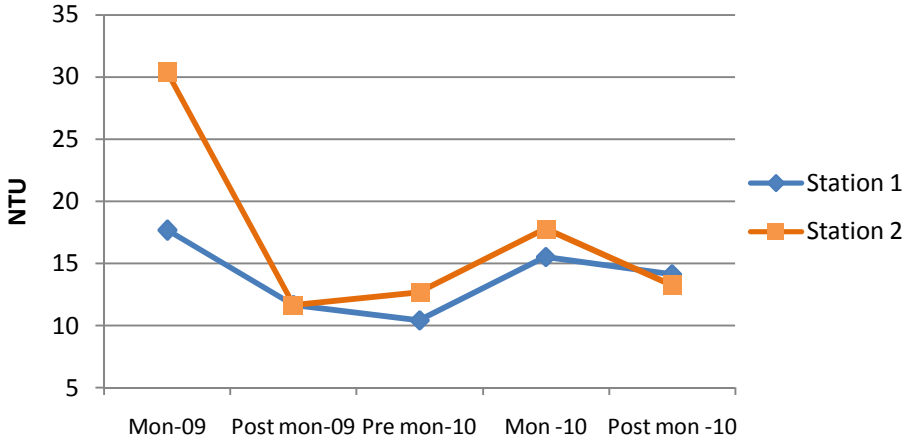

Figure 48 Seasonal variations of turbidity in Dharmadam beach during 2009-2011.

Table 15 ANOVA of turbidity in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	93.251	1.129
Station	3	242.208	2.933
Month	17	72.881	.883
Station * Month	6	29.207	.354
Error	45	82.572	
Total	72		

R^2= .395

Table 16 Mean and standard deviation of turbidity in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	20.9611	9.17869
2	20.3917	8.42682
3	13.4056	6.23392
4	15.9556	11.19786

4.2.12 Nutrients

4.2.12.1 Variations of phosphate at Fort Cochin beach

In station 1 of Fort Cochin beach the phosphate values ranged from 0.3 - 8.7µmole/l (Av. – 3.56µmole/l) during sampling period. At station 1 the peak was observed in February, 2010 (8.7µmole/l) and lowest was in January 2011(0.3µmole/l) (Fig. 49). Seasonally the peak was observed in pre monsoon season (2010) in station 1 (4.82µmole/l+1.03) and the lowest was in post monsoon season (2009), it was 2.02µmole/l (Fig. 50). In station 2 the range of phosphate values was 0.2 - 17µmole/l (Av. – 4.18µmole/l). At station 2 the highest value was observed in February, 2010 (17µmole/l) and lowest was observed in September, 2010 (0.2µmole/l) (Fig. 49). During pre monsoon season the peak was observed as in the case of station 1 (7.12µmole/l±2.17) and the lowest was in monsoon season, 2010 (1.67µmole/l) (Fig. 50, Table 17). ANOVA showed overall significance (R^2 = .521) but no significance between station and month with phosphate in both the beaches were observed (p = 0.451 p> 0.05). Highest mean was observed in station 2 (4.4µmole/l ±4.9) (Table 18).

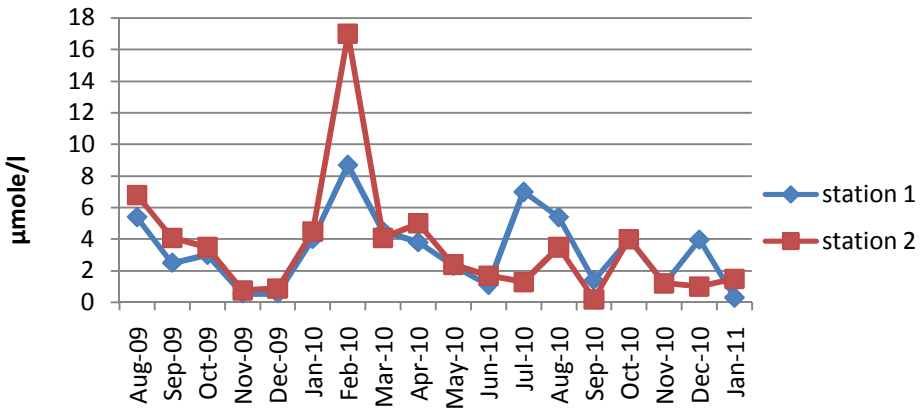

Figure 49 Monthly variations of phosphate in Fort Cochin beach during 2009-2011.

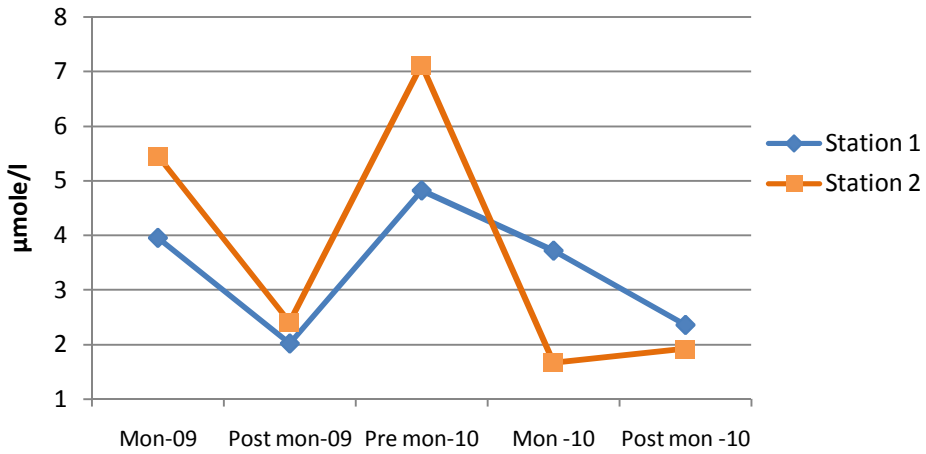

Figure 50 Seasonal variations of phosphate in Fort Cochin beach during 2009-2011.

4.2.12.2 Variations of Phosphate at Dharmadam beach

In Dharmadam beach the range of phosphate was 0.1 - 5.1µmole/l (Av. – 4.38µmole/l). At station 1 the peak value was observed in April, 2010 (5.1µmole/l) and lowest was in December, 2009 (0.1µmole/l) (Fig. 51). Seasonally post monsoon season (2009) showed high value (2.53µmole/l+0.46) and the lowest was in post monsoon season (2010), it was 1.13µmole/l (Fig. 52).

At station 2 the highest value was observed in October 2009 (7.2µmole/l) and lowest was in September 2009 (0.31µmole/l). Station wise monthly average was 3.76µmole/l (Fig. 51). The seasonal average was taken and the highest was observed in post monsoon season, 2009 (3.82µmole/l+1.03) and lowest was in monsoon, 2009 (0.67µmole/l) (Fig. 52). Highest mean was observed in station 1 (3.55µmole/l ±7.6) (Table 18).

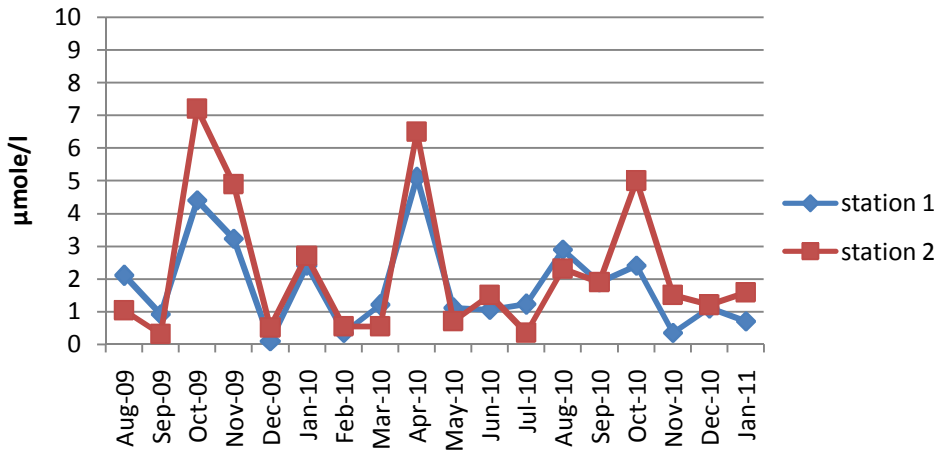

Figure 51 Monthly variations of phosphate in Dharmadam beach during 2009-2011.

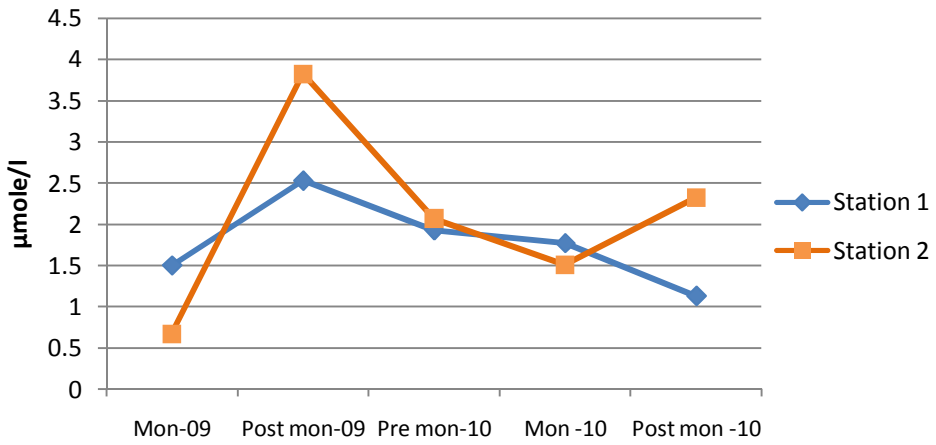

Figure 52 Seasonal variations of phosphate in Dharmadam beach during 2009-2011.

Table 17 ANOVA of phosphate in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	42.989	1.879
Station	3	11.066	.484
Month	17	60.510	2.645
Station * Month	6	22.377	.978
Error	45	22.874	
Total	72		

R^2= .521

Table 18 Mean and standard deviation of phosphate in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	3.5167	2.73539
2	4.4194	4.90819
3	3.5522	7.69517
4	3.3156	5.89446

4.2.13 Silicate

4.2.13.1 Variations of silicate at Fort Cochin beach

At station 1 the range of silicate values was 11 - 80.6µmole/l (Av. – 45.38µmole/l) during the sampling period. In station 1, April month (2010) showed its peak (80.6µmole/l) and lowest was in December, 2010 (11µmole/l) (Fig. 53). Seasonally the highest average value was recorded in monsoon (2009), it was 61.49µmole/l±12.2. The lowest was in post monsoon season (2009), it was 32.6µmole/l (Fig. 54). At station 2 the silicate value ranged from 4.6-79.6µmole/l (Av. –44.03µmole/l) during the sampling period. At station 2 the highest was showed in July, 2010 (79.6µmole/l) and the lowest was shown in January, 2010 (4.6µmole/l) (Fig. 53). Seasonal average was

taken and the highest was observed in monsoon season, 2010 (60.25µmole/l±8.8) and the lowest was in post monsoon season, 2009 (37.8µmole/l) (Fig. 54). ANOVA showed overall significance (R^2 =.738) but no significance between station and month were observed (p = 0.086 p> 0.05) (Table 19). Highest mean was observed in station 1 (45.2µmole/l ±23.5) (Table 20).

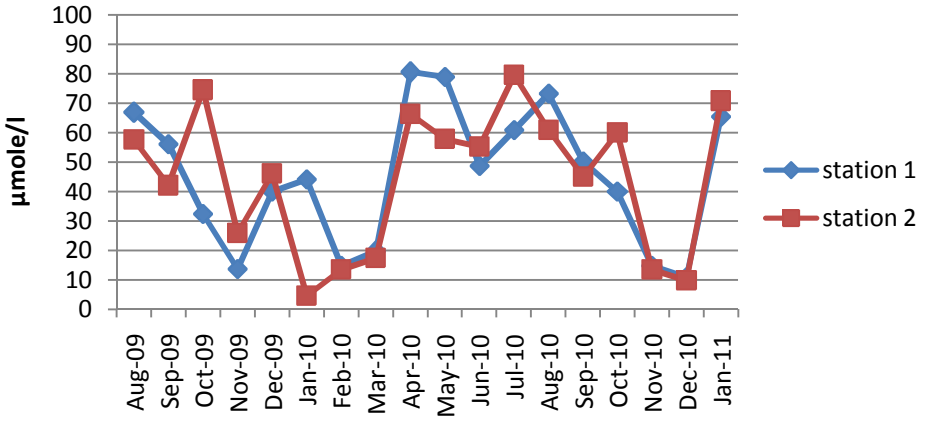

Figure 53 Monthly variations of silicate in Fort Cochin beach during 2009-2011.

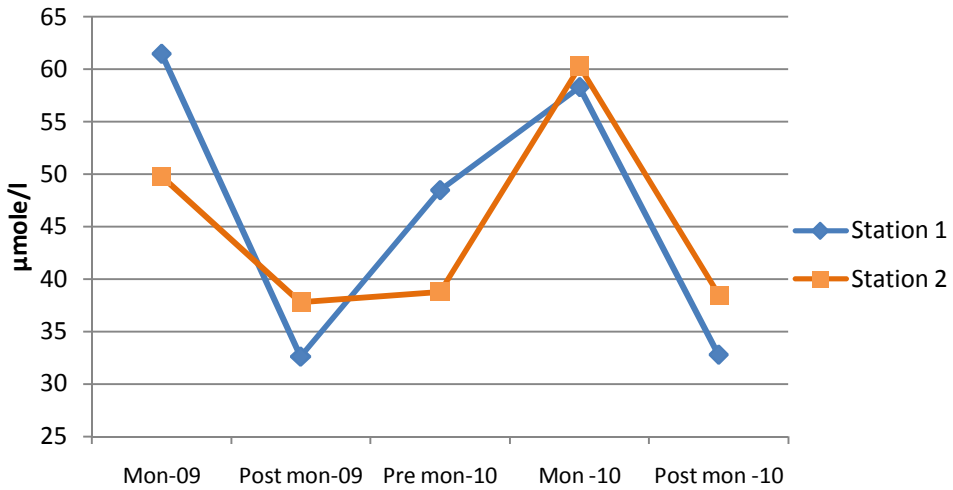

Figure 54 Seasonal variations of silicate in Fort Cochin beach during 2009-2011.

4.2.13.2 Variations of silicate at Dharmadam beach

In station 1 of Fort Cochin beach the range of silicate was 0.6 - 138µmole/l (Av. – 31.67µmole/l) during the sampling period. At station 1, August, 2010 showed its peak (138.5µmole/l) and lowest was in November, 2009 (0.6µmole/l) (Fig. 55). Seasonal average was high in monsoon season, 2010 (87µmole/l±28.8) and the lowest was in pre monsoon season, 2010 (9.4µmole/l) (Fig. 56). At station 2 the silicate value ranged from 0.41 - 154µmole/l (Av. 37.76µmole/l). The highest value was shown in August, 2010 (154µmole/l) and the lowest was in December, 2010 (0.41µmole/l) (Fig. 55). Seasonally monsoon season (2010) showed highest value (90.17µmole/l±29.3) and lowest was in pre monsoon season, 2010 (6.825µmole/l) (Fig. 56). Highest mean was observed in station 2 (33.8µmole/l ± 41.1) (Table 20).

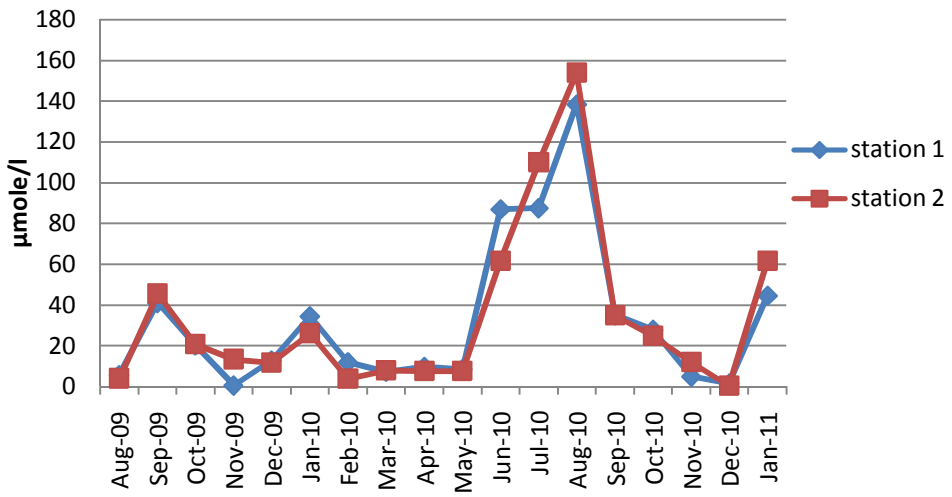

Figure 55 Monthly variations of silicate in Dharmadam beach during 2009-2011.

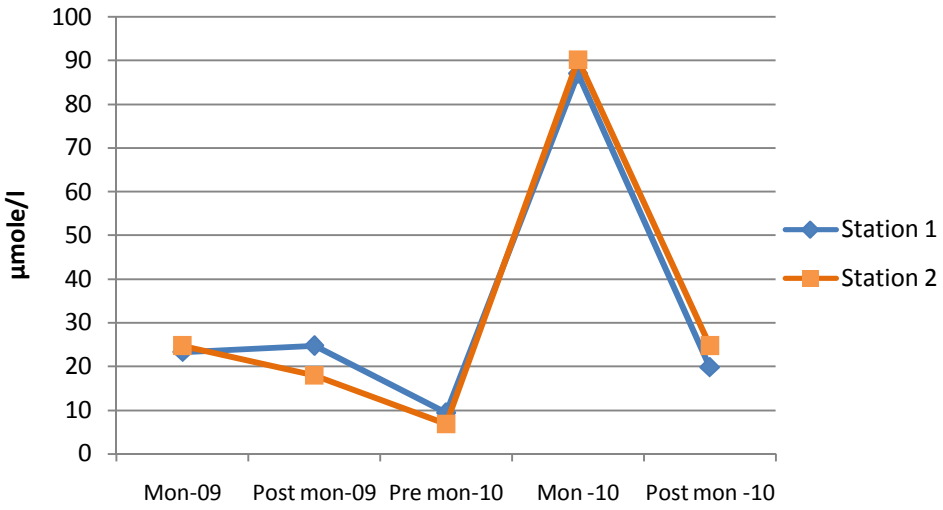

Figure 56 Seasonal variations of silicate in Dharmadam beach during 2009-2011.

Table 19 ANOVA of silicate in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	2097.196	4.875
Station	3	1066.796	2.480
Month	17	1752.436	4.074
Station * Month	6	859.075	1.997
Error	45	430.197	
Total	72		

R^2= .738

Table 20 Mean and standard deviation of silicate in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	45.2267	23.55657
2	43.2944	24.11449
3	32.0828	37.13434
4	33.8056	41.13042

4.2.14 Nitrate

4.2.14.1 Variations of nitrate at Fort Cochin beach

In station 1 the range of nitrate was 0.12 - 2µmole/l (Av. – 0.79µmole/l) during the sampling period. At station 1 the peak was observed in December, 2010 (2µmole/l) and the lowest was in August, 2009 and June, 2010 (0.12µmole/l) (Fig. 57). Seasonal average showed highest in post monsoon season (2010), it was 1.18µmole/l±0.3. The lowest was in monsoon season (2009) and value was 0.52µmole/l (Fig. 58). In station 2 the nitrate value ranged from 0.03 -3.4µmole/l (Av. – 0.83µmole/l). At station 2 the peak was observed in January, 2011 (3.4µmole/l) and lowest was in August, 2009 (0.03µmole/l) (Fig. 57). Seasonally post monsoon season (2010) showed high nitrate value (1.37µmole/l±0.03) (Fig. 58). No significant variation was observed in ANOVA ($p = 0.231 p > 0.05$). Highest mean was observed in station 1 (0.77µmole/l ±0.47) (Table. 22).

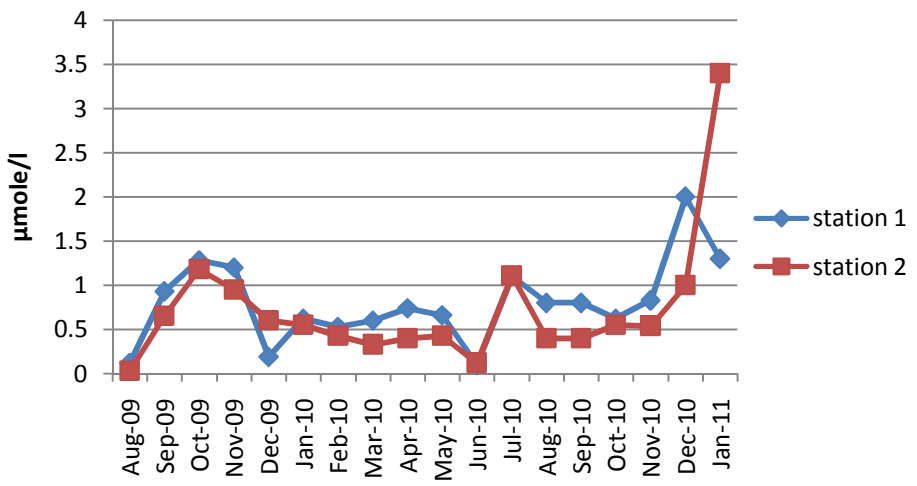

Figure 57 Monthly variations of nitrate in Fort Cochin beach during 2009-2011.

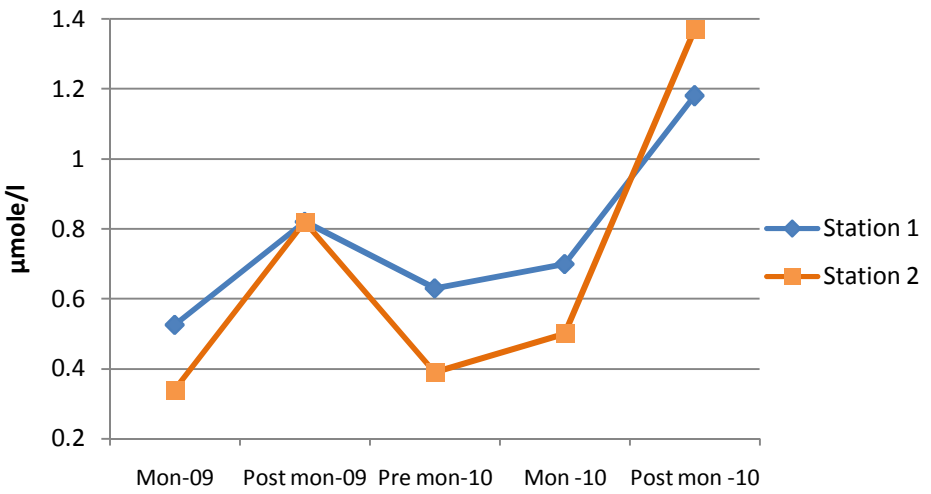

Figure 58 Seasonal variations of nitrate in Fort Cochin beach during 2009-2011.

4.2.14.2 Variations of nitrate at Dharmadam beach

At station 1 the nitrate value ranged from 0.05 - 1.84µmole/l (Av. – 0.78µmole/l) during the sampling period. Highest value was observed in September, 2009 (1.84µmole/l) and lowest was observed in June, 2010 (0.05µmole/l) (Fig. 59). From the seasonal average obtained, it was observed that during pre monsoon season (2010) the nitrate values were high (0.74µmole/l+0.31) and lowest was in monsoon season, 2009 (0.31µmole/l) (Fig. 60). In station 2 the values ranged from 0.05 - 1.6µmole/l (Av. – 0.78µmole/l) during the sampling period. At station 2 the peak was observed in July, 2010 (1.6µmole/l) and lowest was in July, 2010 (0.05µmole/l) (Fig. 59). Seasonally, monsoon season (2010) showed highest value (0.8µmole/l±0.39) and the lowest was in monsoon season (2009), it was 0.3µmole/l (Fig. 60). Highest mean was observed in station 1 (0.69µmole/l ±0.45) (Table 22).

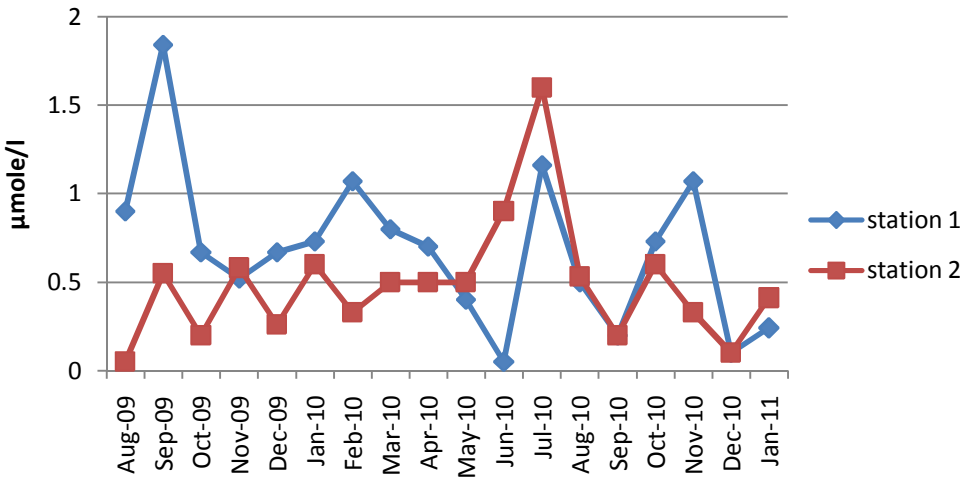

Figure 59 Monthly variations of nitrate in Dharmadam beach during 2009-2011.

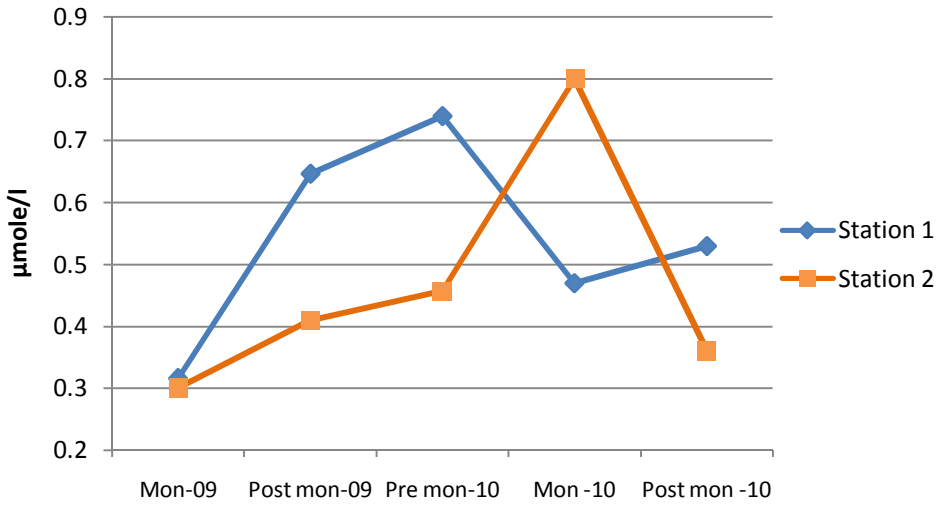

Figure 60 Seasonal variations of nitrate in Dharmadam beach during 2009-2011.

Table 21 ANOVA of nitrate in Fort Cochin and Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	26	.348	1.419
Station	3	.158	.643
Month	17	.377	1.536
Station * Month	6	.347	1.412
Error	45	.246	
Total	72		

R^2= .451

Table 22 Mean and standard deviation of nitrate in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	.7761	.47589
2	.7322	.64578
3	.6933	.45657
4	.5206	.39003

4.2.15 Nitrite

4.2.15.1 Variations of nitrite at Fort Cochin beach

In station 1 the nitrite values ranged from 0.04 - 3µmole/l (Av. – 0.88µmole/l) during the sampling period. At station 1 the highest value was observed in April, 2010 (3µmole/l) and lowest was in December, 2009 (0.04µmole/l) (Fig. 61). Seasonal average was taken and pre monsoon season (2010) showed highest value (1.78µmole/l+0.52) and lowest was in monsoon season, 2009 (0.31µmole/l) (Fig. 62). In station 2, the nitrite value ranged from 0.041 – 4.1µmole/l (Av. – 0.76µmole/l) during the sampling period. At station 2 the highest value was observed in September, 2010 (4.1µmole/l) and lowest was in December, 2009 (0.041µmole/l) (Fig. 61). Seasonally pre monsoon season (2010) showed highest value (2.24µmole/l±0.71). The lowest was in

monsoon and post monsoon season, 2009 (0.41µmole/l) (Fig. 62). ANOVA showed overall significant variation (R^2 = .573) but no significance between station and month in both the beaches were observed (p = 0.405 p> 0.05) (Table 23). Highest mean was observed in station 2 (1.18µmole/l ± 1.18) (Table 24).

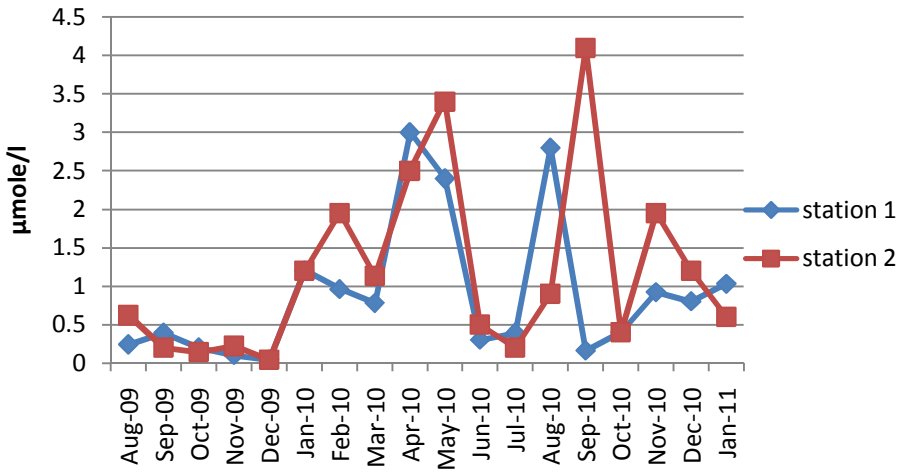

Figure 61 Monthly variations of nitrite in Fort Cochin beach during 2009-2011.

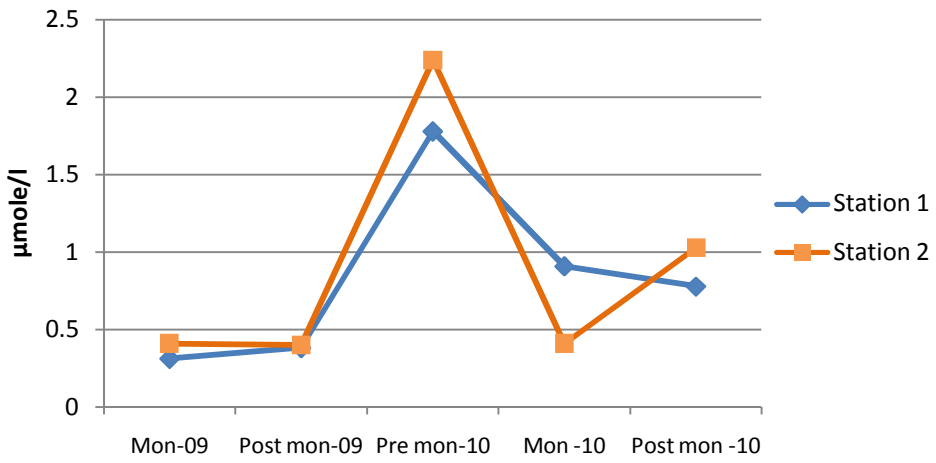

Figure 62 Seasonal variations of nitrite in Fort Cochin beach during 2009-2011.

4.2.14.2 Variations of nitrite at Dharmadam beach

In station 1 the nitrite value ranged from 0.02 - 1.4µmole/l (Av. – 0.51µmole/l) during the sampling period. At station 1 the peak was observed in April, 2010 (1.4µmole/l) and lowest was in January, 2010 (0.02µmole/l) (Fig. 63). Seasonal average was taken and the highest was observed in pre monsoon season (2010), it was 0.79µmole/l±0.20 and the lowest was in post monsoon season (2009), it was 0.19µmole/l (Fig. 63). In station 2 the nitrite values ranged from 0.07 - 1.2µmole/l (Av. – 0.44µmole/l) during the sampling period. At station 2 the highest value was observed in April, 2010 (1.2µmole/l) and lowest was in November, 2009 (0.07µmole/l) (Fig. 63). Seasonally the highest average value was obtained in pre monsoon season (2010) as in the case of station 1 (0.775µmole/l±0.20) and lowest was obtained in monsoon season, 2009 (0.24µmole/l) (Fig. 64). Highest mean was observed in station 1 (0.45µmole/l ±0.44) (Table 24)

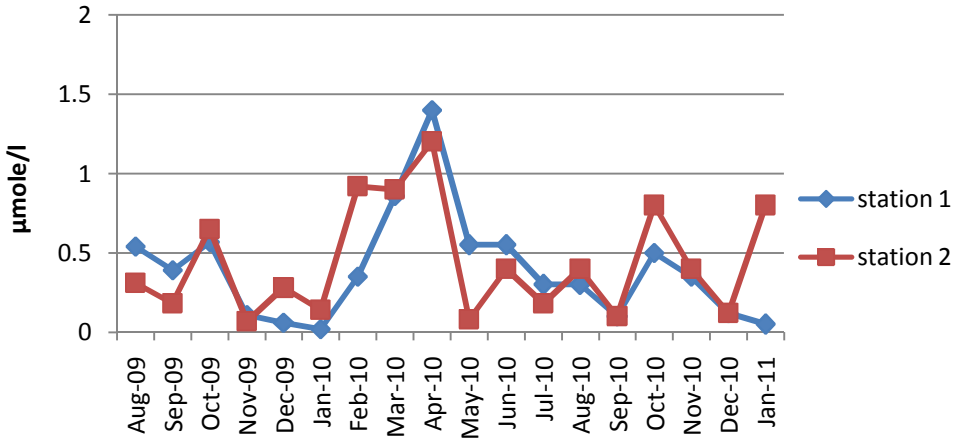

Figure 63 Monthly variations of nitrite in Dharmadam beach during 2009-2011.

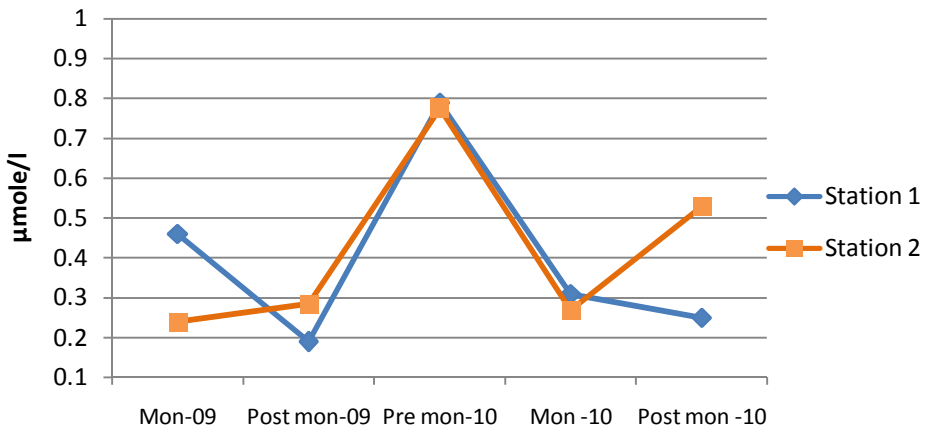

Figure 64 Seasonal variations of nitrite in Dharmadam beach during 2009-2011.

Table 23 ANOVA of nitrite in Fort Cochin and Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	1.106	2.318
Station	3	2.821	5.912
Month	15	.654	1.372
Station * Month	6	.502	1.052
Error	45	.477	
Total	72		

R^2= .573

Table 24 Mean and standard deviation of nitrite in Fort Cochin and Dharmadam beach during 2009-2011.

Station	Mean	Std. Deviation
1	.8828	.92363
2	1.1395	1.18722
3	.4589	.44188
4	.4261	.34442

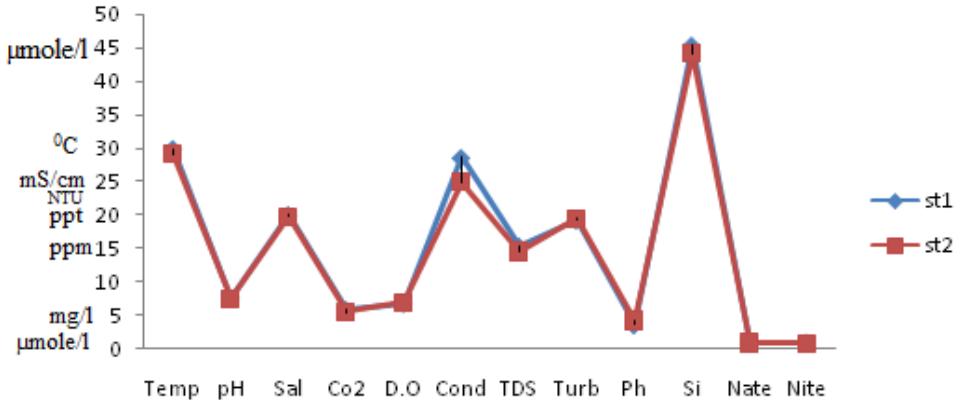

Figure 65 Stationwise mean variations of water quality parameters in Fort Cochin beach during 2009-2011 (Temp – Temperature, Sal – salinity, Cond – conductivity, Turb – Turbidity)

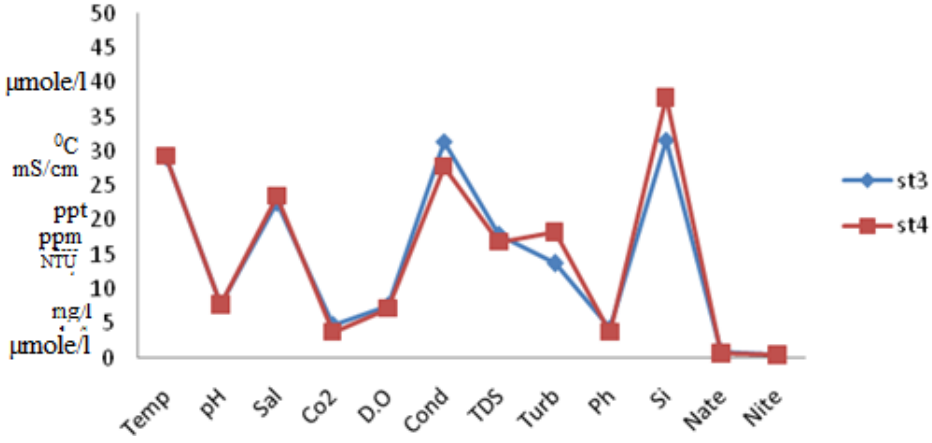

Figure 66 Stationwise mean variations of water quality parameters in Dharmadam beach during 2009-2011 (Ph – Phosphate, Si – silicate, Nate – Nitrate, Nite – nitrite)

4.3 PCA of water quality in Fort Cochin beach

The first five principal components showed 74.8% variance and eigen value greater than one. So five principal components were considered for the analysis. In Fort Cochin beach the first principal component was correlated to salinity, conductivity and TDS. Second principal component was correlated to pH and turbidity. It is negatively correlated to dissolved oxygen. The third, fourth and fifth axis was correlated to nitrite, turbidity and nitrate respectively. Forth component is negatively correlated to silicate (Fig.67, Table 25).

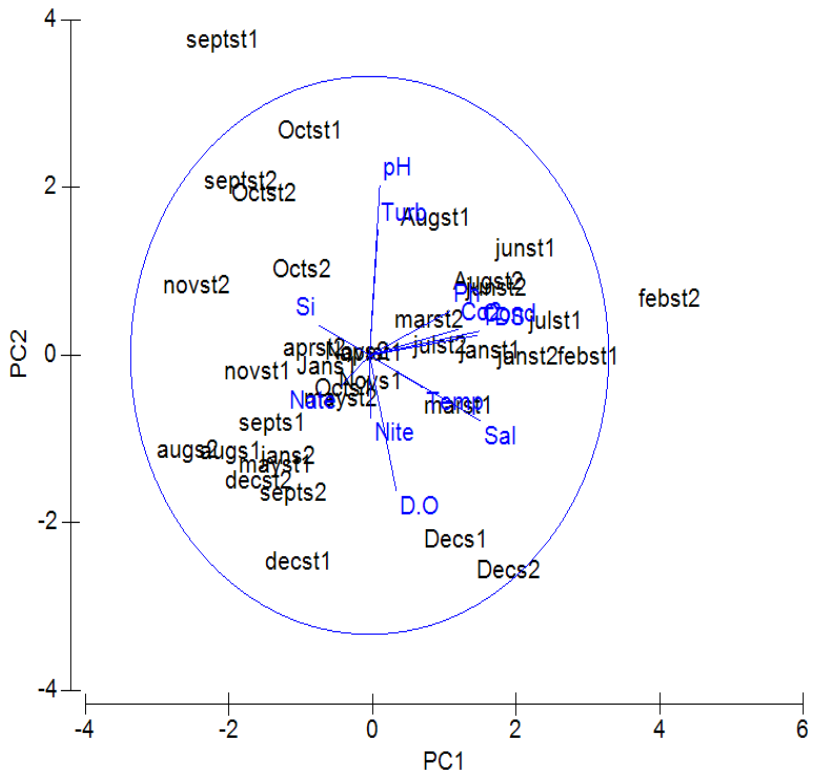

Figure 67 PCA of water quality parameters in Fort Cochin beach during 2009-2011.

PC – Principal components

PC	Eigen values	%Variation	Cum.%Variation
1	2.88	24.0	24.0
2	1.93	16.1	40.1
3	1.68	14.0	54.1
4	1.4	11.7	65.7
5	1.09	9.1	74.8

Table 25.Table of PCA analysis in Fort Cochin beach during 2009-2011

Variable	PC1	PC2	PC3	PC4	PC5
Temperature	0.222	-0.115	0.332	0.007	**0.470**
pH	0.043	**0.610**	-0.088	0.099	0.260
Salinity	**0.466**	-0.235	0.038	0.145	0.173
Co_2	0.368	0.092	0.277	-0.023	-0.034
DO	0.112	**-0.487**	-0.225	0.336	-0.228
Conductivity	**0.459**	0.087	-0.370	-0.256	-0.013
TDS	**0.449**	0.072	-0.399	-0.230	-0.131
Turbidity	0.034	**0.449**	0.115	**0.442**	-0.307
Phosphate	0.335	0.158	0.399	-0.003	0.074
Silicate	-0.212	0.106	-0.079	**-0.625**	0.113
Nitrate	-0.119	-0.108	-0.239	0.224	**0.695**
Nitrite	0.005	-0.225	**0.470**	-0.317	-0.124

4.4 PCA of water quality in Dharmadam beach

First five principal components showed 76.7% variance in monthly water quality data. For the first four principal components eigen values were

greater than one, so first four components are most significant. In Dharmadam beach first principal component is correlated to silicate and negatively correlated to conductivity and TDS. Second principal component was negatively correlated to temperature. Third principal component explained 15.1% variance in water quality and negatively correlated to carbon dioxide, phosphate and positively correlated to dissolved oxygen. Fourth component is correlated to turbidity and negatively correlated to nitrate. Fifth component is correlated to nitrite (Fig. 68, Table 26).

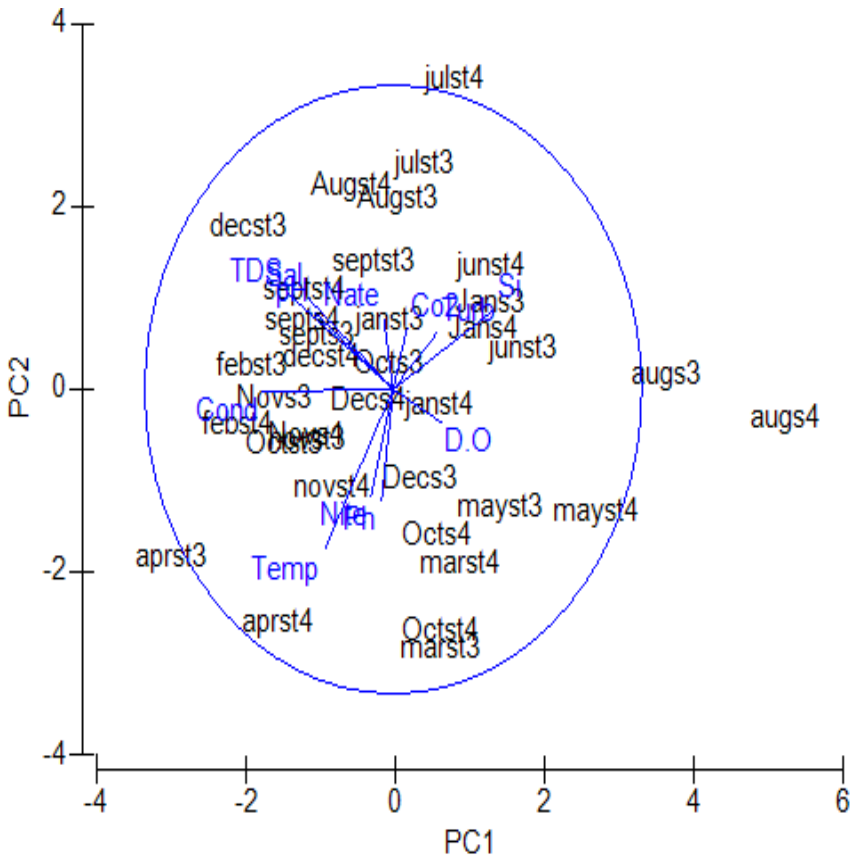

Figure 68 PCA of water quality parameters in Dharmadam beach during 2009-2011.

PC – Principal components

PC	Eigen values	%Variation	Cum.%Variation
1	2.79	23.2	23.2
2	2.18	18.1	41.4
3	1.82	15.1	56.5
4	1.44	12	68.5
5	0.979	8.2	76.7

Table 26 Table showing PCA values in Dharmadam beach during 2009-2011

Variable	PC1	PC2	PC3	PC4	PC5
Temperature	-.276	**-.526**	.125	-.102	-.084
pH	-.316	.253	-.238	-.346	-.227
Salinity	-.374	.303	0.204	.051	.282
Co_2	0.056	.202	**-.425**	.002	-.055
DO	0.193	-.109	**.624**	-.079	.142
Conductivity	**-0.526**	-.006	.045	.226	-.034
TDS	**-.422**	.314	.090	.146	.285
Turbidity	0.177	.187	-.210	**.567**	.181
Phosphate	-.047	-.366	**-.477**	-.084	.103
Silicate	**.406**	.262	-.018	-.145	.320
Nitrate	-.038	.234	-.024	**-.653**	.208
Nitrite	-.090	-.351	-.185	-.049	**.753**

4.5 Discussion

Depending on the weather conditions affecting the tide, the water movement in intertidal zone can be varying from mild to quite intense. The tide is the primary controlling factor of distribution of organisms in intertidal

areas. The tidal cycles of selected beaches were semi diurnal type (Two high and low tides in a day). Davies in 1964 classified tide ranges as micro (≤ 2m,) meso (2-4m) and macro tidal - ≥6m). According to Davis (1985) tides play a passive or indirect role in sediment transport and changes in beach morphology. In the present study the selected beaches have high tide of 1.3m. So it is classified under micro tidal region.

The speed of long shore currents observed was lesser when compared to earlier studies. Samsuddin *et al.* (1987) observed high (0.1-0.5m/s) long shore current velocity in Northern Kerala coast including Dharmadam coast. As per present study the direction of long shore current in Dharmadam beach were towards north in pre monsoon season and post monsoon season, and towards south in monsoon season. In Fort Cochin beach the direction showed similar pattern as Dharmadam beach and onshore-offshore direction was also observed in post monsoon season. Kunte *et al.* (2001) observed upto 0.8m/s velocity in Calangute beach, Goa and 0.16 - 0.18m/s velocity in Mangalore coast. Both Samsuddin *et al.* (1987) and Kunte *et al.* (2001) observed southerly current in monsoon season boosted the erosion of beach sediment in Kerala coast. Saravanan *et al.* (2010) observed upto 0.8m/s velocity of long shore current along the south east coast of India. Present study showed lesser long shore current velocity when compared to above mentioned study.

The physical and chemical parameters also show much variation depending on the weather conditions. The physical and chemical parameters measured from the selected study sites showed variations. As both the beaches selected for the study having different ecological profiles, the abiotic factors also shows variations. Surface water temperature is subjective to the intensity of solar radiation, evaporation, freshwater influx, cooling and mixing

up with adjacent neritic waters (Ananthan *et al.,* 2005). The most varying parameters are mainly temperature and salinity. A change in air temperature leads to extremely hot condition to freezing condition. In tropical region extreme temperature variation is not common and in the present study the air temperature showed normal variation (25-33^{0}C). When compared to air temperature, surface sea water temperature also showed much similarity to the air temperature, indicating the influence of air temperature on surface water.

Temperature being an important factor influences the physico - chemical parameters of coastal water (Sundaramanickam *et al.,* 2008). At station 2 of Fort Cochin beach slight variation in temperature was observed when compared to station 1. In monsoon it showed lesser temperature in Fort Cochin beach. At Dharmadam beach also in monsoon, temperature showed slight variation. During monsoon season due to altered weather conditions and precipitation the temperature observed to be less. Precipitation was prominent in July (2009 and 2010) and in June (2010) in Kannur and Ernakulam district respectively. Generally temperature and dissolved oxygen showing inverse relationships. But in Dharmadam beach it showed opposite condition, dissolved oxygen value was high in pre monsoon season. During this season high temperature value was observed (31-32^{0}C). Pre monsoon maxima and monsoon minima were observed in many studies (Anathan *et al.,* 2005; Palanisami *et al.,* 2013; Sahu *et al.,* 2012). In Correlation analysis, temperature showed significant correlation with salinity (r = .506*) at 5% level in station 1 of Fort Cochin beach, reflecting direct proportionality of both parameters (Table 27). Neves (2006) observed sea water temperature range of 19-23^{0}C from the sandy beaches of southern Brazil. Caetano *et al.* (2003) also monitored similar range of sea water temperature from the sandy beach of

south eastern Brazil. When compared with the present study above mentioned range was lower. Tropical intertidal zones are exposed to above 40^0C, which is higher than temperate intertidal regions (Stillman, 2002).

Salinity is one of the most important factors in intertidal areas. Salinity variation can be occurring by precipitation, fresh water runoff and evaporation etc. pools of rocky beaches experiences sudden variations of temperature and salinity according to precipitation and evaporation. From the study sites it was observed that the salinity showed wide variations during seasons. Salinity at Fort Cochin beach showed a decreasing trend in September and November (2009) months. These are monsoon and post monsoon months and most of the months in monsoon and post monsoon season showed salinity values below 20ppt (mesohaline condition) in both the beaches. Precipitation is the main reason and during October, November months north east monsoon was prominent in Kerala. So high down pour received during these months, which lead to fluctuations in salinity. Ansell *et al.* (1972) also reported a sharp decrease in salinity at Cochin beach with the onset of monsoon. Mesohaline condition (5.68ppt) was observed at station 2 of Fort Cochin beach. Brackish water influx is more in station 2 when compared to station 1 as it is close to the Cochin estuary bar mouth area. Polyhaline condition (30.8ppt) in station 1 of Fort Cochin beach was observed during February 2010. According to Philip the sea water salinity range was 10-34ppt in Fort Cochin beach during 1970. During the present study the range of salinity was lesser than above mentioned study. Priyalakshmi (2008) observed low salinity value from interstitial water of Fort Cochin beach (19.2-30.5ppt). Present study also encountered similar observation in sea water salinity of Fort Cochin beach. At Dharmadam beach also low salinity was observed during October (2009) month

in station 2. High salinity was observed during April, 2010 at station 1 and September, 2010 at station 2 in Dharmadam beach. In both beaches in every seasons variations has been observed. This may be due to tidal action during those seasons. Fluctuations in salinity might occur during a tidal cycle or by heavy rains especially in tropics (Ingole & Parulekhar, 1998). In both the beaches annual and seasonal fluctuations of salinity were prominent. When compared with the study of Neves (2006) in sandy beaches of southern Brazil, the present study met with lower salinity range. He observed 32-34ppt salinity during his study while present study observed below 34ppt. Barboza *et al.* (2012) also described 34ppt water salinity from the sandy beach of South Atlantic Ocean (west coast). Oliff *et al.* (1970) too stated the high range of salinity fron the interstitial water of sandy beach in Africa. In station 1 of Fort Cochin beach salinity showed significant correlation with temperature and conductivity (r =.506*, 0.478* respectively) at 5% level (Table 27). In station 2 of Dharmadam beach salinity and TDS showed significant correlation (r = .725**) at 1% level (Table 30). Based on correlation analysis salinity and tide did not show any significant correlation between them except in station 1 of Dharmadam beach. In station 1, it showed significance at 5% level (r = .481*) (Table 33).

pH of the intertidal zone is an inevitable parameter for the biota, especially for shelled organisms. Various biological activities cause variations in pH (Gupta *et al.,* 1996). The range of pH from Fort Cochin was 6.59-8.25 at both the stations. Both the stations in December, 2009 showed its lowest pH (6.57 & 6.59). Based on the study by Philip (1970) the pH value was between 8-8.4 in Cochin beach. Monsoon season (2009) showed highest values of pH in both the beaches. This may due to discharge of industrial effluent in Fort Cochin beach. Effluents along with fresh water may induce the pH values.

Since the industrial revolution, average surface seawater pH has already been reduced by approximately 0.1 units (Laure Moulin *et al.,* 2011). The peak values in Dharmadam beach during monsoon season may due to fresh water flow with leaf litter from adjacent tidal channel. At Dharmadam beach the pH showed slight alkaline nature. This is mainly because of the high rate of calcium carbonate deposits of shelled organisms. Seawater is slightly basic due to buffering effect of carbonate salts. Ocean acidification may alter the pH condition and the fluctuations may affect the organism. Based on Haye *et al.* (2011) hermit crabs have affected the responses of the organisms due to fluctuated pH value of rocky pool. In station 1 of Fort Cochin beach pH showed significant correlation with turbidity (r = 0.640**) and significant negative correlation with dissolved oxygen (r = -0.600**) at 1% level (Table 27).

Dissolved oxygen in water of intertidal zones is chiefly saturated by addition of atmospheric oxygen with water. The availability of oxygen to the benthic infauna of intertidal areas is by capillary action through the sediment. The dissolved oxygen plays a major role in survival capacity of an organism. Dissolved oxygen is important for respiration of organisms. Variations and solubility of dissolved oxygen may be due to many factors like salinity, temperature, upwelling tides (Canadian water quality guidelines, 1999). Lowest DO observed was 3.06mg/l in September and October, 2009 at station 1 of Fort Cochin beach. DO below 4mg/l is considered to be somewhat detrimental to the fauna surviving in the area (Canadian water quality guidelines, 1999). At station 2 lowest observed value was 3.2mg/l (April, 2010). During these months at both the stations temperature was high (31^0C& 33^0C respectively). Elevated temperature decreases oxygen solubility in water. The inverse relationship between temperature and DO is natural process

(Paul *et al.,* 2006). Seasonally post monsoon season (2010) showed highest values in dissolved oxygen concentration in Fort Cochin beach, which could be due to rainfall and associated wind. In monsoon and post monsoon (2010) season, higher rainfall was reported in Ernakulam district (517mm- 849mm- based on IMD data). The fresh water inflow brings rich dissolved oxygen waters (Rajasegar, 2003). Higher value of DO in post monsoon season may be due to high tidal activity and windy monsoon conditions (Faragallah *et al.,* 2009). In Dharmadam beach pre monsoon season showed highest values of dissolved oxygen. It may be attributed to photosynthetic activity by phytoplankton during summer periods (Sahu *et al.,* 2012). Pre monsoon maxima of dissolved oxygen were reported in many studies (Rajagopalan *et al.,* 1992). Jack *et al.* (2009) observed high dissolved oxygen range in sandy coastal waters of Lybia (8.2 – 10.4mg/l). Priyalakshmi (2008) observed low DO values in seasonal observation from interstitial water of Fort Cochin beach (3.2-6mg/l), contrary to this present study met with higher DO range in seawater when compared to above stated study (4.03-7.7mg/l). In station 2 of Fort Cochin beach dissolved oxygen and salinity showed significant correlation at 5% level (r = 0.520*) (Table 28).

Carbon dioxide absorption is more in intertidal zones than open coastal systems due to more turbulent nature of intertidal area (Dileep kumar *et al.,* 1992). Fluctuations in carbon dioxide are more pronounced in intertidal areas. Carbon dioxide and pH is having inverse relationships. When carbon dioxide increases seawater pH decreases, that could be lead to ocean acidification. It may cause serious effects on biota, mainly for shelled organisms. The calcification rate decreases due to increased ocean acidification (Gattuso et al, 1998). In the present study carbon dioxide values showed variations.

Respirational activities may increase the carbon dioxide in water (Dileep kumar et al, 1992). Station 1 of Dharmadam showed higher value of carbon dioxide in monsoon month (August, 2009). During that time dissolved oxygen concentration was also found to be less. So it could be attributed to respiration of organisms. Monthly average of carbon dioxide values showed limited range but in some months it showed its peak (August, 2009 - Station 1, Dharmadam; February, 2010 –Station 1 and 2, Fort Cochin).

Conductivity and TDS (Total Dissolved Salts) are directly proportional. Conductivity and TDS showed significant correlation at 1% level (r = .967 ** 0.960**) in station 1 and 2 of Fort Cochin beach (Fig. 27 & 28). Conductivity and salinity showed significant correlation at 5% level in Fort Cochin and Dharmadam beach (r = .516* and .698* respectively). In station 2 of Dharmadam beach Conductivity and TDS also showed significant correlation (r = 0.634*) and conductivity and nitrate showed significant negative correlation (r = - 0.652**) at 1% level (Fig. 30). Bhadja *et al.* (2012) also observed high positive correlation between conductivity and TDS in Veraval and Mangrol coast as the present study. Conductivity is important to verify salinity in waters. Here also salinity showed significant correlation with conductivity and TDS in both the beaches. Salinity is a strong contributor to conductivity and dissolved ions in water. Boyd (1981) suggested that fluctuation in sea water conductivity was due to fluctuation in TDS and salinity. Conductivity values were higher in monsoon season (2010) than other seasons in Fort Cochin and post monsoon and monsoon (2009) seasons in Dharmadam beach. The high values of conductivity in monsoon season may be due to intense wave action in monsoon season. Study based on seawater quality in Gujarat coast (Bhadja *et al.,* 2012) observed the high values of conductivity in monsoon season as

the intense wave action of Arabian Sea. Rough tidal action may also vary conductivity values (Vaghela *et al.,* 2010). Andrade *et al.* (2011) reported high conductivity values (> 60µS/cm) when compared to the present study from Mangalore coast. The higher content of dissolved solids in monsoon season due to terrestrial and river runoff may also increase the conductivity of water. Both the beaches are occupied with adjacent water bodies. In monsoon season tidal channels bring fresh water and terrestrial effluents in Dharmadam beach.

TDS is the measure of total dissolved ions, so salinity has close relationship with TDS. In the present study also high positive correlation was observed between salinity, conductivity and TDS. If TDS is high above normal value it may be detrimental to the organism, mainly due to higher ion concentration in water. Monsoon season (2010) showed highest value of TDS in Fort Cochin beach. In Dharmadam beach monsoon and post monsoon season (2009) showed highest values of TDS. Increase of TDS in monsoon and post monsoon season could be attributed to runoff from adjacent system. Dharmadam beach holds rocky outcrops and weathering of rocks may also increase the TDS content in Dharmadam beach. Declined trend of TDS were observed during the study. Sea water has a TDS concentration of approximately 35g/l (Karthikeyan *et al.,* 2014). Present study also detected almost near TDS concentration. In Fort Cochin beach TDS values were higher when compared to Dharmadam beach. Agricultural runoff, industrial and sewage effluents increase the TDS in water (Yap *et al.,* 2011). Fort Cochin beach is exposed to industrial and sewage effluents and it may lead to high values of TDS than Dharmadam beach. TDS showed significant correlation with conductivity and salinity, indicating direct relationship between them.

Turbidity has an important relation with monsoon season because heavy rain and river run off increases mixing of water, thus turbidity of water increases. At Fort Cochin beach, the highest turbidity was monitored in monsoon months (August 2009 and September 2009). But in August 2010 turbidity was very less. Marked seasonal fluctuations were observed in Fort Cochin beach. At Dharmadam beach in August 2009 turbidity was high in both stations. In monsoon months mixing of water will be higher and runoff will be more pronounced. Higher turbidity values in monsoon and post monsoon season may be due to rainwater runoff during south west monsoon (Misra *et al.,* 2005). In the present study beaches are found to be sandy in nature. Clay and silt composition was found to be less. So less turbidity values were observed during the study. Silt and clay will be more suspended in water than sandy particle. In station 1 of Fort Cochin beach and Dharmadam beaches showed low dissolved oxygen during monsoon season in 2009. In intertidal mudflats of Tavy estuary,

UK, Uncles *et al.* (2000) observed high turbidity in that area. This area comprised of muddy mixture, dominated by silt and clay composition. Based on the study of Raghunathan *et al.* (2003), high turbidity reported from Gopnath and Maduva coast (713NTU). When compared to this present study showed lesser turbidity (Max. 53.6 NTU). Sawant *et al.* (2014) observed almost similar turbidity values (9 - 81NTU) from the beaches of Mumbai coast as the present study. Water was clear in both the beaches during sampling period except in monsoon season. Based on EPA (Report of Environmental Protection Agency, USA, 2012) higher turbidity reduces the amount of light penetrating water, which reduces photosynthesis and the production of DO. The increasing turbidity, may negatively affect animal populations due to less dissolved oxygen, causing breathing problem (Russell Argenal *et al.,* 2006).

Nutrients are chemical constituents that take part in essential role in the growth and whole functioning of an organism. Biogeochemical cycling of nutrients in coastal zones under land-ocean interactions is strongly accustomed by fluxes into, through, and out of rivers (Ospina-Alvarez *et al.,* 2013). Tidal flow, fresh water flow from land and seasons determines the distribution of nutrients in coastal water (Damotharan *et al.,* 2010). Phosphates may be limited in surface waters due to primary production (Prabhakaran, 2008). Increased phosphate concentration was observed during the study. In the present study a decreasing trend of phosphates from pre monsoon to monsoon was observed in Fort Cochin beach. Increased value of phosphates in pre monsoon season may be due to ebbing tide and weathering of rocks, which are carried by rivers, may also increase the concentration of phosphates. According to the study on Fort Cochin beach by Jayalakshmi *et al.,* 2000, monsoon season showed peak values of phosphate and nitrate whereas in the present study reverse condition was observed. Monsoon season showed lower phosphate concentration. Dynamic nature of sandy beaches was reflected in the study. In Dharmadam beach a decreasing trend of phosphate from post monsoon to pre monsoon was observed. Higher values of phosphates in monsoon and post monsoon season may be due to high terrigenous substance flow from the river runoff. Biological activities of organisms may decrease the phosphate content in water. Both the beaches are in connection with rivers nearby and river water influx may increase the phosphate content. Study of Dadar coast, Mumbai by Prabhu *et al.* (2009) were recorded high phosphates values ($\geq$8.5ppm). Joshi *et al.* (2013) also reported high values of phosphate from Mumbai coast ($\geq$ 17mg/l).

Silicate has prime importance in intertidal sandy zones as the dominance of silica in sand. Based on the study of Magni *et al.,* 2000 in lower intertidal zone of Japan, silicate value recorded was 5.2- 155µmole/l in sea water and they observed low silicate values in post monsoon season. Present study also illustrated somewhat similar silicate range (4.6-154µmole/l) in sea water. As the above mentioned study silicate value was lower in November, 2009, December and January (2010) months. For biological activities phytoplankton take silicates from water, thus decrease of silicate may occur (Ramakrishnan *et al.,* 1999). Peak values of silicate in station 1 and 2 were observed in monsoon season, 2009 and 2010 respectively. The variation of silicate in coastal water may due to mixing of fresh water with sea water (Purushothaman and Venugopalan, 1972) and biological activities of phytoplankton (diatoms and silicoflagellates) cause variation in silicate (Aston, 1980). In Dharmadam beach also monsoon season (2010) showed peak value of silicates. Terrigenous flow in monsoon season could be the reason for high values. In monsoon season both the beaches showed somewhat low salinity and this could be attributed to high silicate value. Many earlier studies observed high silicate values with low salinity (Magni *et al.,* 2006; Jayaraman, 1954; Ramamurthi, 1953). Seasonal studies showed a sudden fall in silicate concentration in post monsoon season. It may be attributed to increasing population density of phytoplankton (Anatharaj *et al.,* 2012).

Nitrate is the important nutrient for primary production in sea water. The present study observed peak values in post monsoon months (December, 2010 and January, 2011) in Fort Cochin beach and in monsoon month (September, 2009 and July, 2010) at Dharmadam beach. The higher values may be due to oxidation of ammonia (Grasshoff *et al.,* 1999; Rajasegar, 2003). In monsoon

season fresh water influx increased the level of nitrates in sea water. The increased nitrate level may be due to fresh water inflow and terrestrial run off (Santhanam *et al.,* 2003). Coastal upwelling may also increase the nitrate concentration. Nutrient supply in the Arabian Sea is mainly due to the seasonal upwelling processes (Sarangi, 2011). Higher nitrate concentration may be harmful to the organism. If nitrate and phosphate amount increases in water eutrophication occurs and water quality will be depleted (Environmental protection agency USA, 2012). In present study lower nitrate values were observed. Nitrate values were higher in Fort Cochin beach than Dharmadam beach. In Fort Cochin beach nitrate value ranged from 0.03-3.4µmole/l with post monsoon maxima. More or less similar observation was reported by Sahu *et al.,* 2012 in coastal waters of South East coast of India. He observed nitrate value of 0.26-3.7µole/l with maximum value in monsoon season. River discharge and human activities were more pronounced in Fort Cochin beach than Dharmadam beach. It could be the reason for slightly higher value of nitrate in Fort Cochin beach.

According to Dawes (1998) the concentration of nitrite in sea water is 0.01-3µg at/l. The present study also showed lesser value of nitrites. The study based on water quality in Cochin backwaters (Meera *et al.,* 2010) observed low nitrite values than nitrate. Higher value was observed in pre monsoon season in both the beaches. In monthly observations April, 2010 showed highest value in Dharmadam beach and station 1 of Fort Cochin beach. Nitrate and nitrite values showed similarities in the present study. The higher value of nitrites may be due to denitrification, oxidation and reduction of ammonia and nitrate and excretion of planktonic organisms also increase nitrite concentration in sea water (Govinadswami *et al.,* 2000). Based on the study of Jayalakshmi *et al.,* 2000 nitrite values showed irregular variations in Fort Cochin beach. In present study

also irregular variations in nitrate values were observed during monthly observations.

PCA was applied to monthly data against 12 water quality parameters. Principal Component Analysis (PCA) is a statistical method applicable to components that are linear combinations of the original variables (Garizi *et al.,* 2011). In PCA all five principal components were taken according to the percentage variation and eigen values were more than one in almost all the analysis. An important facet of PCA is the production of eigen values, which are the measure of the significance of the components: the components with the highest eigen values are chiefly significant. Also eigen values of 1.0 or larger are considered significant (Pejman *et al.,* 2009; Garizi *et al.,* 2011). From the principal component loadings it was observed that pH, salinity, conductivity, TDS, turbidity, nitrite and nitrate were the main variables in five principal components. These results enlightening the land use/cover relation of both the stations during months. It may be an indicator of anthropogenic activities in both stations. Nitrite and nitrate correlation in third and fifth components were indicated river discharge during the months.

In Dharmadam beach, PCA on water quality showed high loading of three variables, silicate, dissolved oxygen and turbidity. It showed negative correlation with TDS, phosphate, carbon dioxide and temperature. Forth component was correlated to turbidity and negatively correlated to nitrate and the axis going towards monsoon and post monsoon months. It indicated rainfall and mixing of water during those months. So it can be assumed that land use pattern did not exist in this beach whereas it indicating natural conditions and mineralization. From the above results it was observed that more anthropogenic activities during sampling months were observed in Fort

Cochin beach and less anthropogenic activities in Dharamadam beach during sampling months were observed.

In correlation analysis conductivity and TDS showed significant positive correlation in both the beaches, whereas the high positive correlation of conductivity and TDS in both stations of Fort Cochin beach indicating anthropogenically affected water quality status. This correlation result exactly complements with PCA results in Fort Cochin beach. In Fort Cochin beach the drafts man plot showed correlation between conductivity and TDS (0.956) (Fig. 69, Table 35). In Dharmadam beach conductivity and TDS showed correlation between each other (0.668) followed by salinity and TDS (0.602). Phosphate and temperature showed negative correlation (Fig. 70, Table 36).

Highlights

- Both the beaches are micro tidal region with semi diurnal tidal pattern.
- Water quality parameters showed marked seasonal fluctuations
- Spatial variation was comparatively less.
- pH and dissolved oxygen showed significant variation between station and month ($p < 0.05$)
- Significant correlation between salinity, conductivity and TDS were observed in various stations.
- Land use /cover pattern reflected in Fort Cochin area by PCA, indicating more anthropogenic activities.
- Normal conditions reflected in Dharmadam beach by PCA, indicating only climatic variations with less anthropogenic activities.

Correlation analysis of water quality parameters

Table 27 Correlation of water quality parameters of station 1 in Fort Cochin beach during 2009-2011

	Temperature	pH	Salinity	CO_2	DO	Conductivity	TDS	Turbidity	phosphate	Silicate	Nitrate	Nitrite
Temperature	1											
pH	.020	1										
Salinity	**.506***	-.271	1									
Co_2	.197	.004	.368	1								
DO	-.060	**-.600****	.259	-.154	1							
Conductivity	.128	-.038	**.478***	.227	-.089	1						
TDS	-.014	-.154	.464	.186	-.027	**.967****	1					
Turbidity	-.182	**.640****	-.421	.033	**-.571***	-.236	-.234	1				
Phosphate	.202	.021	.429	.462	-.332	.415	.380	-.066	1			
Silicate	-.456	.216	-.403	-.195	-.176	-.060	-.062	-.031	-.083	1		
Nitrate	.088	.267	-.004	-.157	.068	-.347	-.277	.179	-.308	-.209	1	
Nitrite	.055	-.103	-.109	.168	-.020	-.264	-.258	-.339	.153	.526*	.038	1

* Correlation is significant at the 0.05 level

Table 28 Correlation of water quality parameters of station 2 in Fort Cochin beach during 2009-2011

	Temperature	pH	Salinity	CO_2	DO	Conductivity	TDS	Turbidity	Phosphate	Silicate	Nitrate	Nitrite
Temperature	1											
pH	-.118	1										
Salinity	.347	-.144	1									
Co_2	.300	.149	.364	1								
DO	-.105	-.192	**.520***	.270	1							
Conductivity	.187	-.026	**.516***	.271	.267	1						
TDS	.087	-.007	**.514***	.294	.374	**.960****	1					
Turbidity	-.185	.403	.252	.303	.312	.093	.208	1				
Phosphate	.282	.172	**.511***	**.523***	.002	.138	.048	.273	1			
Silicate	-.200	.035	-.464	-.201	-.392	-.209	-.144	-.340	-.418	1		
Nitrate	-.117	.112	-.033	-.149	.212	-.039	-.119	-.332	-.274	.270		
Nitrite	.268	-.277	.100	.158	-.094	-.149	-.167	.026	.167	-.107	-.258	1

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level

Table 29 Correlation of water quality parameters of station 1 in Dharmadam beach during 2009-2011

	Temperature	pH	Salinity	Co_2	DO	Conductivity	TDS	Turbidity	Phosphate	Silicate	Nitrate	Nitrite
Temperature	1											
pH	-.072	1										
Salinity	.103	.375	1									
CO_2	-.409	-.041	-.254	1								
DO	.160	-.245	.062	**-.478***	1							
Conductivity	.336	.211	**.698****	-.177	-.278	1						
TDS	-.103	.187	**.568***	-.002	-.134	**.730****	1					
Turbidity	-.350	.207	-.248	.446	-.293	**-.508***	-.454	1				
Phosphate	.067	.191	.175	.025	.102	-.077	-.203	.250	1			
Silicate	**-.546***	-.154	-.355	-.096	.104	**-.561***	-.199	.297	-.196	1		
Nitrate	.033	.285	.255	.018	-.213	.191	.044	-.184	.202	-.146	1	
Nitrite	**.471***	.140	.028	-.071	-.008	.044	-.112	.268	-.196	-.151	-.203	1

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level

Table 30 Correlation of water quality parameters of station 2 in Dharmadam beach during 2009-2011

	Temperature	pH	Salinity	Co_2	DO	Conductivity	TDS	Turbidity	phosphate	Silicate	Nitrate	Nitrite
Temperature	1											
pH	.131	1										
Salinity	-.077	.394	1									
CO_2	-.140	.019	.159	1								
DO	-.046	-.375	.053	-.145	1							
Conductivity	.442	.257	.394	-.303	-.384	1						
TDS	-.108	.192	**.725****	-.024	-.246	**.634****	1					
Turbidity	**-.547***	-.198	-.045	-.122	-.224	.172	.175	1				
Phosphate	.182	.147	-.250	-.082	.001	-.119	-.342	-.195	1			
Silicate	**-.667****	-.261	-.107	.043	.119	**-.552***	-.181	.159	-.216	1		
Nitrate	-.357	.188	.030	.131	.209	**-.652****	-.145	-.316	.291	**.469***	1	
Nitrite	.415	-.202	.034	-.176	.009	.306	.232	-.008	-.108	-.234	-.293	1

*Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Table 31 Correlation between salinity and tide in station 1 of Fort Cochin beach during 2009-2011

		Salinity	Tide
Salinity	Pearson Correlation	1	-.314
Tide	Pearson Correlation	-.314	1

Table 32 Correlation between salinity and tide in station 2 of Fort Cochin beach during 2009-2011

		Salinity	Tide
Salinity	Pearson Correlation	1	-.021
Tide	Pearson Correlation	-.021	1

Table 33 Correlation between salinity and tide in station 1 of Dharmadam beach during 2009-2011

		Salinity	Tide
Salinity	Pearson Correlation	1	**.481***
Tide	Pearson Correlation	**.481***	1

Table 34 Correlation between salinity and tide in station 1 of Dharmadam beach during 2009-2011

		Salinity	Tide
Salinity	Pearson Correlation	1	.067
Tide	Pearson Correlation	.067	1

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

4.6 Draftsman plot

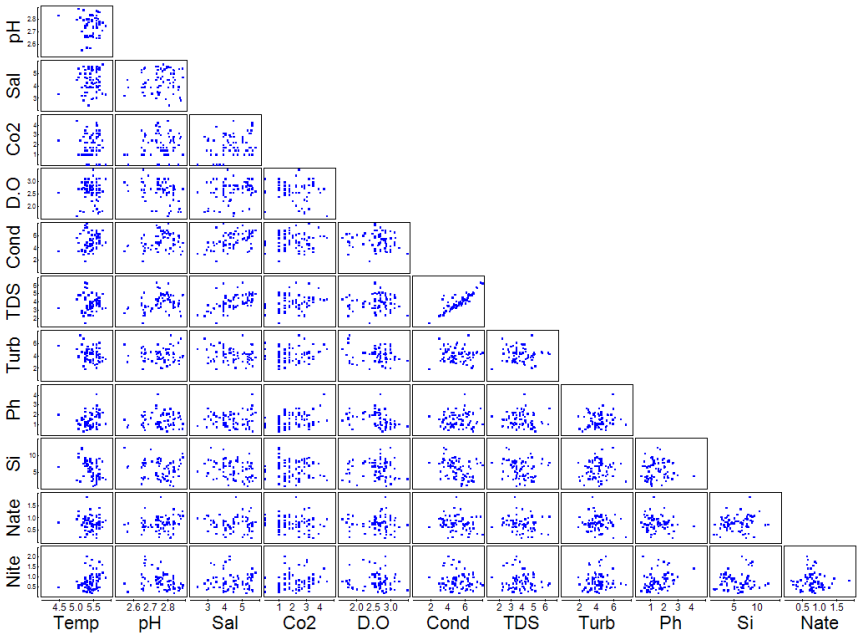

Figure 69 Draftsman plot showing correlation between water quality parameters in Fort Cochin beach during 2009-2011

Table 35 Correlation table of Draftsman plot in Fort Cochin beach during 2009-2011

	Temperature	pH	Salinity	Co_2	DO	Conductivity	TDS	Turbidity	Phosphate	Silicate	Nitrate
Temperature											
pH	-0.027										
Salinity	0.351	-0.122									
Co_2	0.191	0.086	0.389								
DO	-0.098	-0.447	0.373	0.031							
Conductivity	0.130	0.163	0.446	0.268	0.060						
TDS	0.015	0.121	0.445	0.276	0.124	**0.956**					
Turbidity	-0.130	0.457	-0.084	0.151	-0.120	0.077	-0.025				
Phosphate	0.223	0.121	0.443	0.509	-0.173	0.183	0.131	0.148			
Silicate	-0.246	0.056	-0.350	-0.096	-0.288	-0.053	-0.065	-0.251	-0.135		
Nitrate	-0.042	0.095	0.050	-0.140	0.143	-0.122	-0.152	-0.137	-0.191	0.061	
Nitrite	0.180	-0.287	0.074	0.152	-0.033	-0.156	-0.143	-0.117	0.122	0.126	-0.168

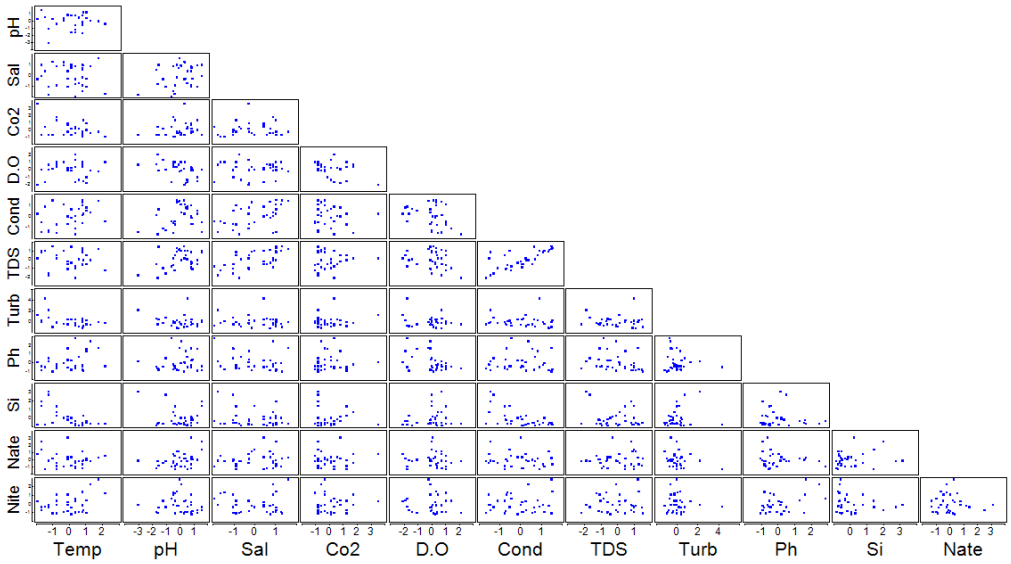

Figure 70 Draftsman plot showing correlation between water quality parameters in Dharmadam beach during 2009-2011

Table 36 Correlation table of Draftsman plot in Dharmadam beach during 2009-2011

	Temperature	pH	Salinity	Co_2	DO	Conductivity	TDS	Turbidity	Phosphate	Silicate	Nitrate
Temperature											
pH	-0.042										
Salinity	-0.304	0.284									
Co_2	0.083	0.102	-0.010								
DO	0.379	-0.420	0.031	-0.379							
Conductivity	-0.094	0.291	0.425	-0.208	-0.294						
TDS	-0.428	0.334	**0.602**	-0.005	-0.183	**0.668**					
Turbidity	0.260	-0.185	-0.062	0.106	-0.234	-0.075	-0.048				
Phosphate	**-0.600**	0.086	-0.248	0.013	-0.435	0.027	-0.245	-0.091			
Silicate	-0.118	-0.170	-0.172	-0.015	0.126	-0.571	-0.189	0.198	-0.070		
Nitrate	0.375	0.363	0.119	0.057	-0.054	-0.095	0.068	-0.269	-0.137	0.207	
Nitrite	-0.042	-0.127	-0.053	0.029	-0.027	0.041	0.027	-0.015	0.412	-0.137	0.024

References

Adam, P., 1990. Saltmarsh Ecology, Cambridge University Press: Cambridge.

Alenius, B. and Munguia, P., 2012. Effects of pH variability on the intertidal isopod, *Paradella dianae*. *Mar. Freshw. Behav. Physiol*., 45: 245-259pp.

Alongi, D.M., 1998. Coastal Ecosystem Processes. New York, USA: CRC Press, 419 pp.

Ananthan, G., Sampathkumar, P. Palpandi, C. and Kannan, L., 2005. Distribution of heavy metals in Vellar estuary, South east coast of India. *J. Ecotoxicol. Environ. Monit.,* 16: 185-191pp.

Anantharaj, K., Govindasamy, C., Natanamurugaraj, G. and Jeyachandran, S., 2012. Characteristics of Water Quality in the Palk Strait, South east Coast of India. *World Journal of Agricultural Sciences,* 8 (5): 525-528pp.

Andersen, F. O., Helder, W., 1987. Comparison of oxygen microgradients, oxygen flux rates and electron transport system activity in coastal marine sediments. *Mar. Ecol. Prog. Ser*., 37: 259-264pp.

Ansell, A.D., Sivadas, P., Narayanan, B., and Trevallion, A., 1972. The ecology of two sandy beaches in South West India. 11. Notes on *Emerita holthuisi*. *Marine Biology*, 17: 311-317pp.

Anxo Conde, Novais, J.M., Dominguez, J., 2013. Distribution of Intertidal macrobenthic assemblages in relation to environmental factors in the Tagus estuary, Western Portugal. *Scientia Marina*, 77: 179-198pp.

Arash Javanshir, 2013. How Salinity Changes in an Intertidal Zone May Affect Population Dynamics of *Littorina scabra* (Linaeus 1758) in Northern Coasts of Persian Gulf. *Turkish Journal of Fisheries and Aquatic Sciences,* 13: 133-138pp.

Aston, S.R., 1980. Nutrients dissolved gases and general biochemistry in estuaries, In E. Olausson and I. Cato (Eds.), Chemistry and Biogeochemistry of Estuaries, New York, Wiley, 233-262pp.

Badhja, P. and Kundu, R., 2012. Status of seawater quality at few important industrial coasts of Gujarat India off Arabian Sea. *Indian Journal of Marine Science*, 41 (1): 954 – 961pp.

Baillie, P. W., 1986. Oxygenation of intertidal estuarine sediments by benthic microalgal photosynthesis. *Estuar. coast. Shelf Sci*., 22: 143-149pp.

Berger, V.J. and A.D. Kharazova., 1997. Mechanisms of Salinity Adaptations in Marine Molluscs. *Hydrobiologia,* 355 (1-3): 115-126pp.

Billen, G., 1978. A budget of nitrogen recycling in North Sea sediments off The Belgian coast. *Estuar. coast. Mar. Sci.,* 7: 127- 146pp.

Boyd, C.E., 1981. Water quality in warm water fish ponds. Craftmaster Printers. Inc. Albana.

Boynton, W.R., Kemp, W.M. and Osborne, C.G., 1980. Nutrient fluxes across the sediment-water interface in the turbid zone of a coastal plain estuary. in: Estuarine perspectives. V.S. Kennedy, editor, Academic Press, New York, 93-109pp.

Brierley, A.S., Kingsford, M.J., 2009. Impact of climate change on marine organisms and ecosystems. *Cuurent Biology*, 19: 602-614pp.

Brotas, V., Amorimferreira, A., Vale, C. and Catarino, F., 1990. Oxygen profiles in intertidal sediments of Ria Formosa (S Portugal). *Hydrobiologia,* 207: 123–129pp.

Brown, A.C., McLachlan, A., 1990. Ecology of sandy shores. *Elsevier*, Amsterdarn, 392pp.

Caetano, M., Madureira, M.J.and Vale, C., 2003. Metal remobilization during resuspension of anoxic contaminated sediment: Short-term lab study. *Water Air Soil Pollut.* 143: 23–40pp.

Callender, E, Harnmond, D.E., 1982. Nutrient exchange across the sediment-water interface in the Potomac River Estuary. *Estuar Coast Shelf Sci.,* 15:395-413pp.

Canadian Council of Ministers of the Environment (CCME), 1999. Canadian Environmental Quality Guidelines. Ottawa, Canada.

Ceballos-Osuna, L., Carter, H. A., Miller, N. A. and Stillman, J. H., 2013. Effects of ocean acidification on early life-history stages of the intertidal porcelain crab *Petrolisthes cinctipes. The Journal of Experimental Biology,* 216: 1405-1411pp.

Chapman, D., 1992. Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition. E&FN, an imprint of Chapman & Hall, University Press, Cambridge, 609pp.

Crain, C.M., Silliman, B.R., Bertness, S.L., Bertness, M.D., 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. *Ecology*, 85: 2539–2549pp.

Crisp, D. J., 1957. Effect of low temperature on the breeding of marine animals. *Nature*, Lond., 166: 311-312pp.

Damotharan, P., Perumal, N.V. and Perumal, P., 2010. Seasonal variation of physico-chemical characteristics of Point Calimere coastal waters (South east coast of India). *Middle-East J. Sci. Res*., 6(4): 333-339pp.

Dando, M. and Burchette, M., 1996. Sealife: A complete guide to the marine environment. Smithsonian Institution press, Washington D.C.

Daniel, R. Pratt, Conrad, A. Pilditch, Andrew, M. Lohrer, Simon, F. Thrush., 2013. The effects of short term increases in turbidity on sandflat microphytobenthic productivity and nutrient fluxes. *Journal of sea research*, 92: 170-177pp.

Davies, J.L., 1964. A morphogenic approach to world shorelines. *Z. Geomorphologie*. 8: 127 – 142pp.

Davis, J.C., 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. *J. Fish. Res. Board Can*. 32 (12): 2295-2332pp.

Davis, R.A., 1985. Beach and nearshore zone, *Coastal Sedimentary Environments*. New York: Springer-Verlag, 379-444pp.

Dawes, C. J., 1998. Marine Botany. New York: John Wiley and Sons, Inc., 480pp.

Dayton, P.K., 1971. Competition, disturbance, and community organisation. The provision and subsequent utilization of space in a rocky intertidal comrnunity. *Ecol Monogr*., 41 351 -389pp.

De la Haye, K.L., Spicer, J.I., Widdicombe, S., Briffa, M., 2011. Reduced seawater pH disrupts resource assessment and decision making in the hermit crab *Pagurus bernhardus*. *Anim. Behav*., 82 (3): 495–501pp.

Deschaseaux, E., Taylor, A., Maher, W., Davis, A., 2010. Cellular responses of encapsulated gastropod embryos to multiple stressors associated with climate change. *J Exp Mar Biol Ecol.,* 383:130–136pp.

Environmental Protection Agency, 2012. Guidelines for water reuse. Washington, USA, 618pp.

Faragallah, H.M., Askar, A.I., Okbah, M.A., and Moustafa, H.M., 2009. Physico chemical characteristics of the open Mediterranean Sea water far about 60 km from Damietta harbor, Egypt. *J. Ecolo. Nat. Environ*., 1, 106-119pp.

Francis Andrade, Aravinda, H.B. and Puttaiah, A.T., 2011. *Indian Journal of Science and Technology*, 4; 553-557pp.

Francis R Barboza, Gomez, J., Lercari, D. and Defeo, O., 2012. Disentagling diversity patterns in sandy beaches along environmental gradients. *Plos one*, 7(7).

Garizi, A. Z., Sheikh, V. and Sadoddin, A., 2011. Assessment of seasonal variations of chemical characteristics in surface water using multivariate statistical methods. *International Journal of Environmental Science and Technology*, Vol. 8, No. 3, 581-592pp.

Gattuso, J. P., Allemand, D., and. Frankignoulle, M., 1999. Photosynthesis and calcification at cellular, organismal and community levels in coral reefs: A review on interactions and control by carbonate chemistry. *Am. Zool.,* 39: 160–183pp.

Gattuso, J. P., Frankignoulle, M., Bourge, I., Romaine, S., and Buddemeier, R.W., 1998. Effect of calcium carbonate saturation of seawater on coral calcification. *Glob. Planet. Chang*., 18: 37–46p.

Gideiri, Y.B.A., 1984. Impact of mining in Central Red sea. Deep Sea Res., 31: 823-827pp.

Govindasamy, C., Kannan, L. and Jayapaul Azariah, 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel Coast, India. *J. Environ. Biol*., 21, 1-7pp.

Grasshoff, K., Ehrdardt, M., Kremling, K., and Anderson, L. G., 1999. Methods of seawater analysis. Wiley.

Gupta, R.K., Sharma, M., Gorai, A.C. and Pandey, P.N., 1996. Impact of Coal Mining Effluents on the physico-chemical charactericts of Raja Tank, Jaria (Dhanbad). *J. Freshwater Biol.,* 8(2): 63-73pp.

Hallfors, G., Kangas, P., Lappalamen, A., 1975. Littoral benthos of the northern Baltic Sea. 111. Macrobenthos of the hydrolittoral belt of filamentous algae on rocky shores in Tvarminne. *Int. Revue ges. Hydrobiol*., 60 (3): 313-333pp.

Hopkinson, C.S. Jr., 1987. Nutrient regeneration in shallow water sediment of the estuarine plume region of the nearshore Georgia Bight, USA. *Mar. Biol*., 94: 127-142pp.

Hutchinson, G.E., 1957. A Treatise on Limnology. *L Geography, Physics and Chemistry*, John Wiley and Sons, New York, 1015 pp.

Hylleberg, J., 1975. Selective feeding by *Abarenicola pacifica* with notes on *Abarenicola vagabunda* and a concept of gardening in lugworms. *Ophelia,* 14: 113pp.

Ingole, B.S. Parulekar, A.H., 1998. Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence. *Indian Journal of Marine Sciences*, 27: 356-361pp.

Isaac, W. E. 1938. The geographical distribution of seaweed vegetation in relation to temperature and other factors, with special reference to South Africa. *C. r Congr. int. Geogr.,* Amsterdam 2 (7): 12-28pp.

James C. Orr, Victoria J. Fabry, Olivier Aumont, Laurent Bopp, Scott C. Doney, Richard A. Feely, Anand Gnanadesikan, Nicolas Gruber, Akio Ishida, Fortunat Joos, Robert M. Key, Keith Lindsay, Ernst Maier-Reimer, Richard Matear, Patrick Monfray, Anne Mouchet, Raymond G. Najjar, Gian-Kasper Plattner, Keith B. Rodgers[1], Christopher L. Sabine, Jorge L. Sarmiento, Reiner Schlitzer, Richard D. Slater, Ian J. Totterdell, Marie-France Weirig, Yasuhiro Yamanaka and Andrew Yool, 2005. Anthropogenic ocean acidification over the twenty first century and its impact on calcifying organisms. *Nature*, 437: 681-686pp.

Jaramillo, E., McLachlan, A., Coetzee, P., 1993. Intertidal zonation patterns of macroinfauna over a range of exposed sandy beaches in south-central Chile. *Mar Ecol Prog Ser*., 101:105-118pp.

Jayalakshmy, K.V., Raveendran, O. and Sreeja, S., 2000. Seasonal Variation of the Environmental Parameters along Fort Cochin Beach. *Fish. Technol*., 37-98pp.

Jayaraman, R., 1954. Seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam (S. India). *Indian J. Fish*., 1: 345-64pp.

Jensen, S.L., Muller-Parker, G., 1994. Inorganic nutrient fluxes in anemone-dominated tide pools. *Pac. Sci*., 48, 32–43pp.

Joel Prashant Jack, Amal Tahir Abdsalam and Naima Saad Khalifa, 2009. Assesment of dissolved oxygen in coastal waters of Benghazi, Libya. *J. Black Sea/Mediterranean Environment*, 15: 135-156pp.

Johnston, E.L. and Keough M. J., 2002. Direct and Indirect effects of repeated pollution events on marine hard- substrate assemblages. Ecol. Appl., 12: 1212- 1228pp.

Karthikeyan, K., Devi, V., Lekameera, R., Nandhagopal, G., Mehta,P.N., and. Thivakaran, G.A., 2014. Water and sediment quality characteristic near an industrial vicinity, Vadinar, Gulf of Kutch, Gujarat, India. *International journal of plant, animal and environmental science*, 4: 219-226pp.

Kemp, W. M., Sampou, P., Caffrey. J., Mayer. M., Henriksen. K. and Boynton, W. R., 1990. Ammonium recycling versus denitrification in Chesapeake Bay sediments. *Limnol Oceanogr*. 35: 1545-1563pp.

Kingsbury, J. M., 1962. The effect of waves on the composition of a population of attached marine algae. *Bull. Torrey Bot. Club,* 89 (3): 143-160pp.

Kneib, R.T., 1984. Patterns of invertebrate distribution and abundance in the intertidal salt marsh: causes and questions. *Estuaries,* 7: 392–412pp.

Kumar, M. D., Rajendran, A., Somasundar, K., Ittekkot, V. and Desai, B. N., 1992. Processes controlling carbon components in the Arabian Sea. In: Oceanography of the Indian Ocean. (B N Desai editor) (Oxford & IBH, New Delhi), 313-325pp.

Leanna O' Grady, 2002. Effects of distance, volume, salinity on a gastropods in tidepools. Marine ecology/Bahamas.

Lewis, J. R., 1964. Ecology of rocky shores. The English Universities Press Ltd, London.

Lindeboom, H. J., Klerk, H. A. J. and Sandee, A. J. J., 1984. Mineralization of organic carbon in the sediment of Lake Grevelingen. *Neth. J. Sea Res*. 18: 492-510pp.

Magni, P., Como, S., Montani, S., Tsutsumi, H., 2006. Interlinked temporal changes in environmental conditions, chemical characteristics of sediments and macrofaunal assemblages in an estuarine intertidal sandflat (Seto Inland Sea, Japan). *Marine Biology*, 149: 1185–1197pp.

Magni, P., Montani, S., 2000. Physical and chemical variability in the lower intertidal zone of an estuary in the Seto Inland Sea, Japan: seasonal patterns of dissolved and particulate compounds. *Hydrobiologia,* 432: 9–23pp.

McLachlan, A. and Jaramillo, E., 1995. Zonation on sandy beaches. *Oceanography and Marine Biology: An Annual Review,* 33, 305–335pp.

McLachlan, A., 1990. Dissipative beaches and macrofauna communities on exposed intertidal sands. *J Coast Res.,* 6: 57-67pp.

McLachlan, A., 1996. Physical factors in benthic ecology: effects of changing sand grain size on beach fauna. *Mar Ecol Prog Ser*., 131:205-217pp.

McLachlan, A., Jaramillo, E., Donn, T.E., Wessels, F., 1993. Sandy beach macrofauna communities and their control by the physical environment: a geographical comparison. *J Coast Res.,* 15:27-38.

McQuaid, C. D. and Branch, G. M., 1984. Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: an analysis of faunal and floral biomass. *Mar. Ecol, prog. Ser.* 19: 145-151pp.

Meera, S. and Bijoy Nandan, S., 2010. Water quality status and primary productivity of Valanthakad Backwater in Kerala. *Ind.J. of Mari. Sci*., 39 (1): 105-113pp.

Misra, S. and Kundu, R., 2005. Seasonal variations in population dynamics of key intertidal molluscs at two contrasting locations. *Aquatic Ecology*. 39: 315-324pp.

Moulin, L., Catarino, A.I., Claessens, T., Dubois, P., 2011. Effects of seawater acidification on early development of the intertidal sea urchin *Paracentrotus lividus* (Lamarck 1816). *Mar. Pollut. Bull*. 62: 48–54pp.

Neves, F. M. and Bemvenuti, C. E., 2006. Spatial distribution of macrobenthic fauna on three sandy beaches from northern Rio Grande do Sul, southern Brazil. *Braz. J. Oceanogr*., 54; 135-145pp.

Nixon, S. W., 1981. Remineralisation and nutrient cycling in coastal marine ecosystems. in: Estuaries and nutrients, B.J. Neilson and LE., Humana Press, Clifton, New Jersey, 111-113pp.

Nixon, S. W., Oviatt, C. A., Hale, S. S., 1976. Nitrogen regeneration and the metabolism of coastal marine bottom communities. In: Anderson, J. M., Macfayden, A. (eds.). The role of aquatic organisms in decomposition processes. Blackwell Scientific Publ., Oxford, 269-283pp.

Norris, R.H., Lake, P.S. and Swain, R., 1982. Ecological effects on mine effluents on the South Elk river, Northeastern Tasmania. *Aust J Mar Freshwater Res*., 33: 789-810pp.

Oliff, W. D., Gardner, B. D., Turner, W. D. and Sharp, J. B., 1970. The chemistry of the interstitial water as a measure of conditions in a sandy beach. *Wat. Res*. 4. 179-188pp.

Ospina-Alvarez, N., Caetano, M., Vale, C., Santos-Echeandía, J., Bernárdez, P. and Prego, R., 2013. Exchange of nutrients across the sediment-water interface in intertidal Ria systems (SW Europe). *Journal of Sea Research*, doi: 10.1016/j.seares.2013.07.002.

Palanisamy, S.K., and Anisa, B.K., 2013. The distribution and diversity of macroinvertebrate fauna in Pondicherry mangroves, India. *Aquatic Biosysytems*, 9: 15.

Parulekar, A.H., Ansari, Z.A. and Ingole, B.S., 1986. Effect of mining activities on the clam fisheries and bottom fauna of Goa estuaries. *Proc. Indian. Acad.Sci.(Anim.Sci.)*, 95: 325-339pp.

Paul, D.K. and Mukherji, P., 2006. A preliminary study of physico chemical characteristic of a perennial fish pond, *J. Hemat,Ecotoxic*., 1;4-56pp.

Pejman, A.H., Bidhendi, G. R. N., Karbassi, A. R., Mehrdadi, N. and Bidhendi, M.E., 2009. Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environmental Science and Technology*, Vol. 6, No. 3, 467-476pp.

Péqueux, A., 1995. Osmotic regulation in crustaceans. *J. Crust. Biol*., 15: 1- 60pp.

Peterson, C.H., 1979. The importance of predation and competition in organizing the intertidal epifaunal communities of Barnegat lnlet, New Jersey. *Oecologia* 39: l-24pp.

Philip, K. P., 1970. The intertidal fauna of the sandy beaches of Cochin. *Proceedings of the Indian National Science Academy*, 38 (B): 317-328pp.

Prabhakaran, M.P., 2008. Ecological studies on the sea grass ecosystem of Minicoy Lagoon, Lakshadweep. Ph.D thesis, Cochin University of Science and Technology, 327pp.

Pravin D Kunte and Wagle, B. G., 2001. Littoral transport studies along west coast of India. IJMS, 30; 57-64pp.

Priyalakshmi, G., 2008. Studies on the taxonomy of interstitial fauna of some prominent beaches of Kerala. *Ph.D Thesis*, Cochin University of Kerala, 327pp.

Purushothaman A., and Venugopalan, V.K., 1972. Distribution of dissolved silicon in the Vellar estuary, *Indian Journal of Marine Sciences*, 1:103-105pp.

Raghunathan, C., Tewari, A., Joshi, H.V., Sravan Kumar, V.G., Trivedi, R.H. and Yasmin Khambhati, 2003. Impact of turbidity on intertidal macrofauna at Gopnath, Madhuva and Veraval coasts (west coast of India). *Indian Journal of Marine Sciences,* 32(3): 214-221pp.

Rajagopalan, M.S., Thomas Mathew, P.A., Naomi, K.J., Kaladhran, P., Balachandran, V.K. and Geetha Antony, 1992. Productivity of the Arabian Sea along the south west coast of India. *Bull. Cent. Mar. Fish. Res. Inst.*, 45: 9-37pp.

Rajasegar, M., 2003. Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *J. Environ. Biol.,* 24,: 95-101pp.

Ralph Gordon Johnson, 1967. Salinity of interstitial water in a sandy beach. *Limnology and Oceanography,* Vol.12. No.1.

Ramachandra, T. V. and Solanki, M., 2007. Ecological Assessement of Lentic Water Bodies of Bangalore. *Envis Technical Report: 25*, Indian Institute of Science, Bangalore.

Ramakrishnan, R., Perumal, P., and Santhanam, P., 1999. Spatio-temporal variations of hydrographical features in the Pichavaram mangroves and Mohi aqua farm, South east coast of India. *Proc. Intl. Sem. Appl. Hydrogeochem*., 197-203pp.

Ramamurthy, S., 1953. Seasonal changes in the hydrogen-ion concentration and dissolved oxygen content of the surface waters of the Madras Coast. *J. Madras Univ*., 23 B (10): 52-60pp.

Revsbech, N. P., Jorgensen, B. B. and Blackburn, T. H., 1980. Oxygen in the sea bottom measured with a microelectrode. *Science,* 207: 1355-1356pp.

Russel, A. and Robert, G., 2006. The Effects of Turbidity on Dissolved Oxygen Levels in Various Water Samples. *California State Science Fair,* Proj.No.S0602.

Sahu, G., Satpathy, K.K., Mohanty, A.K. and Sarkar, S.K., 2012. Variations in community structure of phytoplankton in relation to physico-chemical properties of coastal waters, south east coast of India. *Indian J. Geo Mar. Sci.,* 41(3): 223-241pp.

Samsuddin, M and Suchindan, G.K., 1987. Beach erosion and accretion in relation to seasonal long shore current variation in the Northern Kerala coast, India. *Journal of Coastal Research*, 31; 55-62pp.

Sanjay Prabhu and Neelima Kulkkarni, 2009. Assessement of water quality at Dadar beach, Mumbai, Maharashtra, West Coast of India. *Bionano Frontier,* 3; 59-63pp.

Santhanam, P. and Perumal, P., 2003. Diversity of zooplankton in Parangipettai coastal waters, south east coast of India. *J. Mar. Biol. Assoc. India*, 45: 144-151pp.

Sarangi, R.K., 2011. Remote-sensing-based estimation of surface nitrate and its variability in the southern peninsular Indian waters. *International Journal of Oceanography*, 16pp.

Saravanan, S and Chandrasekar, N., 2010. Potential littoral sediment transport along the South Eastern Coast of India. *Earth Sci. Res. J.*, 14; 2.

Saritha Joshi, Priyanka Tambe, Gayatri Oak and Poonam Kurve, 2013. To study molluscan shells diversity of two fun beaches of Mumbai, Maharashtra. *National Conference on Biodiversity: Status and Challenges in Conservation*, 131-137pp.

Shashikant N. Sawant and Prashant P. Bhave, 2014. Impact of pollution on marine environment – a case study of coastal Mumbai. *International Journal of Advanced Technology in Engineering and Science.* 2; 182-188pp.

Shock, B., Foran, C., Stueckle, T., 2009. Effects of salinity stress on survival, metabolism, limb regeneration, and ecdysis in *Uca pugnax*. *J Crustacean Biol.,* 29:293–301pp.

Silverberg, N., Bakker, J., Edenborn, K. M. and Sundby, B., 1987. Oxygen profiles and organic carbon fluxes in Laurentian Trough sediments. *Neth. J. Sea Res.,* 21: 95-105pp.

Singh, R.P. and Mathur, P., 2005. Investigations of variations in physico-chemical characteristic of a fresh water reservoir of Ajmer city, Rajasthan. *Ind.J. Env. Sci.,* 9: 57 – 61pp.

Southward, A. J., 1955. On the behaviour of barnacles. l. The relation of cirral and other activities to temperature. *J. mar. biol. Ass. U. K.,* 34: 403-422pp.

Southward, A. J., 1958. Note on the temperature tolerance of intertidal animals in relation to environmental temperatures and geographical distribution. *J, mar. biol. ASS. U. K.,* 37: 49-66pp.

Steele, D.H., 1983. Marine ecology and zoogeography. In: South, G. R. (ed.). Biogeography and Ecology of the Island of Newfoundland. Dr. W. Junk Publishers, The Hague, 421-465pp.

Stephenson, T. A., 1944. The constitution of the intertidal fauna and flora of South Africa. Part 11, *Ann. Natal Mus.,* l0 (3): 261-358pp.

Stillman, J.H., 2002. Causes and consequences of thermal tolerance limits in rocky intertidal porcelain crabs, genus *Petrolisthes*. *Integr Comp Biol,* 42:790 –796pp.

Studer, A., Poulin, R., 2012. Effects of salinity on an intertidal host parasite system: is the parasite more sensitive than its host?. *J Exp Mar Biol Ecol.,* 412:110–116pp.

Sundaramanickam, A., Sivakumar, T., Kumaran, R., Ammaiappan, V. and Velappan, R., 2008. A comparative study of physico-chemical investigation along Parangipettai and Cuddalore coast. *J. Environ. Sci. Technol*., 1(1): 1-10pp.

Tablado, A, Lopez Gappa, J.J, Magaldi, N.H., 1994. Growth of the pulmonate limpet *Siphonaria lesson* (Blainville) in a rocky intertidal area affected by sewage pollution. *J Exp Mar Biol Ecol.,* 175: 211–226pp.

Ueda, N., Tsutsumi, H., Yamada, M., Hanamoto, K., and Montani, S., 2000. Impacts of oxygen-deficient water on the macrobenthic fauna of Dokai Bay and on adjacent intertidal flats, in Kitakyushu, Japan, *Mar. Pollut. Bull*., 40: 906–913pp.

Ulf Riebesell , Ingrid Zondervan, BjoÈrn Rost, Philippe D. Tortell, Richard E. Zeebe and Francois M. M. Morel., 2000. Reduced calcification of marine plankton in response to increased atmospheric CO_2. *Nature,* 407: 364-367pp.

Unanam, A.E. and Akpan, A.W., 2006. Analysis of physico chemical characteristics of some fresh water bodies in Essien Udim local government area of Akwalbom state, Nigeria. In: Proceeding of the 21st Annual conference of the Fisheries Society of Nigeria (F150N) Calabar, 13-17th November.

Uncles, R.J., Frickers, P.E., Easton, A.E., Griffiths, M.L., Harris, C., Howland, R.J.M., King, R.S., Morris, A.W., Plummer, D.H. and Tappin, A.D., 2000. Concentrations of suspended particulate organic carbon in the tidal Yorkshire Ouse River and Humber Estuary. *Science of the Total Environment,* 251/252, 233-242pp.

Vaghela, A., Bhadja, P., Ramoliya, J., Patel, N. and Kundu, R., 2010. Seasonal variations in the water quality, diversity and population ecology of intertidal macrofauna at an industrially influenced coast. *Water Science and Technology*, 61(6): 1505-1514pp.

Wheatley, M.G., 1988. Integrated responses to salinity fluctuations. *American zoologist*, 28: 65-77pp.

Yap, C. K., Chee, M. W., Shamrina, S., Edward, F. B., Chiew, W., and Tan, S. G., 2011. Assessment of Surface Water Quality in the Malaysian Coastal Waters by Using Multivariate Analyses. *Journal of Sains Malaysiana,* 40: 1053-1064pp.

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Chapter 5

SEDIMENT CHARACTERISTICS

Contents

5.1 Introduction

Intertidal sediments occupy a unique position between land and sea (Jickells *et al.,* 1998). Intertidal sediments are a part of sediment system that has helped to maintain productivity of the coastal zone via the storage and recycling of nutrients which were imported from offshore waters (Nixon, 1986, 1992).

Suitable coastal environment for the sediments to mount up and sufficient movable or unconsolidated substance are the key features in the formation of beaches. The composition and character of intertidal sediments are largely outlines flooding and drainage. Intertidal areas consist of rocky, sandy and muddy sediments and mixtures. Grain size generally decreases from high energy towards low energy, more sheltered parts (Eisma and de Boer, 1998). The sediments in the intertidal area are well sorted due to the continuous activity of tidal currents and waves. Apart from other ecosystems the intertidal areas features dual tide reversals that may be zero to maximum according to local tide amplitudes. Strength of the currents and waves also vary. This may cause an uneven distribution of sediments. Coastal erosion also changes sediment characteristics and profile.

Animal- sediment relation is the study of relations between organisms and sediments, where the organisms modify the original sediment stuff to hand out a wide spectrum for their life, like respiration, feeding, reproduction and protection (Bromley, 1996).

5.2 Sediment temperature

Organism's population's behavioral, reproductive activity, food and oxygen availability may be influenced by extreme temperatures experienced in the intertidal zone (Eltringham, 1971). Many intertidal species high tolerance for elevated temperature and can also adapt themselves their metabolic activity, or they can be able to hideaway deeper in the sediment or move seaward to conflict the temperature deviation (Brown, 1983). Severe alterations in temperature in intertidal areas will cause seasonal decline in benthic species richness and abundance. Temperature is also a crucial factor for illuminating

dynamics of microbial activity and microphytobenthic primary production on intertidal mudflats (Blanchard & Guarini, 1996).

5.2.1 Variations of sediment temperature at Fort Cochin beach

In station 1 the range of sediment temperature was 27.1-36^{0}C (Av. – 31.03^{0}C) during the sampling period. Temperature of sediment showed its maximum (36^{0}C) in December, 2010 and lowest (27.1^{0}C) was observed in September, 2009 at station 1 (Fig. 71). Seasonally the average temperature value was high in pre monsoon season, 2010 (33.7^{0}C$\pm$1.68) and the lowest was in monsoon season, 2010 (28.8^{0}C) (Fig. 72). In station two the sediment temperature value ranged from 28 - 35^{0}C (Av. – 30.28^{0}C). In station 2 the highest (35^{0}C) was observed in April, 2010 and lowest (28^{0}C) in various months (Fig. 71). Seasonally the average sediment temperature value was high in pre monsoon season, 2010 (32.1^{0}C$\pm$0.30) and the lowest was in post monsoon season, 2009 (28.8^{0}C) (Fig. 72). Highest mean was observed in station 1 (31.03^0 $\pm$2.7) (Table 39). ANOVA showed overall significance (R^2 = .925) but no significance between station and month were observed (Table 37). Sediment temperature in high tide zone was high (33 - 36^{0}C) in station 1 during pre monsoon season and in low and mid tide zone it was 27 - 33^{0}C. 30 - 35^{0}C that in station 2 at high, low and mid tide (28-32^{0}C).

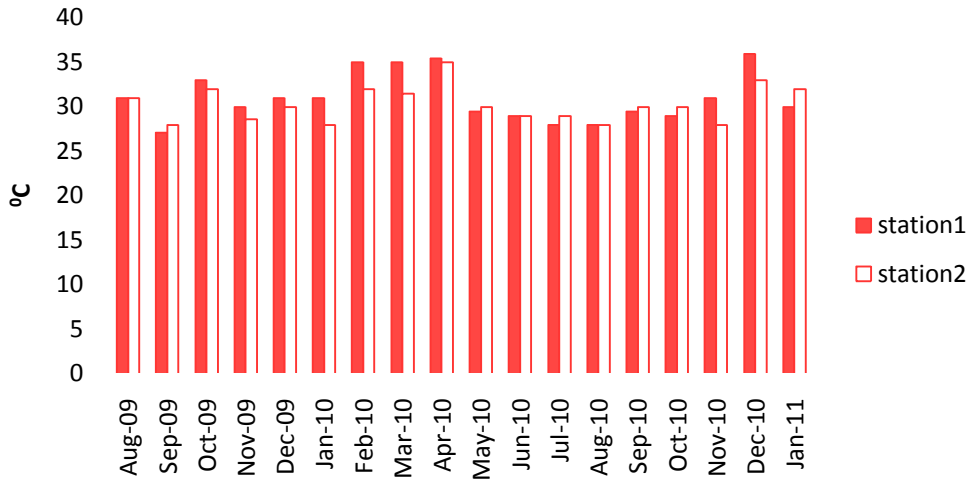


Figure 71 Monthly variations of sediment temperature in Fort Cochin beach during 2009-2011

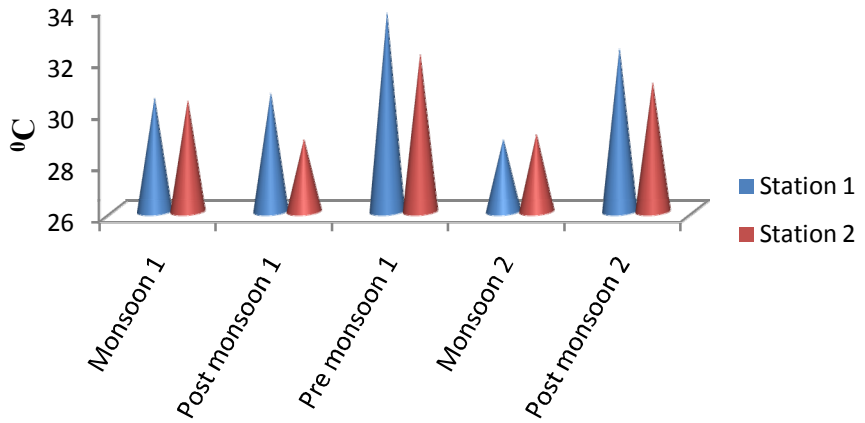


Figure 72 Seasonal variations of sediment temperature in Fort Cochin beach during 2009-2011 (Monsoon 1- Monsoon 2009, Post monsoon 1- Post monsoon 2009, Monsoon 2- Monsoon 2010, Post monsoon 2- Post monsoon 2010)

5.2.2 Variations of Sediment temperature at Dharmadam beach

The range of sediment temperature in station 1 of Dharmadam beach was 27 - 35^{0}C (Av. –30.59^{0}C). The highest was observed during March and April, 2010 (35^{0}C) and lowest was observed in July, 2010, August 2009, 2010

(27^0C) at station 1 (Fig. 73). Seasonally the highest average value was observed in pre monsoon season (2010). The value was 33.3^0C±1.78. The lowest was in monsoon season, 2010 (27.7^0C) (Fig. 74). The range of sediment temperature in station 2 was 27-35^0C (Av. – 30.69^0C). In station 2 temperature ranged from 27 – 35^0C and it showed a peak in April, 2010 (35^0C). The lowest temperature was observed in July, and August, 2010 (27^0C) (Fig. 73). Seasonally the average highest value of sediment temperature was 32.7^0C±0.64 in pre monsoon season (2010) and the lowest was in monsoon season, 2010 (27.7^0C) (Fig. 74). Highest mean was observed in station 2 (30.6^0C ±2.4) (Table 39). Sediment temperature in high tide was high as in the case of Fort Cochin beach due to prolonged exposure (33-35^0C), mainly in pre monsoon season. In low and mid tide the temperature was found to be somewhat similar (27-33^0C). In station 2 of Dharmadam beach also same profiles existed. ANOVA showed overall significance (R^2 = .906) but no significant variation between station and month were observed (Table 38).

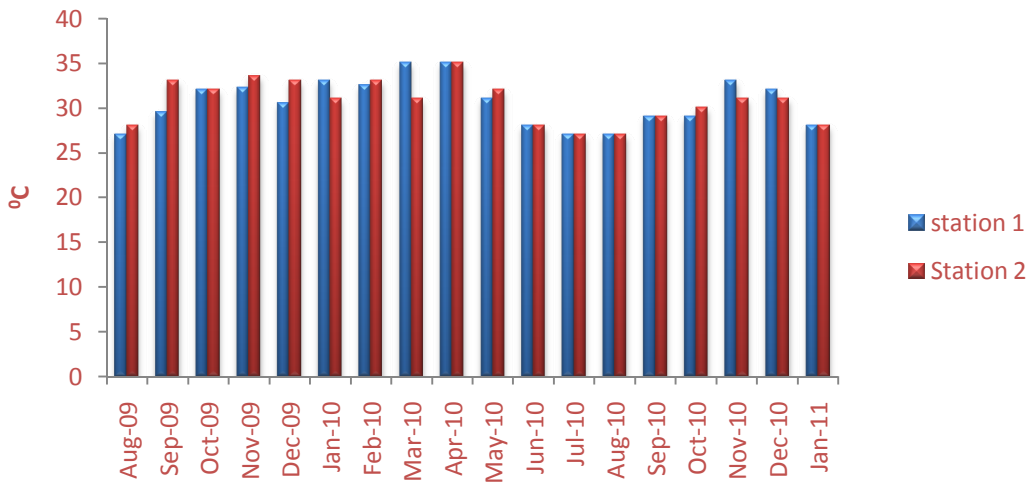


Figure 73 Monthly variations of sediment temperature in Dharmadam beach during 2009-2011

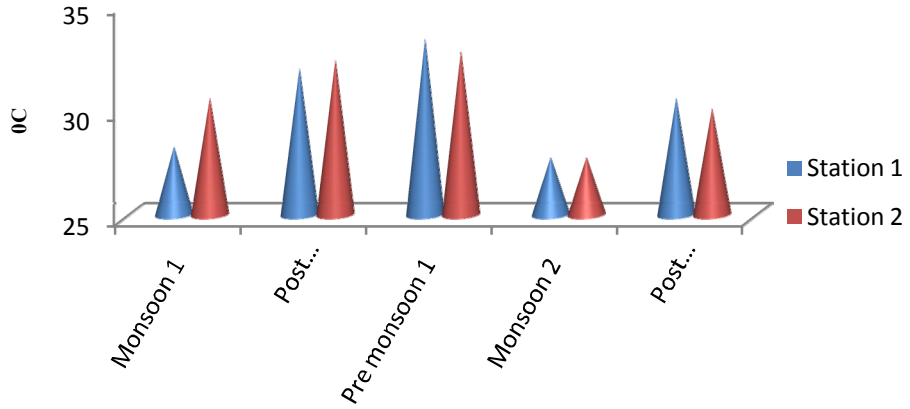


Figure 74 Seasonal variations of sediment temperature in Dharmadam beach during 2009-2011

Table 37 ANOVA of sediment temperature in Fort Cochin beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	8.480	7.244
Intercept	1	25576.333	2.185E4
Month	17	6.467	5.525
Station	1	4.400	3.759
Month * Station	2	.772	.659
Error	13	1.170	
Total	36		

$R^2 = 0.925$

Table 38 ANOVA of sediment temperature in Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	8.969	5.667
Intercept	1	30496.165	1.927E4
Month	17	5.747	3.631
station	1	.007	.004
Month*Station	2	1.305	.824
Error	13	1.583	
Total	36		

$R^2 = .906$

Table 39 Mean and standard deviation of sediment temperature in Fort Cochin and Dharmadam beach during 2009-2011 (1&2- Fort Cochin beach station 1 & 2, 3&4- Dharmadam station 1 & 2).

Station	Mean	Std. Deviation
1	31.03	2.754
2	30.28	1.997
3	30.59	2.648
4	30.69	2.408

5.3 Sediment pH

pH is an important parameter in glancing many crucial biogeochemical processes in marine sediment (Stahl *et al.,* 2006). Heterotrophic respiration, chemoautotrophic activity, photosynthesis, precipitation, and calcium carbonate dissolution all have an intense influence on the overall pH balance in marine sediments (Revsbech *et al.,* 1983; Cai *et al.,* 1995; Reimers *et al.,* 1996; Wenzhöfer *et al.,* 2001). Benthic pH dimensions accordingly offer an important tool for examining the significance of the diverse biogeochemical redox-processes and the condition of the carbonate system (Boudreau and Canfield, 1988).

5.3.1 Variations in sediment pH at Fort Cochin beach

In station 1 the sediment pH value ranged from 6.71 - 8.8 (Av. - 7.92) during the sampling period. Highest pH was observed during August, 2010 (8.8) and lowest was in May, 2010 (6.71) at station 1 (Fig. 75). Seasonally the highest value was observed in monsoon season, 2009 (8.2±0.29) and lowest was in pre monsoon season, 2010 (7.39) (Fig.76). In station 2 the range of pH was 6.74 - 8.2 (Av. -7.6). In station 2 the highest was observed during December, 2010 (8.2) and lowest was in May, 2010 (6.74) (Fig. 75). Seasonally the highest was recorded in post monsoon season, 2010

(7.96±0.18) and the lowest was in pre monsoon season, 2010 (7.28) (Fig. 76). ANOVA showed overall significance (R^2 = 0.639) but no variation between station and month were observed (p = 0.457 p> 0.05) (Table 40). Highest mean was observed in station 1 (7.3 ±0.69) (Table 42).

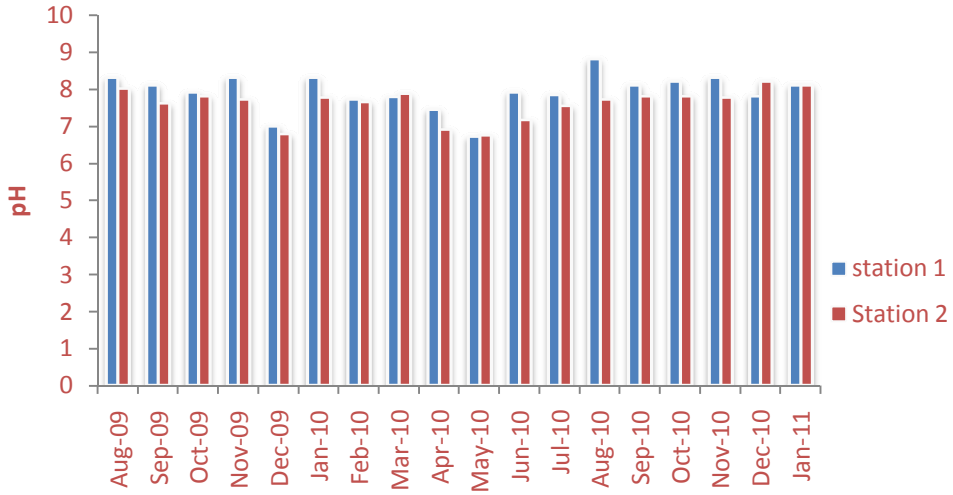


Figure 75 Monthly variations of sediment pH in Fort Cochin beach during 2009-2011

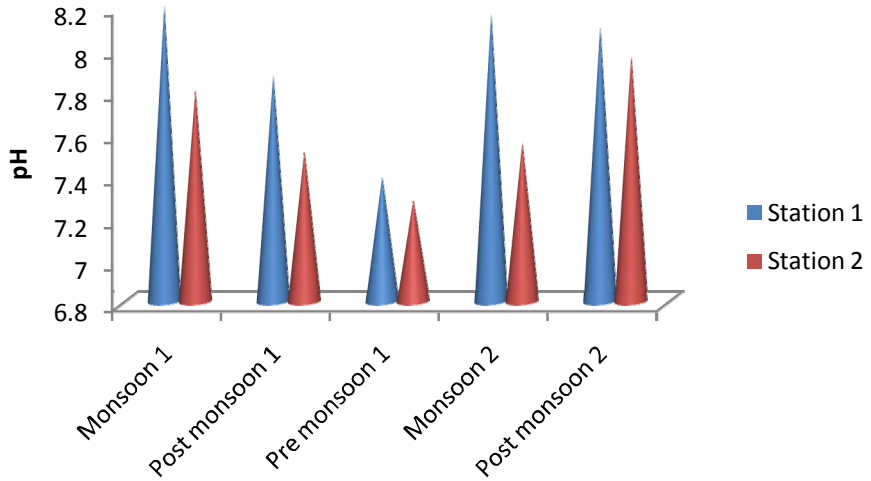


Figure 76 Seasonal variations of sediment pH in Fort Cochin beach during 2009-2011

5.3.2 Variations of sediment pH at Dharmadam beach

In station 1 the pH value ranged from 7.16 - 8.54 (Av – 7.8). The highest pH was showed in the month of September, 2010 (8.8) and lowest was in May, 2010 (7.16) during the sampling period (Fig. 77). In seasonal study during monsoon season (2009), the peak was observed (8.46±0.29) and lowest was in post monsoon season, 2009 (7.64) (Fig. 78). In station 2 of Dharmadam beach the range of pH was 7.07 - 8.72 (Av. – 7.8). At station 2 the highest was observed during January, 2010 (8.72) and lowest was in December, 2009 and May, 2010 (7.07) (Fig. 77). Seasonally the highest value recorded in monsoon season, 2009 (8.25±0.20) and lowest was in pre monsoon season, 2010 (7.62) (Fig. 78). ANOVA showed overall significance (R^2 = .749) but no significant variation between month and station were observed (p = 0.352 p> 0.05) (Table 41). Highest mean was observed in both stations (7.4 ±0.51) (Table 42).

Figure 77 Monthly variations of sediment pH in Dharmadam beach during 2009-2011

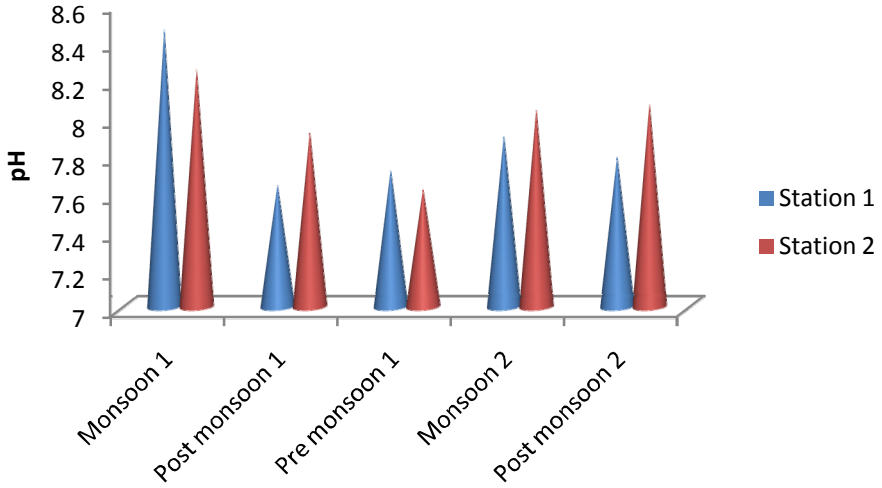


Figure 78 Seasonal variations of sediment pH in Dharmadam beach during 2009-2011

Table 40 ANOVA of sediment pH in Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	28	.586	2.723
Intercept	1	3331.8	1.549E4
Month	17	.559	2.598
Station	3	.791	3.677
Month * Station	6	.209	.970
Error	43	.215	
Total	72		

R^2= .639

Table 41 ANOVA of sediment pH in Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	.280	1.767
Intercept	1	2027.230	1.282E4
Month	17	.322	2.038
Station	1	.065	.414
Month * Station	2	.179	1.131
Error	13	.158	
Total	36		

R^2= .749

Table 42 Mean and standard deviation of sediment pH in Fort Cochin and Dharmadam beach during 2009-2011

Station	Mean	Std. Deviation
1	7.39	.698
2	7.00	.594
3	7.44	.511
4	7.44	.511

5.4 Sediment conductivity

Conductivity is a measure of water's capability to carry out electrical flow. This ability is directly narrated to the concentration of ions in the water. These conductive ions arrive from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds. The electrical conductivity of soil fluctuates depending on the moisture detained by soil particles. Sands have allowed conductivity; silts have a medium conductivity and clay have high conductivity (Grisso *et al.,* 2009). Soil electrical conductivity correlates very strongly with particle size and soil texture.

5.4.1 Variations in conductivity at Fort Cochin beach

In station 1 the range of conductivity was 2.27 - 81.2 mS/cm (Av. – 30.56 mS/cm). At station 1 the highest value was observed in August, 2009 (81.2mS/cm) and lowest was in March, 2010 (2.27mS/cm) (Fig. 79). Seasonally the highest average value was recorded in monsoon season, 2009 (62.3mS/cm±18.5) and the lowest was in pre monsoon season, 2010 (10.6mS/cm) (Fig. 80). In station 2 the range of conductivity observed was 1.96 - 56.2 (Av. – 22.4mS/cm). At station 2 the highest was observed in January, 2011 (56.2mS/cm) and lowest was in May, 2010 (1.96mS/cm) (Fig. 79). In seasonal study the average highest value was observed during post monsoon season, 2010 (33.04mS/cm±10.42) and the lowest was in pre monsoon season, 2010 (4.32mS/cm) (Fig. 80). ANOVA showed overall significance (R^2 = .637) and no significant variation between month and station were observed (p = 0.382 p> 0.05) (Table 43). Highest mean was observed in station 1 (30.5mS/cm ±25.7) (Table 45).

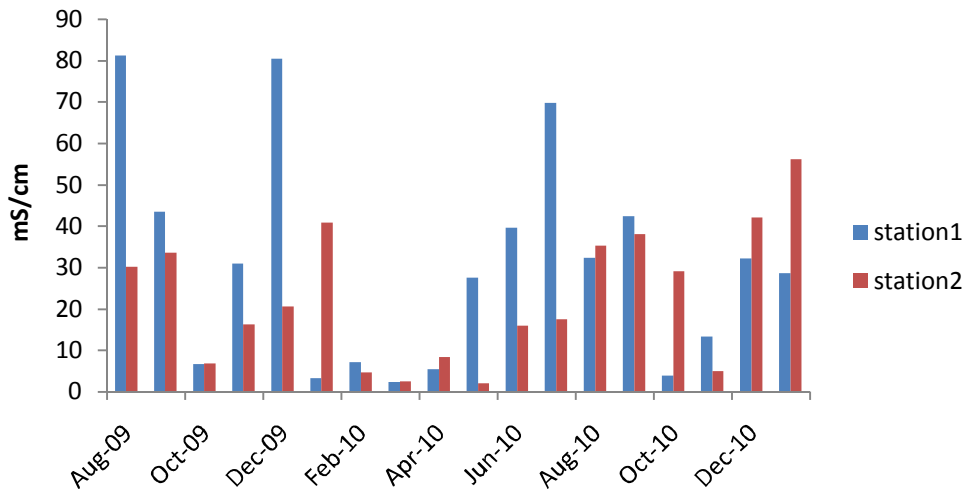


Figure 79 Monthly variations of sediment conductivity in Fort Cochin beach during 2009-2011

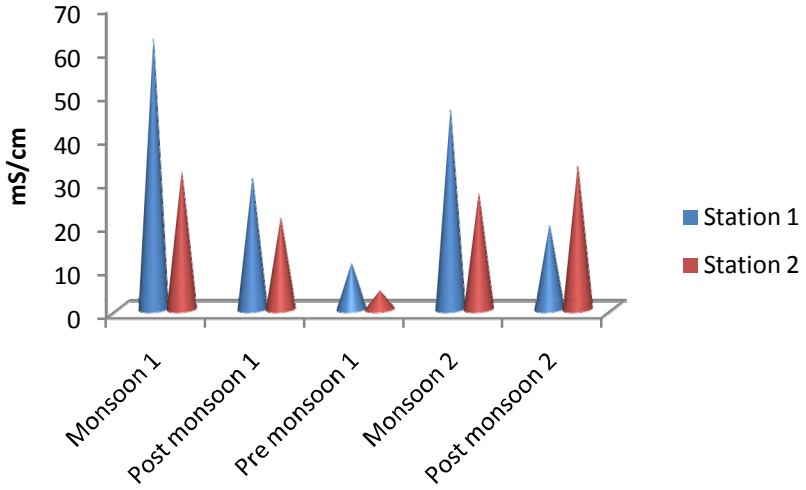


Figure 80 Seasonal variations of sediment conductivity in Fort Cochin beach during 2009-2011

5.4.2 Variations in conductivity at Dharmadam beach

In station 1 the range of conductivity observed was 1.71 - 63.9mS/cm (Av. – 23.57mS/cm) during the sampling period. At station 1 the highest value was shown in August, 2009 (63.9mS/cm) and lowest was in March, 2010 (1.71mS/cm) (Fig. 81). Seasonally the highest average value was recorded in monsoon season, 2009 (41.9mS/cm±12.6). The lowest was in pre monsoon season, 2010 (4.73mS/cm) (Fig. 82). In station 2 the range of conductivity was 1.36 - 40.2mS/cm (Av. - 14.9mS/cm). At station 2 the highest value was shown in August, 2009 (40.2mS/cm) and lowest was in December, 2009 (1.36mS/cm) (Fig. 81). Seasonally the highest average value was recorded in monsoon season, 2009 (21.68mS/cm±5.5) and lowest was in pre monsoon season, 2010 (5.28mS/cm) (Fig. 82). ANOVA showed overall significance (R^2 = .714) but no significant variation between month and station were observed (p = 0.801 p> 0.05) (Table 44). Highest mean was observed in station 1 (23.5mS/cm ±16.9) (Table 45).

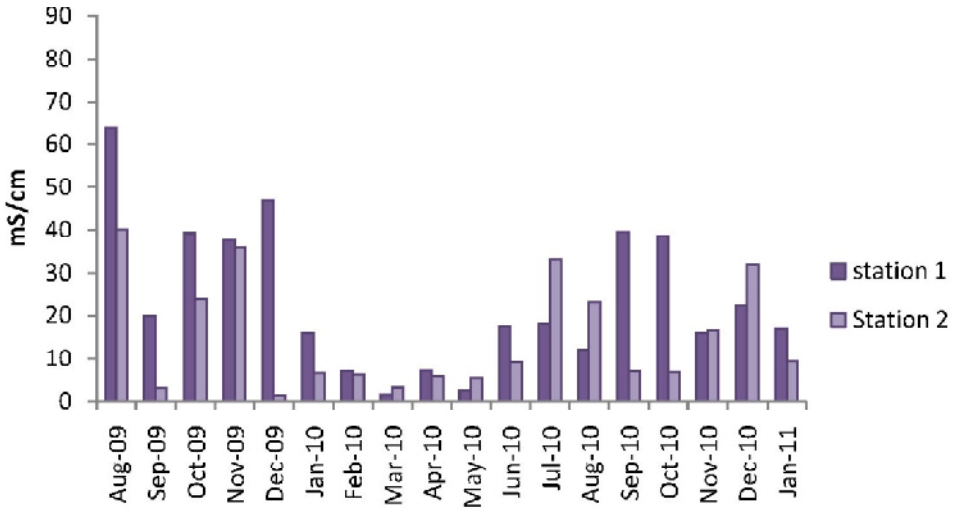


Figure 81 Monthly variations of sediment conductivity in Dharmadam beach during 2009-2011

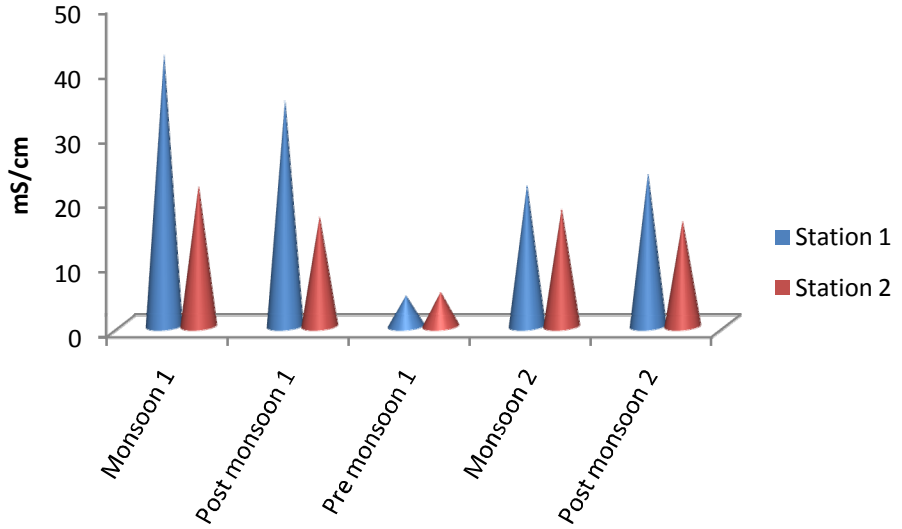


Figure 82 Seasonal variations of sediment conductivity in Dharmadam beach during 2009-2011.

Table 43 ANOVA of sediment conductivity in Fort Cochin beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	28	584.325	2.691
Intercept	1	31637.533	145.688
Month	17	419.464	1.932
Station	3	701.306	3.229
Month * Station	6	237.230	1.092
Error	43	217.160	
Total	72		

R^2= .637

Table 44 ANOVA of sediment conductivity in Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	531.560	1.472
Intercept	1	17618.578	48.783
Month	17	347.332	.962
Station	1	807.317	2.235
Month * Station	2	81.487	.226
Error	13	361.160	
Total	36		

R^2= .714

Table 45 Mean and standard deviation of sediment conductivity in Fort Cochin and Dharmadam beach during 2009-2011

Station	Mean	Std. Deviation
1	30.55	25.786
2	22.46	16.264
3	23.57	16.991
4	15.00	12.834

5.5 Moisture content

Water content or moisture content in sediments is the amount of water cramped in a material, like soil . It expresses the quantity of water present in a wet sample. Moisture content can be expressed on wet or dry basis. Many workers documented that the moisture content can be one of the key factors among sediment factors, which accelerate the sediment transport velocity (Sarre, 1988; Gares, 1988; Cornelis and Gabriels, 2003). The sandy intertidal zone exhibits vertical zonation, with each zone characterized by its moisture content. The zones of retention, resurgence, and saturation are home to a variety of organisms (Karleskint *et al.,* 2010). Thus moisture content plays a major role in distribution of organisms in sandy beaches.

5.5.1 Variations of sediment moisture content at Fort Cochin beach

In station 1 the range of moisture content was 1.01 - 5.73% (Av. – 2.35%) during the sampling period. At station 1 the highest value was showed in February, 2010 (5.73%) and lowest in January, 2010 (1.01%) (Fig.83). The seasonal average values showed its peak in pre monsoon season, 2010 (3.78%±0.88) and lowest was in post monsoon season, 2009 (1.03%) (Fig.84). In station 2 the range of moisture content was 1 - 7.93% (Av. – 3.04%). At station 2 the highest value was observed during February, 2010 (7.93%) and lowest was in November, 2009 (1%) (Fig.83). Seasonally the highest average value was recorded in pre monsoon season, 2010 (4.8%±1.27) and lowest was in post monsoon season, 2009 (1.17%) (Fig.84). ANOVA showed overall significance (R^2 = .924) but no significant variation between month and station was observed (p = 0.559 p> 0.05) (Table 46). Highest mean was observed in station 2 (3.02% ±2) (Table 48).

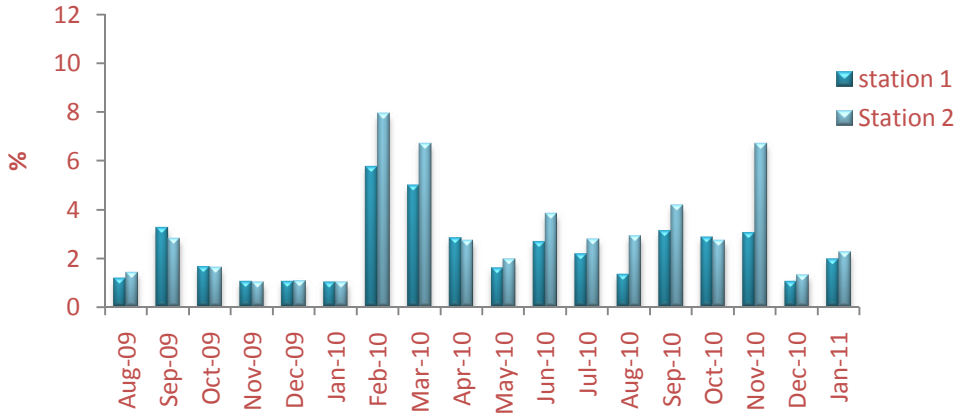


Figure 83 Monthly variations of sediment moisture content in Fort Cochin beach during 2009-2011

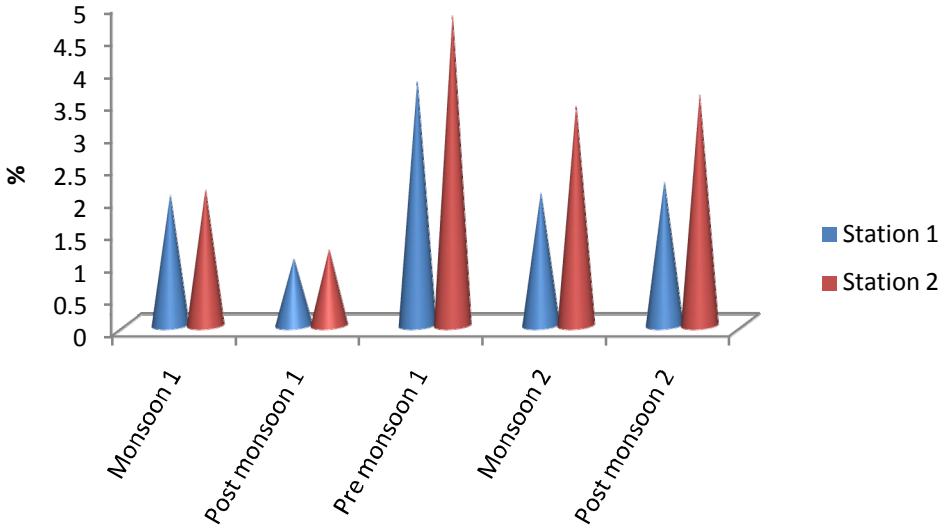


Figure 84 Seasonal variations of sediment moisture content in Fort Cochin beach during 2009-2011

Table 46 ANOVA of sediment moisture content in Fort Cochin beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	4.616	7.155
Intercept	1	179.607	278.386
Month	17	4.984	7.726
Station	1	4.279	6.633
Month * Station	2	.392	.608
Error	13	.645	
Total	36		

R^2= .924

Table 47 ANOVA of sediment moisture content in Dharmadam beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	5.860	7.698
Intercept	17	5.338	7.013
Month	1	4.324	5.681
Station	2	3.297	4.331
Month * Station	13	.761	
Error	36		
Total	22	5.860	7.698

R^2= .929

5.5.2 Variations of moisture content at Dharmadam beach

In station 1 of Dharmadam beach the range of moisture content was 1.48 - 6.4 % (Av. – 3.24%). At station 1 the highest moisture content was shown in December, 2009 and November, 2010 (6.4%) and lowest was shown in September, 2009 (1.48%) (Fig.85). Seasonally the highest average value was recorded in post monsoon season, 2010 (4.14%±0.73) and lowest was in monsoon season, 2009 (1.49%) (Fig.86). In station 2 the range of moisture content was 1.65 - 9.86% (Av. – 3.99%). At station 2 the highest was observed

during December, 2009 (9.86%) and lowest was in September, 2009 (1.65%) (Fig.85). Seasonally the highest average value was observed in post monsoon season, 2010 (5.11%±1.2) and lowest was in monsoon season, 2009 (1.72%) (Fig.86). ANOVA showed overall significance and also significant variation at 5% level between month and station (p =0.036, p < 0.05) were observed (p =0.036, p < 0.05) (Table 47). Highest mean was observed in station 2 (3.9% ±2.3) (Table 48).

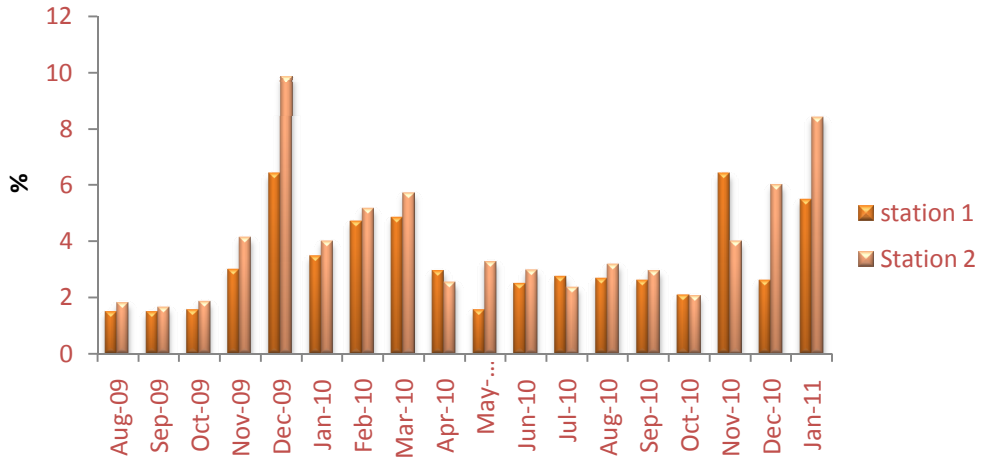


Figure 85 Monthly variations of sediment moisture content in Dharmadam beach during 2009-2011

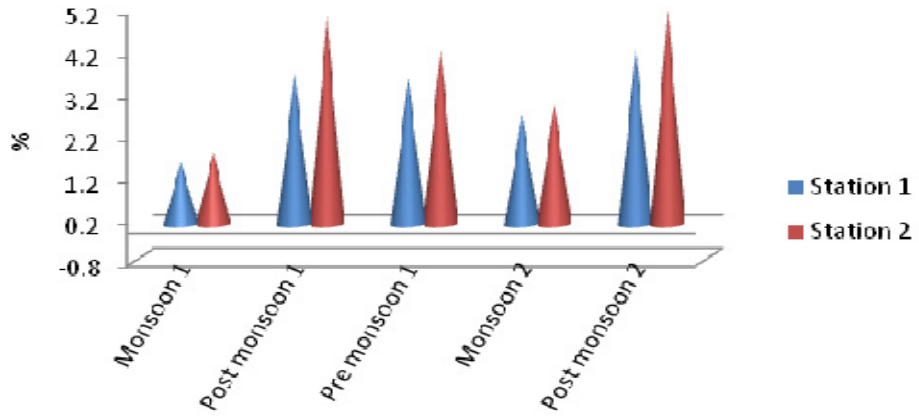


Figure 86 Seasonal variations of sediment moisture content in Dharmadam beach during 2009-2011

Table 48 Mean and standard deviation of sediment moisture content in Fort Cochin and Dharmadam beach during 2009-2011

Station	Mean	Std. Deviation
1	2.31	1.359
2	3.02	2.088
3	3.21	1.638
4	3.94	2.295

5.6 Organic matter

Organic matter comes into the marine environment from various sources, includes organic detritus, vegetation behind the shore line, faunal faeces.

5.6.1 Variation of sediment organic matter at Fort Cochin beach

In station 1 the organic matter value ranged from 0.04 - 3.63% (Av. = 0.55%) during the sampling period. In station1 the peak was observed during August, 2010 (3.63%) and lowest was in December, 2010 (0.04%) (Fig.87). Seasonally highest value was observed during monsoon, 2010 (1.55%±0.52) and lowest was in post monsoon, 2009 (0.08%) (Fig.88). The range of organic matter in station 2 was 0.04 - 2.42% (Av. – 0.57%). In station 2 the highest was observed in July, 2010 (2.42%) and lowest was observed during November, 2009 and January, 2010 (0.04%) (Fig.87). Seasonally, peak was observed in monsoon, 2010 (2.01%±0.67) and lowest was in monsoon, 2009 (0.16%) (Fig.88). ANOVA showed overall significance (R^2 =.725) but no significant variation between month and station were observed (p = 0.184 p> 0.05) (Table 49). Highest mean was observed in station 2 (0.56% ± 0.43) (Table 51).

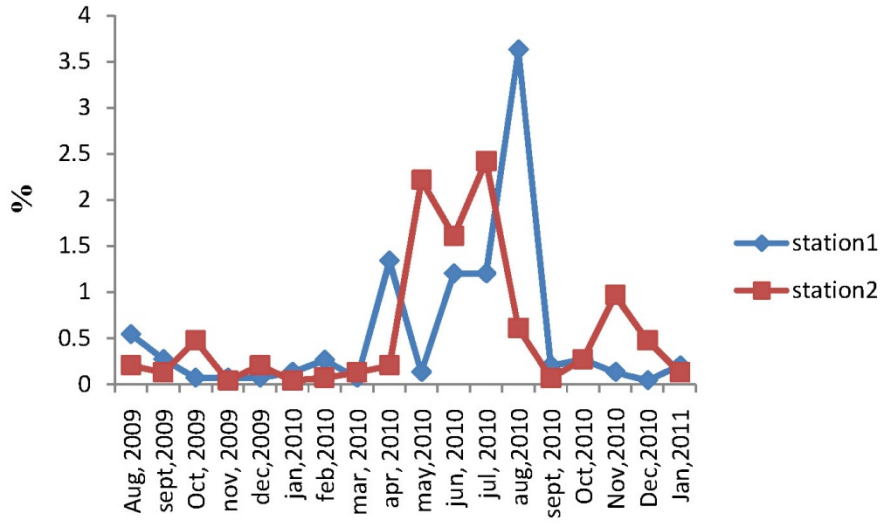


Figure 87 Monthly variations of sediment organic matter in Fort Cochin beach during 2009-2011

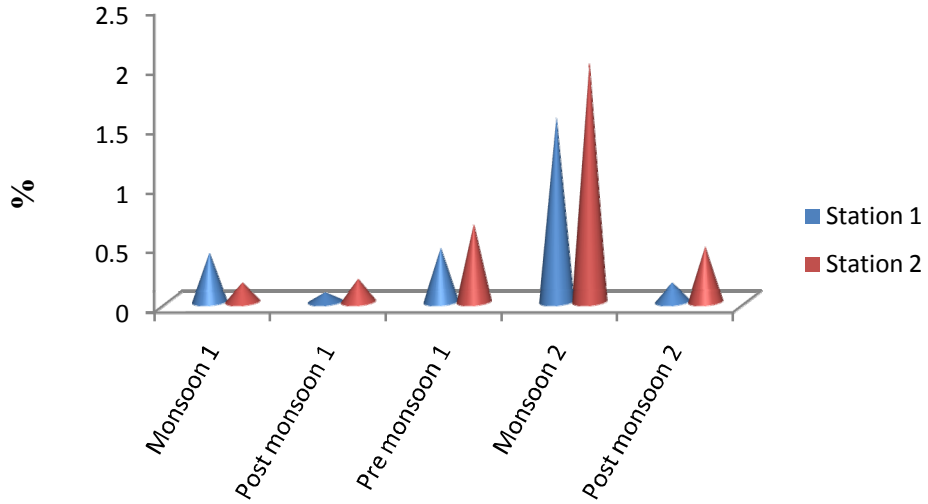


Figure 88 Seasonal variations of sediment organic matter in Fort Cochin beach during 2009-2011

5.6.2 Variation of sediment organic matter at Dharmadam beach

The range of organic matter in station 1 was 0.067- 1.48% (Av - 0.47%). The highest value was observed during June, 2010 (1.48%) and lowest was in February, May, and October, 2010 (0.067%) (Fig.89). Seasonally the peak was observed in monsoon, 2010 (1.1%) and lowest was in pre monsoon, 2010 (0.15%) (Fig.90). In station 2 the range of organic matter was 0.031 - 1.82% (Av. –0.64%). In station 2 the highest was observed in July, 2010 (1.82%) and lowest was in February, 2010 (0.031%) (Fig.89). Seasonally peak was observed in post monsoon, 2010 (1.09%±0.36) and lowest was in post monsoon, 2009 (0.13%) (Fig.90). ANOVA showed overall significance (R^2 = .880) but no significant variation between month and station were observed (p = 0.604 p> 0.05) (Table 50). Highest mean was observed in station 2 (0.62% ± 0.39) (Table 51).

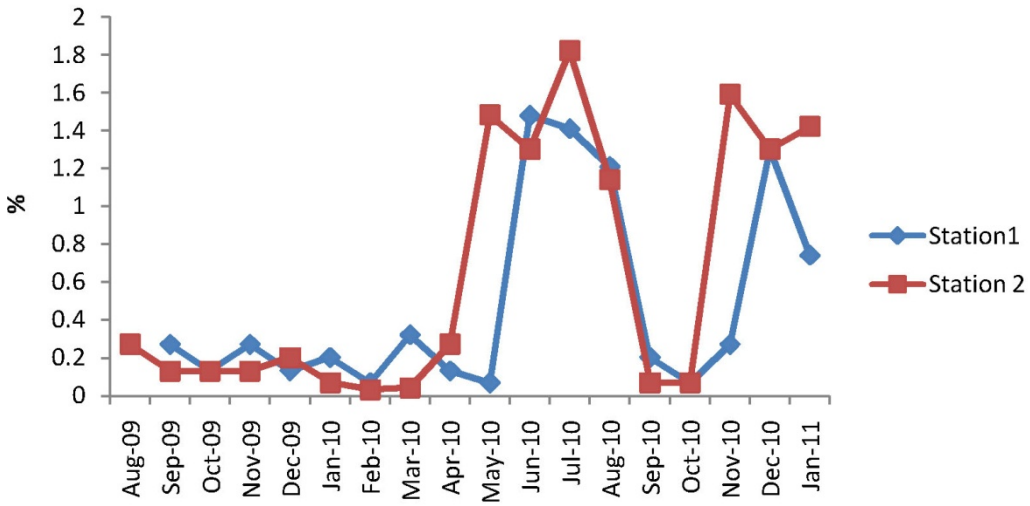


Figure 89 Monthly variations of sediment organic matter in Dharmadam beach during 2009-2011

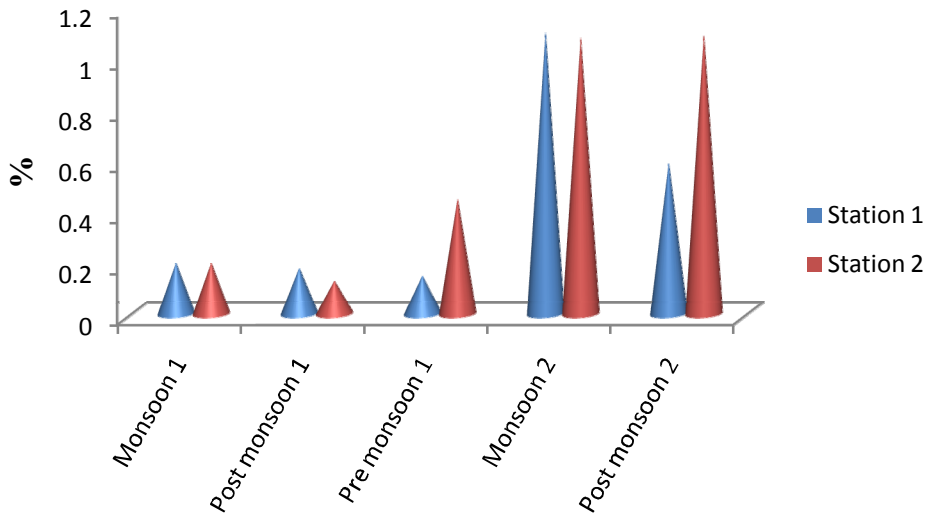


Figure 90 Seasonal variations of sediment organic matter in Dharmadam beach during 2009-2011

Table 49 ANOVA of sediment organic carbon in Fort Cochin beach during 2009-2011.

Source	df	Mean Square	F
Corrected Model	22	.259	1.556
Month	17	.133	.800
Station	1	.019	.113
Month * Station	2	.322	1.933
Error	13	.166	
Total	36		

R^2= .725

Table 50 ANOVA of sediment organic carbon in Dharmadam beach during 2009-2011.

Source	Df	Mean Square	F
Corrected Model	22	.170	4.346
Month	17	.160	4.090
Station	1	.113	2.885
Month * Station	2	.020	.524
Error	13	.039	
Total	36		

R^2= .880

Table 51 Mean and standard deviation of sediment organic carbon in Fort Cochin and Dharmadam beach during 2009-2011

Station	Mean	Std. Deviation
1	.55	.522
2	.56	.436
3	.45	.306
4	.62	.390

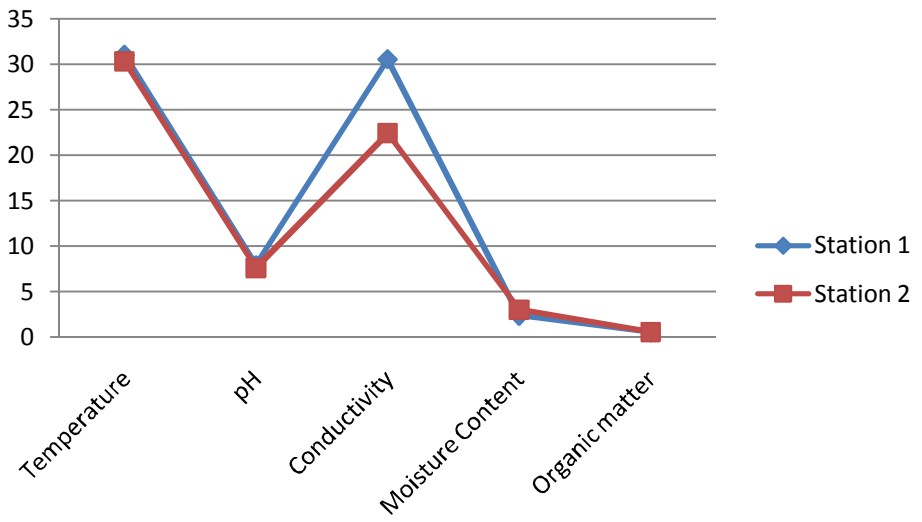


Figure 91 Mean variations of sediment parameters in Fort Cochin beach during 2009-2011

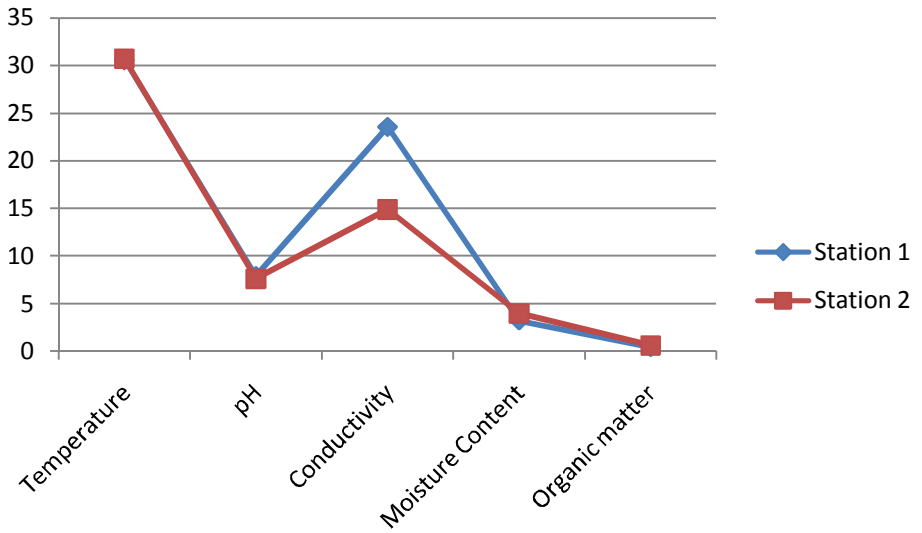


Figure 92 Mean variations of sediment parameters in Dharmadam beach during 2009-2011

5.7 Variations of particle size in Fort Cochin and Dharmadam beach

In station1 of Fort Cochin beach the sediment composition showed dominance of sand (55-95%). Silt was lesser than 35%. Percentage of silt composition was 0.25% and clay composition was very less (0-10%) (Fig.93). In station 2, sandy sediment dominates and the percentage of sand composition was 40 - 100%. 0 - 50% of silt was present and was mainly concentrated in 25% in the diagram. Clay composition was 0 - 10% in station 2 (Fig. 94).

In station 1 of Dharmadam beach sand sediment composition showed a clear dominance (40-80%). Silt composition was 10-50% and clay was less as in the case of Fort Cochin beach (1-15%) (Fig.95). In station 2 the percentage of sand composition was 50-90%. Silt sediment showed 10-50% composition and clay was 1-15% (Fig.96).

Distribution of Silt, Sand and Clay at two stations of Fort Cochin beach during 2009-2011

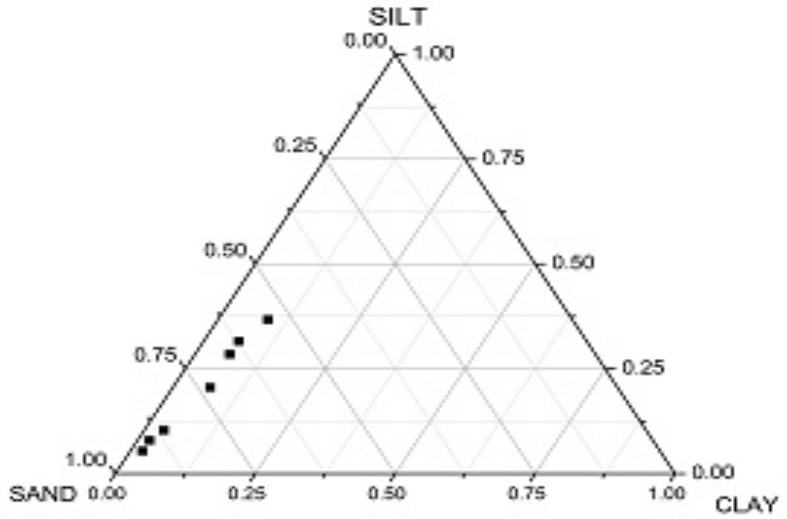


Figure 93 Station 1

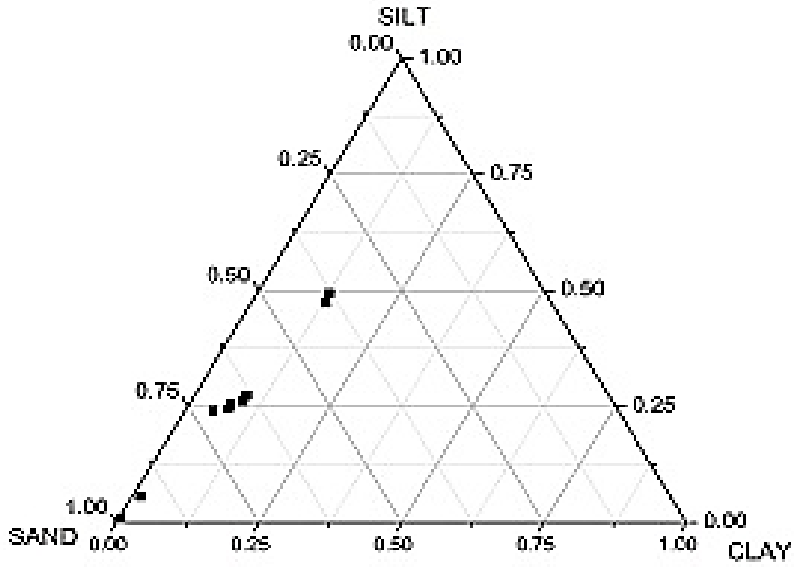


Figure 94 Station 2

Distribution of Silt, Sand and Clay at two stations of Dharmadam beach during 2009-2011

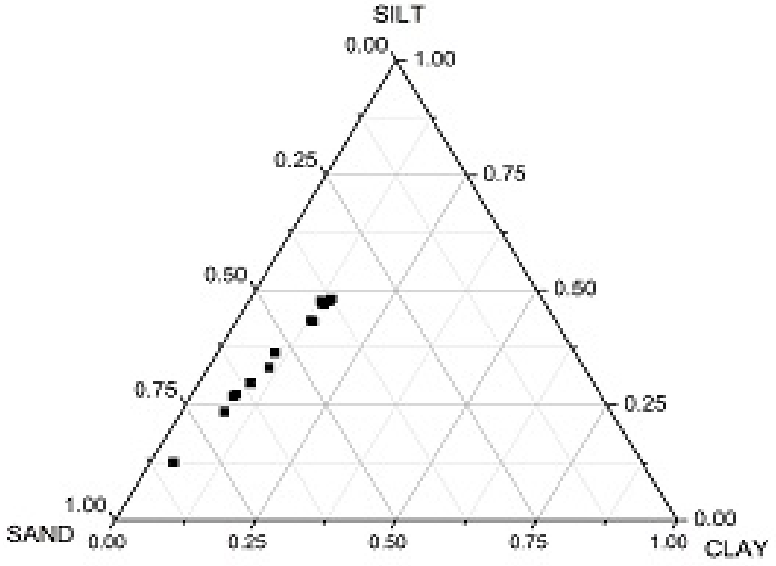


Figure 95 Station 1

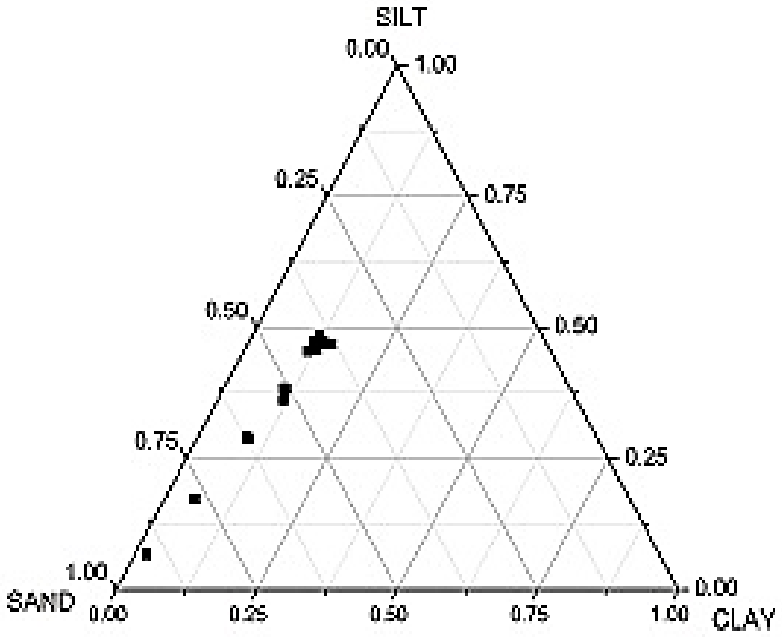


Figure 96 Station 2

5.8 PCA of sediment parameters in Fort Cochin beach

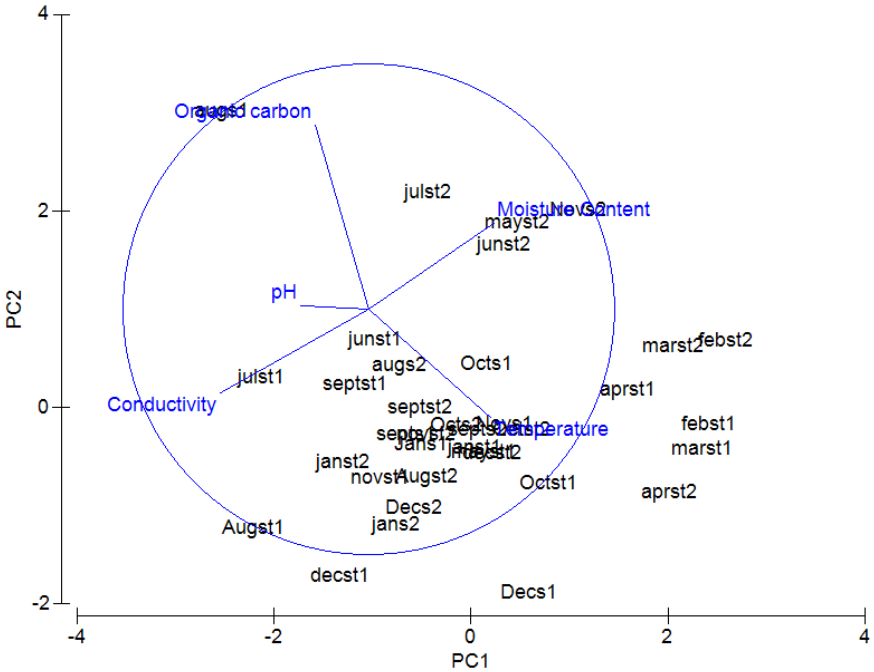


Figure 97 PCA analysis of sediment parameters in Fort Cochin beach during 2009-2011

The first 4 component explained 90% variation, so first four components are important. But the eigen values of first two components were above 1, indicating high significance. PCA analysis of Fort Cochin beach showed that first principal component is correlated to moisture content and negatively correlated to conductivity. These two variables are opposite to each other in the PCA plot, showing negative correlation with each other. Principal component 1 increases with increasing moisture content and decreasing conductivity. In the PCA plot pH and conductivity was positioned closer, showing high correlation between them. Principal component two is correlated with organic carbon. Organic carbon and temperature were positioned opposite to each other showing negative correlation with each other. Principal

component three is negatively correlated to pH and four showed correlation with temperature and negative correlation with moisture content (Fig. 97, Table 52).

Table 52 Table showing PCA Values in Fort Cochin beach during 2009-2011

PC	Eigen values	%Variation	Cum.%Variation
1	1.64	32.8	32.8
2	1.16	23.2	56.0
3	0.973	19.5	75.4
4	0.75	15.0	90.4
5	0.479	9.6	100.0

PC- Principal Components

Variable	PC1	PC2	PC3	PC4	PC5
Temperature	0.497	-0.443	-0.002	**0.611**	0.429
pH	-0.279	0.014	**-0.907**	0.300	-0.093
Conductivity	**-0.606**	-0.342	0.034	-0.232	**0.679**
Moisture Content	**0.511**	0.352	-0.366	**-0.500**	0.481
Organic carbon	-0.217	**0.750**	0.204	0.483	0.339

5.9 PCA of sediment parameters in Dharmadam beach

First three principal components explained 80.1% variance in water quality monthly data. The first two components showed eigen values greater than one, indicating high significance. The first factor accounts for 36% of total variation. First principal component was strongly correlated to temperature and negatively correlated to conductivity. Second principal component was strongly correlated to organic carbon. Organic carbon and temperature showed negative correlation as they were opposite to each other in the PCA plot. Third principal component showed strong correlation with conductivity (Fig.98, Table 53).

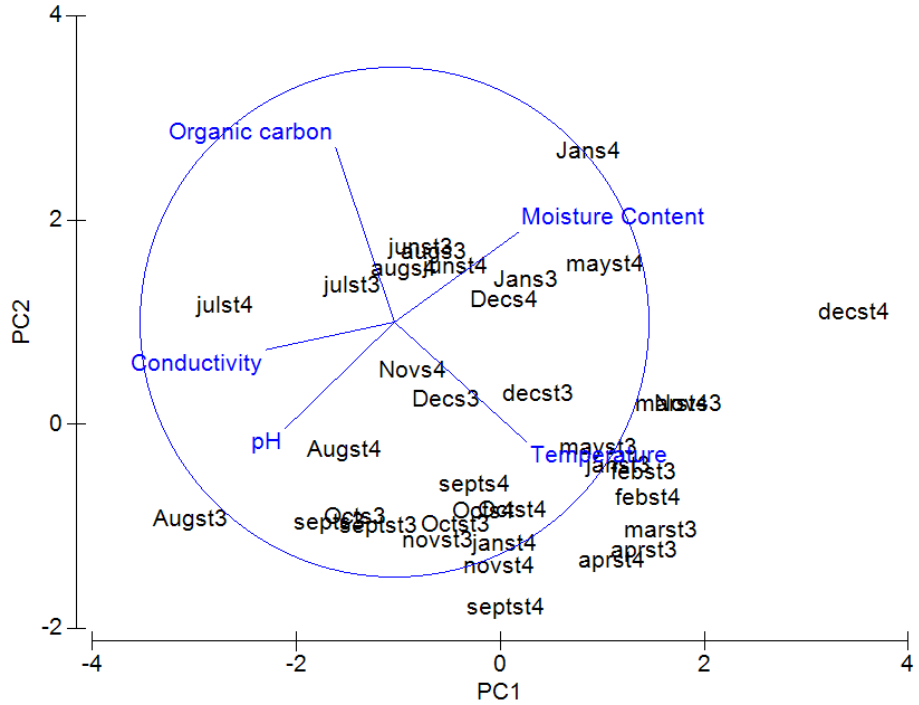


Figure 98 PCA analysis of sediment parameters in Dharmadam beach during 2009-2011

Table 53 Table showing PCA values of sediment parameters in Dharmadam beach during 2009-2011

PC	Eigen values	%Variation	Cum.%Variation
1	1.81	36.2	36.2
2	1.38	27.5	63.7
3	0.817	16.3	80.1
4	0.614	12.3	92.4
5	0.382	7.6	100.0

Variable	PC1	PC2	PC3	PC4	PC5
Temperature	**0.521**	-0.471	-0.124	0.127	**0.690**
pH	-0.428	-0.416	-0.447	**0.646**	-0.161
Conductivity	**-0.506**	-0.109	**0.729**	0.199	0.402
Moisture Content	0.486	0.352	0.307	**0.711**	-0.203
Organic carbon	-0.232	**0.685**	-0.399	0.147	**0.544**

5.10 Discussion

Most of the beaches are composed of different kind of sediments derived from the weathering process and crumbling of gravel eroded from the beach. Sand, mud, pebbles, cobbles are the main sediment composition of different beaches. Quartz and feldspar are the major minerals common in most of the beaches. Another important mineral is the mica. Eventhough not as rich as quartz and feldspar, mica flakes are very visible in beach sand (Pilkey *et al.,* 2004). During the present study the mical flakes were found to be abundant with quartz in Dharmadam beach. Mical flakes giving a shiny nature to the sediment in sunlight and moon light. A black streak on sand and gold like glitter can easily notice and thus one can identify the presence of mica. Fincham (1977) reported mical flakes from the sandy beach of New Zealand. Pilkey (2004) also reported abundance of mical flakes in North Carolina beach. In Fort Cochin beach quartz were found to be dominant. Quartz comprises over 90% of intertidal sands with feldspar, mica, calcite, dolomite etc. (Worden and Burley *et al.,* 2003). The distribution of sediment was showed a uniform pattern in both the beaches. The sandy sediment dominates in both the beaches whereas, silt and clay was found to be less. Taheri *et al.* (2010) also reported abundance of sand fraction in intertidal regions of Oman Gulf. The selected beaches are purely sandy in nature and low silt sediment (below 40%) may be from nearby rivers. Silt and clay usually do not exist in beaches due to motion of currents and waves may make them suspended in water (CERC, 1984). Intertidal sandy beaches have all the sorts of sand and to a minor level silt and clay, whereas sub tidal region restrain all the grades of sand (63µm - 1mm) with low silt and clay particle (Report of UK marine SACs project, 2001). Two things determine the sand particle size on beaches: the energy (height) of the waves, and the size of the material provided to the beach (Pilkey *et al.,* 2014). Sandy particle showed

significant negative correlation with conductivity and organic carbon in station 1 of Dharmadam beach (r = -470* and r = -502* respectively) at 5% level, reflecting the dominance of sandy particle and lesser composition of clay and silt particles in that beach. In sandy soil conductivity and organic carbon generally showing a declined pattern. Silt and organic matter showed significant negative correlation in station 1 and 2 of Dharmadam beach (r = -932** and r = -.903**) at 1% level. Sand and silt also showed significant correlation (0.505*) at 5% level in station 1 of Dharmadam beach. Sandy particle showed significant negative correlation with pH and conductivity (r= -492* and r= -578* respectively) at 5% level in station 1 of Fort Cochin beach and silt and organic carbon showed significant negative correlation at both the stations (station1 and 2) of Fort Cochin beach (r = - 0.980** and r = -.940**respectively) at 1% level.

The study of various sediment parameters is important to understand the organism behaviour in relation to sediment of intertidal areas. Higher temperature was observed in the overall study at both the beaches. In both the beaches pre monsoon months showed higher temperature and during monsoon months the temperature was found to be less. This was due to lower atmospheric temperature due to rainfall. During pre monsoon months (Feb-May) atmospheric temperature will be higher than monsoon months (Jun-Sep) due to solar radiation. In pre monsoon months high tide zone showed slightly higher temperature but low and mid tide showed somewhat similar temperature. Almost similar temperature from low to high tide was observed in both the beaches. It may be due to lesser width of the beach and continuous wave splash. According to the study by Philip (1970) in Fort Cochin beach, he described high sediment temperature in pre monsoon season (35.5^{0}C). In the present study also high sediment temperature has been showed in pre monsoon season (33.7 ^{0}C). Temperature showed variation according to the time of

sampling. Monthly observation on sediment temperature showed higher temperature values than seasonal observation (upto 36^0C) in both the beaches. Jansson (2012) observed higher sediment temperature in sandy beach of Sweden and contrast to the above study, present study showed lower sediment temperature. In Fort Cochin beach, temperature and sand particle composition showed significant correlation (r =0.676**) at 1% level in station 1 (Table 54). In station 1 of Dharmadam beach the sand particle and temperature showed significant correlation (0.777**) at 1% level and temperature and organic carbon showed significant negative correlation at 5% level (-.487*) (Table 56). In station 2 of Dharmadam beach temperature showed significant correlation with silt and significant negative correlation with organic carbon (.524* and -0.502* respectively) at 5% level (Table 57).

Sediment pH showed alkaline nature. Zakaria *et al.* (2011) reported slightly alkaline pH in the intertidal sediments of Teluk Aling, Brazil. The higher value of pH in August showed that crushed shells of organism due to rainfall at Dharmadam beach. The alkaline nature of sediments in Fort Cochin beach is mainly because of industrial effluents from near area. Reddy and Sankaranarayan in 1972 reported that the pH of Cochin backwaters was 7.2-8. The average pH value of station 1 and 2 of Fort Cochin was 7.92 and 7.6 respectively. Ingole *et al.* (1998) reported normal pH value (7-7.6) from the sediments of Siridao beach, west coast of India. Present study showed that in Fort Cochin pH was somewhat acidic to alkaline and in Dharmadam it was neutral to alkaline nature. Different beaches have different physical, chemical and biological profiles and according to that, conditions may vary. In the present study monsoon season showed highest temperature in Fort Cochin beach. In Dharmadam beach monsoon season (2009) showed its highest peak in pH values. It may be attributed to the changes in water quality and pH

during monsoon season and it may influence the sediment pH. Terrestrial runoff and riverine discharges were common in monsoon season and it may be the reason for highest pH in monsoon season. In station 2 of Fort Cochin beach pH and conductivity showed significant correlation (0.594**) at 1% level (Table 55).

Moisture content (MC) showed seasonal variation in Fort Cochin beach. In pre monsoon season moisture content was found to be high in station 2. Station 2 was near to the bar mouth of Cochin backwaters and the sediment texture is finer than station 1. In Fort Cochin, there is no significant variation was observed between station and month in ANOVA, indicating temporal changes has not influenced the moisture content in two stations of Fort Cochin beach. So the water retaining capacity will be more. In Dharmadam beach post monsoon season showed peak moisture content values. Higher the moisture content of the sediments higher the survival capacity of organisms. In Dharmadam beach moisture content showed significant variation between station and month at 5% level. When compared to Dharmadam beach, moisture content in the sediments of Fort Cochin beach was less. The sediment texture of Fort Cochin beach is coarser than sediment of Dharmadam. Finer sediments retain more moisture than coarser sediments. Sediment with different particle size varies in their water holding capacity. Finer sediments hold water more than coarser sand (Colwell, 2010). Goncalves *et al.* (2009) reported lower range of sediment moisture from the beach of western Portugal, compared to present study (3.2%). Present study encountered upto 9.8% MC in Dharmadam beach. Leewis *et al.* (2012) observed higher range of sediment moisture in the sandy beaches along North Sea. Adam *et al.* (2009) observed 0-36% sediment moisture from the mud flats of Belgium coast. Mud particle

usually retains more moisture than sand particle. In correlation analysis , indicating the more water holding capacity of clay than sand (r= 0.997** and 0.998** in station 1 and 2 respectively) (Table 54 & 55). Dharmadam beach also showed significant correlation with clay and moisture content in both the stations. (r = 0.995** and 0.993** in station 1 and 2 respectively) (Table 56 & 57).

Beaches getting moisture continuously by wave spray, tides, precipitation and from nearby channels. For the survival of the organism moisture content of sediment is important. Most of the sandy beach fauna are burrowing in nature. To escape from desiccation at low tide, burrowing organisms need some amount of water content. So moisture content is an inevitable factor in beaches. The water content of sediments is highly correlated to sediment grain size and topography. In the present study also moisture content is significantly correlated to clay particles. In both the beaches clay particles were observed to be less (< 15%), but the correlation indicating the more water holding capacity of clay particles. The main parameters influencing sediment cohesiveness/ erodability are grain size, moisture content, mineralogy, and the biological components (microalgae, macrophytes, macrofauna, bioturbation) (Verpoorter *et al.,* 2009).

Electrical conductivity is a measure of how well a material can able to accommodate the movement of an electric charge (Sonawane *et al.,* 2010). Soil conductivity and resistivity (the inverse of conductivity) have long been used to measure the electrical conductivity of soil. These measurements are representatives of finer grained sediments, such as silts or clays, while sands are characterized by somewhat lower electrical conductivities. In coarser sand dissolved solids can move easily than fine sediments. Due to the abundance of sandy particle, the present study also showed lesser conductivity

of soil in both the beaches. Monsoon season (2009) showed high values of sediment conductivity. In station 2 of Fort Cochin beach post monsoon (2010) showed peak value. Same profile observed in water conductivity values in both the beaches. Intense wave action and deposition of dissolved solids in rainy seasons from adjacent environment may increase the sediment conductivity.

Sandy sediments of most of the beaches are often considered as geochemical deserts since they are generally poor in organic matter (Boudreau *et al.,* 2001). Pioneer works showed that filtration through the sands of exposed beaches characterized a mechanism that boosted the decomposition of organic matter in the coastal zone (Riedl and Macmahan, 1969; Riedl and Machan, 1972; McLachlan *et al.,* 1985; McLachlan and Turner, 1994). Generally fine sediments show higher organic content (silt, clay) rather than coarse sediments like sand. Both the beaches studied were sandy in nature, thus indicating a reducing trend of organic carbon throughout the study. During the present study Fort Cochin showed the highest organic matter (3.63%). Industrial sewage effluents increase the organic carbon content. Significant negative correlation of organic matter with sand indicating that the lower persistence of organic matter in sandy dominated area.

According to the study of Quadrose (2001) on intertidal habitat of Thane creek, he reported an average organic carbon of 2.63% from that area and classified it as much polluted area as the range observed from this creek (1.21-4.4%) according to the classification of Raman and Ganapathi, 1983. In the present study, in Fort Cochin beach organic matter was ranged from 0.04-3.63%. So Fort Cochin beach is considered as polluted beach according to above classification. During monsoon season the % OM showed high values in both stations of Fort Cochin beach (above 1%). Elliott *et al.* (1997)

observed lower organic matter values from a flat sandy beach in Belgium. Dharmadam beach is also a flat sandy beach and revealed low organic matter values as the above mentioned study. Goncalves *et al.* (2009) detected low organic matter value in sandy beach of western Portugal. This observed value of organic matter in above mentioned study was within the range of Organic matter observed from Dharmadam beach. Rizzo *et al.* (2001) observed higher organic matter range from 0.04 to 5.82% in an intertidal beach of Sao Sebastio channel, Brazil. Priyalaksmi in 2008 also observed high organic matter in monsoon season in Fort Cochin beach. Ingole and Parulekhar (1998) reported increased organic matter content from Siridao beach from west coast of India. Arruda *et al.* (2003) also reported high range of organic matter (upto 8%) Barra Velha, Sao Paulo. In Dharmadam beach the average was 0.47% and 0.64% in station 1 and 2 respectively. According to the above mentioned classification it is considered as semi healthy zone. In 2012 study based on tropical sandy beach of West Coast of India by Sivadas *et al.,* they described opposite condition. High OC content was observed in pre monsoon season and monsoon showed low OC content in most of the stations. In the present study the increase of OM in monsoon season may be due to discharge of effluents from adjacent water bodies.

In PCA analysis, Fort Cochin beach showed strong loading of moisture content in the first component, indicating that the active participation of moisture in sediment quality. It also showed negative correlation with conductivity. From this it indicates that dissolved solids from adjacent system did not affect the sediment quality of Fort Cochin beach. Second component was correlated to organic carbon, showing influence of anthropogenic activities. In Dharmadam beach first component was correlated to temperature, reflecting

climatic pattern, natural effects. Land use pattern was not reflected in the sediment quality of both the beaches. In Fort Cochin beach and Dharmadam beaches negative correlation has been observed when draftsman plot is plotted but there is no significant correlation has been observed.

Highlights

- Quartz and mical flakes formed dominant minerals in sediment composition of Fort Cochin and Dharmadam respectively.
- Clear dominance of sandy particle observed in both the beaches. Clay and silt distribution was very less.
- Sediment parameters showed marked seasonal fluctuations.
- Sediment temperature observed to be high and exceeds upto 36^0C in pre monsoon and post monsoon months.
- Sediment pH showed neutral to alkaline nature except some months.
- Sediment conductivity showed lesser values compared to other systems due to poor conductance of sandy particle.
- Moisture content showed seasonal variations in both the beaches. In correlation analysis moisture content and clay particle showed significant correlation at 1% level.
- Organic matter observed to be less in both the beaches. Fort Cochin beach showed much higher organic matter content than Dharmadam beach.
- In PCA analysis both beaches showed natural variations of parameters with less anthropogenic effects.

Table 54 Correlation of sediment parameters in station 1 of Fort Cochin beach during 2009-2011

	Temperature	pH	Conductivity	Moisture content	Organic matter	Clay	Silt	Sand
Temperature	1							
pH	-.341	1						
Conductivity	-.422	-.139	1					
Moisture content	.291	-.017	-.419	1				
Organic matter	-.297	.138	.142	-.131	1			
Clay	.252	.047	-.415	**.997****	-.115	1		
Silt	.327	-.120	-.191	.317	**-.980****	.303	1	
Sand	**.676****	**-.492***	**-.578***	.217	-.390	.164	.380	1

Table 55 Correlation of sediment parameters in station 2 of Fort Cochin beach during 2009-2011

	Temperature	pH	Conductivity	Moisture content	Organic matter	Clay	Silt	Sand
Temperature	1							
pH	.050	1						
Conductivity	-.114	**.594****	1					
Moisture content	.028	-.033	-.452	1				
Organic matter	-.253	-.250	-.346	-.021	1			
Clay	.026	.006	-.423	**.998****	-.046	1		
Silt	.240	.224	.173	.356	**-.940****	.379	1	
Sand	-.368	-.001	.005	-.261	.056	-.264	-.141	1

Correlation of sediment parameters in Dharmadam beach during 2009-2011

Table 56 Correlation of sediment parameters in station 1 of Dharmadam beach during 2009-2011

	Temperature	pH	Conductivity	Moisture content	Organic matter	Clay	Silt	Sand
Temperature	1							
pH	-.176	1						
Conductivity	-.393	.360	1					
Moisture content	.319	-.357	-.186	1				
Organic matter	**-.487***	.046	-.244	-.094	1			
Clay	.330	-.284	-.189	**.995****	-.094	1		
Silt	**.531***	-.154	.139	.439	**-.932****	.440	1	
Sand	**.777****	-.288	**-.470***	.188	**-.502***	.189	**.505***	1

Table 57 Correlation of sediment parameters in station 2 of Dharmadam beach during 2009-2011

	Temperature	pH	Conductivity	Moisture content	Organic matter	Clay	Silt	Sand
Temperature	1							
pH	.188	1						
Conductivity	-.335	-.041	1					
Moisture content	.120	-.419	-.257	1				
Organic matter	**-.502***	-.170	.241	.112	1			
Clay	.119	-.349	-.239	**.993****	.125	1		
Silt	**.524***	.021	-.351	.320	**-.903****	.311	1	
Sand	-.385	-.205	-.014	-.111	-.221	-.123	.164	1

* Correlation significant at 0.05 level
** Correlation significant at 0.01 level

5.11 Draftsman Plot

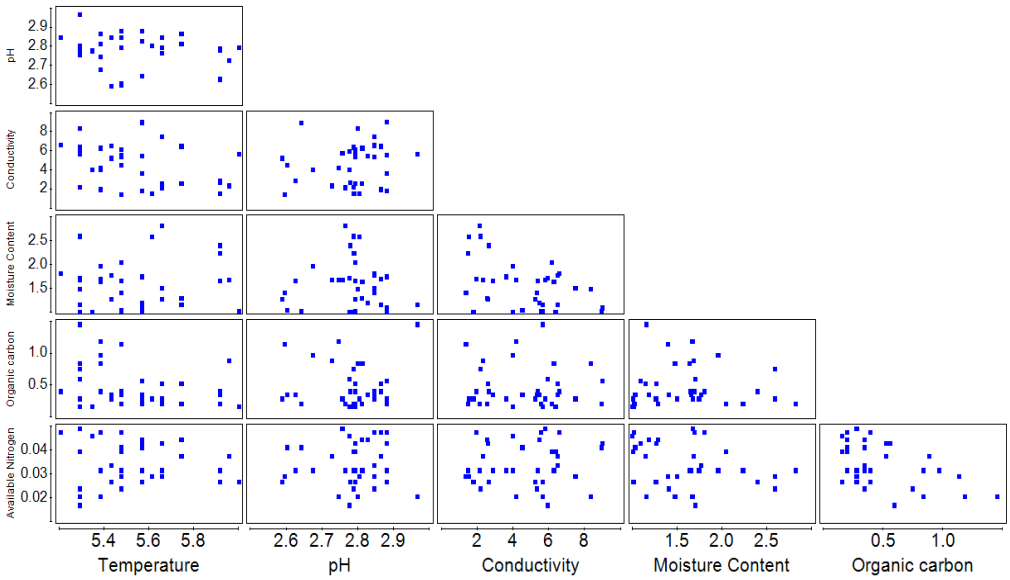


Figure 99 Draftsman plot of sediment parameters in Fort Cochin during 2009-2011

Table 58 Correlation table of Draftsman plot in Fort Cochin during 2009-2011

	Temperature	pH	Conductivity	Moisture Content	Organic carbon
pH	-0.111				
Conductivity	-0.336	0.171			
Moisture Content	0.084	-0.035	-0.444		
Organic carbon	-0.279	-0.015	-0.037	0.033	

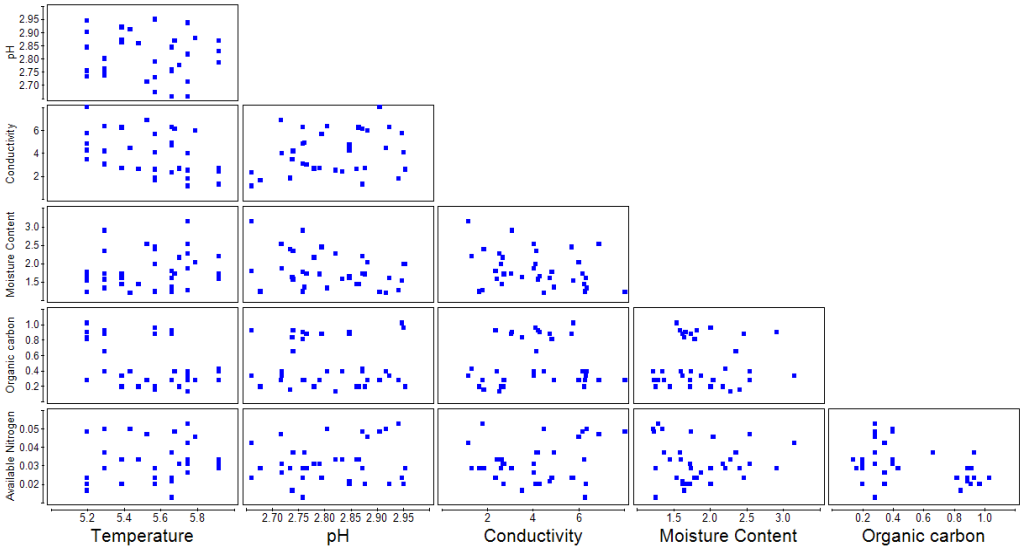


Figure 100 Draftsman plot of sediment parameters in Dharmadam during 2009-2011

Table 59 Correlation table of Draftsman plot in Dharmadam during 2009-2011

	Temperature	pH	Conductivity	Moisture Content	Organic carbon
pH	-0.082				
Conductivity	-0.397	0.245			
Moisture Content	0.217	-0.376	-0.286		
Organic carbon	-0.452	-0.066	0.093	0.082	

References

Adam, S., Monbaliu, J. and Toorman, E.A., 2009. Quantification of bio-physical intertidal sediment properties using hyperspectral measurements. *Continental Shelf Res*., 31(1): S26-S35pp.

Arruda, E.P., Domaneschi, O. and Amaral, A.C.Z., 2003. Mollusc feeding guilds on sand beaches in São Paulo state, Brazil. *Mar. Biol*. 143: 691-701pp.

Blanchard, G. and Guarini, J.M. 1996. Studying the role of mud temperature on the hourly variation of the photosynthetic capacity of microphytobenthos in intertidal areas. Comptes Rendus de L'academie des Sciences serie III - *Sciences de la vie-Life Sciences*, 319 (12): 1153-1158pp.

Boudreau, B. P., and Canfield, D.E., 1988. A provisional diagenetic model for pH in anoxic pore waters: Application to the Foam Site. *J. Mar. Res*. 46: 429-455pp.

Boudreau, B., and others, 2001. Permeable marine sediments: Overturning an old paradigm. EOS, Trans. AUG, 82: 133–136pp.

Bromley, R.G., 1996. Trace Fossils: Biology, Taxonomy and Applications (2 Edition). Chapman and Hall, London, 361pp.

Brown, A.C., 1983. The ecophysiology of beach animals - a partial review. In: (eds. A. McLachlan & T. Erasmus) Sandy beaches as ecosystems. The Hague, Netherlands: Junk. 575 - 605pp.

Cai, W. J., Reimers, C. E. and Shaw, T., 1995. Microelectrode studies of organic carbon degradation and calcite dissolution at a California continental rise site. *Geochim. Cosmochim. Acta,* 59: 497-511pp.

CERC, 1984. Shore Protection Manual. U.S. Army Corps of Engineers, Coastal Engineering Research Center. U.S. Government Printing Office, Washington. D.C.

Colwell, M.A., 2010. Shorebird Ecology, Conservation, and Management. University of California Press, Berkeley, California.

Cornelis, W.M., Gabriels, D. 2003. The effect of surface moisture on the entrainment of dune sand by wind: an evaluation of selected models. *Sedimentology*, 50: 771–790pp.

Eisma, D., De Boer, P., 1998. Intertidal deposits, River mouths, tidal flats and coastal lagoons. CRC press, Bocha Raton.

Elliott, B., Degraer, S., Bursey, M., Vincx, M., 1997. Intertidal zonation of macrofauna on a dissipative sandy beach at De Panne (Belgium): a Pilot study. *Biologisch jaarboek Dodonaea*, 164; 92-108pp.

Eltringham, S. K., 1971. Life in mud and sand. English Universities Press, London, 218pp.

Fincham, A.A., 1977. Intertidal sand dwelling Peracarid fauna of North island, New Zealand. *New Zealand Journal of marine and freshwater research*. 11:4; 677- 696pp.

Gares, P.A., 1988. Factors affecting aeolian sediment transport in beach and dune environments. *J. Coastal Research,* I3: 121-126pp.

Grisso, R., Alley, M., Holshouser, D. and Thomason, W., 2009. Precision farming tools: Soil electrical conductivity. Virginia Cooperative Extenstion.

Ingole, B.S. Parulekar, A.H., 1998. Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence. *Indian Journal of Marine Sciences*, 27: 356-361pp.

Ingole, B.S. Parulekar, A.H., 1998. Role of salinity in structuring the intertidal meiofauna of a tropical estuarine beach: Field evidence. *Indian Journal of Marine Sciences*, 27: 356-361pp.

Jansson, J.K., Neufield. J.P.,Moran, M.A. and Gilbert J.A., 2012. Omics for understanding microbial function dynamics. *Environ. Microbiol*., 14; 1-3pp.

Jickells, T. D., Doting, S., Deuser, W.G., Church, T.M., Arimoto, R and J. M. Prospero, 1998. Air-borne dust fluxes to a deep water sediment trap in the Sargasso Sea, Global Biogeochem Cycles, 12, 311-320pp.

Karleskint, G. Jr., Turner, R. and Small, J. W. Jr., 2010. Introduction to Marine Biology. Brooks/Cole Cengage Learning, Belmont, 356-408pp.

Lies Leewis, Peter M. van Bodegom, Jelte Rozema, Gerard M. Janssen, 2012. Does beach nourishment have long-term effects on intertidal macroinvertebrate species abundance?. *Estuarine, Coastal and Shelf Science*, 113; 172-181pp.

Mclachlan, A., Eliot, I.G., Clarke, D.J., 1985. Water filtration through reflective microtidal beaches and shallow sublittoral sands and its implications for an inshore ecosystem in Western Australia. *Estuarine, Coastal and Shelf Science,* 21, 91–104pp.

Mclachlan, A., Turner, I., 1994. The interstitial environment of sandy beaches. *Marine Ecology,* 15, 177–211pp.

Nixon, S. W. 1992. Quantifying the relationship between nitrogen input and the productivity of marine ecosystems,. Proceedings of Advanced Marine Technology Conference (AMTEC), 5: 57- 83pp.

Nixon, S.W., Oviatt, C.A., Frithsen, J. and Sullivan, B., 1986. Nutrients and the productivity of estuarine and coastal marine systems. *J Limnol Soc sth Afr.,* 12: 43-71pp.

Philip, K. P., 1970. The intertidal fauna of the sandy beaches of Cochin. *Proceedings of the Indian National Science Academy*, 38 (B): 317-328pp.

Pilkey, O.H., and Cooper, J.A.G., 2014. The Last Beach. Duke University Press, Durham, NC, 264pp.

Pilkey, O.H.,. Rice, T.M. and Neal, W.J., 2004. How to Read a North Carolina Beach. University of North Carolina Press, Chapel Hill, North Carolina, 162pp.

Priyalakshmi, G., 2008. Studies on the taxonomy of interstitial fauna of some prominent beaches of Kerala. *Ph.D Thesis*, Cochin University of Kerala, 327pp.

Raman, A.V. and P.N. Ganapati, 1983. Pollution effects on ecobiology of benthic polychaetes in Visakhapatnam harbour (Bay of Bengal). *Mar. Pollut. Bull.*, 14: 46-52pp.

Reddy, C. V. G., Sankaranarayanan, V. N., 1972. Phosphate regenerative activity in the muds of a tropical estuary. *Indian Journal of Marine Sciences,* 1: 57-60pp.

Reimers, C. E., Ruttenberg, K. C., Canfield, D. E., Christiansen, M. B. and Martin, J. B., 1996. Pore water pH and authigenic phases formed in the uppermost sediments of the Santa Barbara Basin. *Geochim. Cosmochim. Acta,* 60: 4037-4057pp.

Revsbech, N. P., Jorgensen, B. B., Cohen, Y. and Blackburn, T. H., 1983. Microelectrode studies of the photosynthesis and O_2, H_2S and pH profiles of a microbial mat. *Limnol. Oceanogr*., 28:1062-1074pp.

Riedl, R. J., and Machan, R. 1972. Hydrodynamic patterns in lotic intertidal sands and their biolimatological implications. *Mar. Biol*. 13: 179–209pp.

Riedl, R.J., Macmahan, E.A., 1969. High energy beaches. In: Odum, H.T., Copeland, B.J., Mcmahan, E.A. (Eds.), Coastal Ecological Systems of the United States. Federal Water Pollution Control Administration, 197–269pp.

Rizzo, A.E., Amaral, A.C.Z., 2001. Environmental variables and intertidal beach annelids of Sao Sebastiao Channel (State of Sao Paulo, Brazil). *Revista de Biologia Tropical* 49; 849-857pp.

Sarre,R.D., 1988. Evaluation of aeolian sand transport equations using intertidal zone measurements, Saunton sands, England. *Sedimentology,* 35: 671-679pp.

Sılvia C. Goncalves, Pedro M. Anastacio, Miguel A. Pardal, Patrıcia G. Cardoso, Susana M. Ferreira, Joao C. Marques, 2009. Sandy beach macrofaunal communities on the western coast of Portugal – Is there a steady structure under similar exposed conditions?. *Estuarine, Coastal and Shelf Science,* 81; 555–568pp.

Sivadas S. K., Ingole B., Ganesan P., Sautya S.,Nanajkar M., 2012. Role of environment heterogenecity in structuring the macrobenthic community in a tropical sandy beach, west coast of India. *Oceanogr*., Vol.68 295-305pp.

Stahl, H., Glud, A., Schröder, C. R., Klimant,I., Tengberg, A. and Glud, R. N., 2006. Time-resolved pH imaging in marine sediments with a luminescent planar optode. *Limnol. Oceanogr.,* 4: 336-345pp.

Taheri, M., Yazdani Foshtomi, Maryam and Bagheri, H., 2010. Community Structure and Biodiversity of Intertidal Sandy Beach Macrofauna in Chabahar Bay, Northeast of Oman Gulf, IR Iran. *Journal of the Persian Gulf*, 1; 17-25pp.

UK Marine SAC's Project, 2001. Guidelines for water skiing. London, UK Marine SAC's project.

Verpoorter, C.V., Carreere, V., Combe, J.P., 2009. Sediment characterization in the intertidal zone of Bourgneuf bay (France) using the automated modified Gaussian model (AMGM). EGU General Assembly, Vienna, Australia.

Vilas. Y. Sonawane and Anil. M. Khole, 2010. Water quality of some drinking waters in Parbhani City: A case study. *J. Chem. Pharm. Res*., 2(5): 104-107pp.

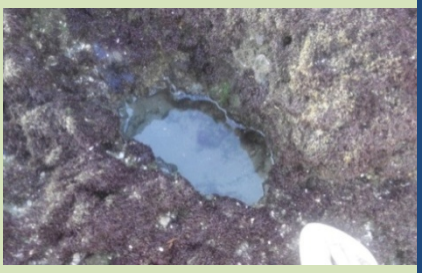
Wenzhöfer, F., Adler, M., Kohls, O., Hensen, C., Strotmann, B., Boehme, S. and Schulz, H. D., 2001. Calcite dissolution driven by benthic mineralization in the deep-sea: In situ measurements of Ca2+, pH, pCO_2 and O_2. *Geochim. Cosmochim. Acta,* 65: 2677-2690pp.

Worden, R.H., Burley, S.D., 2003. Sandstone diagenesis: the evolution of sand to stone. In: Sandstone Diagenesis Ancient and Recent. Reprint Series Volume 4 of the International Association of Sedimentologists. Blackwell Publishing Ltd, 3-44pp.

Zakaria, L., Yee, T.L.,Zakaria, M. and Salleh, B., 2011. Diversity of Microfungi in Sandy Beach Soil of Teluk Aling, Pulau Pinang. *Trop Life Sci Res.,* 22(1): 71–80pp.

Chapter 6

INTERTIDAL COMMUNITIES AND COMMUNITY ANALYSIS



Contents

6.1 Macrobenthos

Macrobenthos are an integral and important element of all ecosystems (Asadujjaman *et al.,* 2012). They play a significant role in energy pathway and nutrient cycling and also an essential link in aquatic food chain (Shafiqul Islam *et al.,* 2013). The intertidal is a home to many organisms, animals and plants. In intertidal areas the benthic macrofaunal community is structured by environmental variables (Zajac and Whitlach 1982; Menge and Olson, 1990).

Some species depend on sediment grain size whereas for other species emersion time, salinity also could be the controlling factor for macrobenthic distribution (Ysebaert *et al.,* 2002).

Rocky shores are difficult place to live; biologically it is rich and easily accessible. A rocky intertidal shore covers different gradients of physical conditions during the time of immersion and emersion. It experiences both conditions, completely marine below low tide levels and totally terrestrial at highest levels above high tide (Underwood, 2000). The formations of benthic ecosystem in intertidal areas are influenced by temperature, substratum and hydrodynamic forces (McCoy and Bell 1991; Menge *et al.,* 1985). Zonation can be easily seen in rocky shores. Space is the most limiting factor in rocky shores. With ample primary productivity the food supply is abundant on rocky shores (Ricketts and Calvin, 1968). In general, models of distribution are mainly determined by abiotic factors (desiccation and temperature) from the high tide to low tide zone, and by biotic factors (competition and predation) from the low tide to the high tide zone (Russell, 1991; Little & Kitching, 1996; Sumich, 1999).

Sandy shores are highly dynamic ecosystem so the adaptations must be powerful and fast in this condition. On the contrary to rocky shores, desiccation is not at all a problem due to the burrowing nature. The abundance of fauna on sandy shores are controlled by physico chemical parameters of water and sediment. Shores are abode of many organisms.

6.2 Fort Cochin

Fort Cochin beach is an open beach with high wave intensity. The disturbances will be high due to high wave intensity, may lead to a lower diversity of organisms. As the Fort Cochin beach is a hot spot in tourism, it is

anthropologically more influenced. Industrialization and shipping also create polluted environment. Morphology of the beach was also deteriorating mainly due to beach erosion.

As it is highly dynamic the existence of the organism is risky. Sediment transport and dredging also cause unbalanced ecosystem. From two stations observed in this beach 24 species have been collected. Amphipods (42%) dominated in the beach followed by polychaetes (28%) (Fig.103). Apart from these bivalves, oligochaetes, mole crabs, isopods, mysids and tanaids, were also observed. The beach at Fort Cochin produced fewer species and the vertical distribution of organisms was not consistent throughout the sampling. Scattered burrows of an *Ocypode* crab occurred around high tide region but none was obtained in the quantitative samples. The tidal migrants *Emerita* sp. and *Donax* sp. were characteristic inhabitants of mid tide zone. There were many opportunistic species of polychaetes on this beach and gastropod obtained was empty shells of *Murex* species, inhabited by hermit crabs.

6.2.1 Station 1

Distribution of organisms in different tide zones

It is purely sandy in texture and covered with the weed, dead Eichornia from high to low tide. High intertidal region of this station only receives splash of waves. It stays dry in low tide time, and has terrestrial influence. The observed organism from high tide was *Emerita* sp. *Emerita rathbunae?* has been observed from this zone (They are tidal migrants, when tide changes they change their position. They are mostly seen in breaking waves).

Mid tide zone of station 2 mainly holds amphipod species. There were 8 species of amphipods identified from this zone. Apart from these mysids and

tanaids were also observed from this zone. *Spheromopsis* sp., (Isopod), *Amphilochus picadurus, Microdeutopus gryllotalpa, Gammaropsis* sp., *Gnathopleustes pachychaetus.*, *Hyalella* sp., *Callopius carinatus* (Amphipods) were identified from this zone.

Low tide zone was characterized by amphipods and *Emerita* sp. Amphipod species like *Amphilochus picadurus, Callopius carinatus* and mole crab, *Emerita rathbunae* were obtained from this zone. The dominant species in station 1 was *Amphilochus picadurus* (Amphipod).

Distribution of organisms in different tidal heights

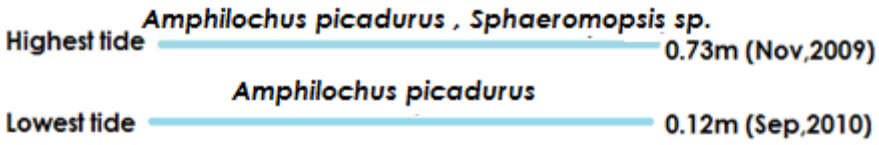


Figure 101 Distribution of organisms in highest and lowest tides in station 1 of Fort Cochin beach during 2009-2011

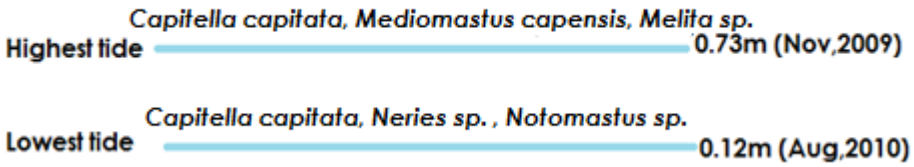


Figure 102 Distribution of organisms in highest and lowest tides in station 2 of Fort Cochin beach during 2009-2011

6.2.1.1 Spatial, monthly and seasonal variations of faunal groups in station 1 of Fort Cochin beach.

In station 1 of Fort Cochin beach highest percentage abundance was shown by amphipods (62.1%) followed by bivalves (12.8%) (Fig. 105). Among the amphipods, *Amphilochus picadurus* was the dominant species and

the density was 26 no./m^2 (Table 61). The lowest percentage abundance was shown by polychaetes (0.67%), mainly contributed by Arenicolidae? (Fig 105). Total species density of amphipods was 92 no. /m^2 (Av. 5.1 no./m^2) (Table 61, Fig.112). In August 2009, highest density (32no./m^2) of organisms was observed, mainly contributed by amphipods. The lowest total density of organisms was observed in February and October, 2010 (Fig.106 & 107). The organisms were absent during most of the months and numerical abundance were also less. Seasonally, amphipods showed highest density (32no./m^2) in monsoon season, 2009. In monsoon season, 2010 the density of amphipods was low (12 no./m^2). The lowest total density of organisms was observed in post monsoon season, 2010. During post monsoon season, 2010 amphipods were absent. Seasonally polychaetes showed lowest density, only 1 no./m^2 in monsoon, 2009. Oligochaetes were completely absent during all seasons (Fig.110).

6.2.1.2 Biomass variations of faunal groups in station 1 of Fort Cochin beach

In station 1 the highest biomass was shown by bivalves (3.2g/m^2) followed by polychaetes (0.41g/m^2). The lowest biomass was observed in mole crab species 0.03g/m^2. The biomass of macrofauna in station 1 varied from 0.03 - 3.2g/m^2 (Fig.113). The average biomass of organisms in station 1 was 0.55g/m^2.

6.2.2 Station 2

6.2.2.1 Distribution of organisms in different tide zones

Station two comprised of fine sandy texture. It is situated 500m distance from station 1. When compared to station 1 purely marine condition do not exist in this station as it is situated close to Cochin backwaters. The intensity of the wave was less when compared to station 1. The anthropogenic disturbances are more when compared to station 1. Chinese dip net operation

was another disturbance to the zone. This region was covered with Eichornia, dead fishes, empty shells and waste from industries and oil slicks from ships. Overall it was a chancy place for organisms to survive. This station was dominated by polychaetes, mainly *Neries* sp., *Heteromastus* sp., *Capitella capitata*, *Mediomastus capensis*, *Puliella armata*, *Notomastus* sp. etc followed by amphipods, *Microdeutopus gryllotalpa, Gibberosus* sp., *Callopius carinatus, Melita* sp., *Amphilochus picadurus, Paramicrodeutopus schmitti.* Apart from *Emerita* sp., mysids and oligochaetes were also observed from this station.

High tide zone of this station was comprised of polychaetes mainly *Capitella capitata*, *Mediomastus capensis* and some species of amphipods also were identified from this zone, mainly *Microdeutopus gryllotalpa, Gibberosus* sp., *Paramicrodeutopus schmitti*. This zone is covered with empty shells of gastropods.

Mid tide zone was characterized by *Nereis* sp., *Heteromastus* sp., *Capitella capitata, Puliella armata*, mysids and oligochaetes. Amhipod *Melita* sp. has been observed from this zone. Low tide zone comprised of mysids. At station 2 the dominated species was *Capitella capitata* (polychaete).

6.2.2.2 Spatial, monthly and seasonal variations of faunal groups in station 2 of Fort Cochin beach

In station 2 of Fort Cochin beach the highest percentage abundance was shown by polychaetes (49.46%) followed by amphipods (25.5%) (Fig.105). *Capitella capitata* was the dominant polychaete species in station 2 (33no./m^2) (Table 61). The lowest percentage abundance was shown by mole crabs (3.72%) (Fig.105). The average density of polychaetes was 5.16 no./m^2 (Fig.112). The highest total density of organisms was observed during November, 2009, mainly contributed by amphipods (29no./m^2). The lowest

total density was observed in April, September, October and November, 2010 (Fig.108 & 109). Seasonally polychaetes were observed during all seasons and highest was observed during post monsoon, 2009 (34 no./ m^2). In post monsoon season (2009) amphipods also contributed same as polychaetes (34no./m^2). Seasonally highest total density of organisms was observed in post monsoon season, 2009 and lowest density was observed in post monsoon season, 2010. Mysids were lesser in post monsoon season (2010) and density was 1 no./m^2 (Fig.111).

6.2.2.3 Biomass variations of faunal groups in station 2 of Fort Cochin beach

In station 2 the biomass of macrofauna ranged from 0.0092-1.116g/m^2. The average biomass was 0.253g/m^2. The highest biomass was shown by polychaetes (1.116g/m^2) followed by mysids (0.116g/m^2). The lowest was shown by mole crabs (0.0092g/m^2) (Fig.113).

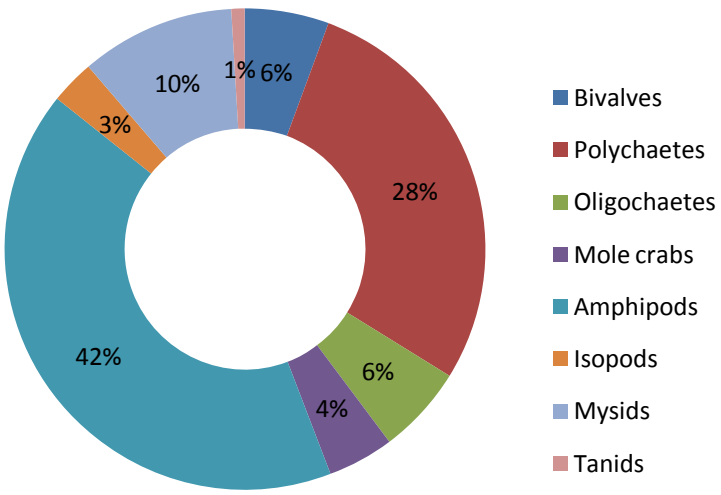


Figure 103 Percentage composition of faunal groups in Fort Cochin beach during 2009-2011

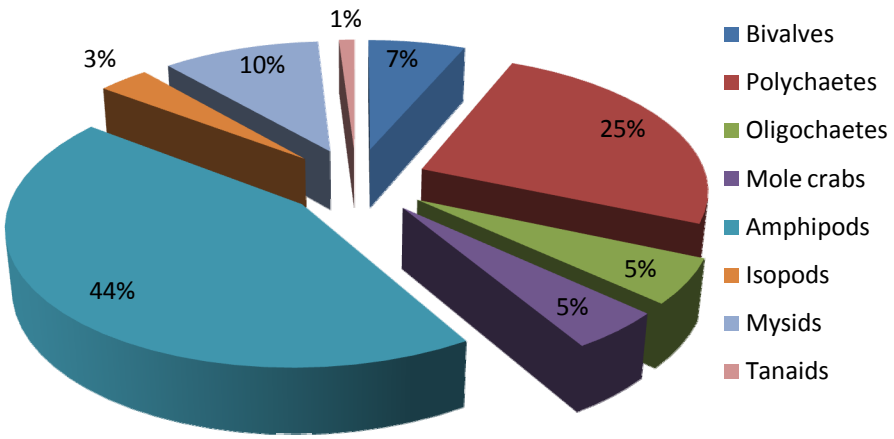


Figure 104 Percentage abundance of faunal groups in Fort Cochin beach during 2009-2011

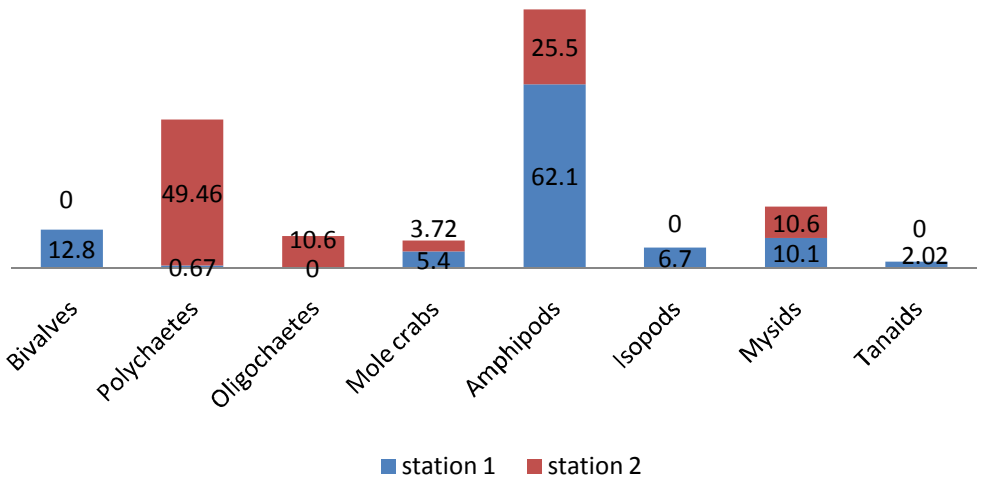


Figure 105 Spatial percentage abundance (%) of faunal groups in Fort Cochin beach during 2009-2011

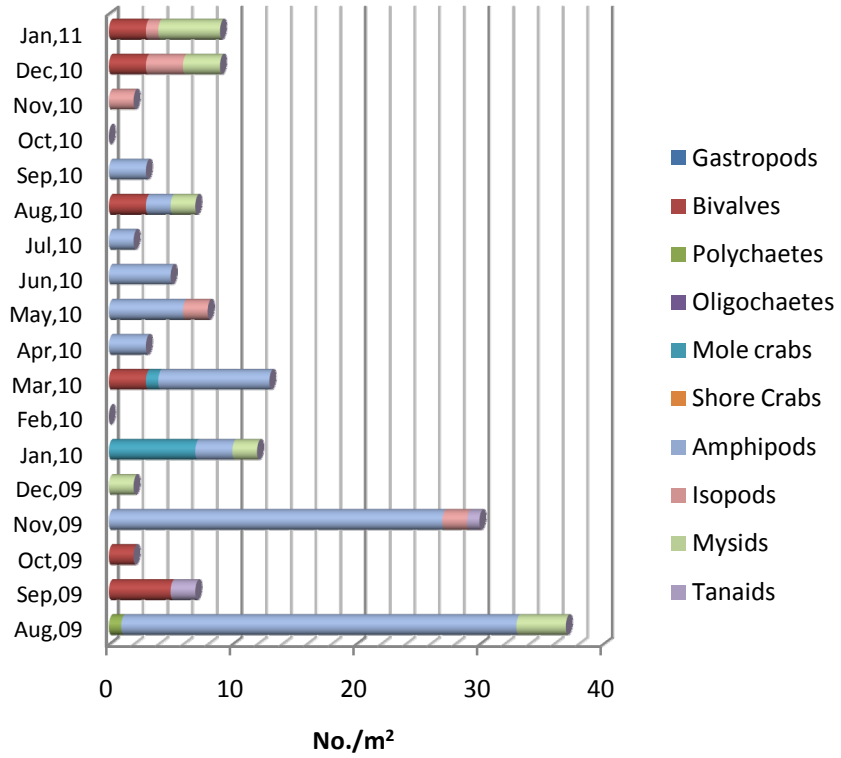


Figure 106 Monthly variations in faunal density (no./m^2) of station 1 in Fort Cochin beach during 2009-2011

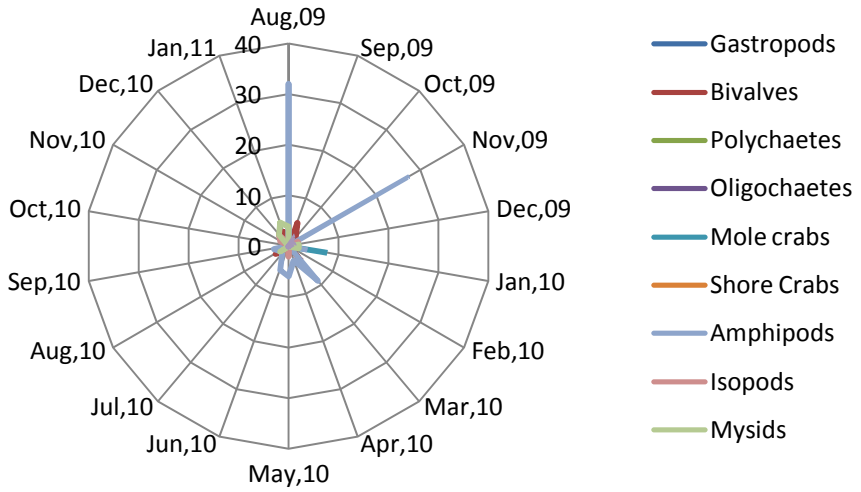


Figure 107 Radar chart showing monthly variations in faunal density (no./m^2) of station 1 in Fort Cochin beach during 2009-2011.

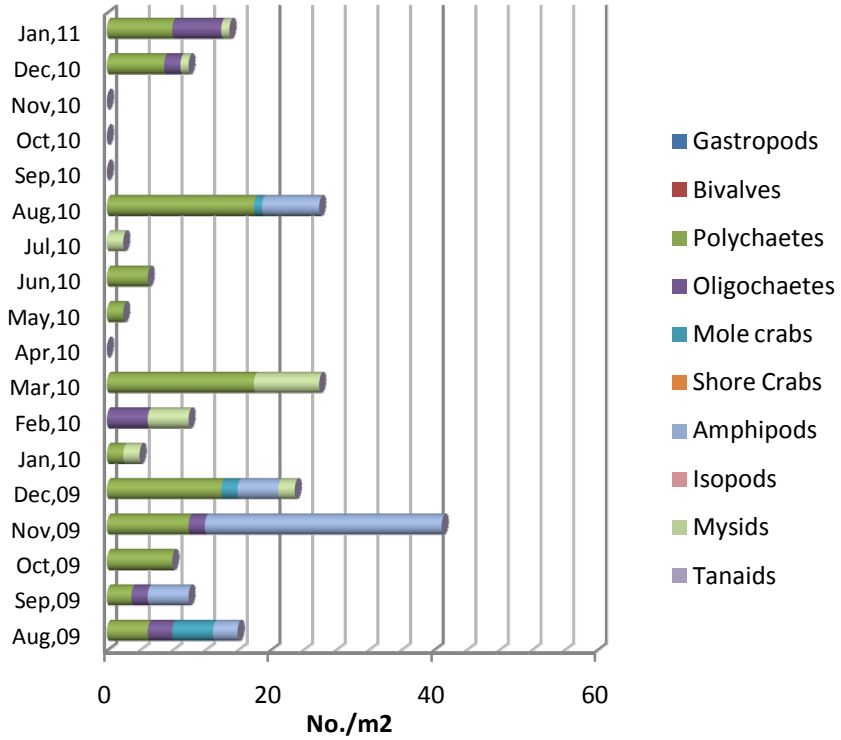


Figure 108 Monthly variations in faunal density (no./m^2) of station 2 in Fort Cochin beach during 2009-2011

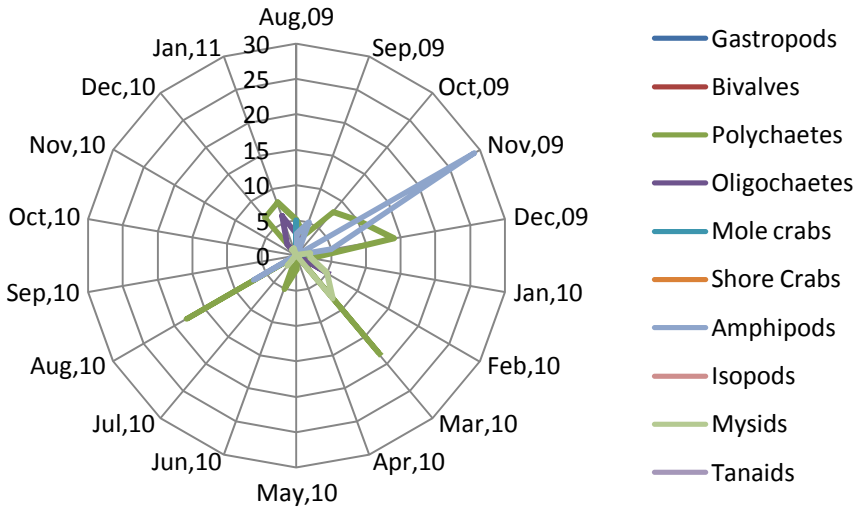


Figure 109 Radar chart showing monthly variations in faunal density (no./m^2) of station 2 in Fort Cochin beach.

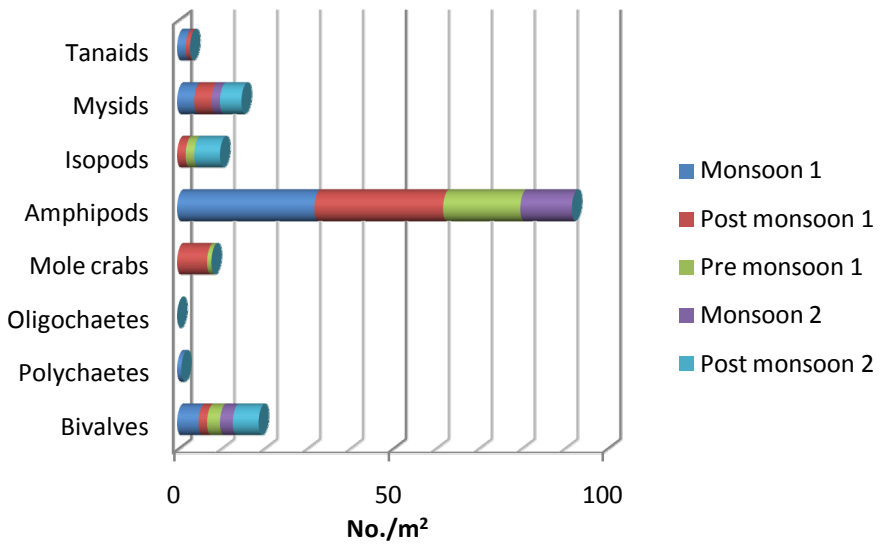


Figure 110 Seasonal variations in faunal density (no./m^2) of station 1 in Fort Cochin beach during 2009-2011 (Monsoon 1- Monsoon- 2009, Post monsoon 1- Post monsoon- 2009, Monsoon 2- Monsoon- 2010, Post monsoon 2 – Post monsoon- 2010)

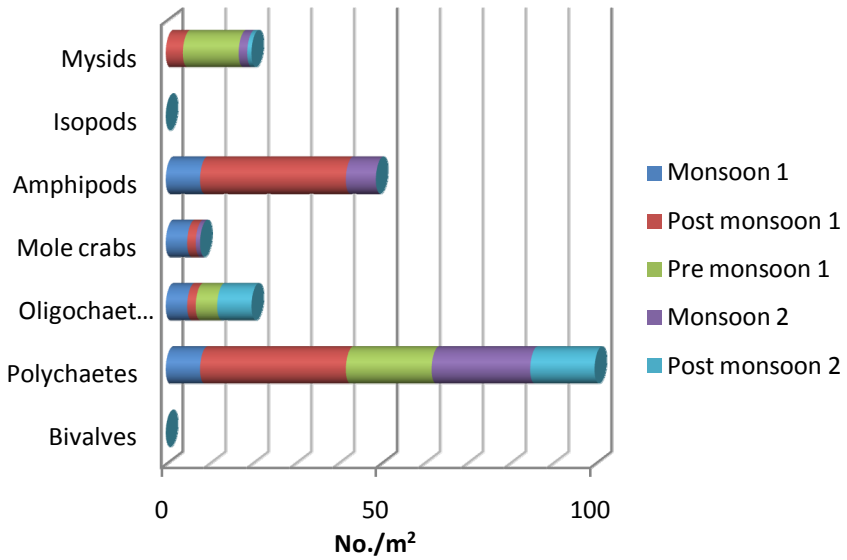


Figure 111 Seasonal variations in faunal density (no./m^2) of station 2 in Fort Cochin beach during 2009-2011

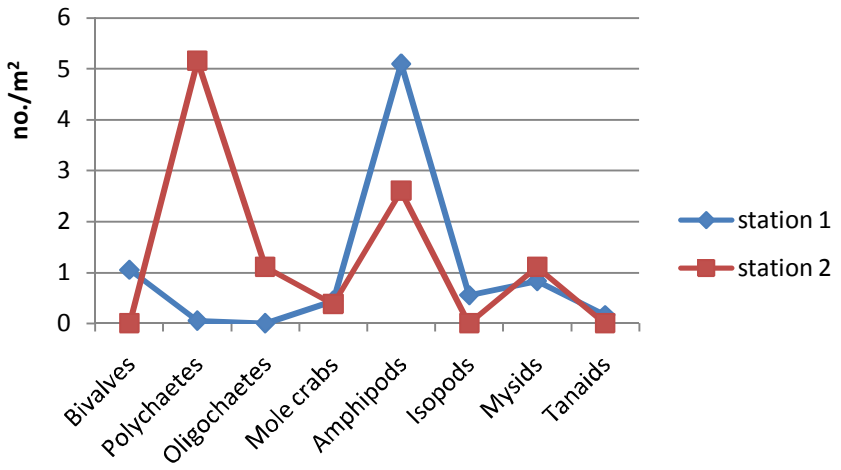


Figure 112 Station wise mean density variations (no./m^2) of faunal groups in Fort Cochin beach during 2009-2011

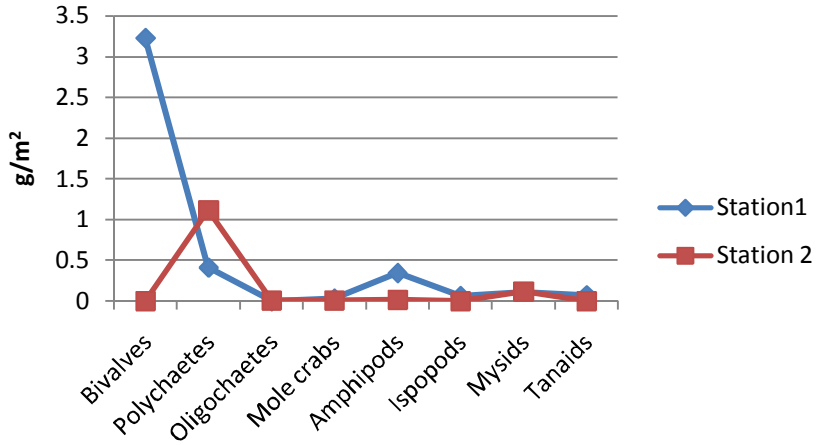


Figure 113 Biomass (g/m^2) variations of total faunal groups in Fort Cochin beach during 2009-2011

Table 60 ANOVA of density of fauna in Fort Cochin beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	26	14.952	5.524
Intercept	1	433.218	160.054
Month	17	11.279	4.167
Station	3	65.877	24.338
Month* Station	6	1.748	.646

R^2= .232

Table 61. Composition, distribution and numerical abundance (no./m^2) of intertidal fauna in different tide levels in Fort Cochin beach during 2009-2011.

Species	Station1	Station2	Qua1		Qua2		Qua3		Qua4	
			St1	St2	St1	St2	St1	St2	St1	St2
Polychaetes										
Arenicolidae?	1	0	1	-	-	-	-	-	-	-
Nereis sp.	0	18	-	-	-	18	-	-	-	-
Capitella capitata	0	33	-	9	-	13	-	11	-	-
Mediomastus capensis	0	10	-	10	-	-	-	-	-	-
Puliella armata	0	17	-	-	-	-	-	17	-	-
Notomastus sp.	0	10	-	-	-	10	-	-	-	-
Heteromastus sp.	0	5	-	-	5	-	-	-	-	-
Oligochaetes	0	20	-	-	-	10	-	10	-	-
Amphipods										
Amphilochus picadurus	26	0	-	-	4	-	10	-	12	-
Microdeutopus gryllotalpa	10	3	4	1	2	3	-	3	-	-
Amphithoe lacertosa	2	0	-	-	-	-	2	-	-	-
Gammaropsis sp.	2	0	-	-	-	-	2	-	-	-
Gnathopleustes pachychaetus	20	0	-	-	8	-	12	-	-	-
Hyalella sp.	10	0	-	-	-	-	10	-	-	-
Calliopius carinatus	12	0		-	8	-	-	-	4	-
Gibberosus sp.	0	3	-	3	-	-	-	-	-	-
Paramicrodeutopus schmitti	0	10	-	10	-	-	-	-	-	-
Aoridae?	3	0	-	-	-	-	3	-	-	-
Melita sp.	7	32	7	-	-	26	-	6	-	-
Isopods										
Shaeromopsis sp.	10	0	-	-	4	-	-	-	6	-
Mysids	15	20	-	-	8	4	4	6	3	10
Tanaids	3	0	-	-	3	-	-	-	-	-
Mole crabs										
Emerita rathbunae?	8	0	3	-	-	-	-	-	5	-
Megalopa larvae of *Emerita rathbunae?*	0	7	-	7	-	-	-	-	-	-
Bivalves										
Donax incarnates	19	0	-	-	-	-	-	-	19	-

(Note : Qua- Quadrate, Qua 1-High tide zone, Qua 2 & 3- Mid tide zone, Qua 4- Low tide zone, St- Station)

6.3 Similarity indices of Fort Cochin beach

6.3.1 Cluster analysis with SIMPROF (Similarity Profile) test

Similarities of organisms in monthly aspects with SIMPROF (similarity profile) test was done for total groups (Bray Curtis similarity) using PRIMER

software. Significant seasonal similarity between faunal groups was not observed in both the stations of Fort Cochin beach in cluster analysis (Red lines indicate significance of the similarity could not be differentiated) (Fig. 114& 115).

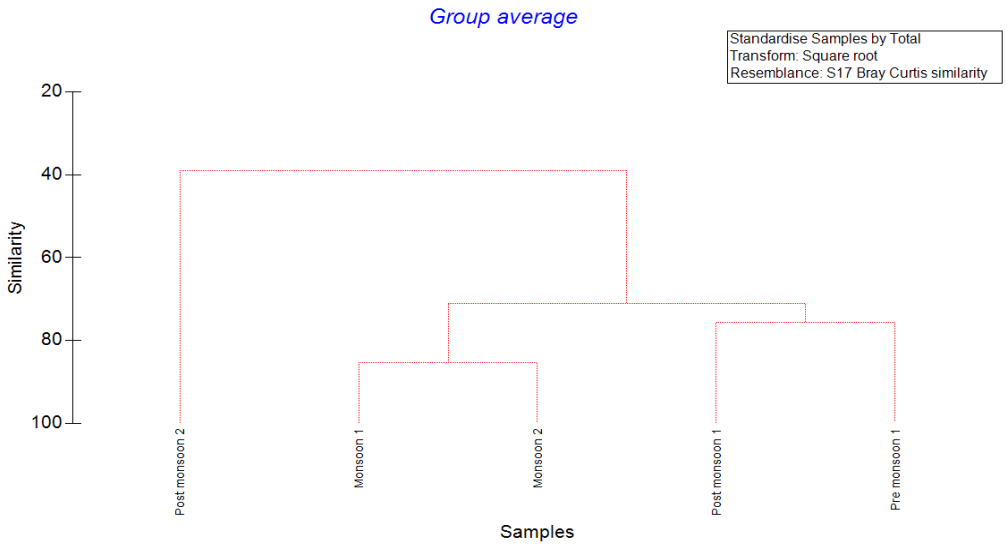


Figure 114 Dendrogram showing seasonal similarities of faunal groups in station 1 of Fort Cochin beach with SIMPROF test.

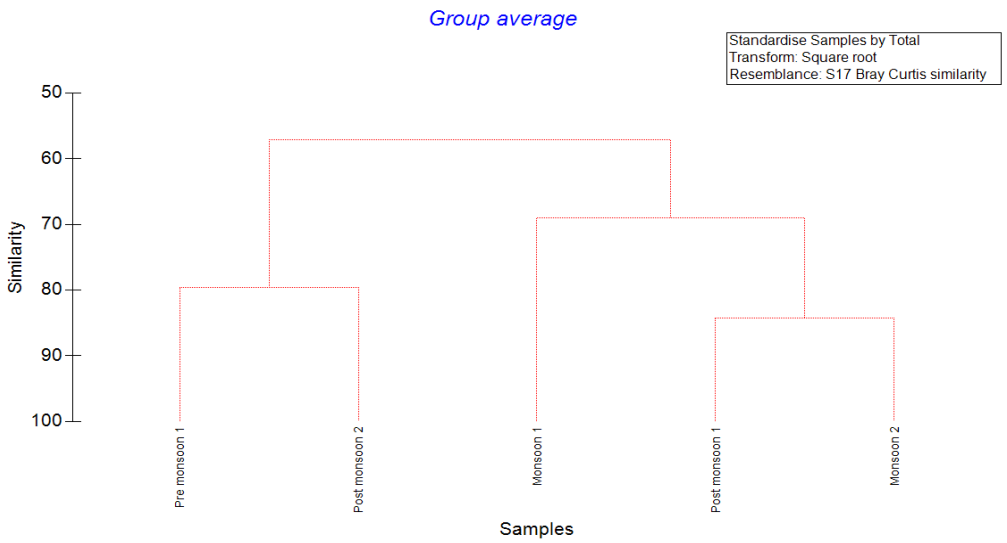


Figure 115 Dendrogram showing seasonal similarities of faunal groups in station 2 of Fort Cochin beach with SIMPROF test.

6.4 Non-metric multidimensional scaling (MDS)

Ordination plots were made between groups and individual species on monthly basis to explore the trends between samples. Bubble plots also performed to know the relative abundance of organisms. As amphipods and polychaetes formed the dominant organisms from this beach bubble plots also had been done to know the distribution and abundance of these dominant species on monthly basis. At station 1 the amphipod *Amphilochus picadurus* and at station 2 the polychaete *Capitella capitata* formed the dominant one.

In MDS plots species similar in composition will close together and species different in composition will far apart. The ordination of total groups from Fort Cochin beach showed the stress value of 0.25. Stress value is signifying the degree to which these relationships can be effectively represented on a two dimensional plot. The MDS plot gave good stress value (0.25) for observing monthly distribution pattern of total macro faunal groups. The MDS plotting (based on Euclidean distance to find the distance/ dissimilarity between samples) of total groups at Fort Cochin beach showed that majority of the samples grouped closely and can assume that almost similar in composition. But some stations formed different group. The segregated stations showed the presence of only one species, different from other sample. For example February station 1 and October station 1 (2010) formed segregated groups, which are characterized by absence of organisms during those months. Samples grouped within the circles showing significantly separate groups at a Euclidean distance of 20 (Fig.116).

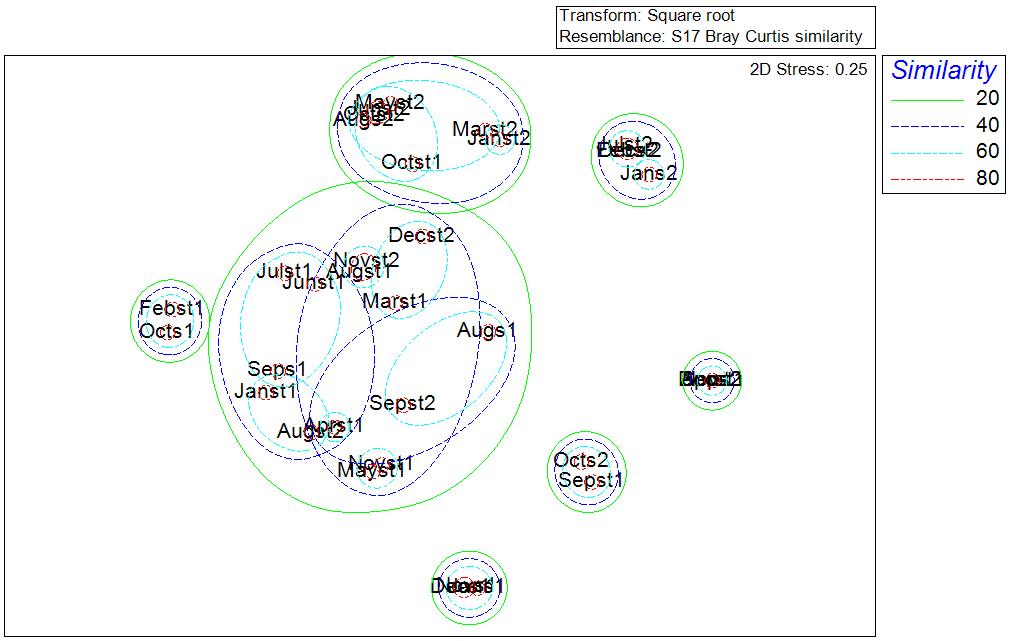


Figure 116 Non- metric multidimensional scaling (MDS) ordination plot of faunal groups of two stations of Fort Cochin beach on monthly basis (2009-2011)

6.5 BEST analysis

BEST analysis was done to find out the correlation between organisms and environmental factors of both the beaches. BEST analysis of total groups with water quality parameter in Fort Cochin beach showed that the best correlation coefficient (rho) as 0.164 and between sediment showed the best correlation coefficient (rho) as 0.165. Twelve water quality parameters were analysed against the total macrofaunal groups of Fort Cochin beach. Significance level of samples showed at 23% level significance. Among the water quality parameters checked three parameters showed significant correlations with biota. DO, Nitrate and nitrite showed best match with faunal groups at Fort Cochin beach. The best correlation coefficient (Rho) for macrofaunal groups was 0.164 (Fig.117, Table 62).

BEST analysis between sediment parameters and organisms were also done to find out the interaction between them. At Fort Cochin beach, sample showed at 28% level of significance with sediment parameters. Conductivity showed best match with total faunal groups. The best correlation coefficient with faunal groups was 0.165 (Fig.118, Table 63).

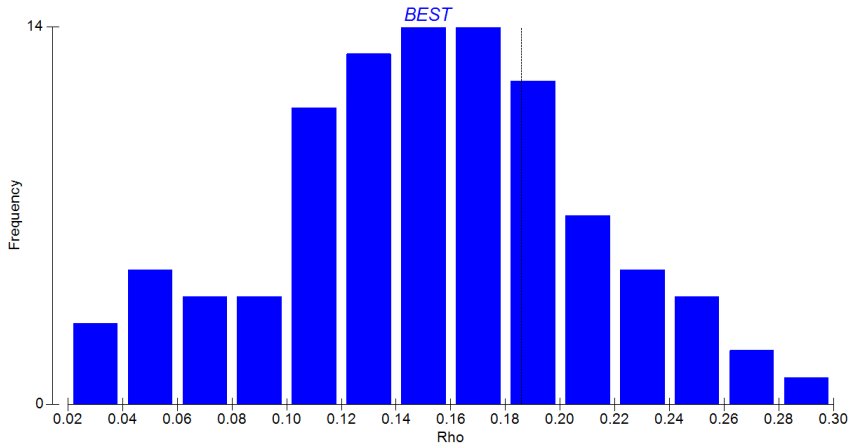


Figure 117 Histogram showing the BEST results for faunal groups and water quality parameters (station 1&2) of Fort Cochin beach during 2009 – 2011

Table 62 BEST correlation tables for faunal groups and water quality parameters (station 1&2) of Fort Cochin beach during 2009 – 2011

SI No.	Variables	Correlation coefficient	Variables Selected
1	Temperature	0.164	5,11,12
2	pH	0.160	5,11
3	Salinity	0.159	2,5,11,12
4	Co_2	0.154	5,9,11,12
5	DO	0.153	2,5,9,11,12
6	Conductivity	0.144	2,5,11
7	TDS	0.140	5,9,11
8	Turbidity	0.139	2,5,9,11
9	Phosphate	0.138	5,12
10	Silicate	0.136	5,9,12
11	Nitrate	0.135	5,9
12	Nitrite	0.132	5,2,12

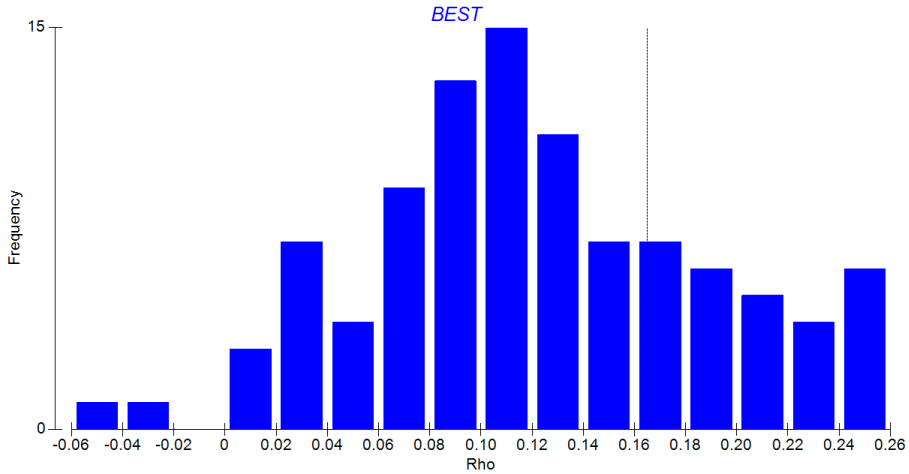


Figure 118 Histogram showing the BEST results for faunal groups and sediment parameters (station 1 &2) of Fort Cochin beach during 2009 - 2011

Table 63 BEST correlation tables of faunal groups with sediment during 2009-2011

SI No.	Variables	Correlation coefficient	Variables Selected
1	Sediment temperature	0.165	3
2	Sediment pH	0.121	3,5,6
3	Sediment conductivity	0.117	3
4	Moisture Content	0.113	5,6
5	Organic matter	0.107	1,3
6	Sand particle	0.102	1,3,5

6.6 Bubble plots

The bubble plot of total groups from station 1 and 2 of Fort Cochin beach were shown the abundance of *Capitella capitata* and *Amphilochus picadurus*. In the figure (119 & 120), bubbles were drawn based on relative abundance of dominant group of macro invertebrates. It shows the abundance of *Capitella capitata* in station 2. Ordination based on MDS bubble plots of

total groups showed the abundance of *Amphilochus picadurus* during most of the months. Larger size of bubbles shows higher abundance.

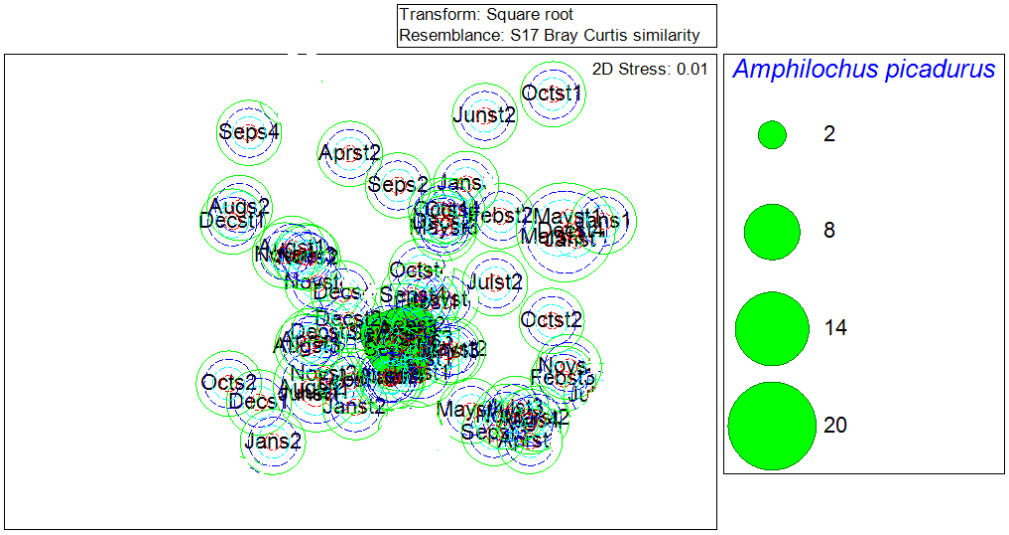


Figure 119 Bubble plot showing monthly variations of *Amphilochus picadurus* in station 1 of Fort Cochin beach.

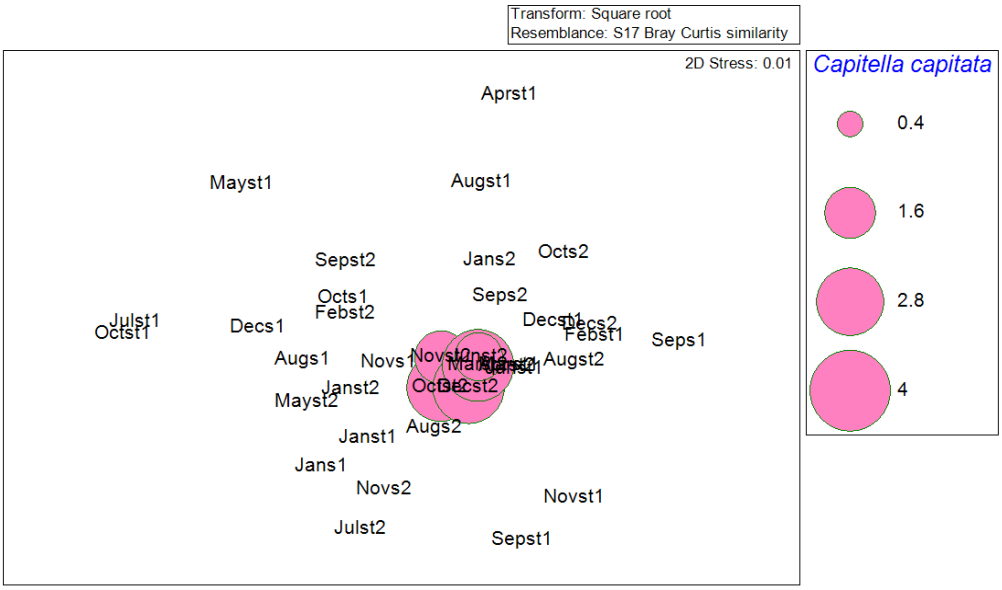


Figure 120 Bubble plot showing monthly variations of *Capitella capitata* in station 2 of Fort Cochin beach.

6.7 Abundance Biomass Curve (ABC plot)

In ABC plot, abundance and biomass k-dominance lines are present in same plot and these lines point out the disturbances in community structure of the area. In station 1 of Fort Cochin beach the biomass curve lies above the abundance curve. So it clearly indicates the undisturbed nature of the community. But at the end of lines, they are coinciding with each other and showed a tendency to reverse the condition. W value showed positive value, indicating undisturbed community. W values are signifying the degree to which the biomass curve lies above the abundance curve (Fig.121).

In station 2 the condition was opposite to the station 1. The abundance curve lies above the biomass curve. It is showing gross disturbances to the community. W value also supports this result. It is negative value, representing disturbed community (Fig.122).

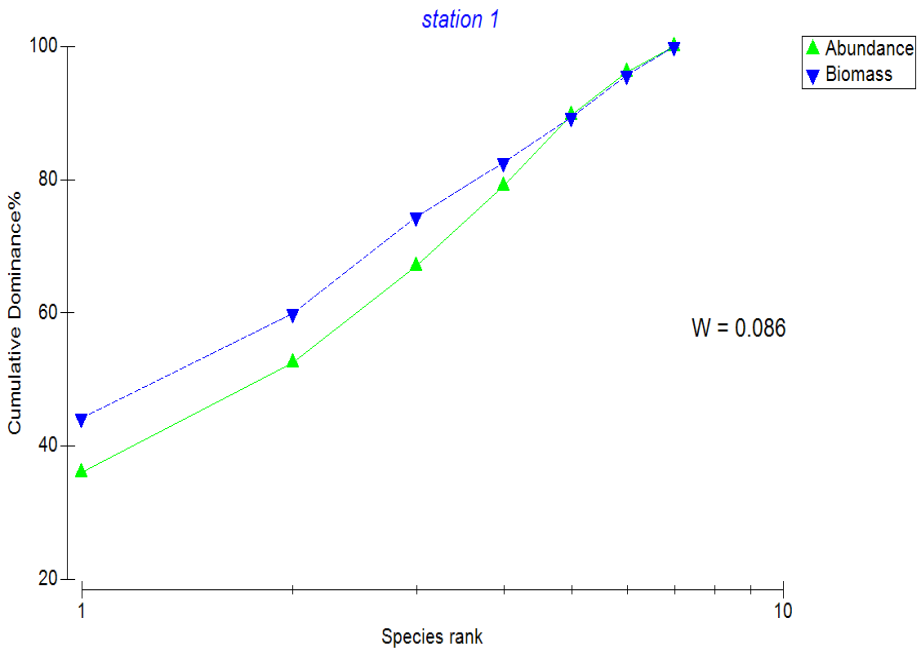


Figure121 Abundance biomass Curve (ABC curve) of faunal groups at station 1 of Fort Cochin beach

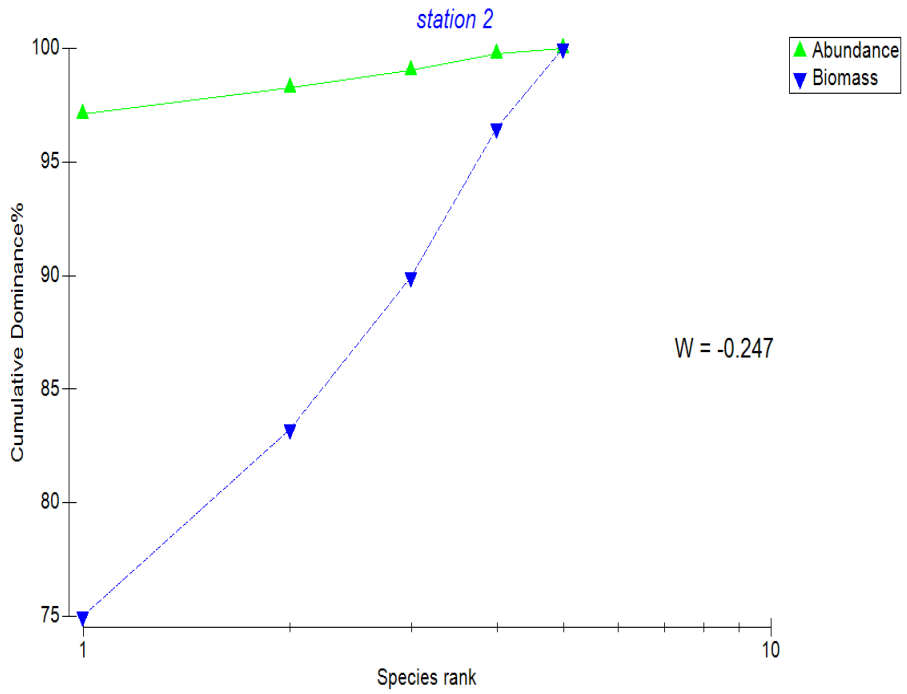


Figure 122 Abundance biomass Curve (ABC curve) of faunal groups at station 2 of Fort Cochin beach

6.8 Geometric class plots

Geometric class plots are multiple frequency polygons, plotted in a single graph and number of species fall into a set of geometric abundance classes. Number of species represented by a single individual (Class 1), 2-3 individual (Class 2) and 4-7individual (Class 3) etc. Impact on assemblages change the normal form of species abundance distribution, lengthening the right tail and some species become dominant, rare species disappear. (Clarke and Gorley, 2006). In Fort Cochin beach the highest percentage species abundance class was observed in station 1 and maximum of seven geometric classes were represented in the geometric class plot analysis (Fig.123). Presence of opportunistic species and unhealthy system depicted from the above results.

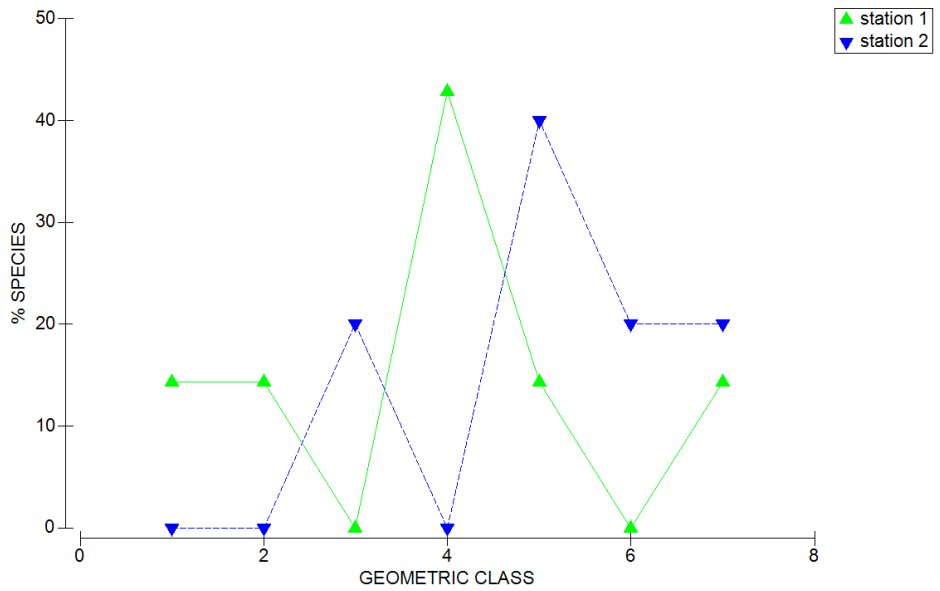


Figure 123 Geometric class plot of faunal groups in two stations of Fort Cochin beach during 2009-2011

6.9 Biotic indices

Biotic index is a scale to measure the quality of the environment. Present study used two biotic indices to check the ecological status of the selected beaches. BOPA and AMBI index were observed using macroinvertebrates as indicators.

6.9.1 Benthic Opportunistic Polychaete/Amphipod ratio - BOPA index (Indices based on ecological strategies)

Polychaete/ amphipod ratio of Fort Cochin beach was taken to know the quality of ecological status. According to the BOPA classification, 0.0000-0.0457 will be classified as high ecological status. In station 1 the BOPA index value was 0.01 and it is classified under high quality status. In station 2 the BOPA index value was 0.15 and according to the classification the value between 0.1396-0.1938 will be moderate ecological status. As per the value station 2 was having moderate ecological status (Table 64).

Table 64 (f_P – opportunistic polychaete frequency, f_A – Amphipod frequency except *Jassa*)

Stations	f_P	f_A	BOPA index
Station 1	0.006	0.621	**0.01 (High)**
Station 2	0.494	0.239	**0.15 (Moderate)**

6.9.2 AMBI (AZTI's Marine Biotic Index)

For the assessment of benthic quality of the selected beaches AMBI was calculated and according to AMBI classification macrofauna were classified into five ecological groups based on the organism's sensitivity to stress. In station 1 of Fort Cochin beach AMBI index showed that the observed macrofauna were coming under group 1. Group 1 species are very sensitive to organic enrichment and present only in non polluted condition. The AMBI index value was 0.867. According to the classification the value in between 0-1.2 is classified as unpolluted condition with high ecological staus. Station 1 of Fort Cochin beach showed unpolluted nature with sensitive organism (Fig.124). In station 2 the AMBI index showed dominance of group 3 organisms. These are tolerant species and may present in normal conditions and if organic enrichment occurs, the population increases. The AMBI value was 3.5 and the value 3.2 - 5 is considered as moderately polluted condition with moderate ecological status. The benthic community health is transitional to pollution in station 2 according to AMBI classification (Fig.125).

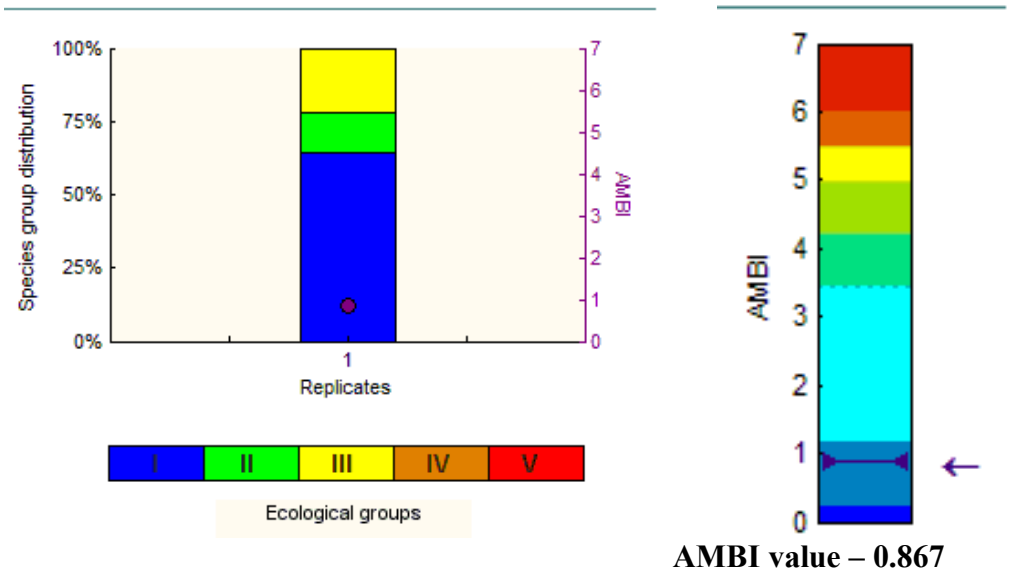


Figure 124 AMBI value and relative abundance of ecological groups in station 1 of Fort Cochin beach

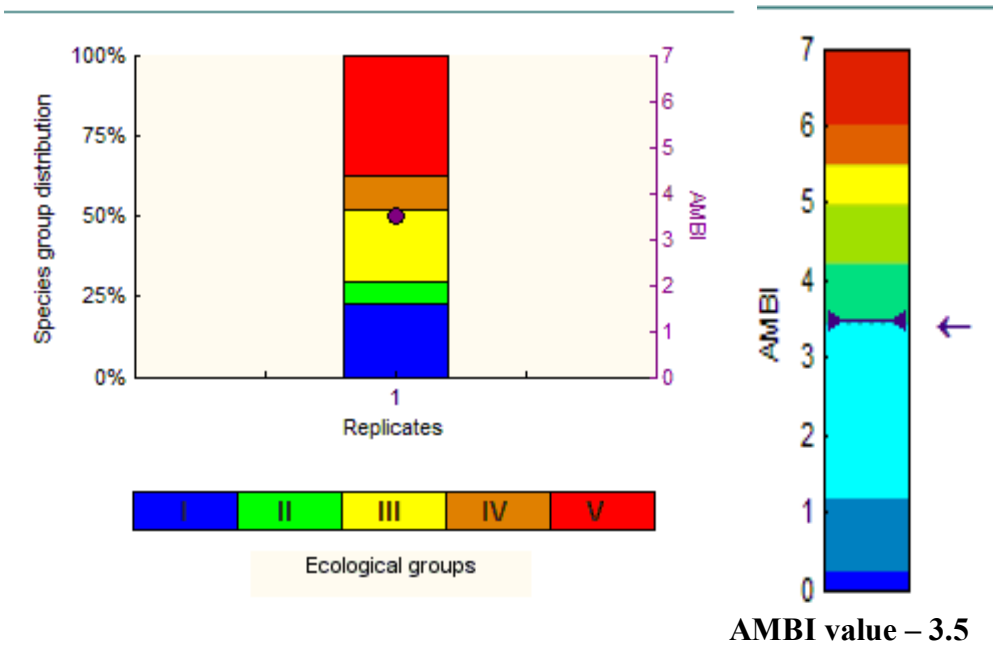


Figure 125 AMBI value and relative abundance of ecological groups in station 2 of Fort Cochin beach

6.10 Diversity indices

Shannon- Wiener Diversity index was used to find out the diversity indices of both the beaches on monthly basis. At Fort Cochin beach the diversity index was found to be high during December, 2010 (H'= 1.09) at station 1 (Fig.126) with low species dominance (λ'= 0.33) (Fig.132). At station 2, August (2009) was observed to be highest in diversity (H'=1.3) (Fig.127) with low dominance (λ'=0.26) (Fig.133). In diversity index analysis some months showed zero values due to absence of species. Richness showed highest values in August, 2010 and August, 2009 at station 1 and 2 (d= 1.02 and 1.08 respectively) (Fig. 128 & 129). Evenness showed its peak in December, 2010 (J'= 1) at station 1 and in January and February, 2010 (J' = 1) at station 2 of Fort Cochin beach (Fig.130 & 131). Lesser diversity was observed in November, 2009 in station 1 (H'= 0.38) and in March, 2010 at station 2 (H'= 0.61) (Fig.126 & 127).

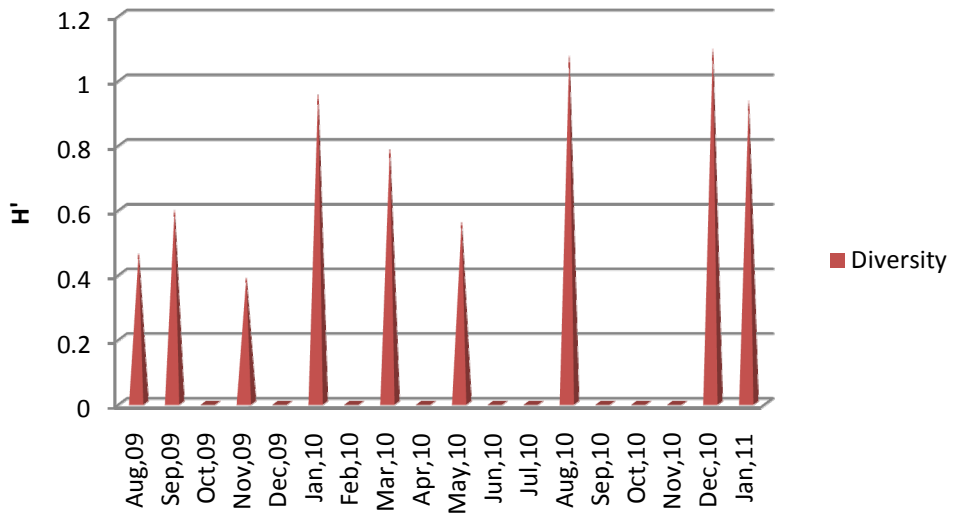


Figure 126 Diversity index of Fort Cochin beach (station 1) during 2009-2011

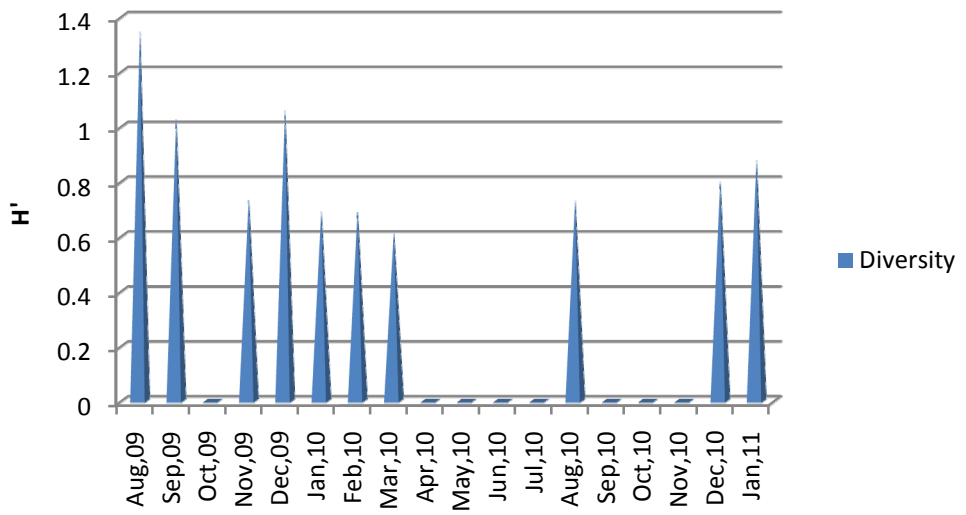


Figure 127 Diversity index of Fort Cochin beach (station 2) during 2009-2011

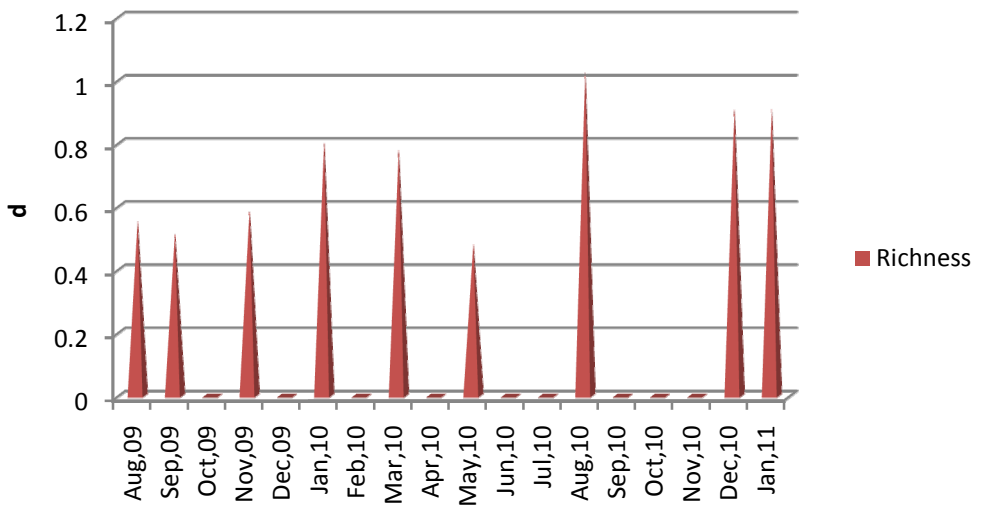


Figure 128 Species richness of Fort Cochin beach (station 1) during 2009-2011

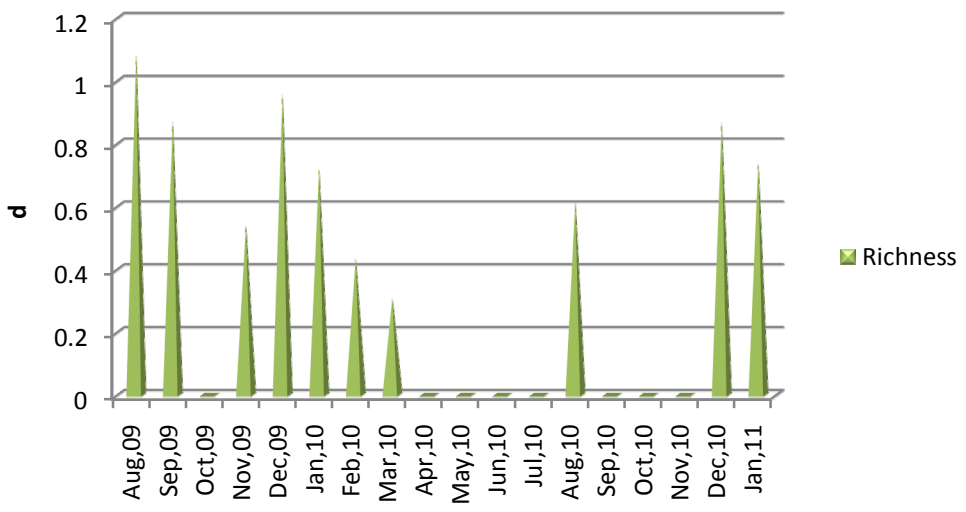


Figure 129 Species richness of Fort Cochin beach (station 2) during 2009-2011

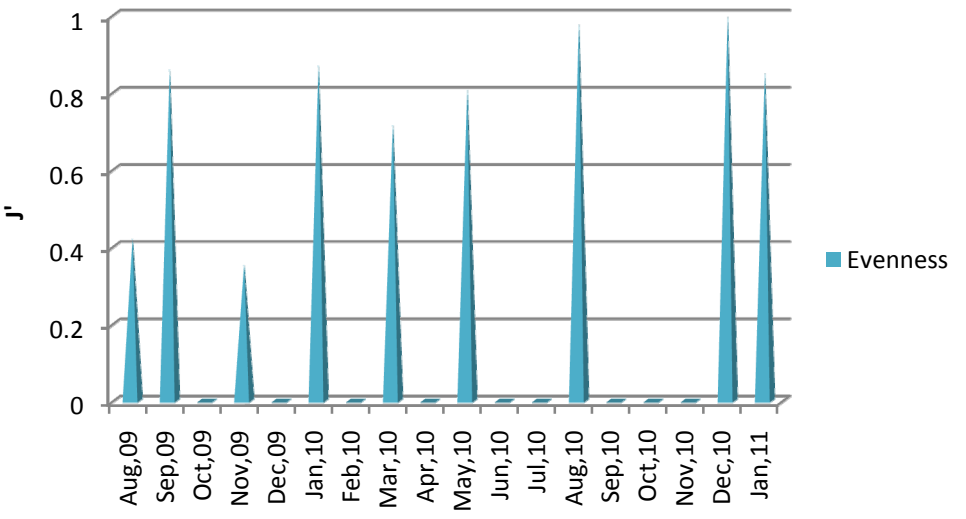


Figure 130 Species evenness of Fort Cochin beach (station 1) during 2009-2011

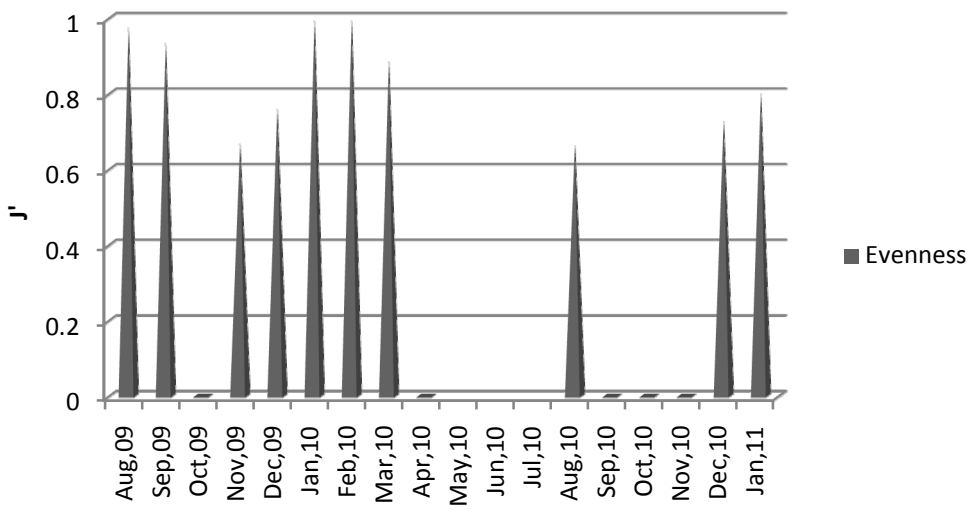


Figure131 Species evenness of Fort Cochin beach (station 2) during 2009-2011

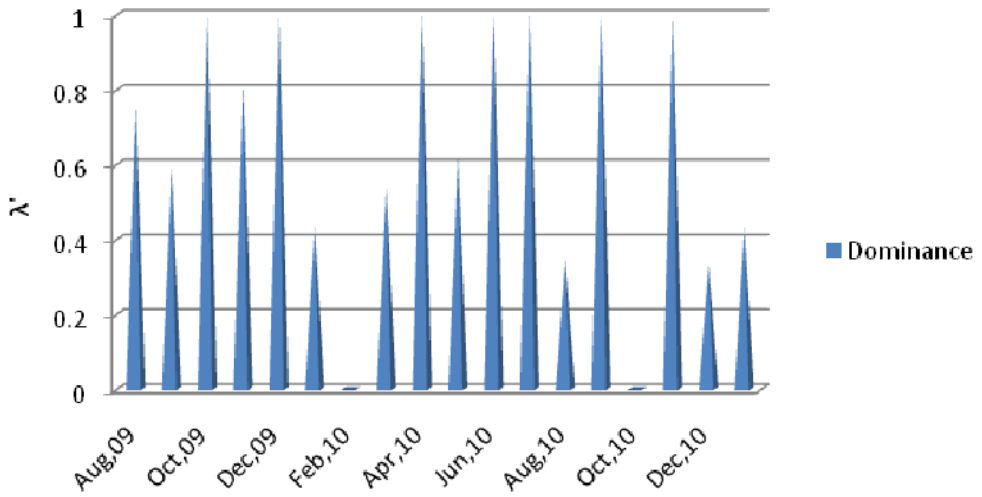


Figure 132 Dominance index of Fort Cochin beach (station 1) during 2009-2011

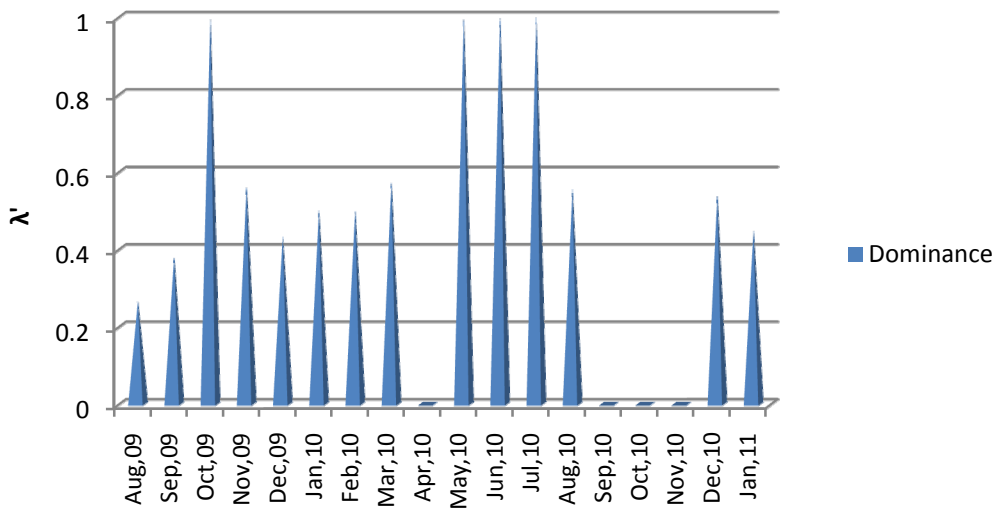


Figure 133 Dominance index of Fort Cochin beach (station 2) during 2009-2011

Table 65 Seasonal values of diversity indices in station 1 of Fort Cochin beach during 2009-2011(d – Margalef's richness, j'- Pielou's Evenness, H'-Shannon Wiener Diversity, λ'-Simpson's Dominance)

	d	j'	H'(loge)	λ'
Monsoon 1	1.057029	0.573635	0.92323	0.552686
Post monsoon 1	1.305946	0.632636	1.133531	0.460302
Pre monsoon 1	0.943974	0.588033	0.815186	0.586806
Monsoon 2	0.705912	0.731598	0.803742	0.543253
Post monsoon 2	0.705912	0.996783	1.095078	0.33564

In station 1 of Fort Cochin beach seasonal diversity index showed highest diversity in post monsoon season, 2009 (Post monsoon 1) (H'= 1.13) with high species richness (d=1.3). Species evenness was observed high in post monsoon season, 2010 (post monsoon 2) (j'= 0.99) with lesser dominance of species (λ'= 0.33). Lesser diversity was observed in monsoon season, 2010 (Monsoon 2) (H'=0.80) (Table 65).

Table 66 Seasonal values of diversity indices in station 2 of Fort Cochin beach during 2009-2011

	d	j'	H'(loge)	λ'
Monsoon 1	0.920783	0.980618	1.359426	0.263314
Post monsoon 1	0.923631	0.66242	1.066124	0.404432
Pre monsoon 1	0.549815	0.88442	0.971634	0.411357
Monsoon 2	0.857999	0.617751	0.856385	0.535354
Post monsoon 2	0.629316	0.721251	0.792375	0.503472

In station 2 diversity index showed higher diversity with less species dominance in monsoon, 2009 (Monsoon 1) (H'= 1.3, λ'= 0.26). Post monsoon season, 2010 (Post monsoon 2) showed lesser diversity when compared to other seasons (H'= 0.79). High evenness was showed in monsoon season, 2009 (j'= 0.98) and high richness was observed in post monsoon season, 2009 (Post monsoon 1) (d=0.923) (Table 66).

6.11 Dharmadam beach

Dharmadam is an open pristine beach when compared to Fort Cochin beach, where tourism and minor fishing activities are developing. Sediment is fine sediment when compared to Fort Cochin. Wave intensity was also less. Beach erosion occurs in lower level at rainy season. Fresh water discharge is from Anjarakkandy River. From two stations observed from this zone about thirty four species of macro invertebrates were obtained. Among the identified samples, gastropods, tanaids, and polychaetes formed the dominant organisms in order of faunal composition. The number of tanaids (25%) was highest at station 1 when compared to other groups whereas in station 2, gastropods (21%) were dominant (Fig. 141). The distribution of organisms from high tide

to low tide marks was almost consistent throughout the sampling. Around high tide zone of the studied sites were characterized with burrows of *Dotilla* and *Ocypode* crabs. The amphipod (*Pontocrates altamarinus*) occurred in a zone around mean high water at the time of the collection and the sea star, *Astropectan irregularis* was spotted at about these tidal levels at both the stations.

6.11.1 Station 1

Distribution of organisms in different tide zones

Station 1 of this beach is characterized by fine sediment texture and low intensity waves. It is a clean beach with 15-30m length. 15- 30m transect was taken perpendicular to the beach. Four quadrates were taken within the transect. The high tide zone receives only water spray and mostly terrestrial in nature. It will only be covered in spring tides. This zone comprised of *Ocypode* sp., *Dotilla* sp., polychaetes (*Scolelepis (Scolelepis) squamata*), tanaids and isopods (*Eurydice peraticis*).

Mid tide zone of this beach was characterized by polychaetes *Scolelepis (S.) squamata*, *Glycera longipinnis*, *Paraonides caratula.*, *Glycera* sp., *Nereis* sp., *Prionospio ehlersi*, *Prionospio* sp., *Prionospio sexoculata*, *Owenis fusiformis*, *Spio filcornis*. The other organisms observed were *Ocypode* sp., *Dotilla* sp., juveniles of ocypods, *Emerita holthuissi*, isopod (*Eurydice peraticis)*, mysids, tanaids, amphipods (*Pontocrates altamarinus*), *Donax incarnatus* (Bivalve), *Nassarius* sp. and seastars.

Low tide zone of this beach is characterized by polychaetes (*Scolelepis (scolelepis) squamata), Glycera longipinnis*., *Ocypode* sp., *Dotilla* sp., juvenile ocypodes, *Eurydice peraticis*, mysids, tanaids, *Pontocrates altamarinus* and seastars.

6.11.2 Spatial, monthly, seasonal variations of faunal groups in station 1 of Dharmadam beach

In station 1 the highest percentage abundance was shown by tanaids (53.42%) followed by polychaetes (13.68%). The lowest was shown by bivalves (0.26%). The percentage abundance of isopods was 11.84% and percentage abundance of other organisms observed from station 1 was below 10% (Fig. 143). In tanaid group, only species identified from station 1 was *Tanzanapseudes* sp. and the density was 203no./m^2 (Table 66). The highest density of *Tanzanapseudes* sp. was shown in October, 2009 (62no./m^2) and lowest was in July and September, 2010 (2no./m)^2. The monthly average density of tanaids was 11.27no./m^2 (Fig. 150). Highest total density of organisms was observed in October, 2009 and lowest was in October, November, 2010 and January, 2011 (Fig.144 & 145). Seasonally post monsoon season, 2009 showed highest total density of organisms and lowest was in post monsoon, 2010. Tanaids were the abundant groups in post monsoon season, 2009 and the density was 103no./m^2. Lowest density was shown in post monsoon season, 2010 and lowest density was shown by shore crabs (1no./m^2) (Fig. 148). In ANOVA significant variation was shown between month and station ($p = 0.031$, $p < 0.05$) in both stations at 5% level (Table 65).

6.11.3 Biomass variations in total faunal group

In station 1 the highest biomass was shown by echinoderms (10. 29g/m^2) followed by taniads (1.56g/m^2). The lowest was shown by mysids (0.046g/m^2). The biomass ranged from 0.046 - 10.29g/m^2. The average biomass was 1.296g/m^2 (Fig.151).

6.11.4 Station 2

Distribution of total faunal groups in different tide levels

Station 2 is characterized by mixed type of sediments, fine sediment and laterite rock formation. It is rocky and sandy type beach, situated 500m distance from station 1. Rocky fragments of Dharmadam beach hold variety of organisms. Epifauna is more pronounced in this station. From high to low tide scattered rock formation occurs. Vertical distributions of organisms were also there on rocky zone of Dharmadam beach. The epifauna residing there are mainly gastropods like *Littorina* species (Periwinkles) and *Patella* sp (Limpets). Bivalves residing there is *Perna viridis* and *Crassostrea* sp. Barnacles and sea anemones were also present, but none was obtained in quantitative sampling because these were totally absent within the transect selected. These were mid and low tide organisms and these were absent from the rock which was sampled. To check the percentage cover of samples it was observed separately at lowest low tides.

High tide region of sandy zone of this station occupies polychaetes like *Scolelepis (scolelepis) squamata, Prionospio* sp., *Prionospio ehlersi*, *Prionospio sexoculata*, *Neanthes willeyi*, *Glycera longipinnis*, *Aonidella cirrobranchiata* and isopods (*Eurydice peraticis*). At rocky zones of Dharmadam beach, periwinkles (*Littorina* sp.), hermit crabs and limpets occupy the high water mark of intertidal zone.

Mid tide region of this station holds polychaetes (*Scolelepis (Scolelepis) squamata*, *Glycera longipinnis, Prionospio pinnata, Prionospio saldanha* and shore crabs, *Ocypode* sp. were also common. The other organisms collected from this zone were *Emerita* sp., (*Emerita holthuissi, Emerita talpoida*?), Isopods obtained were *Eurydice peraticis* and *Sphaeromopsis* sp. Tanaids, gastropods like

Turbo setosus., *Nassarius* sp., *Trochus maculatus shells, Natica gemosa, cymasium* sp., *Bufonaria* sp., *Turricula javana* and sea urchins were abundant at mid tide region and extended up to low tide region at the time of collection.

Low tide region of this zone holds polychaetes (*Scolelepis (Scolelepis) squamata,* amphipods (*Pontocrates altamarinus)*, tanaids, *Diogene* sp., sea urchins (*Psammechinus milaris*). At low tide region, on rocks sea anemones and several species of gastropods like *Nassarius dorsatus* were present. Shells of bivalves, like *Crassostrea* sp. and *Perna viridis* were visible at mid tide region and *Perna viridis* was extended up to low tide level (none was obtained in sampling).

Epifauna

From station 2 of Dharmadam beach lot of epifauna were observed as this region comprised of scattered laterite rocks. In the quantitative sampling only littorinids, other gastropods (*Turbo setosus*., *Trochus maculates*, *Natica gemosa*, *Cymasium* sp., *Bufonaria* sp., *Turricula* sp. And *Nassarius* sp.), *Patella* sp. (Limpets), hermit crabs and sea urchins were obtained. During the time of sampling *Ligia* species (Sea lice, Isopod) were observed. *Littorina* species were abundant in the high tide zone of rocks (Fig. 136). *Patella* species were observed in high and mid tide zone but abundance was very less. Apart from *Patella* species, Rayed limpets (*Cellana radiata*) and *Cellana radiata capensis*? were also observed in high and mid tide region of rocky zone, but only at different seasons. The rocks which held these rayed limpets were small and exposed only at lowest low tides. Whelks were the other organism observed in the mid tide region of station 2. These whelks were observed only in one rock among the scattered rocks and were grazing on barnacles. Acorn barnacles (*Semibalanus balanoides*) (Fig. 135), sea anemones and sea urchins

(*Psammechinus milaris)* were also observed from mid and low tide zones of different rocks. *Perna viridis* and *Crassostrea* sp. were abundant in low tide zones, but it is exposed only in lowest low tides. It is difficult to get the whole organisms as it is fastly removed by the local fishermen due to its commercial importance. Other organisms observed were rock crabs (*Grapsus* sp.) and sand castle worms (*Phragmatopoma* species) (Fig. 134). It is a reef forming marine polychaete and these are commercially valued due to its wide application. The glue produced by the organisms is powerful for medical applications also.

Figure 134 Sand castle worms (*Phragmatopoma* species in low tide zone of rocky beach area in Dharmadam beach)

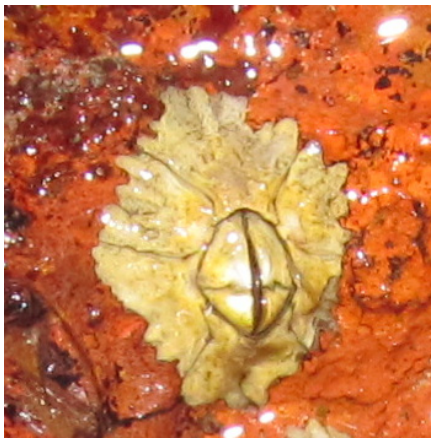


Figure 135 Acorn barnacle (*Semibalanus balanoides*) from rocky shore of Dharmadam beach

Figure 136 *Littorina* sp. from rocky shore of Dharmadam beach

Percentage cover of epifauna in lowest low tide

Percentage cover of epifauna was observed in lowest low tide during the sampling period. Percentage cover of *Littorina* sp. showed that in upper zone of the rock, dominant species were these gastropods. In June, 2010 100% occurrence of *Littorina* sp. were observed in upper zone of the rock. In May 2010 the percentage cover of *Littorina* sp. was 90.91% and in September, 2009 the percentage cover of *Littorina* sp. was 92.86%. *Patella* species were also present in the upper zone. Percentage cover of *Patella* species was 7.14% (Sep, 2009) and 9.09% (May, 2010). *Patella* species were totally absent in June, 2010 in the upper zone (Fig.137).

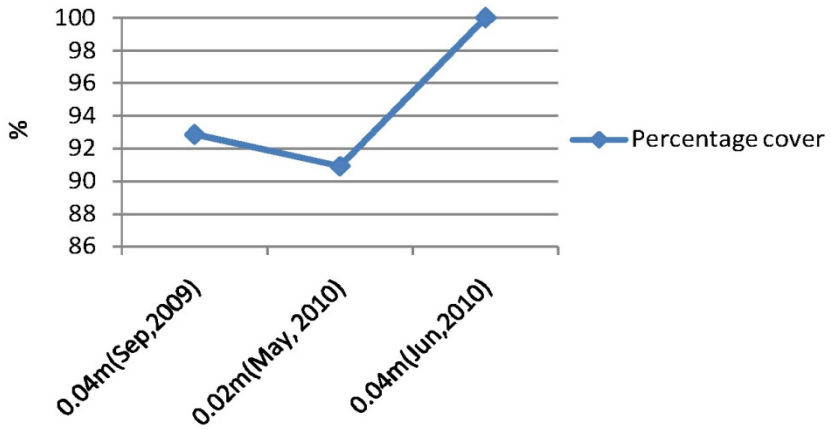


Figure 137 Percentage cover of *Littorina* sp. on rocks at lowest low tide during 2009-2011

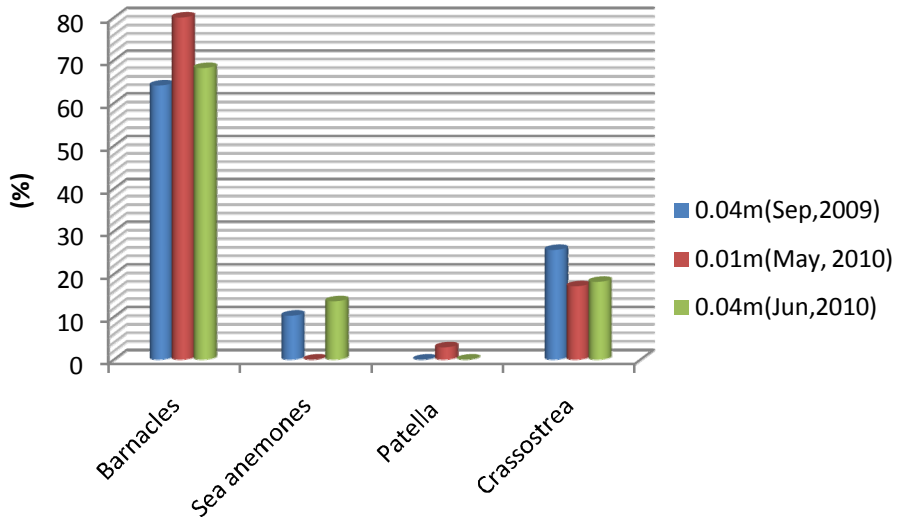


Figure 138 Percentage cover of different epifauna at lowest low tides during 2009-2011

Acorn barnacles were residents of mid tide zone on rocks. Barnacles were counted separately (using 0.625m^2 quadrate) as they were not obtained in quantitative sampling. Percentage cover values showed that barnacles were dominant at the mid tide zone (64.1-80%) and they are occupied in the mid

tide zone with sea anemones, *Patella* sp. and *Crassostrea* sp. The abundance of sea anemones and others were limited. *Crassostrea* species showed 18-25% of occurrence. *Patella* species were very less and absent in mid tide zone during the study period. The percentage cover of *Patella* sp. was varied from 0 - 2.85%. Barnacles were observed to be the permanent residents of mid tide zone (Fig.138).

Distribution of organisms in different tidal levels

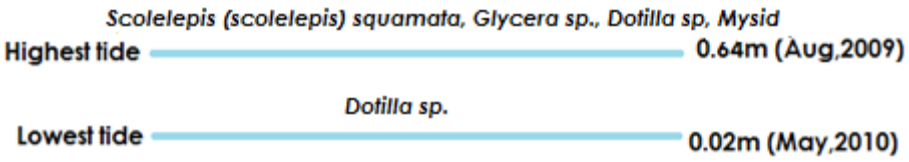


Figure 139 Distribution of organisms in highest and lowest tides in station 1 of Dharmadam beach during 2009-2011

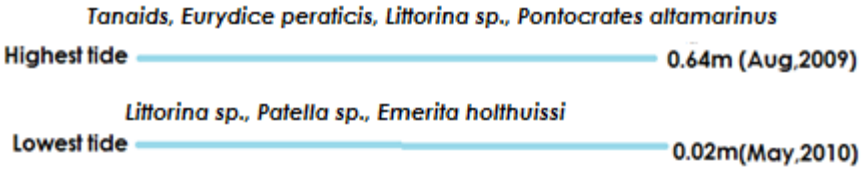


Figure 140 Distribution of organisms in highest and lowest tides in station 2 of Dharmadam beach during 2009-2011

6.11.5 Spatial, monthly, seasonal variations of faunal groups in station 2 of Dharmadam beach

In station 2 of Dharmadam beach the highest percentage abundance was shown by gastropods (44.88%) followed by mole crabs (16.01%). The lowest percentage abundance was shown by echinoderms (1.94%). Tanaids were observed to be less when compared to station 1 and the percentage abundance was 11.65%. Percentage abundance of polychaetes and amphipods were 15.53 and 11% respectively. Percentage abundance of other organisms observed

from station 2 was below 11% (Fig 143). In gastropods *Littorina* species showed highest density (161 no./m^2). In gastropods lowest density was shown by *Patella* species (3 no./m^2) (Table 66). The monthly average density of gastropods were 12.6 no./m^2. The lowest average density was shown by echinoderms (0.66 no./m^2) (Fig. 150). Bivalves (*Donax* sp.) were totally absent in station 2. The highest density and abundance of organisms were observed in December, 2009 and lowest was in October, 2010. Highest abundance of gastropods were observed in August and October, 2009 (41 and 38no./m^2 respectively) and lowest was in July, 2010 (2no./m^2). Highest abundance of mole crabs was observed in March, 2010 (60no./m^2). Gastropods were observed in almost all months during the sampling except in October and November, 2010. Mole crabs were observed only in September, December, 2009 and March, 2010 (Fig.146 & 147). Seasonally the highest density was observed during post monsoon season, 2009. In post monsoon (2009), the highest density was shown by gastropods (90 no./m^2). The lowest was in post monsoon season, 2010 and lowest density was shown by mysids and shore crabs (1no./m^2) (Fig. 149).

6.11.6 Biomass variations in total faunal group in station 2 of Dharmadam beach

In station 2 the biomass ranged from 0.04 - 44.37g/m^2. The highest was shown by echinoderms (44.37g/m^2) and lowest was by mysids (0.04g/m^2). The second highest biomass was shown by gastropods (4.57g/m^2). The average faunal biomass was 4.61g/m^2 (Fig.151).

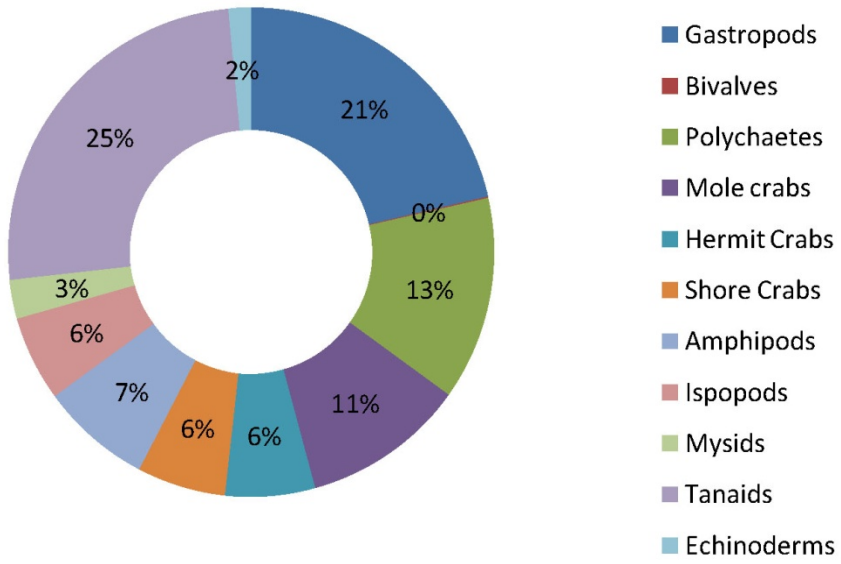


Figure 141 Percentage composition of faunal groups in Dharmadam beach during 2009-2011

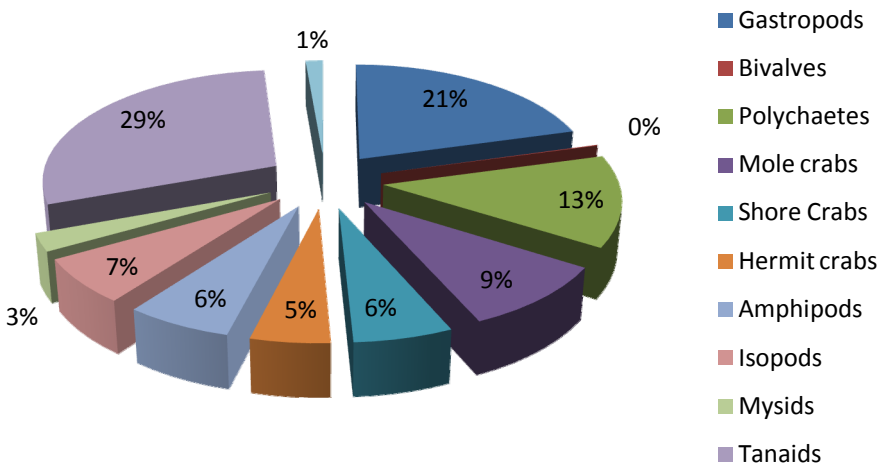


Figure 142 Percentage abundance of faunal groups in Dharmadam beach during 2009-2011

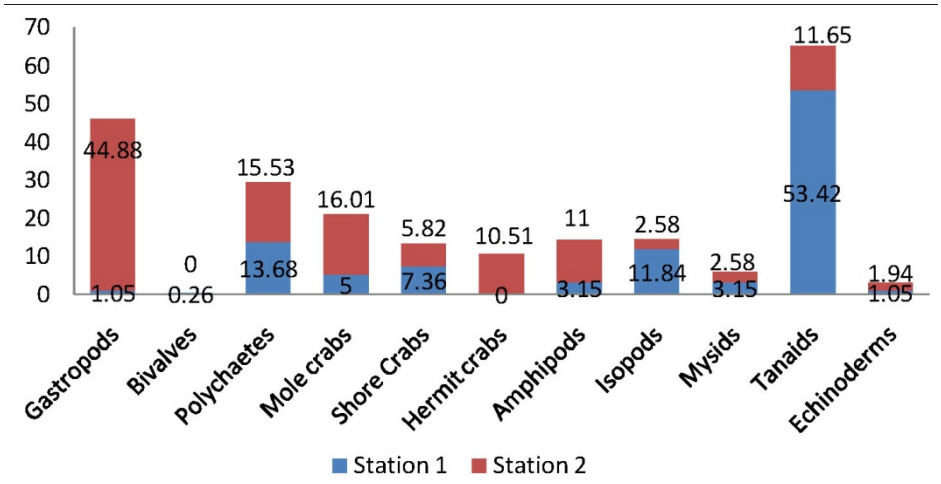


Figure143 Spatial percentage abundance (%) of faunal groups in Dharmadam beach during 2009-2011

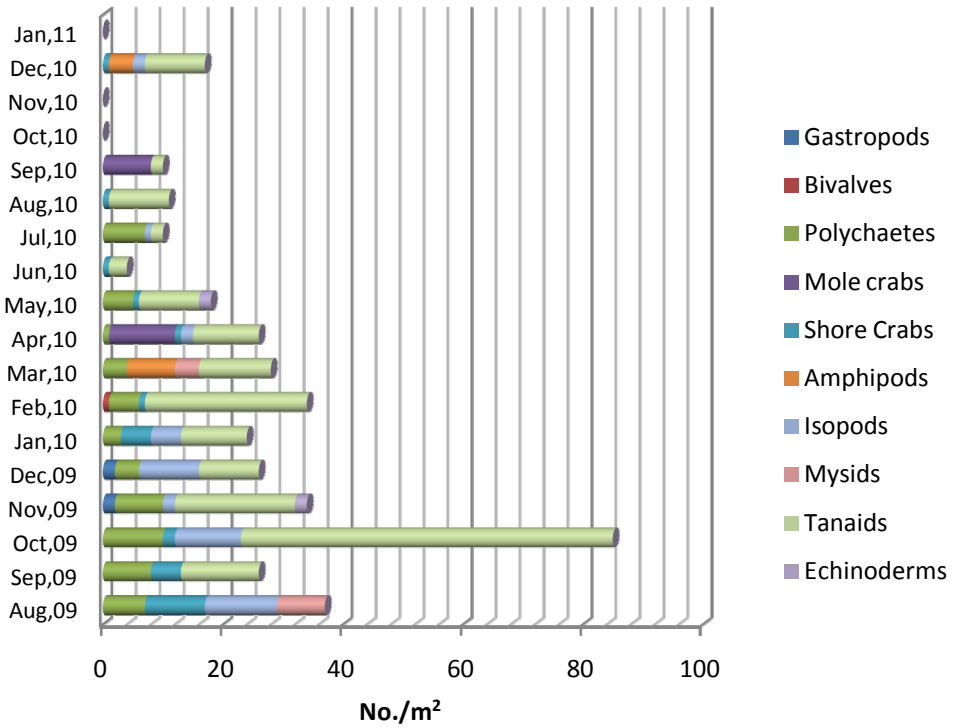


Figure 144 Monthly variations in faunal density (no./m^2) of station 1 in Dharmadam beach during 2009-2011

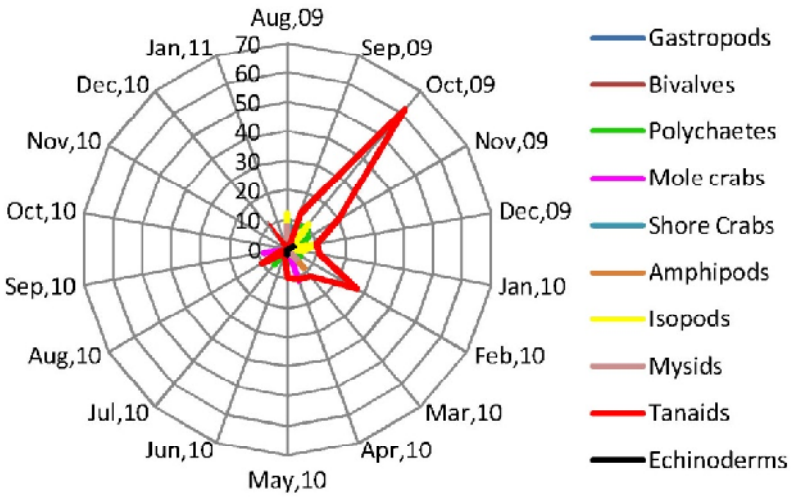


Figure145 Radar chart showing monthly variations in faunal density (no./m^2) of station 1 in Dharmadam beach during 2009-2011

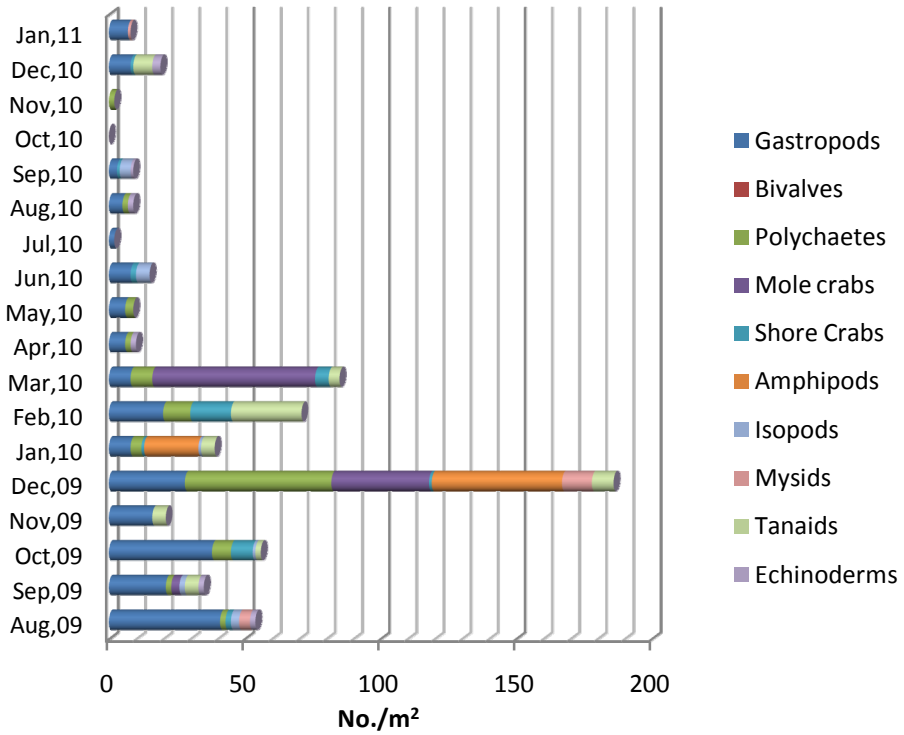


Figure 146 Monthly variations in faunal density (no./m^2) of station 2 in Dharmadam beach during 2009-2011

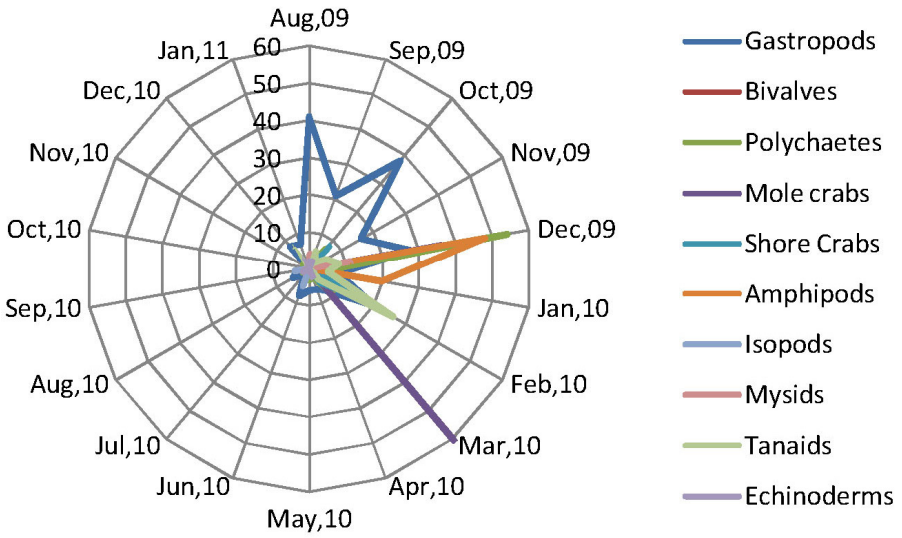


Figure147 Radar chart showing monthly variations in faunal density (no./m^2) of station 2 in Dharmadam beach during 2009-2011

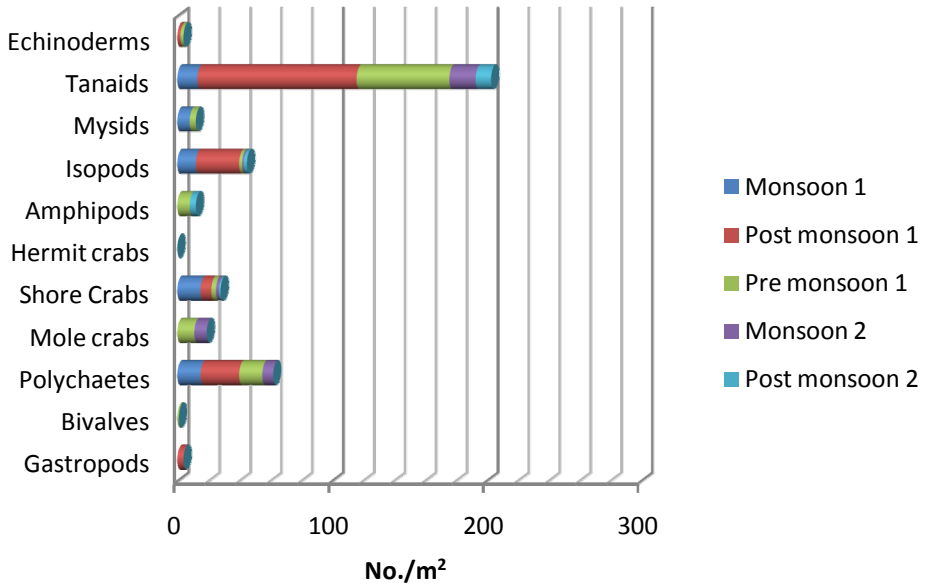


Figure148 Seasonal variations in faunal density (no./m^2) of station 1 in Dharmadam beach during 2009-2011

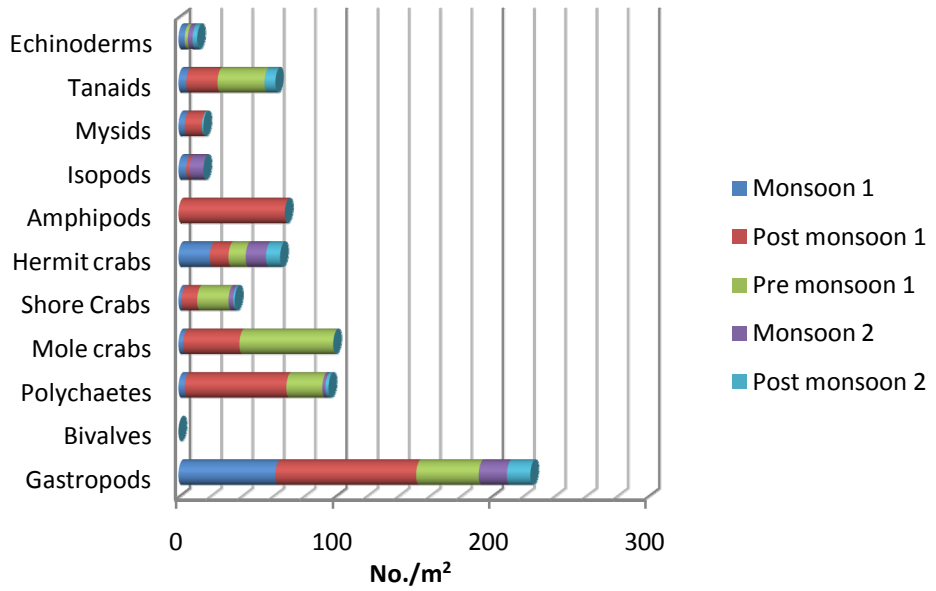


Figure149 Seasonal variations in faunal density (no./m^2) of station 2 in Dharmadam beach during 2009-2011

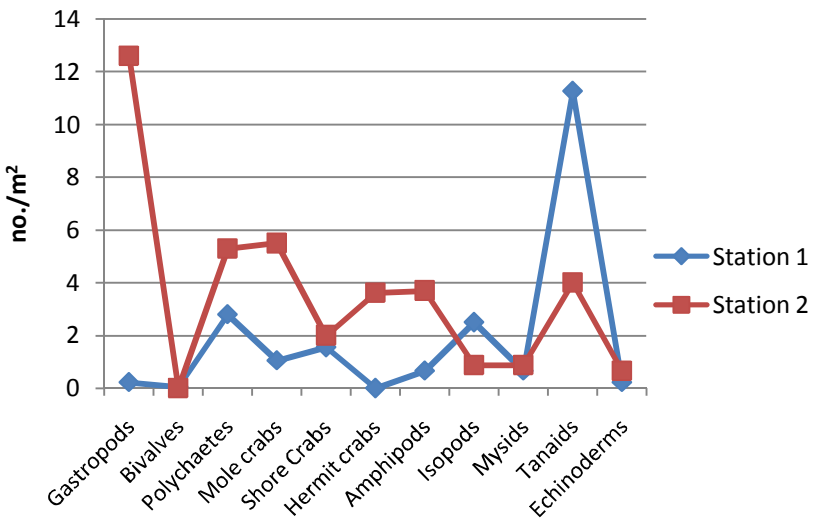


Figure150 Mean variations of total faunal group in Dharmadam beach during 2009-2011

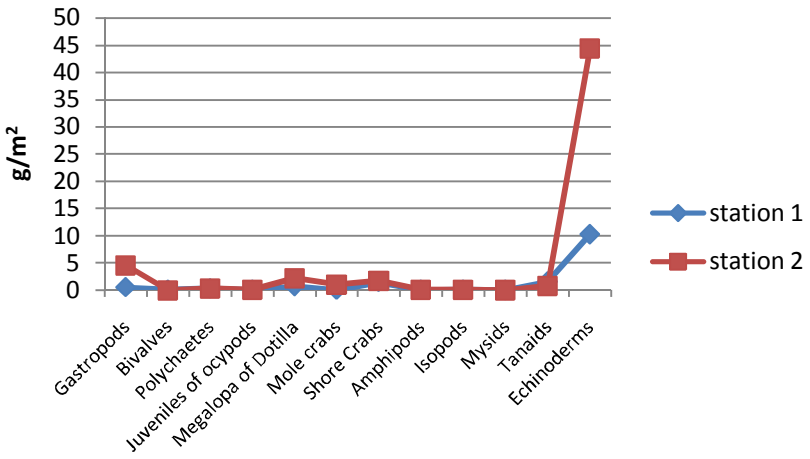


Figure151 Biomass (g/m^2) variations of total faunal groups in Dharmadam beach during 2009-2011

Table 65 ANOVA of faunal groups in Dharmadam beach during 2009-2011

Source	df	Mean Square	F
Corrected Model	71	7.882	3.040
Month	1	433.992	167.393
station	17	11.275	4.349
Month * station	3	66.564	25.674
Error	45	3.796	1.464*
Total	430	2.593	

R^2 = .334

Table 66 Composition, distribution and numerical abundance (no./m^2) of intertidal fauna in different tidal levels in Dharmadam beach during 2009-2011

Species	Station1	Station2	Qua1		Qua2		Qua3		Qua4	
			St1	St2	St1	St2	St1	St2	St1	St2
Polychaetes										
Scolelepis squamata	23	46	7	5	3	11	6	7	7	23
Glycera longipinnis	5	4	2	1	1	1	1	2	1	
Paranoides caratula	1	_	1	-	-	-	-	-	-	-
Prionospio ehlersi	11	3	-	3	-	-	11	-	-	-
Prionospio sp.	3	29	-	28	-	-	3	-	-	1
Glycera sp.	4	_	1	-	1	-	2	-	-	-
Prionospio sexoculata?	1	4	-	4	-	-	1	-	-	-
Owenis fusiformis	1	_	-	-	-	-	1	-	-	-
Spio filcornis	1	_	-	-	1	-	-	-	-	-
Nereis sp.	2	_	2	-	-	-	-	-	-	-
Neanthes willeyi	_	2	-	2	-	-	-	-	-	-
Aonidella cirrobranchita	_	1	-	1	-	-	-	-	-	-
Prionospio pinnata	_	6	-	-	-	6	-	-	-	-
Prionospio saldanha	_	1	-	-	-	1	-	-	-	-
Crabs										
Ocypod sp.	2	12	1	-	1	6	-	1	-	5
Juvenile of *Ocypod* crab	23	7	6	-	7	-	5	4	5	3
Megalopa of *Dotilla* crab	3	17	1	-	1	3	1	-	-	14
Megalopa of *Emerita holthuissi*	19	83	-	-	-	11	19	52	-	20
Megalopa of *Emerita talpoida?*	_	16	-	-	-	-	-	14	-	2
Isopods										
Eurydice peraticis	45	14	15	7	20	5	10	1	-	1
Sphaeromopsis sp.	_	2	-	-	-	2	-	-	-	-
Amphipods										
Pontocrates altamarinus	12	68	-	-	-	-	1	50	11	18
Tanaids										
Tanzanapseudes sp.	203	72	56	26	52	23	71	3	24	20
Hermit Crabs										
Diogene sp.	_	65	-	15	-	30	-	-	-	20
MYSIDS	12	16	-	-	-	-	8	16	4	-
Echinoderm										
Astropecten irregularis	4	2	-	-	1	-	2	1	1	1
Psammechinus milaris	_	10	-	-	-	-	-	2	-	8
Molluscs										
Donax incarnatus	1	_	-	-	-	-	1	-	-	-
Nassarius dorsatus	4	8	-	-	-	-	2	8	2	-
Turricula javana	_	4	-	-	-	-	-	2	-	2
Littorina sp.	_	161	-	161	-	-	-	-	-	-
Turbo setosus	_	30	-	-	-	18	-	12	-	-
Patella sp.	_	3	-	2	-	1	-	-	-	-
Natica gemosa	_	4	-	-	-	4	-	-	-	-
Cymasium sp.	_	10	-	-	-	10	-	-	-	-
Bufonaria sp.	_	8	-	-	-	8	-	-	-	-

(Note: Qua-Quadrate, Qua 1-High tide zone, Qua 2 & 3- Mid tide zone, Qua 4- Low tide zone, St- Station)

6.12 Diversity indices

At Dharmadam beach the higher diversity was observed in August, 2009 (H'= 1.3) with low dominance of species (λ'= 0.26) at station 1 (Fig. 152 & 158) and at station 2 the highest was found in December, 2009 (H'= 1.64) with low dominance of species (λ'= 0.21) (Fig. 153 & 159). Zero values in the diversity index analysis showed the absence of organisms during sampling time. Species richness at station 1 showed the highest value in April, 2010 (d = 1.2) (Fig.154) and station 2 showed highest richness in September, 2009 (d = 1.4) (Fig.155). Evenness index showed the peak value in August 2009 (j'= 0.98) at station 1 (Fig.156) and in February, 2010 (j'= 0.95) at station 2 (Fig.157). The low species diversity was observed in August, 2010 at station 1 and this month more abundance of tanaids were observed. At station 2, in Dharmadam beach the lowest species diversity was observed in January, 2011 (H' = 0.37). High dominance of species were observed in July and November, 2010 in station 2 (λ' = 1) and August, 2010 in station 1 (λ'= 0.83) (Fig 158 & 159). The abundance of tanaid and polychaete species in the study area clearly showed the probability of less species diversity of that beach.

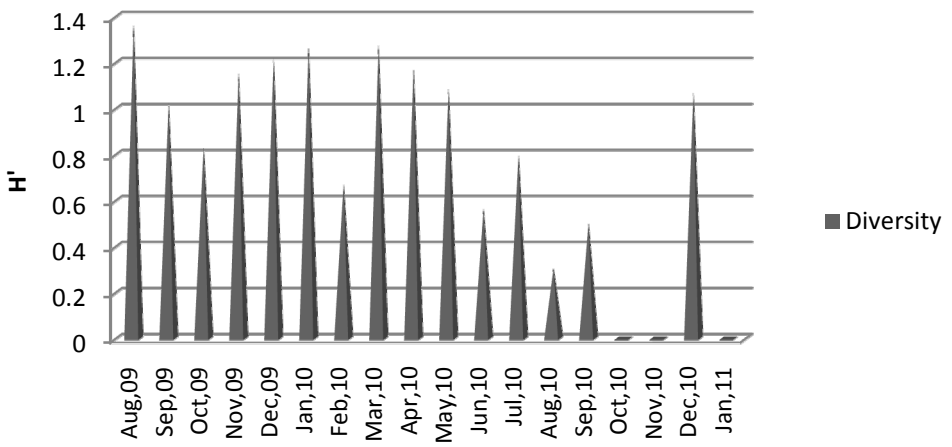


Figure 152 Diversity index of Dharmadam beach (station 1) during 2009-2011

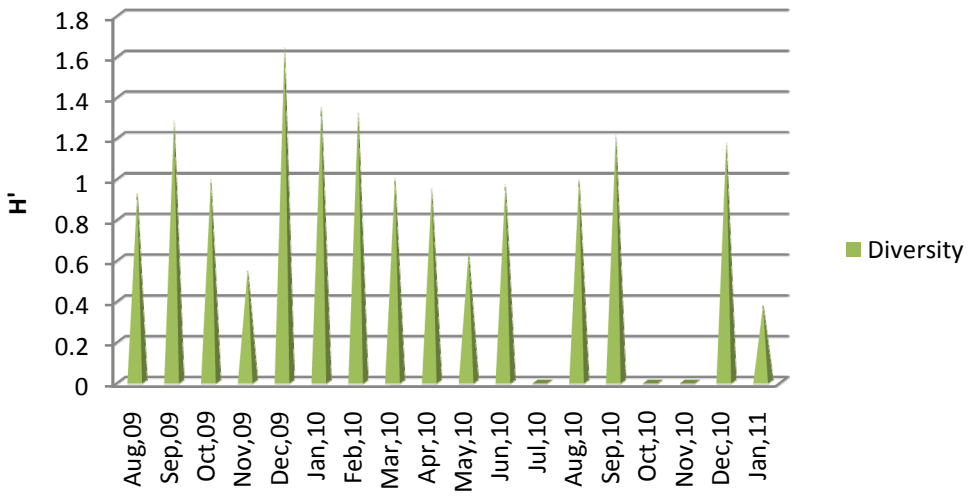


Figure153 Diversity index of Dharmadam beach(Station 2) during 2009-2011

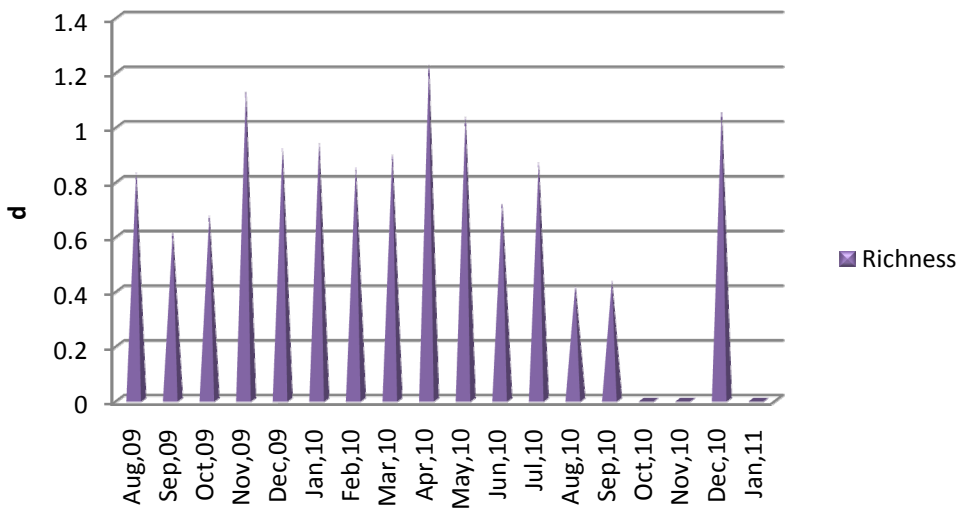


Figure 154 Species richness of Dharmadam beach (station 1) during 2009-2011

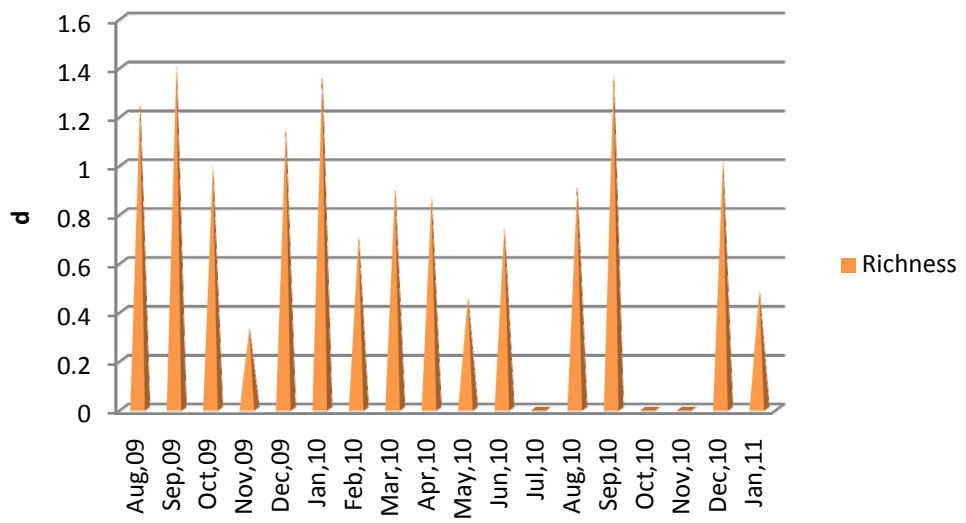


Figure 155 Species richness of Dharmadam beach(Station 2) during 2009-2011

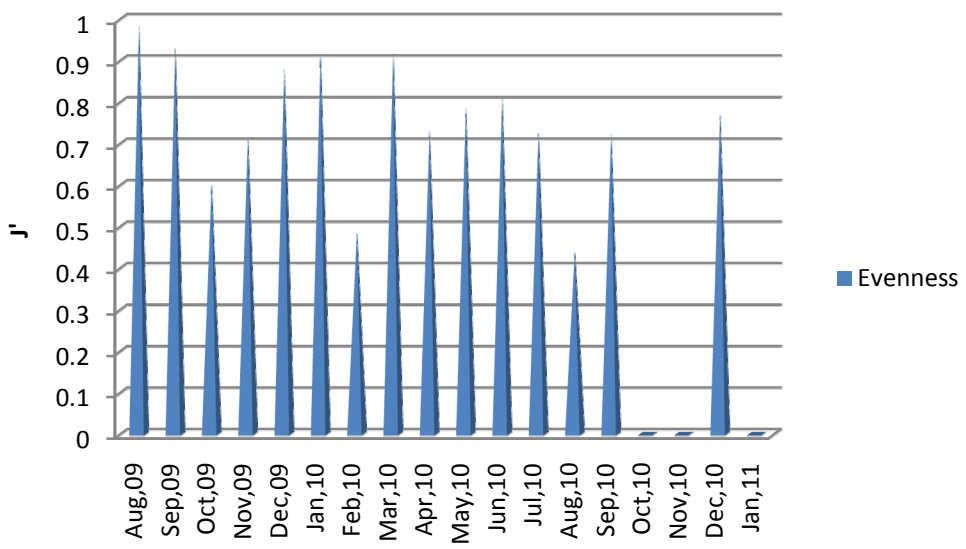


Figure156 Evenness index of Dharmadam beach(Station 1) during 2009-2011

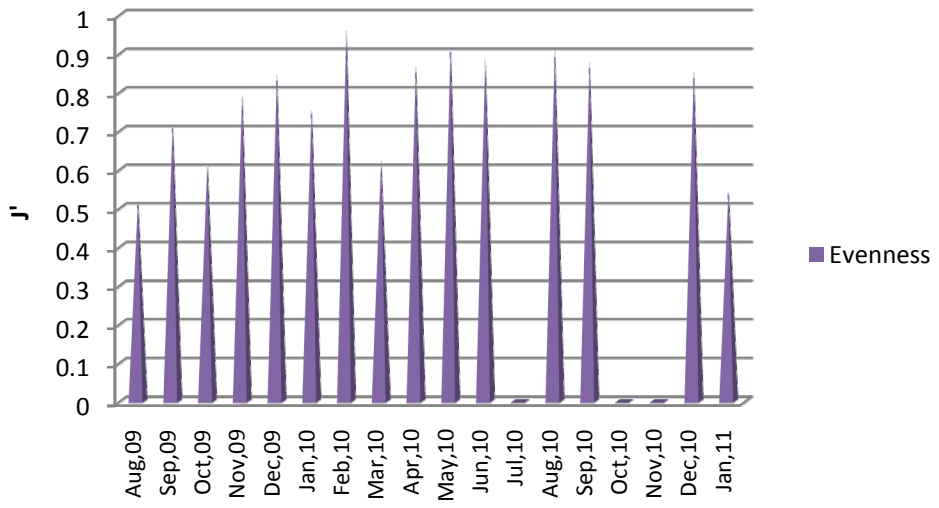


Figure 157 Evenness index of Dharmadam beach (station 2) during 2009-2011

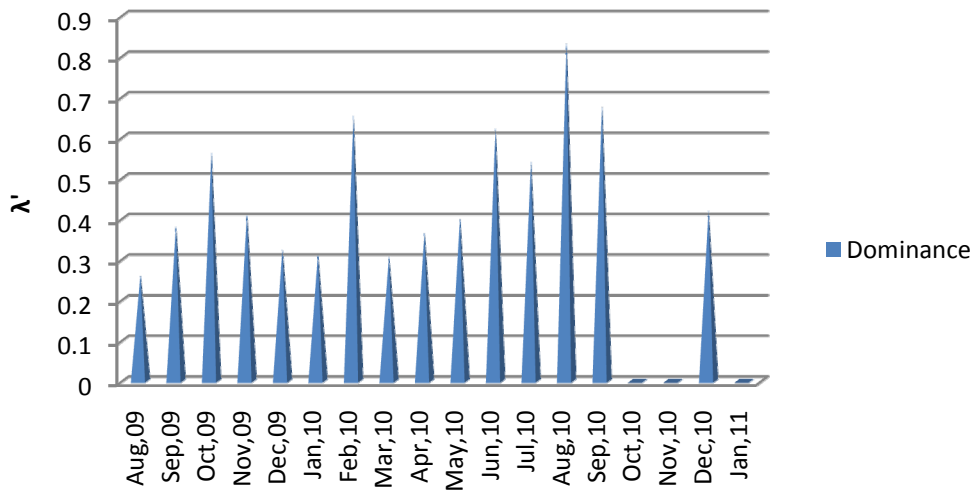


Figure 158 Dominance index of Dharmadam beach (station 1) during 2009-2011

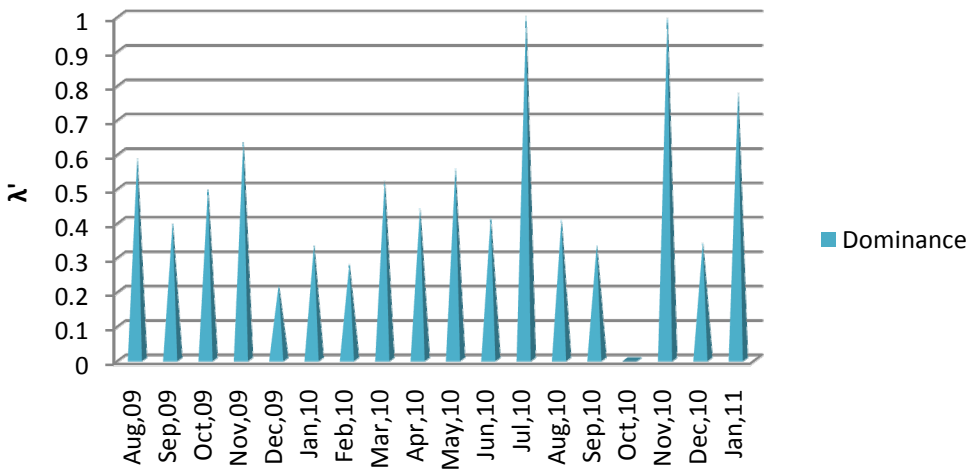


Figure 159 Dominance index of Dharmadam beach (station 2) during 2009-2011

Table 67 Seasonal values of diversity indices in station 1 of Dharmadam beach during 2009-2011

	d	j'	H'(loge)	λ'
Monsoon 1	0.965453	0.986021	1.58694	0.208365
Post monsoon 1	0.974678	0.644797	1.155321	0.423199
Pre monsoon 1	1.715472	0.658709	1.447331	0.359915
Monsoon 2	1.125066	0.792279	1.275125	0.332245
Post monsoon 2	1.058868	0.772576	1.071018	0.418685

Seasonally diversity index showed higher diversity in Monsoon, 2009 (Monsoon 1) in station 1 of Dharmadam beach (H'=1.58) with low dominance of species (λ' = 0.20). Pre monsoon season, 2010 showed higher species richness (d=1.71) and higher species evenness was shown in monsoon season, 2009 (Monsoon 1) (j'=0.98). Higher dominance was observed in post monsoon season, 2009 (Post monsoon 1) (λ'= 0.42) with uneven disribution (j'= 0.64). A decreasing trend of diversity was observed from season to season (monsoon, 2009 to post monsoon, 2010).

Table 68 Seasonal values of diversity indices in station 2 of Dharmadam beach during 2009-2011

	d	j'	H'(loge)	λ'
Monsoon 1	1.575636	0.729052	1.51602	0.312664
Post monsoon 1	1.416186	0.850716	1.869215	0.179949
Pre monsoon 1	0.974678	0.925924	1.659033	0.216204
Monsoon 2	1.125066	0.887624	1.428576	0.266939
Post monsoon 2	1.594645	0.825951	1.479906	0.274102

In station 2 diversity index showed higher diversity in post monsoon season, 2009 (Post monsoon 1) (H'=1.86) with lesser dominance (λ' = 0.17). Species evenness was more in pre monsoon season, 2010 (j'=0.92) with lesser richness of species (d= 0.97) and high species richness was observed in post monsoon season, 2010 (d= 1.59). Monsoon, 2010 showed lesser diversity (H'= 1.42) with comparatively even distribution of species (d= 0.88).

6.13 Cluster analysis

Similarities of organisms in seasonal aspects with SIMPROF (similarity profile) test was done for total groups. There is no significant clusters were obtained for macro faunal groups with seasons in both stations (Fig. 160 & 161).

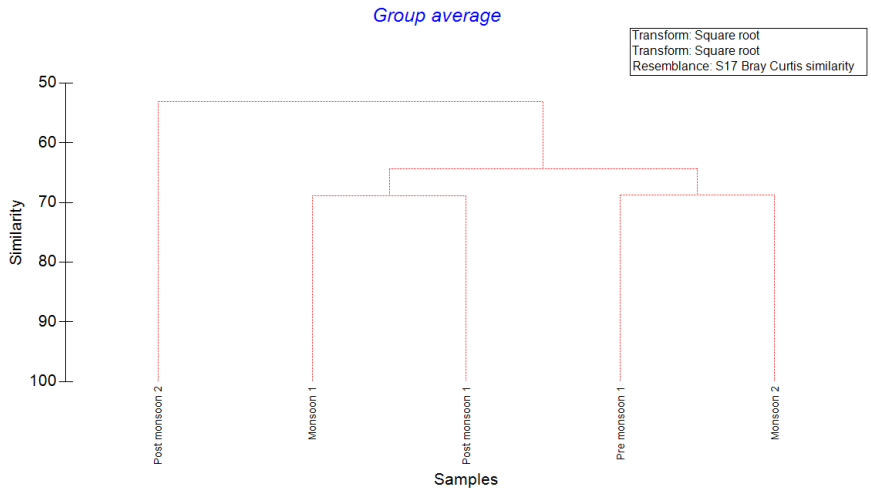


Figure160 Dendrogram showing seasonal similarities of faunal groups in station 1 of Dharmadam beach with SIMPROF test.

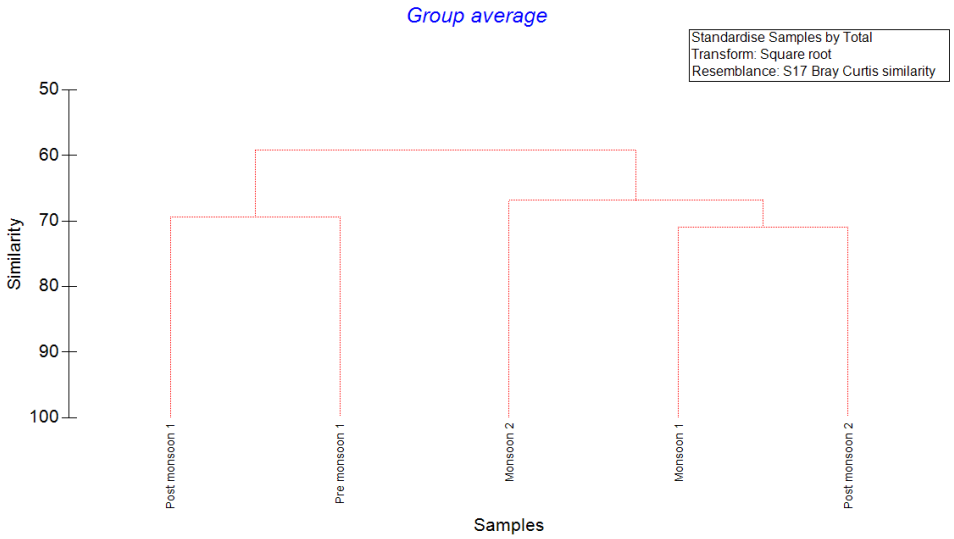


Figure 161 Dendrogram showing seasonal similarities of faunal groups in station 2 of Dharmadam beach with SIMPROF test.

6.14 Non-metric multidimensional scaling

Ordination plots were made between groups and individual species on monthly basis to explore the trends between samples. The ordination plot of total groups from Dharmadam beach showed significant groupings in almost all months with good stress value (0.2). Four months, October 2010 at station 1 and October, November 2010 and January 2011 at station 2 displayed as segregate groups. Main reason for this segregation is abundance of species was low or absent in those months. Samples grouped within the circles showing significantly separate groups at a Euclidean distance of 20 (Fig.162).

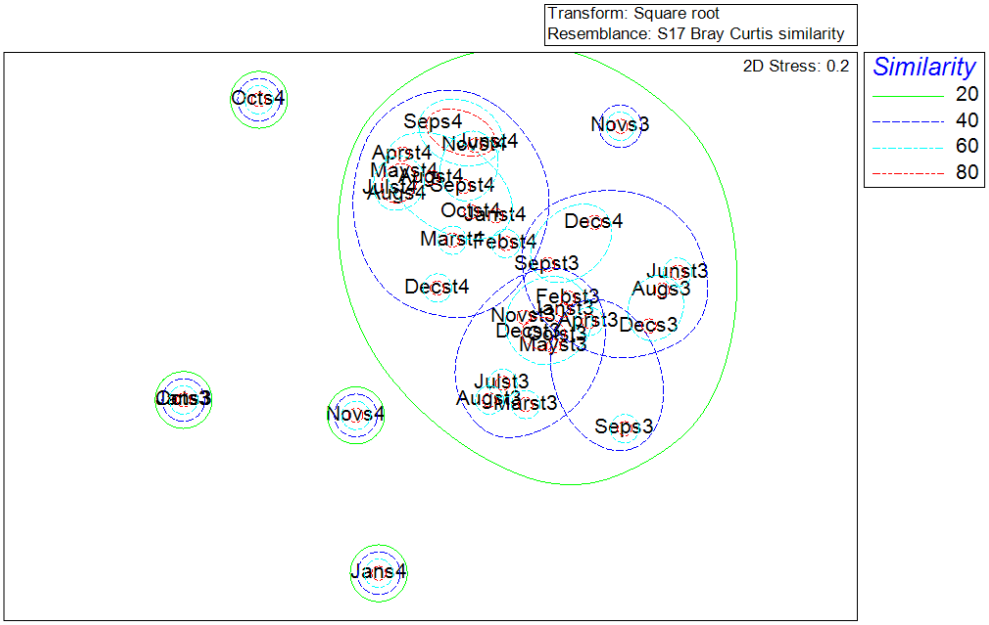


Figure162 MDS Ordination plot of faunal groups from two stations of Dharmadam beach during 2009-2011

6.15 BEST analysis

BEST analysis was carried out to check the influence of water quality parameters on faunal groups collected from the beach on monthly basis. The results showed that the BEST correlation coefficient (Rho) for total groups from Dharmadam beach was 0.139. From the BEST analysis it was inferred that water salinity, nitrate, nitrite, conductivity were the best matching variables with faunal groups on monthly basis at Dharmadam beach (Fig. 163, Table 69).

The sediment parameters with the faunal groups showed best correlation coefficient (Rho) 0.095. In Dharmadam beach sample showed 62% significance with sediment parameters in BEST analysis. Organic carbon showed the best match with organisms (rho=0.095) (Fig. 164, Table 70).

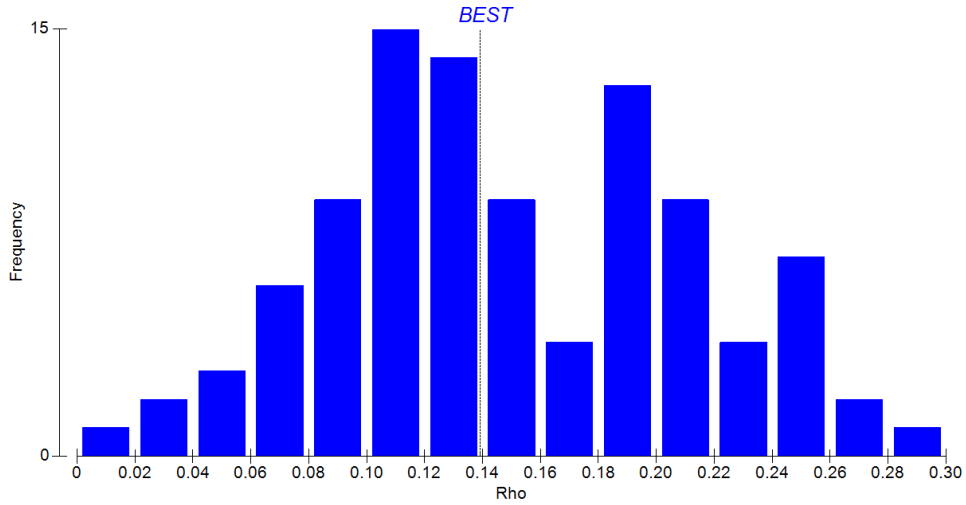


Figure 163 Histogram showing the BEST results of faunal groups and water quality (station 1&2) of Dharmadam beach during 2009-2011.

Table 69 BEST correlation table of faunal groups with water quality (station 1&2) of Dharmadam beach during 2009-2011

Si No.	Variables	Variables selected	Best correlation values (rho)
1	Temperature	3,6,11,12	0.139
2	pH	6,9,11	0.136
3	Salinity	3,6,9,11	0.133
4	Carbon dioxide	6,11,12	0.133
5	Dissolved Oxygen	6,9,11,12	0.131
6	Conductivity	3,6,9,11,12	0.127
7	TDS	3,6,11	0.121
8	Turbidity	3,11,12	0.108
9	Phosphate	3,6,7,11,12	0.108
10	Silicate	6,11	0.107
11	Nitrate	3,6,7,9,11,12	0.102
12	Nitrite	3,6,7,9,11	0.102

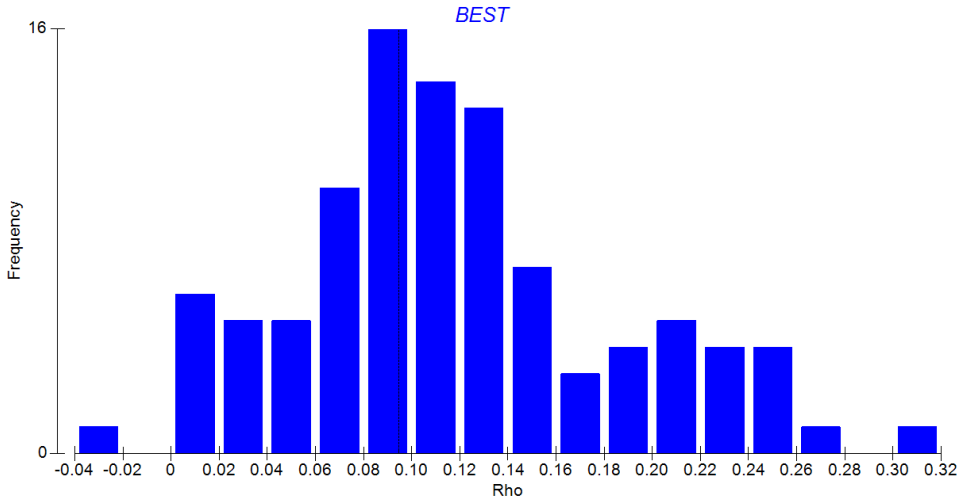


Figure 164 Histogram showing the BEST results of faunal groups and sediment parameters (station 1&2) of Dharmadam beach during 2009-2011.

Table 70 BEST correlation table of faunal groups with sediment parameters during 2009-2011

SI No.	Variables	Correlation values (Rho)	Selections
1	Sediment temperature	0.095	5
2	Sediment pH	0.087	4,5
3	Sediment conductivity	0.082	1,4,5
4	Moisture content	0.062	1,5
5	Organic carbon	0.059	3-5
6	Sand particle	0.058	1,3-5

6.15.1 Bubble plots

In Dharmadam beach bubble plots showed dominance of *Scolelepis (Scolelepis) squamata* in almost all months. The size of the bubble indicates that during December, 2009 at station 2 showing highest abundance of this species when compared to other months. But when compared to other polychaetes *Prionospio* species were more in December, 2009. The segregation of a bubble clearly shows the abundance of *Prionospio* sp. in December, 2009. The bubbles are used to explore the relative sizes of variables assist in exploring the trends in

variables between samples (Clarke and Warwick, 2001). The bubble plot showed highest abundance of *Littorina* species in station 2 and these are abundant during almost all months. In station 1 *Littorina* species were completely absent. Bubble plot showed the relative abundance of *Scolelepis (Scoleleips) squamata* and *Littorina* sp. at station 1 and 2 respectively (Fig. 165 & 166).

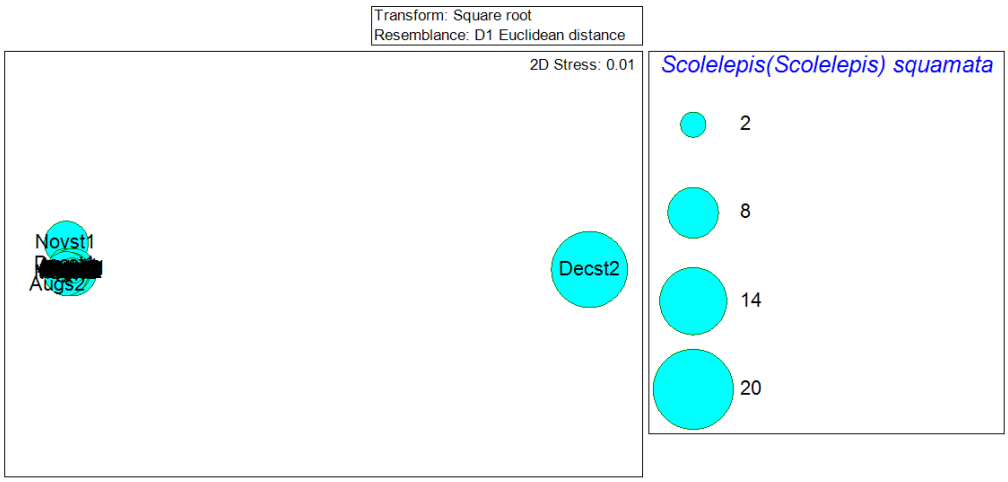


Figure 165 Bubble plot showing monthly variations of *Scolelepis* species at station 1 of Dharmadam beach during 2009-2011.

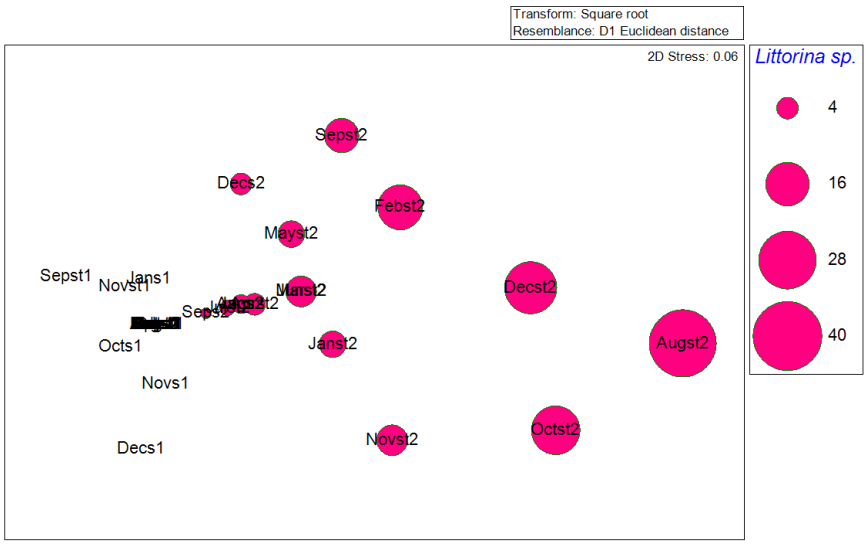


Figure 166 Bubble plot showing the monthly variations of *Littorina* species at station 2 of Dharmadam beach during 2009-2011.

6.15.2 Abundance biomass curve

In station 1 of Dharmadam beach the biomass curve lies above the abundance curve. The W value also showed positive value, indicating undisturbed community of that area (Fig.167). In station 2 also biomass lies above the abundance curve and positive W value, so an undisturbed community structure (Fig. 168).

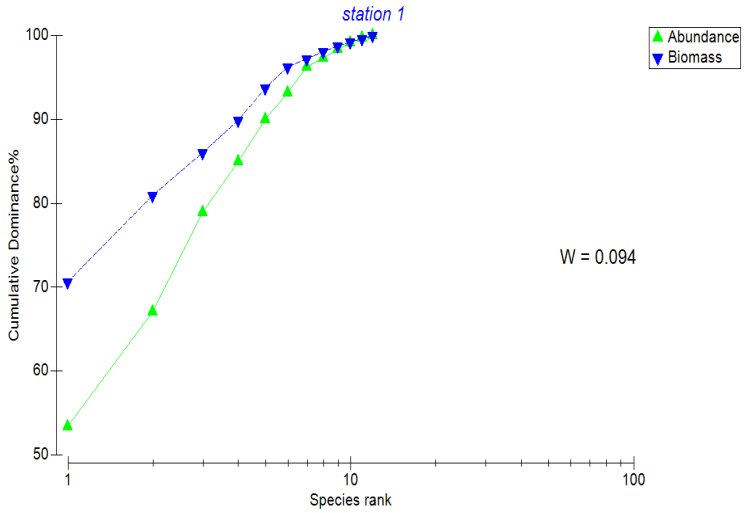


Figure 167 ABC curve of station 1 in Dharmadam beach during 2009-2011

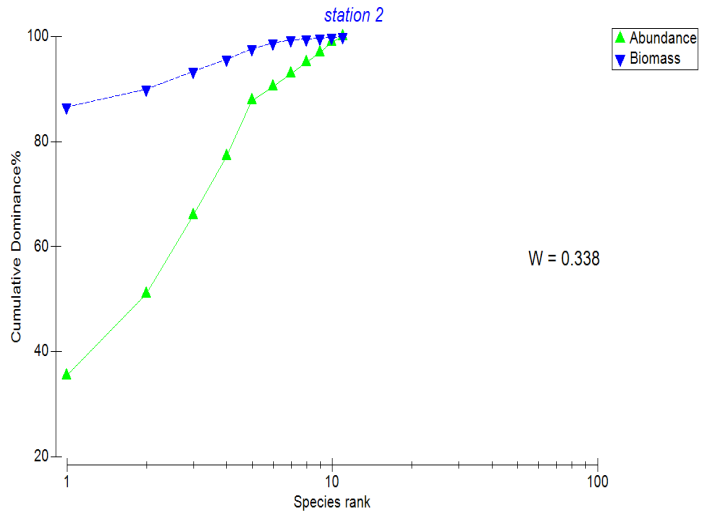


Figure 168 ABC curve of station 2 in Dharmadam beach during 2009-2011

6.15.3 Geometric class plot

In Dharmadam beach highest percentage of species abundance class was recorded in station 2 as per geometric class plot and maximum of eight abundance classes were represented in both stations. The higher abundance classes indicating unhealthy system. It is clearly indicating the occurrence of opportunistic species in Dharmadam beach (Fig. 169).

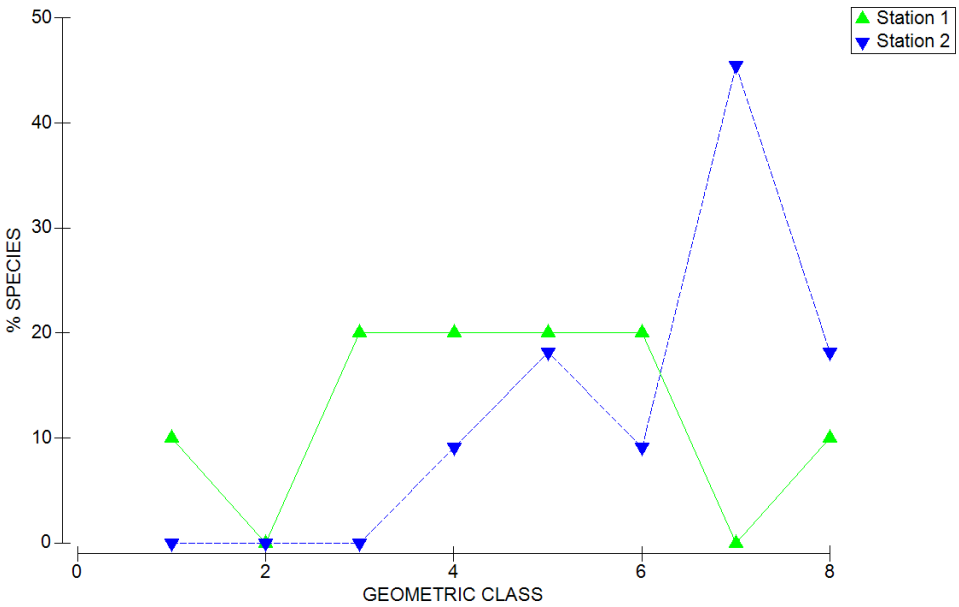


Figure 169 Geometric class plot of faunal groups in two stations of Dharmadam beach during 2009-2011

6.16 Biotic indices

6.16.1 Benthic Opportunistic Polychaete/Amphipod ratio- BOPA index (Indices based on ecological strategies)

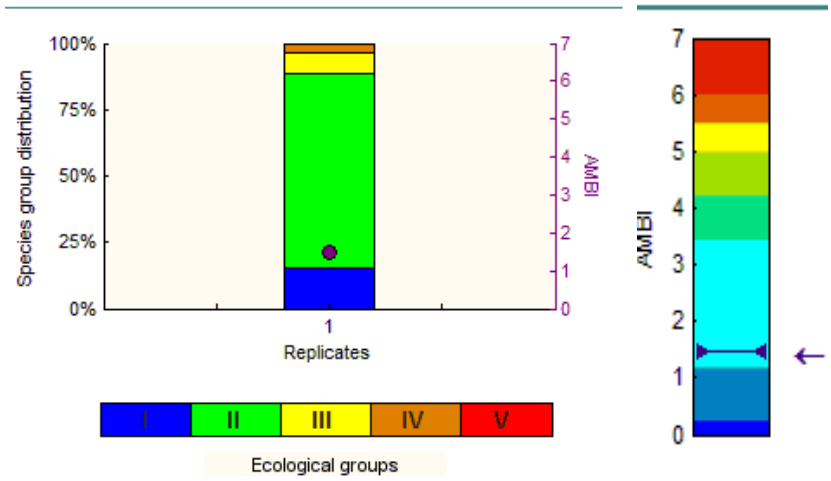
In Dharmadam beach both stations showed lesser value (0.04). According to the classification 0.04 and below will consider as high ecological status area. The two station of Dharmadam beach showed high ecological status based on BOPA index (Table 71).

Table 71 (f_P – opportunistic polychaete frequency, f_A – Amphipod frequency except *Jassa*)

Stations	f_P	f_A	BOPA index
Station 1	0.136	0.032	**0.04 (High)**
Station 2	0.129	0.096	**0.04 (High)**

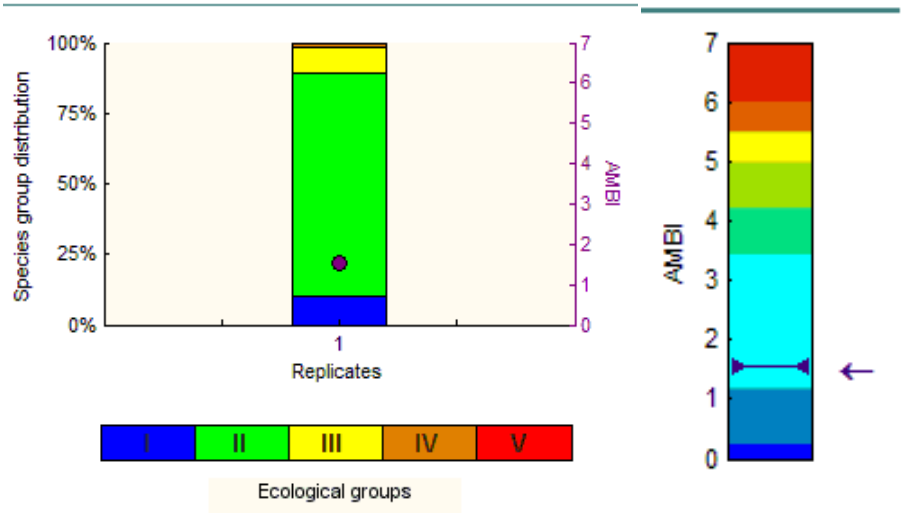
6.16.2 AMBI (AZTI's Marine Biotic Index)

In station 1 of Dharmadam beach AMBI index showed dominance of group 2 organisms. According to the classification the group 2 organisms are species unresponsive to enrichment and variation is less with time. The AMBI value was 1.491, it is coming under slightly disturbed nature with good ecological status according to the classification. An unbalanced community health was observed in station 1. The value from 1.2-3.2 is considered as slightly polluted (Fig. 170). In station 2 also similar condition was observed. Organisms were coming under group 2 and AMBI value was 1.545. So it was classified under slightly disturbed with good ecological status (Fig. 171).



AMBI value – 1.491

Figure 170 AMBI value and relative abundance of ecological groups in station 1 of Dharmadam beach



AMBI value – 1.545

Figure 171 AMBI value and relative abundance of ecological groups in station 2 of Dharmadam beach

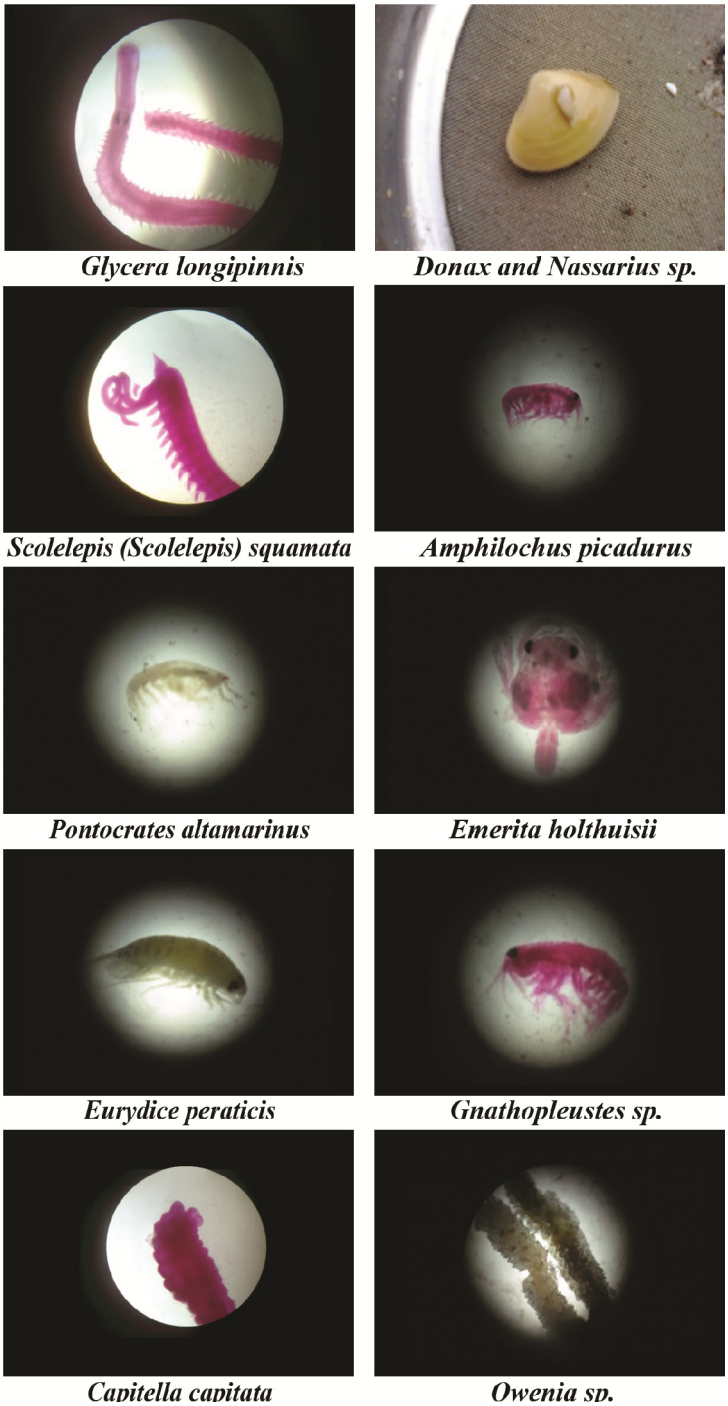


Figure 172 Macrofauna obtained from both the beaches during 2009-2011 (Magnification – X 40)

6.17 Discussion

Intertidal macroinvertebrate fauna take part in a significant role in the sandy beach food chain, where filter feeders and deposit feeders yield large quantities of particulate organic matter, episammic microflora and even meiofauna (McLachlan and Brown, 2006). Amphipods formed the dominant group at Fort Cochin beach. High abundance and wide distribution of amphipods often play major role in the ecology of benthic habitats (Conlan, 1994). Amphipods are considered as sensitive to pollution (Carretero *et al.,* 2011). Among amphipods *Melita* sp. found to be more in number in station 2 when compared to other species. At station 1 it is found to be *Amphilochus picadurus*. The dominant organism in station 2 of Fort Cochin beach was polychaetes. As the polychates often dominate in terms of biomass, abundance and species, these are the important component in macrobenthic community (Sivadas *et al.,* 2010). Among polychaetes observed from station 2 of Fort Cochin beach *Capitella capitata* was found to be more abundant. Polychaetes are one of the most useful organisms in impact studies. As the group contains both sensitive and tolerant species, they have been identified as indicators for environmental disturbances (Zajac *et al.,* 2003). The dominance of some species belonging to the families Spionidae and Capitellidae was reported as indicator of organic pollution (Tsutsumi, 1990). *Capitella capitata* is used as pollution indicator (Pearson and Rosenberg, 1978; Tsutsumi *et al.,* 1984). The capitelid polychaetes, especially the *Capitella capitata* are classified as r-strategists species, having the capacity to colonize new habitats swiftly (Tsutsumi 1990). In undisturbed circumstances these r-strategist species are substituted by k-strategist species (Pianka 1970, Gray 1981). The abundance of *Capitella* sp. in Fort Cochin beach agrees that the presence of stress factor

there. *Capitella capitata* is mainly associated with highly organic rich areas, wheras the present study observed low organic matter content in Fort Cochin beach. Dahl (2007) reported similar observation from Adventfjorden, abundance of *Capitella capitata* with low organic matter. In Fort Cochin beach *Capitella capitata* was found in high and mid tide level. Several studies reported distribution of *Capitella* sp. from upper intertidal (Dauer & Simon, 1975; Amaral, 1979; Shackley, 1981). The dominance of opportunistic species like *Neries* sp., *Mediomastus capensis, Capitella capitata, Notomastus and Heteromastus* species indicate that station 2 of Fort Cochin beach is under stress from anthropogenic activities. Varadharajan *et al.* (2010) reported polychaetes as the dominant species from intertidal regions of south east coast of India. They have also reported similar polychaete species as observed in the present study, *viz Capitella capitata*, *Prionospio pinnata*, *Heteromastus* species, *Glycera* species etc.

Dharmadam beach showed dominance of tanaids, gastropods and polychaetes. At station 2, presence of latertite rocks gave suitable substratum for gastropods. So the abundance of gastropods were high in station 2 and main contributors were *Littorina* sp. These are common inhabitor of rocky zones and are well adapted. Beach slope, local current regime and reproductive periodicity of invading species are the main reasons for variation in spatial distribution within the intertidal zone (McIntyre, 1977). Peracarid crustaceans are the most diverse and numerically prevailing organism among benthic faunas (Dauby *et al.,* 2001). Present study also observed the dominance of amphipods and tanaids in station 1 of Fort Cochin and Dharmadam beach respectively. Guerra-García in 2009 observed dominance of tanaids was more in the zones where sea water conductivity was more. In the present study sea

water conductivity was observed to be one of the best matching variables with fauna in Dharmadam beach. The dominance of tanaids in Dharmadam beach could be attributed to this. Torres Alfaro *et al.,* (2011) also documented abundance of tanaids in the intertidal sandy beaches of Mexico. They observed denser group of tanaids from subtidal region, whereas present study observed the distribution of tanaids in all zones, from high to low tide. Among polychaetes *Scolelepis (Scolelepis)* squamata was found to be abundant and distributed in all tidal levels from high to low tide. According to Bortone (2005), the salinity range of S*colelepis squamata* was 17-35ppt. In this study also the range of salinity at station 1 was 17.5-33ppt (the abundance of *Scolelepis* species is more in station1). *S.squamata* is known to tolerate oscillations in salinity (Rizzo and Amaral, 2001). This could be one of the reasons for the abundance of *Scolelepis* species in that area. High abundance of S.*squamata* may greatly affect community structure, as it consumes larvae and juveniles of other species (Dauer, 1983), while it may also abets establishment of non-opportunistic meiofauna species (Maria *et al.,* 2011). Reis *et al.* (2000) reported occurrence *S.squamata* from upper intertidal in the intertidal region of Sao Sebastio Island as the present study.

Variations of abundance of faunal species were significantly different in various stations of Dharmadam (mainly polychaetes and gastropods) and they showed seasonal similarity, in almost all seasons. Larvae of mole crabs (*E.holthuisi*) were more abundant in pre monsoon season, 2010 at station 2 and was present in monsoon (2010) and post monsoon (2009) season. It could apparently be related to recruitment periods. According to the study on two sandy beaches along South-West coast of India by Ansell *et al.* (1972), there were two main periods of recruitment, one in pre-monsoon period and the

other in monsoon periods. This exactly complements with the present study data. In Fort Cochin beach the dominant groups, amphipods and polychaetes showed seasonal similarity, observed in almost all seasons. In station 1 of Fort Cochin beach polychaetes were abundant in post monsoon season, 2009. It may be attributed to recruitment of larvae in post monsoon months. In monthly observation polychaetes and amphipods were present in most of the month in station 2 and 1 respectively. Crustaceans, polychaetes and molluscs are most dominant organisms in the exposed sandy beaches. High density of mole crabs in station 2 of Dharmadam beach in March, 2010 could be attributed to recruitment period and high abundance of tanaids in October, 2009 could be connected to reproductive periodicity. Rumbold *et al.* (2012, 15) were reported high abundance of tanaids in post monsoon season. Tanaids were showed seasonal changes in density in station 1 of Dharmadam beach. Similar observation was reported by Pennafirme *et al.* (2009) from the coastal lagoon of south eastern Brazil. In Fort Cochin beach amphipods showed high density during November, 2009 in station 2. Prato *et al.* made similar observation in 2003 and reported high occurrence of amphipods in post monsoon season.

In 1970, Philip described that in mid tide region of Fort Cochin beach *Eurydice* sp. (Isopod) were abundant. But in the present study these species were totally absent and only one isopod species (*Sphaeromopsis* sp.) identified from mid tide and low tide region of station 1 during 2009-2011. He also recorded amphipods, mysids, Capetellid polychaetes, *Emerita* sp and *Donax* species as in the present study. When compared to his study the diversity and abundance were found to be less in the present study. It may be due to altering weather conditions and changing sediment characteristics due to erosion and accretion of sediment. Anthropogenic disturbances also increased as the

development of beach tourism and fishing activities. Anthropogenic disturbances may affect in growth rate, recruitment and mortality of organisms (Tablado *et al.,* 1994; Johnston and Keough, 2002).

In Fort Cochin beach the organisms are more concentrated in mid tide zone when compared to other zones. High tide zone of station 1 was dry with minimal organism concentration. According to the study of Ansell *et al.,* 1972 they reported presence of *Eurydice* sp (isopod) throughout the study. In the present study *Eurydice* sp. was completely absent and it was replaced by *Sphaeromopsis* sp. in Fort Cochin beach. Govinadan Kutty and Nair (1966) mentioned the occasional distribution of isopods from Cochin beaches. In Dharmadam beach also mid tide zone was abundant when compared to other zones. Some organisms like tanaids, mysids, mole crabs and bivalves were common among two beaches, but most of the other organisms showed difference in their species. When both beaches are compared some of the organisms were absent. Gastropods were totally absent from Fort Cochin beach and oligochaetes were present only in station 2 of Fort Cochin beach. In sandy beach of Dharmadam beach sea star (*Astropecten irregularis*) was common, but no sea stars were recorded from Fort Cochin beach. In rocky area of Dharmadam beach the organisms especially gastropods were almost consistent throughout the sampling. In terms of ecological adaptation, molluscs are highly successful animal groups and they are found in nearly all habitats ranging from deepest ocean trenches to the intertidal zone, freshwater and land (Vaghela and Kundu, 2011).

Sandy beaches are highly dynamic in nature. Present study observed exposed sandy beaches in Dharmadam and Fort Cochin. Exposed sandy beaches can be portrayed in terms of the communication between wave

exposure, tide ranges and sediment characteristics (Rodil *et al.,* 2004). The fauna of exposed sandy beaches are poorer when compared to protected beaches (Gauld and Buchanan, 1956). Ansell *et al.* (1972) observed steep, exposed continuous sandy surf beach in Cochin. Fort Cochin beach is coarser than Dharmadam beach. Very coarse sediments have a tendency to support a small number of macrofaunal species because these sediments have the tendency to move and subject to a elevated level of desiccation when exposed at low tide. Finer sediments have the tendency to be steadier and preserve some water between high tides, and therefore prop up a greater diversity of species. Species richness, as well as total abundance and biomass of the macro infauna tend to be inclined in narrow beaches with coarse sands and steep slopes than wider flat beaches (Short and Wright, 1983). Present study observed small number of macrofauna from both the beaches and macrofauna monitored from Fort Cochin beach is even lesser than Dharmadam beach. Medium and fine sand shores generally maintain a high range of oligochaetes, polychaetes, and burrowing crustaceans, (Connor, 2004). Swash control hypothesis (McLachlan, 1990) suggested that the key factor limiting the distribution of species along dissipative to reflective beach is swash climate and it may be the key determining factor for organisms live in mid and high intertidal and have poor capacities to swim. Swash climate is not so important for high tide fast moving species like *Emerita* sp. and crabs (Brazeiro, 2001).

Based on the study of Gohil and Kundu in Dwaraka coast of Gujarat (South west coast) in 2012, they described many species like sponges, platyhelminthes, brain corals etc. Study of macrofauna from Madhuva and Veraval coast of Gujarat (Tewari *et al.,* 2003) described wide variety of gastropods and bivalves from the coast. In the present study organisms were

less compared to above mentioned studies. *Dotilla* species were recorded from both coasts according to the study by Berlie *et al.,* 2008 in the east Coast of India and Harkantra *et al.,* 1985 in west coast of India. Joshi *et al.* (2013) reported *Perna viridis, Donax* sp., *Trochus* sp., *Natica* sp. from the Mumai coast as the present study.

The study based on the east coast of India (In Tamil Nadu coast) by Berlie *et al.* in 2008, reported *Emerita asiatica* from that coast. In the present study *Emerita holthuiisi* was common. These are from family Hippidae from northern part of Arabian Sea (Tirmizi, 1977). Polychaetes observed were mainly arachianellid, pisionid, capitellid, glycerid and polydorid species from Tamil Nadu coast (Berlie *et al.,* 2008). In the present study also capitellid, glycerid and pisionid species were observed.

James *et al.* (1996) observed isopods, amphipods, bivalves and polychaetes from a sandy beach of Australia (Pacific coast). These organisms are well adapted for exposed sandy beaches. Present study also observed similar macrofauna, but the species obtained were different from their study. They observed, mainly *Hemipodus* sp. (polychaete) and *Actaecia* sp. (isopod). Boudreaux *et al.* (2006) reported twenty five sessile and sixty four motile species from intertidal oyster reefs in Florida. Study of intertidal macrofauna in Amazon region by Morais *et al.* (2014) reported eighty five taxa from that region and species richness were also higher. Abundance and biomass increases from tropical to temperate region and dissipative beaches dominating in temperate region (Soares, 2003). High abundance and biomass of dissipative beaches may due to greater food availability and greater productivity (McLachlan, 1990). Quan *et al.* (2012) reported *Crassostrea* sp., *Balanus* sp., polychaetes and crustaceans from intertidal oyster bed in China.

Hwang *et al.* (2015) observed arthropods and molluscs as dominant organisms from intertidal regions of Yubudo Island, South Korea. Taheri *et al.* (2010) reported polychaetes were the dominant organisms in the intertidal sandy beach of Chabahar bay. Domingo *et al.* (2008) also reported *Scolelepis* and *Donax* species from sandy beach of Tunisia, but species were different. They observed *Scolelepis mesnili* and *Donax trunculus*. Present study observed similar groups as above mentioned studies with different species contribution.

From these observations it is clearly assumed that the community structure of each shore is different and it will vary according to the substratum they live, abiotic factors, climatic variations and sediment characteristics. Some studies showed that other environmental variables like, nutrients and availability of food may be the important factor for structuring the community (Rodil *et al.,* 2006; Cisneros *et al.,* 2011). In most ecosystems, community structure appears as an outcome of the complex interaction among biotic and environmental variables (Sivadas *et al.,* 2012). The Shannon Wiener diversity index of Dharmadam beach showed that the beach system supports high abundance of two or three species which has led to less species richness as well as low species evenness. From the two beaches observed monthly diversity values were lesser in Fort Cochin beach than Dharmadam beach. Species richness and diversity were comparatively higher in Dharmadam beach than Fort Cochin beach in seasonal observation. Taheri *et al.* (2010) observed low diversity of macrofauna in monsoon season in Oman Gulf, but the present study observed high diversity in station 1 of Dharmadam and station 2 of Fort Cochin beach in monsoon season (2009). October, 2010 showed zero values in diversity indices in both the beaches. This clearly

enlightens the interruption of sampling due to heavy rain in that month. None of the organisms were obtained except dead shells and broken pieces of organisms.

The low species diversity in August, 2010 at station 1 was mainly due to the abundance of only one group, tanaids. Shore crab was also observed in that month but was below 2 in number. Species diversity is interrelated with relative species abundance in a community (Whittaker, 1965; Hulbert, 1971). One or few species dominating a community shows low evenness while those communities that have more even distribution will have a high evenness. The species evenness observed in both the beach agrees with the statement. High evenness of species is an indication of healthy ecosystem. Present study observed low evenness in both the beaches thus low ecosystem health. The distribution of organisms was not even in monthly and seasonal observations in both the beaches, indicating less diversity of species. Communities with lower number of organisms that are dominated by one or few species are least diverse. Some studies revealed that sandy beach ecosystems wherein species evenness and diversity are influenced by the population dynamics of numerically abundant species (Holland and Polgar, 1978; Dexter, 1984). The present study agrees with this statement, at Fort Cochin beach among polychaetes, *Capitella capitata* was found to be abundant in station 2, where species evenness and diversity was found to be low. Corbisier (1991) reported low diversity and low evenness of species in Ponta da Praia beach in Brazil due to the abundance of *Scolelepis (scolelepis) squamata*. In Dharmadam beach diversity and evenness were low and abundance of tanaids and polychaetes (mainly *S. squmata*) were observed. Species richness and abundance of sandy beaches are related to environmental variables such as sediment type,

granulometry, water temperature, salinity, dissolved oxygen, bottom topography and wave energy (Armonies and Reise, 2000).

When compared to Dharmadam beach Fort Cochin beach showed decreasing trend in diversity. The zero values of diversity index indicate the absence of different species in these months and presence of only one group (Isopod) in these months, which is below five in number. This indicates the fact that both beaches are generally less diverse and Fort Cochin beach is lesser diverse than Dharmadam beach. Due to high dynamic nature of sandy beaches especially in Fort Cochin erosion is more than that of Dharmadam beaches, leading to less diversity of species. Oil leakages and industrial pollution are also a threat to Fort Cochin beach and every month during sampling the obtained organisms were less. Species richness and evenness were also found to be less. According to Khan *et al.* 2004, the Margalef richness index will be higher (2.5-3.5) in healthy environment. In the present study the richness index was below two in both the beaches. From this it clearly portrays the unhealthy community of the beach. Species richness, total abundance and biomass of macrofauna have the tendency to enhance from reflective beaches (narrow beaches with steep slopes and coarse sand) to dissipative beaches (beaches with flat slopes and fine sands; Short and Wright 1983). This agrees with the present study. The total macrofaunal biomass of Fort Cochin beach is less (0.009-3.2g) when compared to Dharmadam beach (0.04 - 44.37g). Tewari *et al.* (2003) observed 2.03-5.82g/m^2 biomass range in Madhuva and Veraval coast. Veloso *et al.* (2003) also observed high biomass (above 200 dry weight g/m^2) of macrofauna from the beaches of Brazil. Present study showed comparatively less biomass when compared to above mentioned study. In station 2 of Dharmadam beach biomass was comparatively higher (44.37) due to the presence of sea urchins.

Ecological relationship of fauna with abiotic and biotic facors

Three Way ANOVA was done to find out significant variation of macrofauna between month and station. Macrofauna from Dharmadam beach showed significant variation between station and month (F = 1.46). Cluster analysis were done (Bray- Curtis similarity with SIMPROF) for detecting any similarity with seasonal abundance of macrofauna from the selected beaches. Based on seasonal similarities, total macrofaunal groups of Fort Cochin beach showed no significant similarities. In Dharmadam beach also no similarity were observed between seasonal macrofaunal abundance. Draftsman scatter plot were also done to find out the interaction between organisms. Many of the organisms showed negative interaction with others. The dynamics of an ecosystem has been determined by the interactions between and within the communities. In Dharmadam beach Draftsman scatter plot showed correlation between some organisms. Isopods and hermit crabs showed high correlation (0.773) followed by mole crabs and polychaetes (0.678), hermit crabs and polychates (0.649), mole crabs and shore crabs (0.573) (Fig.174, Table 73).

MDS analysis of both the beaches depicted that species are almost similar in composition in monthly basis with exception of some months, due to the absence of organisms. In Dharmadam beach also significant grouping was observed in almost all months except three or four months.

Abundance Biomass Curve (ABC curve) is commonly applied to find out the point of disturbances in community (Warwick *et. al*, 1987). Disturbed nature of community were analysed from Fort Cochin beach. In station 2 the level of disturbance is more and W value (Warwick value) was -0.247. It is indicating a highly disturbed nature. In station 1 it was 0.086 (W value). W value of 0.001-0.085 was considered as moderate disturbed condition in the

study of macrofauna from Mumbai coast (Dutta *et al.,* 2010). The intertidal sandy shore fauna are highly sensitive to natural and anthropogenic disturbance, on the other are highly adaptive too ((McLachlan & Brown 2006).

Polychaetes, bivalves and crustaceans are the most established macrobenthic organisms and are regarded as environmental indicators (Ingole *et al.,* 2006). According to Ingole *et al.* (2006) mysids are also used as environmental indicator. According to Gesteira *et al.* (2000) amphipods are excellent bio indicators of the impact of oil spills on soft - bottom macrobenthic communities. Polychaete/amphipod ratio was used to monitor environmental impacts by using opportunistic polychaetes and amphipods. Gesteira and Dauvin (2000) suggested the use of polychaetes/amphipod ratio or BOPA index for detecting the impact of pollution. All stations except station 2 of Fort Cochin beach showed high ecological status based on BOPA index. AMBI (Borja *et al.,* 2000; Muxikaa *et al.,* 2005) was also performed to know the community disturbance and ecological status of the system. When compared with these two indices and ABC curve enlightened the similar condition in both the stations of Fort Cochin. Station 1 showed undisturbed and station 2 showed moderate polluted condition in AMBI, BOPA and ABC curve calculation. Polychaetes were observed to be absent in station 1 of Fort Cochin beach except *Arenicola?* sp. So the BOPA index showed high ecological status in this station. But Eichornia wrack was persistent throughout the sampling in station 1 of Fort Cochin beach. Tourism is also active in the beach area. From the above results it may be assumed that the species present in station 1 have the capacity to self adapt with the stress condition. In station 2 of Fort Cochin beach opportunistic polychaete species were abundant and the condition agrees with the results of biotic indices.

In Dharmadam beach high and good ecological status were observed in AMBI, BOPA and ABC curve. But the community from Dharmadam beach was observed to be slightly disturbed when AMBI was performed. The presence of opportunistic species in Dharmadam beach could be connected to the AMBI results. *Scolelepis* and *Prionospio* species were common in Dharmadam beach and these are opportunistic polychaetes. From this it could be assumed that the pristine nature of Dhramadam beach could be altered in future due to human activities. The accumulation of opportunistic polychaetes may be an indication to this situation. Wide variations in salinity were encountered in Dharmadam beach and this may proliferate the abundance of *Scolelepis* species there as they are euryhaline species. These opportunistic species were observed in all seasons but high abundance was observed during post monsoon season and pre monsoon season. Post monsoon season (2009) showed highest abundance of this species in both the stations. This may be due to increased salinity in pre monsoon months. It triggers the reproduction of benthic fauna and recolonization in post monsoon season (Benventi *et al.,* 1997). In other seasons the abundance of opportunistic polychaetes were very less except *Scolelepis*, that was present in almost all seasons. From the above observations it reflects the developing tourism activities that may perhaps affect the shaping of benthic faunal structure of Dharmadam beach.

Geometric class plots analysed in both the selected beaches were portrayed similar observation as biotic indices and ABC curve. Both the beaches analysed were represented more abundance classes (Seven in Fort Cochin and eight in Dharmadam beach), indicated the presence of opportunistic species. Opportunistic polychaetes were abundant in both the beaches and that reflected in the geometric class plots.

In a harsh environment like intertidal zones the interaction between organisms and environmental variables are a must for the healthy survival of the organisms. The statistical analysis justified the interaction of organisms with environmental variables that existed in the study area. The results showed that the BEST correlation coefficient (Rho) for total groups from Dharmadam beach was 0.139 for salinity, conductivity, nitrate and nitrite. This correlation was enlightening the response and behaviour of organism with fluctuations of these parameters. In Fort Cochin beach dissolved oxygen, nitrate and nitrite showed best correlation (0.164). BEST analysis between sediment parameters and macrofauna showed that organic matter and conductivity have best correlation with macrofauna in both beaches (0.165 and 0.095 in Fort Cochin and Dharmadam respectively). So from these observations it is found that sediment parameters are important in shaping the organism's behaviour in an intertidal zone. Species may prefer sediments having particular level organic carbon (Kevin Black, 1998) and some organisms can change the organic carbon content of these sediments by burrowing, feeding and extracellular polymeric material (Rhoads, 1963, Eckman *et al.,* 1981). From the present study on sediment parameters, it was observed that sediment characteristics have prime importance in the distribution and abundance of fauna. A sandy beach ecosystem covers unique physical and ecological traits, and makes available an array of ecosystem services (Schlacher *et al.,* 2008; Defeo *et al.,* 2009).

Highlights

- Amphipods and polychaetes formed the dominant groups in Fort Cochin beach, whereas gastropods and tanaids were the dominant groups in Dharmadam beach.
- Seasonal variations were discernible.
- Monthly similarities of species composition were observed in MDS plot.
- Biomass observed to be less in both beaches. In Fort Cochin beach biomass was lesser than Dharmadam beach.
- Diversity, richness and evenness were observed to be less in both the beaches. When compared to Fort Cochin beach, higher diversity and richness were observed in Dharmadam beach .
- BEST analysis between biota with water quality parameter showed salinity, conductivity, nitrate, nitrite in Dharmadam beach and dissolved oxygen, nitrate and nitrite in Fort Cochin beach as best matching variables. With sediment it showed organic carbon in Dharmadam and conductivity in Fort Cochin as the best matching variables.
- AMBI, BOPA index and ABC curve showed undisturbed and moderately disturbed condition in station 1 and 2 of Fort Cochin beach.
- In Dharmadam beach ABC curve and BOPA showed undisturbed condition, whereas AMBI showed slightly disturbed community from there.
- Geometric class plot was also represented similar condition as biotic indices and ABC curve.

Draftsman plot

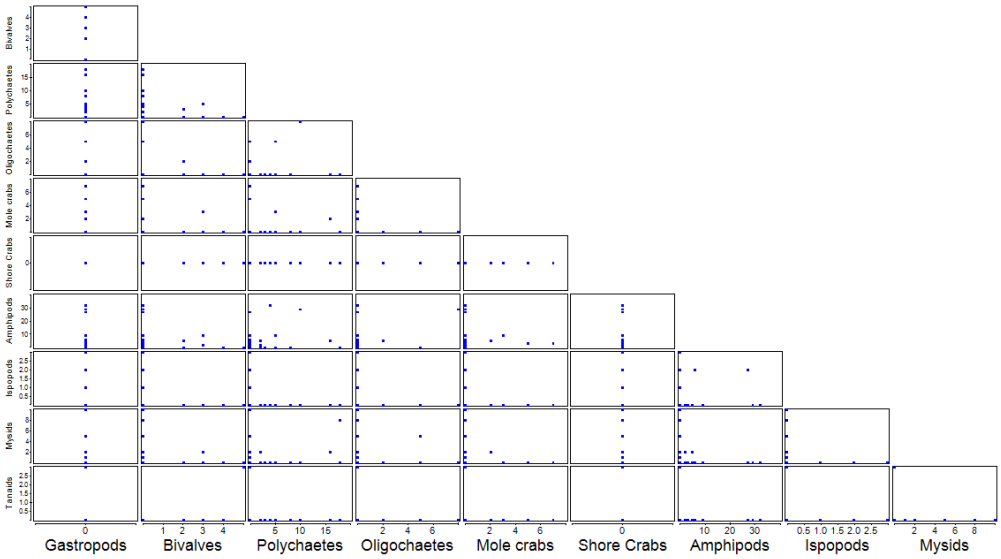


Figure 173 Draftsman scatter plot showing interaction between total groups of Fort Cochin beach.

Table 72 Correlation table of Draftsman plot of Fort Cochin beach

	Bivalves	Polychaetes	Oligochaetes	Mole crabs	Amphipods	Isopods	Mysids
Bivalves							
Polychaetes	-0.09674						
Oligochaetes	-0.17756	-0.10247					
Mole crabs	0.041905	0.073206253	0.14086905				
Amphipods	-0.01836	0.172036263	0.063979882	0.20905929			
Isopods	-0.17383	-0.26231841	-0.15959167	-0.135612	0.10971873		
Mysids	-0.10127	0.128795765	-0.19919862	-0.0726085	-0.2305266	-0.19502	
Tanaids	0.494019	-0.11217517	-0.06824615	-0.0579917	-0.1128553	-0.06681	-0.0834

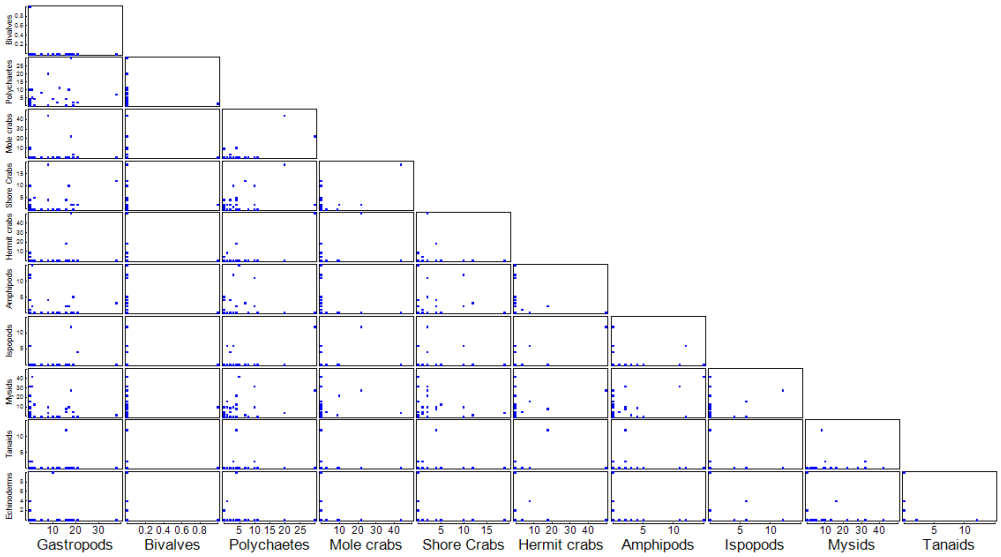


Figure 174 Draftsman scatter plot showing interaction between faunal groups in Dhramadam beach during 2009-2011.

Table 73 Correlation table of Draftsman plot during 2009-2011

	Gastropods	Bivalves	Polychaetes	Mole Crabs	Shore Crabs	Hermit crabs	Amphipods	Isopods	Mysids	Tanaids
Gastropods										
Bivalves	-0.123									
Polychaetes	0.306	-0.082								
Mole crabs	0.089	-0.050	**0.678**							
Shore Crabs	0.339	-0.014	0.429	**0.573**						
Hermit crabs	0.239	-0.043	**0.649**	0.353	-0.010					
Amphipods	-0.062	-0.079	0.065	-0.141	0.167	-0.084				
Isopods	0.152	-0.054	0.518	0.275	0.072	**0.773**	0.078			
Mysids	-0.153	0.037	0.436	0.119	-0.040	0.323	0.480	0.235	1q1	
Tanaids	0.140	-0.037	0.021	-0.066	0.041	0.287	0.003	-0.071	0.075	
Echinoderms	-0.007	-0.042	-0.051	-0.075	-0.144	0.006	-0.118	0.075	-0.085	-0.055

References

Amaral, A.C.Z., 1979. Ecologia e contribuição dos anelí- deos poliquetos para a biomassa bêntica da zona das marés, no litoral norte do Estado de São Paulo. *Bol. Inst. Oceanogr. S. Paulo* 28: 1-52.

Ansell, A. D., P. Sivadas, B. Narayanan and A. Trevellion, 1972. The ecology of two sandy beaches in south west India. II Note on *Emerita holthuisi*. *Mar. Biol*. 17: 311–317pp.

Armonies, W. & K. Reise, 2000. Faunal diversity across a sandy shore. *Mar. Ecol. Prog. Ser*. 196: 49–57pp.

Asadujjaman, M., Hossain, M.B., Shamsuddin, M., Amin, M.A. and A.K.M. Azam, 2012. Occurrence and abundance of macrobenthos of Hatiya and Nijhum Dweep Islands, Bangladesh. *Middle-East J. Sci. Res*., 11: 184-188pp.

Benventi, C. E., 1997. Benthic invertebrates. *In:* U. Seeliger, C. Odebrecht & J. P. Castello. The coast and the sea in the warm temperate south western Atlantic. *Springer Verlag*, Heidelberg, New York, pp. 43-46pp.

Berlie, T., Namboothri, N., Mohan, A. and Shanker, K., 2008. A protocol for ecological monitoring of sandy beaches and intertidal faunal on the Indian Coast. UNDP/UNTRS, Chennai and ATREE, Bangalore, India, 537pp.

Bharath singh Gohil., Rahul Kundu., 2012, Diversity of the intertidal macrofauna at west coast of Gujarat, India, *Life science Leaflets* 12: 135-145pp.

Borja, A., Franco, J. and Pérez. V., 2000. A marine biotic index to establish the ecological quality of soft bottom benthos within European estuarine and coastal environments. *Marine Pollution Bulletin,* 40: 1100–1114pp.

Boudreaux, M. L., 2005. Native and invasive competitors of the oyster *Crassostrea virginica* in Mosquito Lagoon, Florida. Masters Thesis, University of Central Florida. 104 pp.

Brazeiro, A., 2001. Relationships between species richness and morphodynamics in sandy beaches: what are the underlying factors? *Marine Ecology Progress Series,* 224; 35-44pp.

Cisneros, K.O., Smith, A.J., Laudien, J., Schoeman, D.S., 2011. Complex, dynamic combination of physical, chemical and nutritional variables controls spatio-temporal variation of sandy beach community structure. *PLoS ONE* 6.

Clarke, K. R. and Warwick, R. M. 2001. Change in marine communities: An approach to statistical analysis and interpretation. Plymouth, PRIMER-E. 172pp.

Clarke, K.R., Gorley, R.N., 2006. Primer V6: user manual/tutorial. PRIMER-E, Plymouth.

Conlan, K.E., 1994. Amphipod crustaceans and environmental disturbance-a review. *J Nat Hist,* 28(3): 519-554pp.

Connor, D.W., Allen, J.H., Goldeling, N., Howell, K.L., Liberknecht, L.M., Northen, K.O., Reker, J.B., 2004. The marine habitat classification for Britain and Ireland. Version. 04.05. Joint Nature Conservation Committee, Peterborough.

Corbisier, T.N., 1991. Benthic macrofauna of sandy intertidal zone at Santos Estuarine System, São Paulo, Brazil. Boletim do Instituto Oceanográfico, São Paulo, 39 (1): 1-13pp.

Datta, S.N., Chakraborty, S.K., Jaiswar, A.K. and Ziauddin, G., 2010. A comparative study on intertidal faunal biodiversity of selected beaches of Mumbai coast. *Journal of Environmental Biology,* 981-986pp.

Dauby, P., Scailteur, Y., De Broyer, C., 2001. Trophic diversity within the eastern Weddell Sea amphipod community. *Hydrobiologia,* 443; 69–86pp.

Dauer, D. M., Simon, J. L., 1975. Lateral or along-shore distribution of the polychaetous annelids of an intertidal sandy habitat. *Mar. Biol.*, 31: 363-37pp.

Dauer, D.M., 1983. Functional morphology and feeding behaviour of *Scolelepis squamata* (Polychaeta: Spionidae). *Marine Biology,* 77; 279-285pp.

Defeo, O., McLachlan, A., Shoeman, D. S., Schlacher, A., Dugan, J., Jones, A., Latra, M., Scapini, F., 2009. Threats to sandy beach ecosystems: A review. *Estuar. Coast. Shelf Sci*., 81, 1-12pp.

Dexter, D. M., 1984. Temporal and spatial variability in the community structure of the fauna of four sandy beaches in south-east New South.Wales. *Australian Journal of Marine and Freshwater Research,* 35; 663–72pp.

Eckman,J. E., Nowell, A. R., and Jumars P.A.,. 1981. Sediment destabilization by animal tubes. *J. Mar. Res*. 39: 361-374pp.

Gauld, D. T., Buchanan, J. B., 1956. The fauna of sandy beaches in the Gold Coast. Oikos, 7 293-307pp.

Gomez Gesteira, J.L., Dauvin, J.C., 2000. Amphipods are good bio indicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin* 40; 1017-1027pp.

Govindan Kutti, A.G., Nair, B.N., 1966. Preliminary observation on the interstitial fauna in the south west coast of India. *Hydrobiologia*, 28, 101-122pp.

Gray, J. S., 1981. *The Ecology of Marine Sediments*. Cambridge, University Press, Cambridge.

Guadalupe Minerva Torres Alfaro and James Lowry, 2011. Peracarids from three low-energy fine-sand beaches of Mexico: western coast of Gulf of California. Brill., 15; 311-324pp.

Harkantra, S. N. and Parulekar, A.H., 1985. Community structure of sand dwelling macrofauna of an estuarine beach in Goa, India. *Mar. Ecol. Prog. Ser*., 30: 291- 294pp.

Holland A. F., Polgar T. T., 1976. Seasonal changes in the structure of an intertidal community, *Mar. Biol.* 37: 341-348pp.

Hwang, H., Han, J.H., Lee, S.,Ryu, Y.M., Paik, I.H., Min, H.K., Paek, W.K., 2015. Invertebrates fauna in the intertidal regions of Yubudo Island, South Korea. *Journal of Asia Pacific Biodiversity*., 8; 66-71pp.

Ingole, B., Sivadas, S., Goltekar, R., Clemente, S., Nanajkar, M., Sawant, R., 2006. Ecotoxicological effect of grounded MV river princess on the intertidal benthic organisms of Goa. *Environ Int*, 32: 284-289pp.

J.A. de la ossa Carretero, Del Pilar Ruso, Y., Gimenez Casalduero, F., Sanchez Lizaso, J.L., Dauvin, J.C., 2011. Sensitivity of amphipods to sewage pollution. *Est.Coast. Shelf. Sci*., 1-10pp.

J.M. Guerra-García, E. Baeza-Rojano, M.P. Cabezas, I. Pacios, J.J. Díaz-Pavón & J.C. García-Gómez, 2009. Spatial patterns and seasonal fluctuations of the intertidal Caprellidae (Crustacea: Amphipoda) from Tarifa Island, Southern Spain. *Zool. baetica*, 20: 59-71pp.

James, R. J. and Fairweather, P. G., 1996. Spatial variation of intertidal macrofauna on a sandy ocean beach in Australia. *Estuarine and Coastal Shelf Science,* 43; 81–107pp.

Johnston, E.L. and M.J. Keough, 2002. Direct and indirect effects of repeated pollution events on marine hard-substrate assemblages. *Ecol. Appl*., 12, 1212-1228pp.

Kevin, S. Black, 1998. Suspended Sediment Dynamics and Bed Erosion in the High Shore mud at Region of the Humber Estuary, UK. *Marine Pollution Bulletin,* 37; 122-133pp.

Khan, S.A., P. Murugesan, P.S. Lyla and S. Jayanathan, 2004. A new indicator macroinvertibrate of pollution and utility of graphical tools and diversity indices in pollution monitoring studies. *Current Sci.,* 87; 1508-1510pp.

Krause Jensen, D., Carstensen, J, Dahl, K., 2007. Total and opportunistic algal cover in relation to environmental variables. *Marine Pollution*, 55; 114-125pp.

Little, C. and Kitching, J. A. 1996. The Biology of Rocky Shores. Oxford, Oxford University Press., 252pp.

Maria, T.F., Esteves, A.M., Vanderbeke, J., Vanreusel, A., 2011. The effect of the dominant *Scolelepis squamata* on nematode colonisation in sandy beach sediments: an experimental approach. *Estuarine, Coastal and Shelf Science* 94,; 272-280pp.

McCoy, E.D., Bell, S.S., 1991. Habitat structure: the evolution and diversification of a complex topic, Chapman and Hall, New York, 3-27pp.

McIntyre, A. D. (1977). Sandy foreshores. In 'The Coastline'. (Ed. R. S.K. Barnes.) 31-477pp.

McLachlan, A, 1990. Dissipative beaches and macrofaunal communities on exposed intertidal sands. *Journal of Coastal Research,* 6, 57–71pp.

McLachlan, A., Brown, A., 2006. The Ecology of Sandy Shores. New York: Academic Press, 373 pp.

Menge, B.A., Lubchenco, J. and Ashkenas, L.R., 1985. Diversity, heterogeneity and consumer pressure in a tropical rocky intertidal community. *Oecologia,* 65:394-405pp.

Menge, B.A., Olson, A.M., 1990. Role of scale and environmental factors in regulation of community structure. *Trends Ecol. Evol*., 5; 52–57pp.

Morais, Gisele Cavalcante; Lee and James Tony, 2014. Intertidal benthic macrofauna of rare rocky fragments in the Amazon region. Revista De Biologia Tropical, 62; 69-86pp.

Muxika, I., Borja, A. and Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. *Ecological Indicators,* 5: 19–31pp.

Pearson, T. H. and Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol.* Ann. Rev., Aberdeen, 16: 229-311pp.

Pennafirme, S, Soares-Gomes, A., 2009. Population biology and reproduction of *Kalliapseudes schubartii Mañé-Garzón*, 1949 (Peracarida, Tanaidacea) in a tropical coastal Lagoon, Itaipu, southeastern Brazil. *Crustaceana*, 82: 1509-1526pp.

Perez-Domingo, S., Castellanos, C., Junoy, J., 2008. The sandy beach macrofauna of Gulf of Gab`es (Tunisia), *Mar. Ecol*., 29 (S1), 51–59pp.

Philip K. P., 1970. The intertidal fauna of the sandy beaches of Cochin, *Proc.Indian natn.Sci.Acad*., 38(B): 317-328.

Pianka, E.R. 1970. On "r" and "k" selection. *Amer. Natur*., 104: 592-597pp.

Prato, E. and Biandolino, F., 2003. Seasonal changes in population of the Amphipod *Gammarus aequicauda*. *Mediterranean Marine Science*, 4**;** 49-56pp.

Quan, W.-M., Humphries, A.T., Shi, L.-Y. and Chen, Y.-Q., 2012. Determination of trophic transfer at a created intertidal oyster (Crassostrea ariakensis) reef in the Yangtze River estuary using stable isotope analyses. *Estuar. Coasts*., 35:109-120pp.

Raghunathan, C., Tewari, A., Joshi, H.V., Sravan Kumar, V.G., Trivedi, R.H. and Yasmin Khambhati, 2003. Impact of turbidity on Intertidal macrofauna at Gopnath, Madhuva and Veraval coasts (West coast of India). *Indian Journal of Marine Sciences,* 32(3): 214-221pp.

Reis, M. O.; Morgado, E. H.; Denadai, M. R. and Amaral, A. C. Z., 2000. Polychaete zonation on sandy beaches of São Sebastião Island, São Paulo State, Brazil. *Rev. Bras. Oceanogr*., 48:107-117pp.

Rhoads, D. C., 1963. Rates of sediment reworking by Yoldia limatula in Buzzards Bay, Massachusetts, and Long Island Sound. *J. Sediment. Petrol*., 33: 723-727pp.

Ricketts, E., F., and Calvin, J., 1968. Between Pacific Tides, Stanford press, California, 614pp.

Rizzo, A.E., Amaral, A.C.Z., 2001. Environmental variables and intertidal beach annelids of Sao Sebastiao Channel (State of Sao Paulo, Brazil). *Revista de Biologia Tropical,* 49; 849-857pp.

Rodil, I.F., Lastra, M., 2004. Environmental factors affecting benthic macrofauna along a gradient of intermediate sandy beaches in northern Spain. *Estuarine, Coastal and Shelf Science,* 61; 37-44pp.

Rodil, I.F., Lastra, M., Sanchez-Mata, A.G., 2006. Community structure and intertidal zonation of the macroinfauna in intermediate sandy beaches in temperate latitudes: north coast of Spain. *Estuarine, Coastal and Shelf Science* 67.

Rumbold, C.E., Obenat, S.M., Spivak, E.D., 2012. Comparison of life history traits of *Tanais dulongii* (Tanaidacea: Tanaididae) in natural and artificial marine environments of the south-western Atlantic. *Journal of crustacean biology*, 32; 891-898pp.

Russell, G., 1991. Vertical distribution. In 'Intertidal and Littoral Ecosystems; Intertidal Ecosystems of the World. 43-65pp.

Saritha Joshi, Priyanka Tambe, Gayatri Oak and Poonam Kurve, 2013. To study molluscan shells diversity of two fun beaches of Mumbai, Maharashtra. *National Conference on Biodiversity: Status and Challenges in Conservation*, 131-137pp.

Schlacher, T.A., Schoeman, D.S., Dugan, J., Lastra, M., Jones, A., Scapini, F., McLachlan, A., 2008. Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts. *Marine Ecology an Evolutionary Perspective,* 29, 70-90pp.

Shackley, S. E., 1981. The intertidal soft sediments and their macrofauna in the greater Swan sea Bay Area (worm's head to Nash Point), South Wales. *Estuar. coast. Shelf Sci.,* 12(5): 535-548pp.

Shafiqul Islam, M., Nurul Azim Sikder, M., Al-Imran, M., Belal Hossain, M., Debbrota Mallick and Monjur Morshed, M., 2013. Intertidal Macrobenthic Fauna of the Karnafuli Estuary: Relations with Environmental Variables. *World Applied Sciences Journal*, 21 (9): 1366-1373pp.

Short, A. D. and Wright, L. D. (1983). Physical variability of sandy beaches. In 'Sandy Beaches as Ecosystems'. (Eds A. McLachlan and T.Erasmus.) Developments in *Hydrobiology*, 19; 133–45pp.

Sivadas S. K., Ingole B., Ganesan P., Sautya S.,Nanajkar M., 2012. Role of environment heterogenecity in structuring the macrobenthic community in a tropical sandy beach, west coast of India. *Oceanogr*., Vol. 68; 295-305pp.

Sivadas, S., Ingole, B., Nanajkar, M., 2010. Benthic polychaetes as good indicators of anthropogenic impact, *Ind, J. Mar. Sci*., 201-211pp.

Soares M.S.C., Sousa L.and Barreiros, J.P., 2003. Feeding habits of the lizardfish *Synodus saurus* (Linnaeus, 1758) (Actinopterygii: Synodontidae), from the Azores. Aqua - *J. Ichthyol. Aquat. Biol*., 7(1): 29-38pp.

Stephen A. Bortone., 2005. Estuarine indicators, CRC press, 290pp.

Stuart H. Hulbert., 1971. The non-concept of species diversity: A unique and alternative parameters, *Ecology*, 52, 517-586pp.

Sumich, J. L., 1999. An Introduction to the Biology of Marine Life. Boston: McGraw-Hill Companies.

Tablado, A, Lopez Gappa, J.J, Magaldi, N.H., 1994. Growth of the pulmonate limpet *Siphonaria lesson* (Blainville) in a rocky intertidal area affected by sewage pollution. *Journal of Experimental Marine Biology and Ecology,* 175: 211–226pp.

Taheri, Mehrshad; Yazdani Foshtomi, Maryam and Bagheri, Hossein, 2010. Community Structure and Biodiversity of Intertidal Sandy Beach Macrofauna in Chabahar Bay, Northeast of Oman Gulf, IR Iran. *Journal of the Persian Gulf,* 1; 17-25pp.

Tirmizi, N.M., 1977. On *Emerita holthuissi Sankolli*, 1965 from Pakistan (Decapoda, Hippidae). Crustaceana 32(1): 108–109pp.

Tsutsumi, H., 1990. Population persistence of *Capitella sp*. (Polychaeta; Capitellidae) on a mud flat subject to environmental disturbance by organic enrichment. *Mar. Ecol. Progr. Ser.* 63: 147-156pp.

Tustsumi,H., Kikuhi, T., 1984. Study of the life history of *Capitella capitata* in Amakusa, South Japan including a comparison with other geographical region. *Marine Biology*, 80; 315-321pp.

Underwood, A.J., Experimental ecology of rocky intertidal habitats: what are we learning?. *Journal of Experimental Marine Biology and Ecology*, 250: 51–76pp.

Vaghela, A. and Kundu, R. 2011. Spatio temporal variations of hermit crab (crustacea: decapoda) inhabiting rocky shore along Saurashtra coast, western part of India. *Ind. J. Geo-Mar Sc.*

Varadharajan, D., Soundarapandian, p., Gunalan, B. and Babu, R., 2010. Seasonal abundance of macrobenthic composition and diversity along the south east coast of India. *European J.Apl.Sci.,* 2; 1-5pp.

Veloso, V.G., Soares, S.H. Caetano, Cardoso, R.S., 2003. Composition, structure and zonation of intertidal macroinfauna in relation to physical factors in microtidal sandy beaches in Rio de Janeiro state, Brazil. *SCI. MAR*., 67 (4): 393-402pp.

Warwick, R.M., T.H. Pearson and Ruswahyuni, 1987. Detection of pollution effects on marine macrobenthos: Further evaluation of the species abundance/biomass method. *Mar. Biol.*, 95, 193-200pp.

Whittaker R. H., 1965. Dominance and diversity inland plant communities, *Science* 147: 256-260pp.

Ysebaert, T., and Herman, P.M.J., 2002. Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. *Marine Ecology Progress Series,* 244: 105–124pp.

Zajac, R.N., Lewis, R.S., Poppe, L.J., Twichell, D.C.,Vozarik, J., DiGiacomo-Cohen, M.L., 2003. Responses of infaunal populations to benthoscape structure and the potential importance of transition zones. *Limnol Oceanogr,* 48:829–842pp.

Zajac. R. N. and Whitlach, R. W., 1982. Responses of estuarine infauna to disturbance, Spatial and temporal variations in initlal recolonization. *Mar Ecol. Prog. Ser*., 10: l-14pp.

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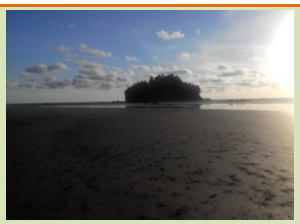
Chapter 7

ECOLOGICAL COMPARISON OF TWO BEACHES



Contents

7.1 Introduction

Dark green coconut trees and loaded white sand embrace the beauty of the beaches of Kerala. Beaches of Kerala extent along the 590km Arabian Sea coastline. In the northern parts of Kerala, particularly in Kannur (Dharmadam beach is in Kannur district of Kerala), the outcrops scramble afar the shore from the fringe of the beaches (Avinash *et al.,* 2009). Kerala coasts clamp cliffs, rocky outcrops, estuaries etc. Mostly the beaches are composed of sand (When compared to other sediment types sandy sediments are widespread on beaches) with different grain size in conjunction with broken shells of molluscs. Some of the beaches in northern part of Kerala, mainly Dharmadam beach has been recognized as crescent shaped pocket beaches (beaches have crescent shape that is the results of the waves twisting (Carl Hobbs, 2012).

Kerala coast is generally described as a submerging coast. Contrary to this Dharmadam beach is an emergent coast. The Kerala coasts having elevated population density and it gives terrific stress on coastal ecosystem. The reclamation of land for urbanization, farming and different other actions, the ecosystem suffers high pressure (Kumudranjan *et al.,* 1999). Ecology of Kerala beaches are somewhat unrepresented and limited studied. So knowing ecology of beaches will lead to an attempt towards proper management and protection of coastal areas.

Sandy beaches, covering 70% of all continental margins are the distinct prime coastal ecosystem on earth (McLachlan and Brown 2006). Sandy beaches are physically organized environments and mostly be deficient in biological structure. Sandy beaches support diminutive in-situ primary production (McLachlan and Brown, 2006).

A search on stressed and a complete pristine beach came to an end in Fort Cochin and Dharmadam beach respectively. An ease of availability of samples without any risk also accelerated the selection of beaches. The two beaches have its own specialty and Dharmadam beach is so far unrepresented to the world in intertidal studies.

7.2 Morphology and Basic features

Fort Cochin and Dharmadam beaches are sandy beaches, whereas at some portions of Dharmadam beach holds laterite rock formation on sandy basement (Fig. 175). These laterite rocks are weathering products of basalt. Dharmadam laterite rocks are primary laterites and are mainly composed of iron oxides. The Green island situated in the vicinity of the shore at 100 m towards west of Dharmadam beach is fashioned by greatly eroded primary

laterites (Avinash *et al.,* 2009). This green island is 5 acre island with full of coconut palms and other vegetations. It also gives ecological importance to the Dharmadam beach. The sediment of this beach is mainly composed of quartz with mical flakes. The mica flat flakes on the surface of the beach grains glint in light (sunlight or moonlight) (Fig. 177). Mangroves are also reported from Cochin estuary and Dharmadam (Kumudranjan *et al.,* 1999). Apart from the beach Dharmadam island is also spotted as mangrove area (Fig. 176). Thus the ecological importance of beach increases as it is the most productive coastal habitats in the world. Vegetation mainly plays an important role on beaches for preventing beach erosion and also for stabilization of the beaches.

Fort Cochin beach is also a sandy beach with coarser sand. The sand mainly composed of quartz. It is highly attracted by tourists due to the presence of Chinese dip nets, a unique attraction of Fort Cochin beach. Fort Cochin beach has an extensive berm with much steeper slope when compared to Dharmadam beach. Anthropogenic activities are major problem in Fort Cochin beach. This is accelerated by dead organisms, oil slicks, Eichornia wrack and industrial wastes. Stone walls have been deposited intermittently to avoid beach erosion. During October and December, 2009 Fort Cochin beach showed accretion of sand and a wide portion had been formed along with the beach. During October to March all the beaches show accreting tendency under the influence of north westerly waves (Jayappa *et al.,* 2009).Wave action is more intense in Fort Cochin beach when compared to Dharmadam beach. The frequency of waves is different in both beaches. Number of waves per minute at Fort Cochin was 9 no. (avg) and number of waves per minute at Dharmadam was 6no. (avg). Waves do not normally reach the beach perfectly parallel to the shoreline. Relatively, they arrive at a slight angle, called the

"angle of wave approach." Angle of approach of waves at Fort Cochin beach is 100-110^0. Angle of approach of waves at Dharmadam beach is 90-110^0. Coastal tidal ranges vary from coast to coast. When the tidal range is lower than 2 meters it is classified as micromareal. Here at both the beaches maximum tidal amplitude is 1.3m, so it is classified under micro tidal region.

Ripple formation was a common feature in Dharmadam beach. According to Chakrabarti (2005) energy levels of waves and currents of intertidal region exerts strong control on ripple formation patterns. In Fort Cochin beach ripple formation was totally absent. In Dharmadam ripple formation was observed in almost all months during sampling (Fig.209). The ripple observed was somewhat symmetrical and formed as a result of back and forth motion of wave action. The upper crest of the ripple was not so straight. Tidal channel is also a permanent feature in Dharmadam beach. It is important for the birds and marine larval forms. The channel observed to be deep in monsoon season due to high influx of water and shallow during pre and post monsoon season. Laterite rock formation of Dharmadam beach also gives numerous micro habitats to the epifauna as it has number of holes and small pools. The iron oxide rich laterite rocks are not so strong and change in shape and position was also observed seasonally during the study. Weathering of rocks may increase due to intense wave action of rocky areas.

Avian fauna were also observed from both the beaches, eagles and crows were common in Fort Cochin and Dharmadam beaches. Sea gulls were observed occasionally in Dharmadam beach and most of the time during sampling in Fort Cochin beach. King fishers were also frequent visitors in Dharmadam beach.

The presence of honey comb like structures of sand below the rocks were also another attraction of Dharmadam beach. These are made by sand

castle worms and these sandy formations are very delicate. Sand castle worms are abundant in low tide region and it is exposed only in lowest low tides.

Figure 175 Laterite rocks on Dharmadam beach

Figure 176 Dharmadam Island

Figure 177 A moving sea star in the mid tide region of dharmadam beach. This picture also shows the sparkling nature of the sediment during sunny days due to the presence of mica flakes in the sediments of Dharmadam beach

7.2.1 Human impacts

Fort Cochin beach is known for its beauty as well as pollution. In this beach main sources of pollution are industry, fishing, run off of from near areas, shipping (oil slicks) and tourism etc. Dead and decaying Eichornia washed towards the beach also creates disturbances to intertidal organisms (Fig. 180). It always receives dead and decaying fishes and heavy load of sewage (Fig.178). Dharmadam beach is pristine natured. The only human impact on that beach is fishing. Tourism is slowly developing there as the Dharmadam Island near to this beach and rocky outcrops of that beach is attracted by tourists (Fig.179).

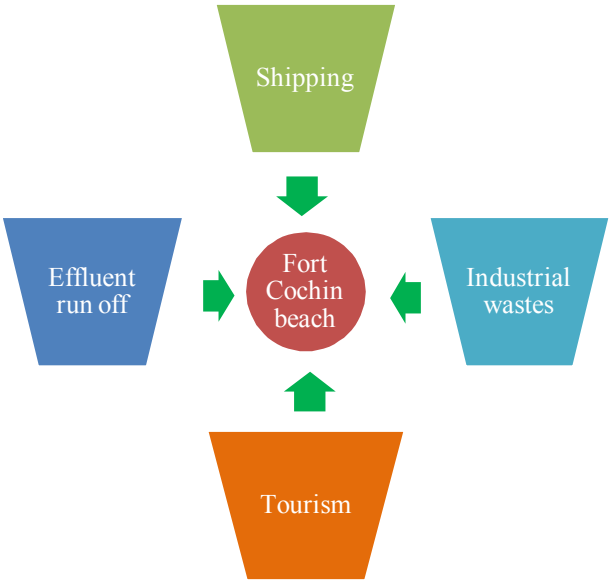


Figure 178 Pictorial representation of human impacts on Fort Cochin beach

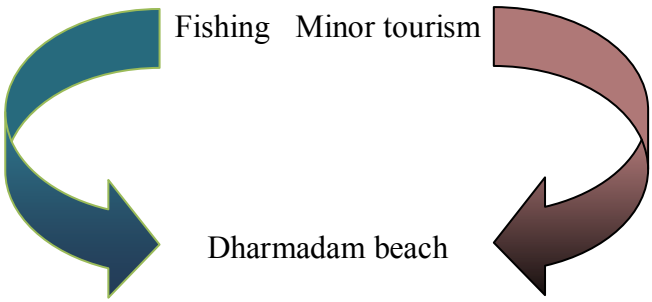


Figure 179 Pictorial representation of human impacts on Dharmadam beach

Figure 180 Eichornia wrack and sewage on the beach face of Fort Cochin beach

7.2.2 Beach vegetation

Both the beaches have shore vegetation near to the shore line. Dharmadam beach holds variety of flora when compared to Fort Cochin beach. The major plants observed from the Dharmadam beach are coconut trees (*Coccos nucifera*), *Pandanus* sp., *Casuarina* sp., beach morning glory or rail road vine (*Ipomoea pescaprae*), Mangroves (*Avicennia* sp.), *Hibiscus tiliaceus, Clerodendrum infortunatum,* Almond tree (Badam), Banyan tree etc (Fig. 181, 82, 84, 85). A small forest of casuarinas sp. is also there in the shore line of the Dharmadam beach. At Fort Cochin beach the major plants are

Coccunt trees (*Coccos nucifera*), May flower tree or Gulmohar (*Delonix regia)* (Fig. 183), *Jarul (Lagerstroemia speciosa)***,** Banyan tree *(Ficus bengalensis),* rail road vines ***(****Ipomoea pescaprae***)** etc.

Figure 181 ***Ipomoea pescaprae***

Figure 182 ***Pandanus*** **sp**.

Figure 183 ***Delonix regia***

Figure 184 ***Casuarina*** **sp.**

Figure 185 Mangrove vegetation (*Avicennia* sp.) on rocky beach cliff of Dharmadam beach

The faunal diversity is also different and species composition showed variation in both the becahes. The zonation pattern of organisms in Dharmadam and Fort Cochin beach has been showed below. In station 1 of Dharmadam beach ghost crabs and soldier crabs were dominant inhabitors of high tide zone (Fig.186). Mid tide zone of station 1 was rich in organisms when compared to high and low tide during the study period. Tanaids and polychaetes were common in all tidal levels of station 1. Station 2 was characterised with scattered laterite rocks. Epifaunal organisms were abundant due to the presence of rocks (Fig.187). station 1 of Fort Cochin beach was charecterised with gently sloping intertidal region and organisms were less when compared to Dharmadam beach. Mole crabs were the common inhabitor of high tide zone during the study period and mid tide zone was dominated by amphipods (Fig.188). Station 2 of Fort beach is also gently sloping and orgnisms were less. Polychaetes were the common inhabitor of station 2 (Fig. 189).

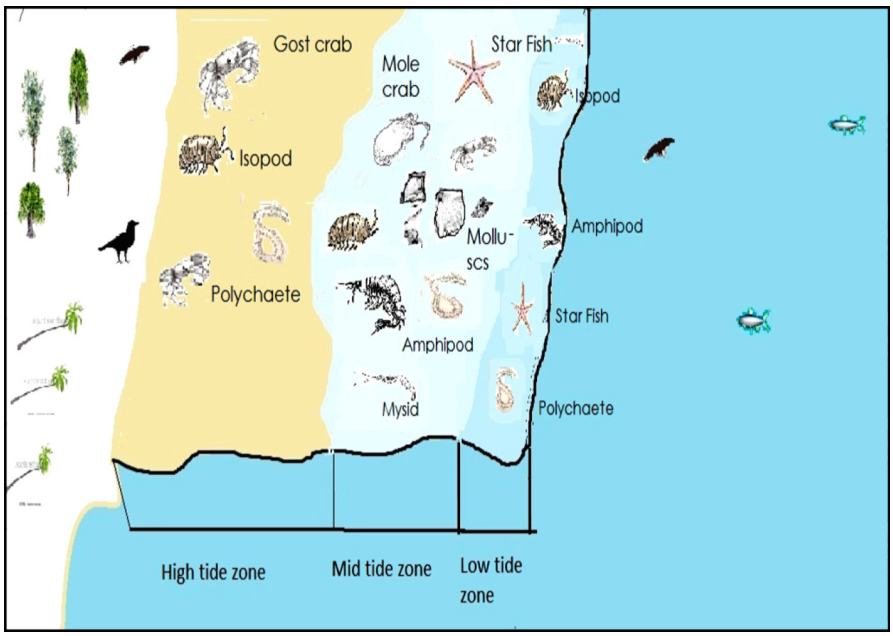


Figure 186 Zonation pattern of Dharmadam beach (station 1)

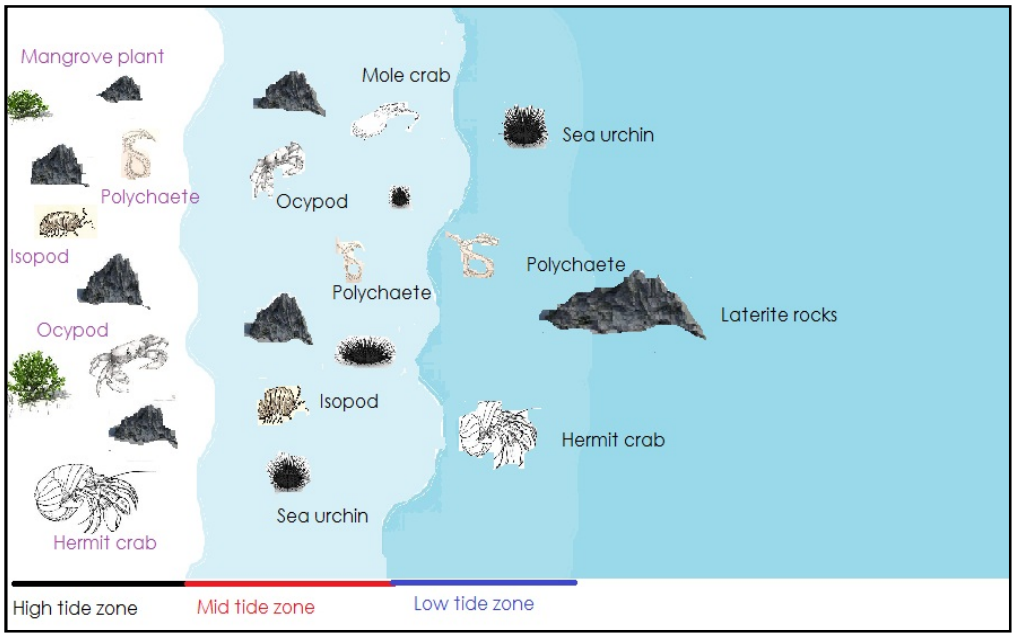


Figure 187 Zonation pattern of Dharmadam beach (station 2)

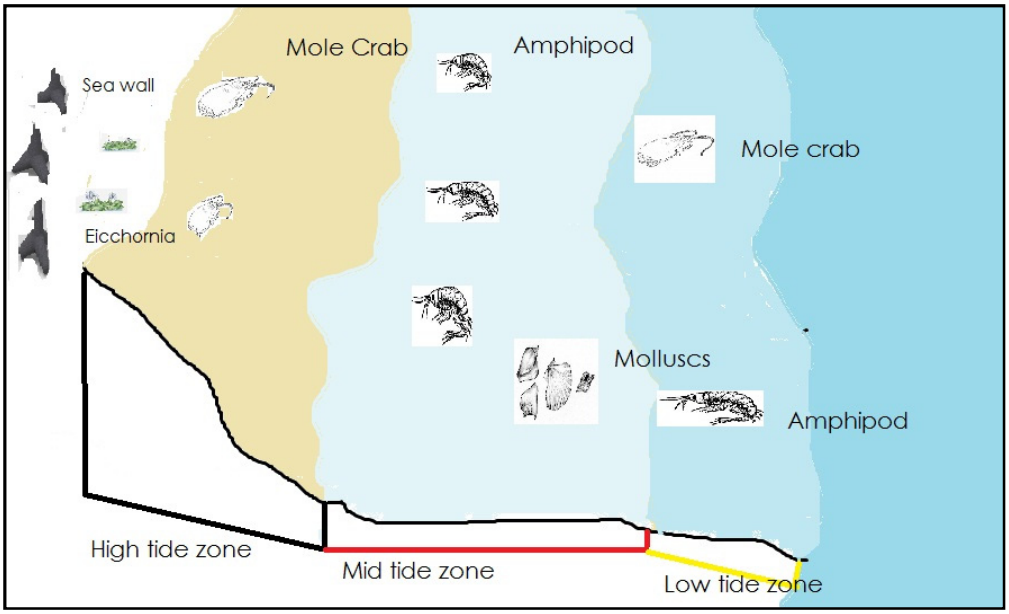


Figure 188 Zonation pattern of Fort Cochin beach (station 1)

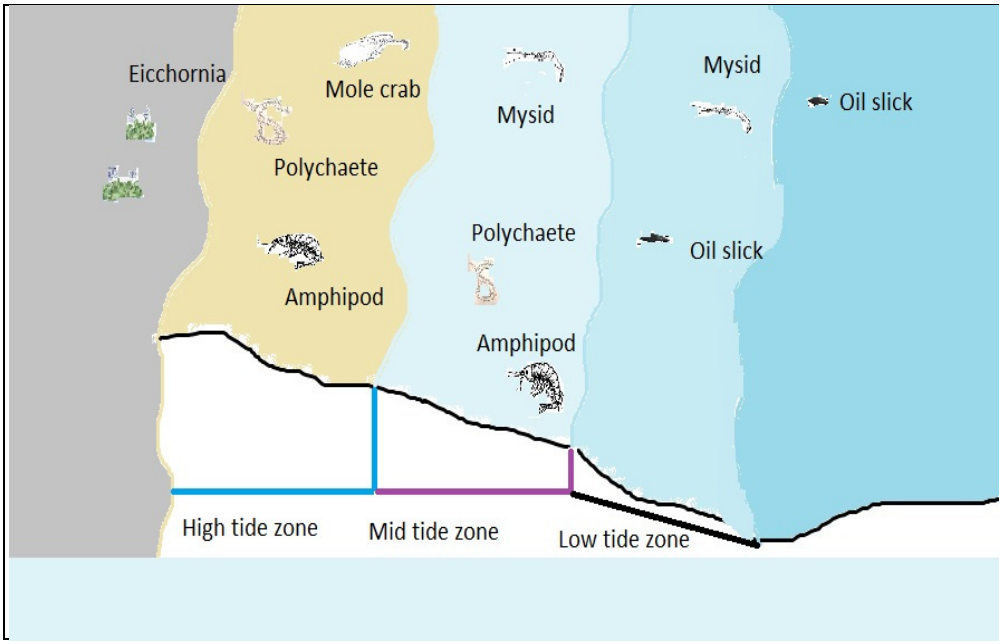


Figure 189 Zonation pattern of Fort Cochin beach (station 2)

7.3 Similarity of dominant macrofauna with tide height using ANOSIM

Similarity of polychaetes, amphipods and gastropods were observed with tide height to know their significance level with different tidal height. Gastropods from Dharmadam beach showed no significant segregation with tide height (R = 0.09, p> 0.05) (Fig.190). Amphipods from Fort Cochin beach showed that there was no significant segregation with tidal height (R=0.04, p > 0.05) (Fig.191). Polychaetes from both the beaches were also observed. In Fort Cochin beach and Dharmadam beach polychaetes showed no significant segregation with tidal height (R = 0.02, p > 0.05 and R = -0.067, p > 0.05) (Fig.192 & 193). All the R values observed were close to zero. As per Clarke *et al.,* 2006, R values close to zero implying no segregation between samples. The significance level observed were also higher than alpha significance value (0.05), indicating no significance between samples.

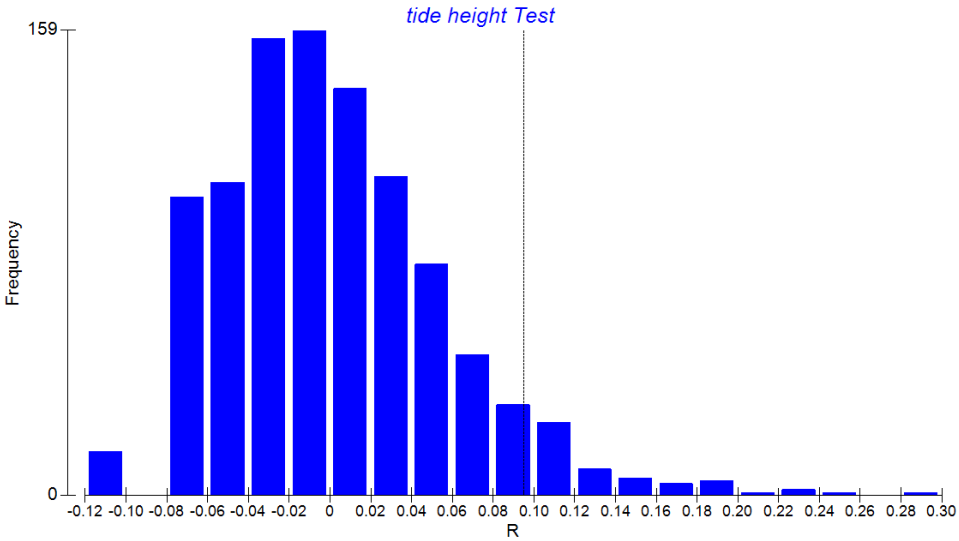


Figure 190 Histogram showing ANOSIM similarities with gastropod species and tidal height in Dharmadam beach during 2009-2011. (Global R = 0.09, *p* > 0.05)

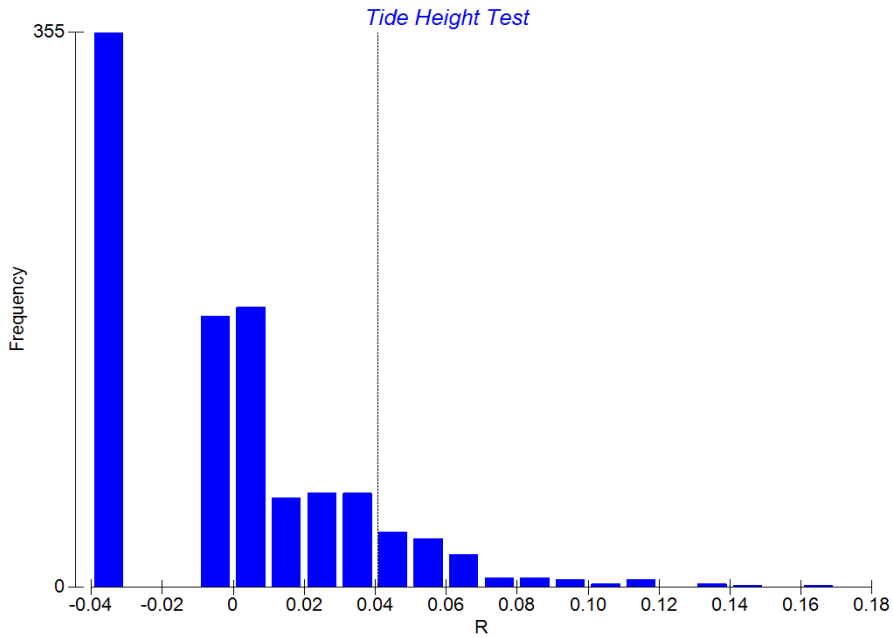


Figure 191 Histogram showing ANOSIM similarities with amphipod species and tidal height in Fort Cochin beach during 2009-2011. (Global R = 0.04 *p* > 0.05)

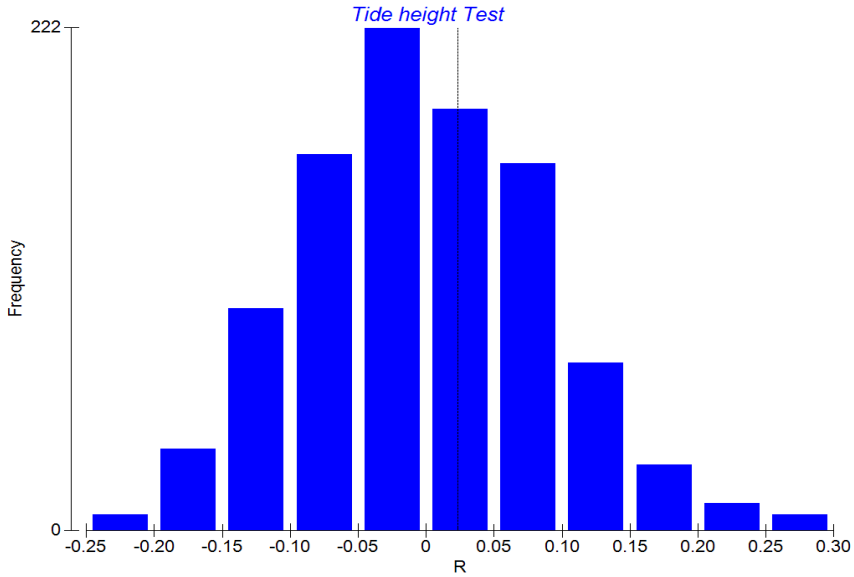


Figure 192 Histogram showing ANOSIM similarities with polychaete species and tidal height in Fort Cochin beach during 2009-2011. (Global R = 0.02 *p* > 0.05)

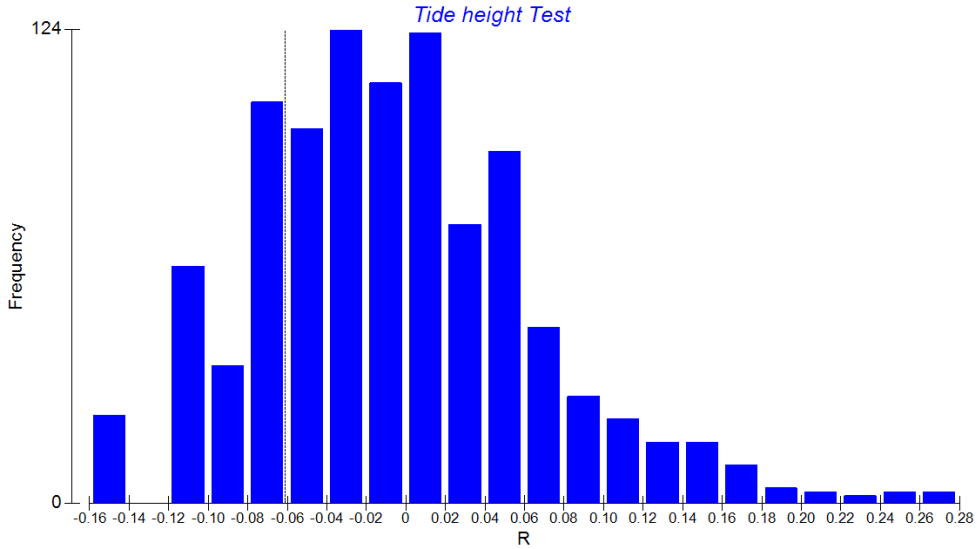


Figure 193 Histogram showing ANOSIM similarities with polychaete species and tidal height in Dharmadam beach during 2009-2011. (Global R = -0.067 *p* > 0.05)

7.3.1 Similarity of total groups with different abiotic factors using ANOSIM

Total faunal groups in Fort Cochin beach with dissolved oxygen showed R value -0.059 and significance level p< 81%, p > 0.05. This near zero R value indicating no significant segregation of samples with DO variation. Gastropods showed 0.053 R value and significant level p< 14%, p> 0.05 with salinity in Dharmadam beach. Amphipods showed -0.035 R value and p< 88%, p> 0.05 with salinity in Fort Cochin beach. Total faunal groups in Dharmadam beach showed global R value 0.03 and significance level p< 17%, p > 0.05 with dissolved oxygen. Polychaetes in Dharmadam beach showed -0.024 R value and significance level p< 71%, p > 0.05 with temperature and in Fort Cochin beach polychaetes showed -0.072 R value and significance level p < 93%, p> 0.05 with temperature. The all above mentioned analysis were showed near zero R value and thus no significant segregation with abiotic factors.

7.4 SIMPER analysis of polychaetes with tidal height.

Groups 0.53 & 0.21

Average dissimilarity = 99.26%

Table 74. SIMPER tables showing dissimilarity with polychaetes in different tidal heights during 2009-2011 (Av. Abund- Average abundance, Av. Diss- Average dissimilarity, Contrib%-Percentage contribution, Cum%-Cumulative percentage).

	Group 0.53	Group 0.21			
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Contrib%**	**Cum.%**
***Nereis* sp.**	0.00	0.72	23.48	23.65	23.65
Neanthes willeyi	0.50	0.29	21.61	21.77	45.42
***Prionospio* sp.**	0.00	1.32	10.47	10.55	55.97
Capitella capitata	0.00	0.45	8.51	8.58	64.54
Scolelepis (Scolelepis)squamata	0.00	0.74	7.32	7.37	71.92
Prionospio sexoculata?	0.00	0.61	5.64	5.68	77.60
***Glycera* sp.**	0.00	0.45	4.78	4.82	82.42
Puliella armata	0.00	0.20	3.81	3.84	86.25
***Heteromastus* sp.**	0.00	0.20	3.81	3.84	90.09

Groups 0.73 & 0.21

Average dissimilarity = 97.33%

	Group 0.73	Group 0.21			
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Contrib%**	**Cum.%**
Mediomastus capensis	1.32	0.00	24.84	25.53	25.53
Capitella capitata	0.87	0.45	19.91	20.46	45.99
***Nereis* sp.**	0.00	0.72	15.89	16.33	62.31
***Prionospio* sp.**	0.00	1.32	8.23	8.46	70.77
Scolelepis(Scolelepis) squamata	0.00	0.74	5.66	5.81	76.58
Prionospio sexoculata?	0.00	0.61	4.38	4.50	81.08
***Glycera* sp.**	0.00	0.45	3.68	3.78	84.86
Puliella armata	0.00	0.20	2.83	2.90	87.77
***Heteromastus* sp.**	0.00	0.20	2.83	2.90	90.67

Group 0.53 and 0.21 indicates the tdial heights and the comparison between 0.53 and 0.21m tidal height, the average dissimilarity was 99.26% and *Nereis* species generated about 23.4% dissimilarity, followed by *Neanthes willeyi* at about 22%. When groups 0.73 and 0.21 was compared, the average dissimilarity was 97.33% and highest dissimilarity was showed by *Mediomastus capensis* (24.8%) followed by *Capitella capitata* (19.91%). All other tidal heights showed 100% dissimilarity between groups and only similarity observed was in 0.47m tidal height group and the only contributor was *Nereis* species at about 100% similarity.

7.5 Cluster analysis

Cluster analysis of monthly diversity of faunal groups of four stations were done using PRIMER to find out any similarity between the four stations, but no significant similarity was obtained when the SIMPROF test was applied.

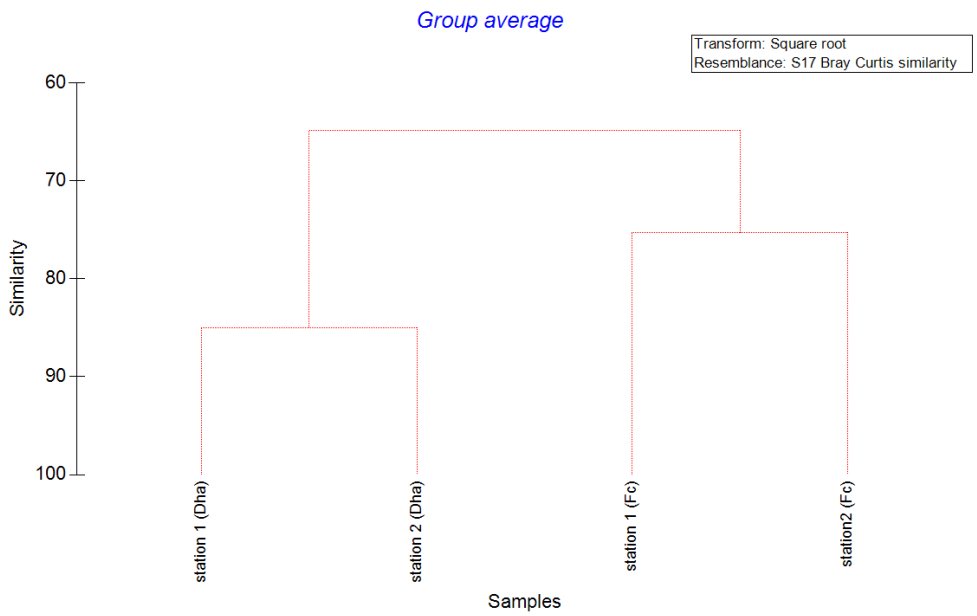


Figure 194 Dendrogram showing monthly diversity similarities of faunal groups in four stations during 2009-2011.

7.6 CASWELL (V- Statistics) (CASWELL's neutral model)

Table 75 CASWELL diversity tables of total fauna (Seasonal) in station 1 of Fort Cochin beach during 2009-2011

Column1	N	S	H'	E[H']	SD[H']	V(N.D.)	F-ratio	DF1	DF2
Monsoon 1	44	5	0.92323	1.10669	0.231947	-0.790955	0.611193	12.84736	5.836306
Post monsoon 1	46	6	1.133531	1.281617	0.22332	-0.663109	0.685473	17.32377	6.895656
Pre monsoon 1	24	4	0.815186	0.997488	0.200498	-0.909241	0.556372	12.44452	4.850703
Monsoon 2	17	3	0.803742	0.780106	0.184376	0.1281932	1.112883	8.959972	3.658224
Post monsoon 2	17	3	1.095078	0.780106	0.184376	1.7083131	126.4998	8.959972	3.658224

Table 76 CASWELL diversity tables of total fauna (Seasonal) in station 2 of Fort Cochin beach during 2009-2011

Column1	N	S	H'	E[H']	SD[H']	V(N.D.)	F-ratio	DF1	DF2
Monsoon 1	26	4	1.359426	0.983261	0.206506	1.8215687	20.73867	11.76364	4.821861
Post monsoon 1	76	5	1.066124	1.014284	0.262563	0.1974393	1.151402	9.776229	5.73642
Pre monsoon 1	38	3	0.971634	0.670012	0.231864	1.3008568	4.894904	5.295563	3.387525
Monsoon 2	33	4	0.856385	0.942574	0.2229	-0.386672	0.760784	10.08728	4.748622
Post monsoon 2	24	3	0.792375	0.729949	0.207623	0.3006733	1.306806	6.966809	3.518615

Caswell neutral model was applied to seasonal abundance data to compare the Shannon Wiener diversity (H') with the predicted diversity values (E[H']) as proposed by Caswell (1976) in his neutral model, which measures theoretical diversity for a sample of observed number of species (S) and individuals (N) under model assembly rules for the community, which are ecologically neutral (Clarke and Gorley, 2006). In station 1 of Fort Cochin beach the V value was negative in monsoon, post monsoon (2009) and pre monsoon (2010) seasons (-0.79, -0.66 and -0.90 in monsoon, post monsoon and pre monsoon season respectively). The predicted diversity values were also higher than actual diversity values (E[H'] = 1.1 and H' = 0.92 in monsoon season, E[H']= 1.2 and H' = 1.1 in post monsoon season, E[H']= 0.99 and H'= 0.81 in pre monsoon

season), indicating lesser diversity values than 'neutrality'. From the negative value of V implies excessive dominance of species in monsoon and pre monsoon season (Table 75). It may be due to any disturbances to the assemblage during that time.

In station 2 of Fort Cochin beach monsoon season (2010) showed negative V value (-0.3) and higher predicted diversity (0.94) than actual diversity (0.85). Other seasons showed positive V value indicating greater diversity than 'neutrality' (Table 76).

Table 77 CASWELL diversity tables of total fauna (Seasonal) in station 1 of Dharmadam beach during 2009-2011

Column1	N	S	H'	E[H']	SD[H']	V(N.D.)	F-ratio	DF1	DF2
Monsoon 1	63	5	1.58694	1.044528	0.253049	2.1435003	38.14866	10.66291	5.76679
Post monsoon 1	169	6	1.155321	1.057956	0.29076	0.3348646	1.259096	9.663228	6.702459
Pre monsoon 1	106	9	1.447331	1.534649	0.24382	-0.358124	0.833287	22.49605	9.712527
Monsoon 2	35	5	1.275125	1.149418	0.216246	0.5813136	1.526503	14.72242	5.892206
Post monsoon 2	17	4	1.071018	1.062105	0.17141	0.0519976	1.036899	16.42477	5.013379

Table 78 CASWELL diversity tables of total fauna (Seasonal) in station 2 of Dharmadam beach during 2009-2011

Column1	N	S	H'	E[H']	SD[H']	V(N.D.)	F-ratio	DF1	DF2
Monsoon 1	85	8	1.51602	1.45596	0.240838	0.2493789	1.152247	20.51536	8.785225
Post monsoon 1	284	9	1.869215	1.35475	0.29075	1.7694436	3.54381	15.41602	9.586715
Pre monsoon 1	169	6	1.659033	1.057956	0.29076	2.0672582	8.669789	9.663228	6.702459
Monsoon 2	35	5	1.428576	1.149418	0.216246	1.2909292	3.16122	14.72242	5.892206
Post monsoon 2	23	6	1.479906	1.433729	0.165107	0.2796839	1.185053	28.53489	7.125738

In station 1 of Dharmadam beach pre monsoon season showed negative V value and higher predicted diversity (E[H'] = 1.5) due to excessive dominance of species (Table 77). In station 2 all seasons showed positive V value, indicating greater diversity than neutrality and thus a healthy environment during all seasons (2009-2011) (Table 78)

Plates of different ecological features of Dharmadam and Fort Cochin beach.

Figure 195 Holes and sand balls made by *Dotilla* sp.in Dharmadam beach.

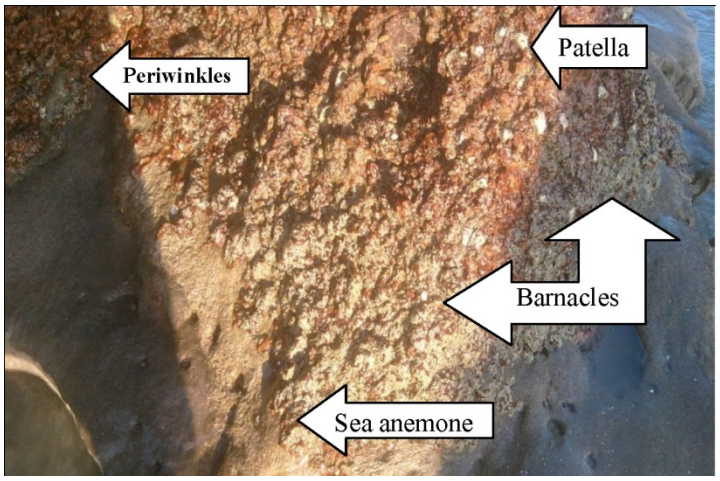


Figure 196 The vertical zonation of organisms in rocky zone of Dharmadam beach

Figure 197 Picture showing distribution of Barnacles on laterite rocks of Dharmadam beach.

Figure 198 Picture showing distribution of *Littorina* sp. on laterite rocks of Dhramadam beach.

Figure 199 Dettached mussel clamp on Dharmadam beach.

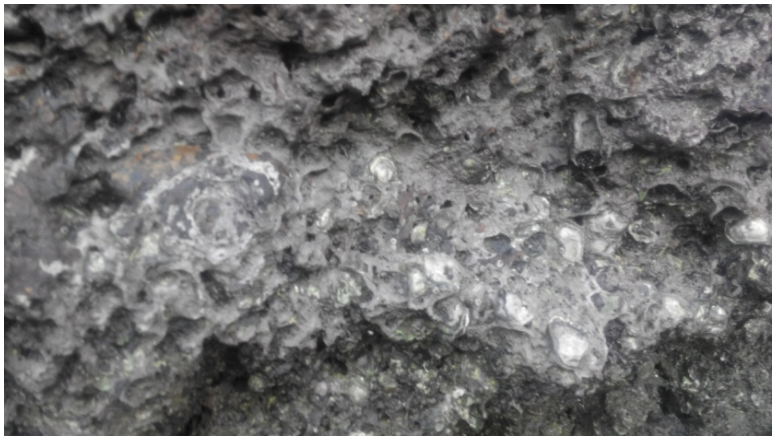


Figure 200 *Crassostrea* shells on rocky area of Dharmadam beach.

Figure 201 Tide pools on rocky area of Dharmadam beach

Figure 202 Burrows of *Dotilla* crabs in high tide region of Dharmadm beach

Figure 203 Red Algae on rocks of Dharmadam beach (Not obtained in quantitative sampling)

Figure 204 Barnacle (*Semialanus balanoides*) on rocks of Dharmadam beach

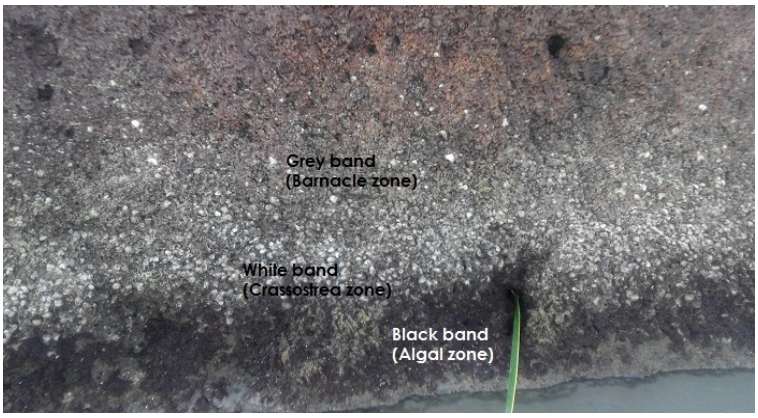


Figure 205 Vertical zonation banding pattern in Dharmadam beach

Figure 206 Formation of tidal channel on Dhramadam beach

Figure 207 Anjarakkandi river

Figure 208 Rail road vines on Dharmadam beach

Figure 209 Swash/backwash ripple formation in Dharmadam beach

Figure 210 Salt marsh beside the shore line of Dharmadam beach

Figure 211 Fort Cochin beach showing accretion of sand and Eichornia wrack in 2009

Figure 212 Intertidal zone of Fort Cochin in 2009

Figure 213 Intertidal zone of Fort Cochin in 2015 (width of the intertidal zone increased due to accretion of sand).

Figure 214 Eichornia wrack and plastic wastes in low tide region of Fort Cochin beach in 2015.

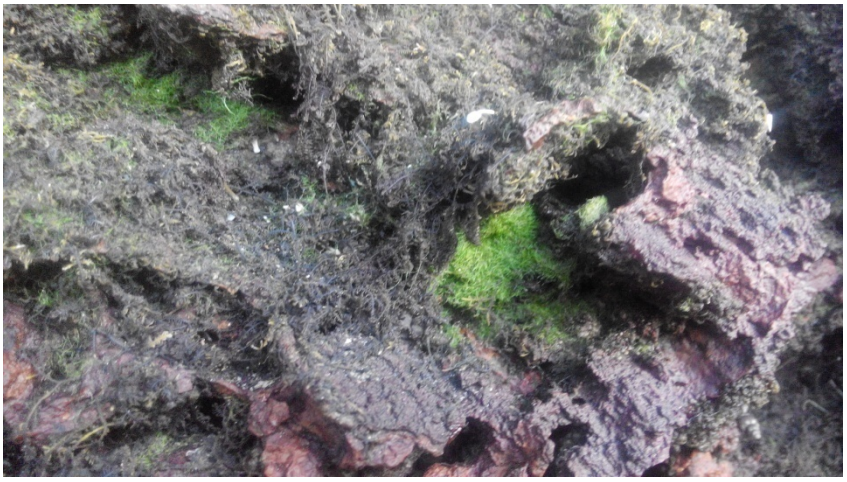


Figure 215 Green algae on rocks of Dharmadam beach.

7.7 Discussion

The contrasting nature of two shores (Fort Cochin and Dharmadam) of south west coast of India has full of opportunities to compare and close examine the ecological function and processes. Fort Cochin beach is facing threats due to anthropological invasions and natural processes leading to its destruction. The pristine Dharmadam beach is presently in a face of calm, but development of tourism there lead to a risk in future.

As the coasts are showing different profile patterns, comparative study of shores are receiving more attention nowadays. Fort Cochin beach and Dharmadam beaches are situated 279km apart and as move towards to the southern part of Kerala, the coasts showing some morphological difference. The present study showed that Fort Cochin beach is morphologically different from Dharmadam beach. Although the selected beaches are lying in the same coast (South west coast of India), these are showing dissimilarity in their hydrological and sediment profiles. Somewhat sloppy nature of Fort Cochin

beach and flat nature of Dharmadam beach shows the intensity characteristics of waves on those beaches. Somewhat high intense nature of waves of Fort Cochin than Dharmadam endorses the profile difference of both the beaches. These profile difference have number of reasons like tide, wave and wind patterns. Erosion and accretion is also an important factor in coastline morphology. Most of the beaches in Kerala show evidence of erosion and deposition owing to waves of monsoon and fair whether seasons (Jayappa *et al.,* 2009). Fort Cochin beach is more prone to accretion and erosion than Dharmadam beach due to intense wave action and deposition of sand in the banks of Cochin estuary by dredging activities also accelerate the accretion process.

The present study revealed that both the beaches selected were open and striaght beaches. The coastline of Kerala consists of open, sandy, straight or barrier type beaches (Jayappa *et al.,* 2009). These beaches are immensely utilizing for human welfare, tourism and fishing are the main activities. Beaches are frivolous assets and thus they are of immense social and cultural importance to humans (Schlacher *et al.,* 2007).

Zonation patterns studied showed clear dissimilarity in both beaches. Prevailing hydrological and sediment parameters of those beaches may be the reason for dissimilar zonation patterns of both the beaches. In ANOSIM analysis, dominant fauna showed insignificant variation with tidal height. From this it could be indicated that the distribution and behaviour of amphipods, gastropods and polychaetes from both the beaches were not have any effect from tidal height and is not very important. The other abiotic factors like DO, salinity and temperature also showed no significant segregation with total faunal groups. SIMPER analysis on polychaetes with tidal height showed same results as ANOSIM. In ANOSIM also polychaetes and tidal height showed insignificant

segregation, which supports the SIMPER data. In SIMPER almost all polychaete species showed dissimilarity with tidal heights except *Neanthes willeyi*. From this it could be attributed that the organism's distribution and tidal height have insignificant variation. Intertidal species prefer different physiological and biological condition for their ecological needs. Caswell neutral model showed comparatively lesser diversity than neutrality in majority of the seasons in station 1 of Fort Cochin beach, indicating stress to the assemblage over there during those seasons and complete positive value of station 2 of Dharmadam beach showed a greater diversity than' neutrality'. Beach vegetation of both beaches showed dissimilarity. Dharmadam beach holds herbs and shrubs than Fort Cochin beach. Trees were also there in Dharmadam beach but lesser when compared to Fort Cochin beach. In Fort Cochin beach large trees are dominating.

Coastal zones restrain assorted and fruitful habitats imperative for anthropogenic actions, expansion and survival. Management of beaches as functional ecosystems and security of their unique biodiversity necessitates management intercession.

Highlights

- Fort Cochin beach is exposed sandy beach and is mainly composed of quartz whereas Dharmadam beach is exposed sandy beach with rocky outcrops, mainly composed of quartz with mical flakes.
- Number of waves per minute and angle of approach of the waves were different at both the beaches.
- Ripple formation was common in Dharmadam beach whereas in Fort Cochin it was absent.

- Common avian fauna of both beaches were eagles, crows and sea gulls.
- Human impacts were more in Fort Cochin beach than Dharmadam beach. Fishing, effluent discharge, oil slicks and waste disposal were common in Fort Cochin beach.
- Beach vegetation showed dissimilarity, herbs and shrubs are common in Dharmadam beach and in Fort Cochin large trees are dominating.
- Both the beaches showed dissimilar zonation patterns and the organisms were rich in Dharmadam beach than Fort Cochin beach.
- ANOSIM analysis of faunal groups with tidal height and other abiotic factors showed insignificant variation. In SIMPER analysis almost all polychaetes showed dissimilarity with tidal heights except *Neanthes willeyi.*
- Caswell neutral model showed negative V value in majority of the seasons in station 1 of Fort Cochin beach and lesser diversity than 'neutrality' was observed. In Dharmadam beach only pre monsoon season showed negative V value in the case of station 1 and other seasons in both the stations showed positive V value and greater diversity than 'neutrality'.

References

Caswell, H., 1976. Community structure: a neutral model analysis. *Ecol. Monogr*. 46: 327-354pp.

Chakrabarti, A., 2005. Sedimentary structures of tidal flats: A journey from coast inner estuarine region of east coast of India. *Journal of Earth system science*., 114; 353-368pp.

Clarke, K.R., Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Hobbs, C.H., 2012. The Beach Book: Science of the Shore. Columbia University Press, 195 pp.

McLachlan, A., Brown, A., 2006. The Ecology of Sandy Shores. New York: Academic Press, 373pp.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., Defeo, O., 2007. Sandy beaches at the brink. Diversity and Distributions, 13; 556–560pp.

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Chapter 8

CONCLUSION

Beach ecosystem portrays strong relationship between abiotic and biotic factors depending on the substratum of the region. In intertidal zone the substratum plays an important role in morphology of the zone, faunal composition and distribution. This study observed the intertidal faunal composition, community structure and interaction of abiotic factors in the sandy beach and sandy with rocky outcrop ecosystem. Several studies are available on the biota of intertidal zones in different parts of the world and also in Indian coast. But the information on the community structure, diversity and faunal assemblages of the rocky, sandy and muddy habitats of the Kerala coast especially Kannur and Fort Cochin coasts are deficient. This study made an effort to study the Kannur and Cochin coastal stretches to explore the community structure over there.

Chapter 1, this chapter provides framework on intertidal zones, their characteristics, and ecological importance. Importance of waves and tides in the intertidal zones are also included in and details of major types of shores, their division and characteristics are also incorporated. Towards the end of the section the macrofaunal community and their importance, scope of the study and objectives are also listed.

Chapter 2, this chapter contains the review on intertidal zones and the macrofaunal community. The history of intertidal research and works of intertidal fauna from different parts of the world were included. The reviews on different shores and their intertidal features are described. Brief review on intertidal macrofauna and brief review on intertidal fauna in India are also incorporated.

Chapter 3, elaborates the description of study area including the transect selected for the study and various methodologies for analyzing hydrographic and sediment parameters. Macrofaunal collection and identification methods are also depicted. Two stations selected for the study were Fort Cochin and Dharmadam beach. Samples were taken during low tide time and different hydrographic and sediment parameters were analysed. Twelve water quality parameters and five sediment parameters were analysed as per standard measurement criteria. Epifauna and macrofauna were collected by using a quadrate ($0.625m^2$) and were mostly identified upto species level. The chapter also presents the different statistical analysis including the SPSS Vs 16 and PRIMER Vs. 6.1.8 and were employed to analyse and correlate the data.

Chapter 4, different hydrographical parameters were analysed to find out the interaction of water quality parameters with macrofauna residing there. The impact of global climate change can be easily perceived in intertidal zones. Evaluation of hydrographic parameters is crucial for the study of influence of global climate change. Tidal height and long shore currents were measured and seasonal fluctuations were observed. Temperature, pH, carbon dioxide, salinity, dissolved oxygen, TDS, turbidity, conductivity and inorganic nutrients (nitrate, nitrite, phosphate and silicate) of two sampling sites were done. Water pH and dissolved oxygen showed significant variation with

station and month at 1% level. Marked seasonal variations have been showed in the hydrographical data. Decreased amount of dissolved oxygen (≤4mg/L) in Fort Cochin stations have proven the deterioration in water quality there. The effect of tidal height has showed migration of some organisms like *Emerita* sp. A tidal height of 1.3m was experienced in the coast during the study period. The increased amount of carbon dioxide (20mg/l) in station 1 of Dharmadam beach clearly reflected the respiration of organisms during August, 2009. From the statistical analysis it is concluded that from the twelve hydrographic parameters analyzed, salinity, conductivity and TDS showed significant correlation. PCA (Principal Component Analysis) values of Dharmadam showed normal conditions in hydrography and in Fort Cochin, land use pattern were reflected.

Chapter 5 - This chapter deals with the sediment characteristics of two sampling sites. Sediment temperature, pH, conductivity, moisture content, organic matter, and particle size were analyzed for the study. Although the quantity of measured organic matter was lesser in amount and particle size measured was showing sand dominant beaches (40-95%) in both sampling sites. Fort Cochin showed coarser sand than Dharmadam beach. Seasonal fluctuations were observed in sediment temperature values. pH showed alkaline trend during the study. Organic matter content was higher in Fort Cochin beach (Upto 3.63%) when compared to Dharmadam beach and showed wide seasonal fluctuations. Moisture content also showed seasonal fluctuations and Dharmadam beach showed more water holding capacity than Fort Cochin beach due to its fine sediment nature. The moisture content values were higher in Dharmadam beach, observed upto 9.86%. Sediment conductivity was found to be less. ANOVA of moisture content showed 5% significant

variation with station and month in Dharmadam beach. Sediment parameters showed wide variation in seasonal data due to the erosive and accretive nature of the coast. During October-November months, accretion of sand was common in Fort Cochin beach. In PCA analysis, sediment quality showed a climatic variation that was less affected by anthropogenic activities.

Chapter 6 - illustrates the macrofaunal groups from selected intertidal habitats. Amphipods (42%) and polychaetes (28%) were the major groups in Fort Cochin beach and tanaids (25%) and gastropods (21%) in Dharmadam beach. In station 1 *Amphilochus picadurus* (26no./m^2) were the most abundant amphipod and highest density of organisms was observed in August, 2009 (32no./m^2). In station 1 of Fort Cochin beach highest biomass was shown by bivalves (3.2g/m^2). In station 2 of Fort Cochin beach *Capitella capitata* (33no/m^2) were the most abundant polychaete species and highest biomass was shown by polychaetes (1.116g/m^2). Similar organisms observed from both the beaches were tanaids, mysids, mole crabs and bivalves. Epifaunal organisms were abundant in Station 2 in Dharmadam beach. Twenty five species were identified from Fort Cochin beach and thirty four species from Dharmadam beach. In station 1 of Dharmadam beach, tanaids (203no/m^2) were abundant that in station 2 *Littorina* species (161n0./m^2) were abundant. Highest biomass was showed by echinoderms in both the stations (10.29g/m^2 and 44.37% in station 1 and 2 respectively. In both the selected beaches, most of the macrofaunal organisms showed seasonal variations. In both the beaches mid tide zone was observed to be having higher diversity zone when compared to other zones. Biomass of macrofauna was higher in Dharmadam beach when compared to Fort Cochin beach. Diversity indices (Shannon Wiener index) showed low diversity values from both the beaches, when compared to Fort

Cochin beach, Dharmadam showed higher diversity values. Abundance of one or two species leads to low species evenness and richness in both the beaches. In both the beaches diversity, richness and evenness were found to be less. Cluster analysis (Bray Curtis with SIMPROF) displayed seasonal similarity of total faunal groups that were insignificant in Fort Cochin and Dharmadam beach. Best matching variables obtained for macrofauna were salinity, conductivity, nitrate and nitrite with hydrography and organic matter with sediment in Dharmadam beach. In Fort Cochin beach, dissolved oxygen, nitrate and nitrite were the best matching variables with hydrography and conductivity with sediment. Biotic indices were performed to know the ecological status of the selected beaches. BOPA (Benthic Opportunistic Polychaete Amphipod ratio) showed undisturbed and moderate polluted condition in two stations of Fort Cochin beach. In Dharmadam, it showed undisturbed condition. But the AMBI index showed slightly disturbed condition in Dharmadam beach. In Fort Cochin beach the AMBI showed same condition as in the case of BOPA index, moderately polluted condition in station 2 and unpolluted condition in station 1. Abundance biomass curve also performed and Dharmadam beach showed undisturbed condition in both stations. In Fort Cochin, it showed undisturbed and disturbed condition in station 1 and 2 respectively. Geometric class plots of both the beaches showed more than 7 abundance classes of species and depicted disturbed nature of the beaches.

Chapter 7- This chapter deals with the comparison of both sampling sites in account of their profile, floral characteristics, sediment nature, physical characters, pollution, anthropological activities and zonation pattern. The important morphological features have been disclosed in this section. Profile

showed gentle slope and flat nature in Fort Cochin and Dharmadam beach respectively. Based on tidal classification the entire coast is classified under microtidal region. The sediment composition was also different. Mical flakes were common in Dharmadam beach and quartz and feldspar were in Fort Cochin beach. Man made changes were more in Fort Cochin when compared to Dharmadam beach. Floral composition showed some similarity. Rail road vines and *Cauarina* sp. were common in both the beaches. ANOSIM (Analysis of Similarity) and SIMPER (Similarity Percentage) was computed to get the similarity between different factors with organisms, but none were showed similarity except *Nereis* species in 0.47m tidal height. Photographs of different ecological features of both the beaches were also included in this chapter.

Coastal zone regulation act (2011) of Ministry of Environment and Forests, Govt. of India, restricts all developmental activities and waste disposal within 500m of high tide zone of the intertidal region that comes under CRZ 1, the most ecologically sensitive zone. However gross violation has been observed in Fort Cochin beach but such violations were not evident in Dharmadam beach during the study, probably in future there is a potential threat from intense human interventions in that beach and adjoining areas. Therefore based on the study the following recommendations are put forth for effective management of the degrading littoral region of the south west coast of India.

- The study has established that the hydrologic regime combined with the environmental and biodiversity status of the Fort Cochin and Dharmadam regions are facing tremendous pressure from various human activities. So it is vital to protect these marine systems as

they regulate the possible climate change phenomenon and regulating the trophic structure of the coastal system.

- Necessary modifications need to be implemented by the regulatory bodies to include the littoral zones and other coastal zones under the Marine Protected Areas (MPA) in category 1 for overall protection and conservation of the region.
- The Fort Cochin beach and adjoining areas are severely impacted so it is proposed to have a "holiday period" to regulate the increasing various human activities (Fishing, mining and industrial), so that the ecosystem rejuvenates to its pristine condition.
- Dharmadam beach having different hydrological pattern as compared to Fort Cochin displayed normal hydrographical conditions with increased biodiversity trends. Population interactions were not very conducive in Fort Cochin as compared to Dharmadam region due to its disturbed nature, so specific community based interactions on various populations need to be initiated to evolve at the threat and vulnerability of these organisms. The threat from encroachment and human activities looms large in this beach area, so governmental and non-governmental organisations as well as local self-government agencies should see that the trophic character of the environment is maintained for the livelihood objectives of the region.
- The general trend observed was the degrading rocky regions as compared to sandy shores from intense developmental works. Many of the organisms collected during the study were from the rocky

regions and it is very important to have a blanket ban on destroying the rocky surface and its shores.

- The general awareness and ecological importance of the intertidal zones are to be given more thrust along with the concept of protection and conservation of our marine ecosystems.

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Annexure

Monthly abundance (no./m^2) of faunal groups in station 1 of Fort Cochin beach during 2009-2011

Months	Aug,09	Sep,09	Oct,09	Nov,09	Dec,09	Jan,10	Feb,10	Mar,10	Apr,10	May,10	Jun,10	Jul,10	Aug,10	Sep,10	Oct,10	Nov,10	Dec,10	Jan,11
Gastropods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	0	5	2	0	0	0	0	3	0	0	0	0	3	0	0	0	3	3
Polychaetes	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mole crabs	0	0	0	0	0	7	0	1	0	0	0	0	0	0	0	0	0	0
Shore Crabs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipods	32	0	0	27	0	3	0	9	3	6	5	2	2	3	0	0	0	0
Isopods	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	2	3	1
Mysids	4	0	0	0	2	2	0	0	0	0	0	0	2	0	0	0	3	5
Tanaids	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Monthly abundance (no./m^2) of faunal groups in station 2 of Fort Cochin beach during 2009-2011

Months	Aug,09	Sep,09	Oct,09	Nov,09	Dec,09	Jan,10	Feb,10	Mar,10	Apr,10	May,10	Jun,10	Jul,10	Aug,10	Sep,10	Oct,10	Nov,10	Dec,10	Jan,11
Gastropods	0	0	0	0	0	0	0		0	0		0	0	0	0	0	0	0
Bivalves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaetes	5	3	8	10	14	2	0	18	0	2	5	0	18	0	0	0	7	8
Oligochaetes	3	2	0	2	0	0	5	0	0	0	0	0	0	0	0	0	2	6
Mole crabs	5	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0
Shore Crabs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipods	3	5	0	29	5	0	0	0	0	0	0	0	7	0	0	0	0	0
Isopods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mysids	0	0	0	0	2	2	5	8	0	0	0	2	0	0	0	0	1	1
Tanaids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Monthly abundance (no./m^2) of faunal groups in station 1 of Dharmadam beach during 2009-2011

Months	Aug,09	Sep,09	Oct,09	Nov,09	Dec,09	Jan,10	Feb,10	Mar,10	Apr,10	May,10	Jun,10	Jul,10	Aug,10	Sep,10	Oct,10	Nov,10	Dec,10	Jan,11
Gastropods	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalves	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Polychaetes	7	8	10	8	4	3	5	4	1	5	0	7	0	0	0	0	0	0
Mole crabs	0	0	0	0	0	0	0	0	11	0	0	0	0	8	0	0	0	0
Shore Crabs	10	5	2	0	0	5	1	0	1	1	1	0	1	0	0	0	1	0
Amphipods	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	4	0
Isopods	12	0	11	2	10	5	0	0	2	0	0	1	0	0	0	0	2	0
Mysids	8	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Tanaids	0	13	62	20	10	11	27	12	11	10	3	2	10	2	0	0	10	0
Echinoderms	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0

Monthly abundance (no./m^2) of faunal groups in station 2 of Dharmadam beach during 2009-2011

Months	Aug,09	Sep,09	Oct,09	Nov,09	Dec,09	Jan,10	Feb,10	Mar,10	Apr,10	May,10	Jun,10	Jul,10	Aug,10	Sep,10	Oct,10	Nov,10	Dec,10	Jan,11
Gastropods	41	21	38	16	28	8	20	8	6	6	8	2	5	3	0	0	8	7
Bivalves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaetes	2	2	7	0	54	4	10	8	2	3	0	0	2	0	0	2	0	0
Mole crabs	0	3	0	0	36	0	0	60	0	0	0	0	0	0	0	0	0	0
Shore Crabs	2	0	8	0	1	1	15	5	0	0	2	0	0	1	0	0	1	0
Amphipods	0	0	0	0	48	20	0	0	0	0	0	0	0	0	0	0	0	0
Isopods	3	2	1	0	0	1	0	0	0	0	5	0	0	4	0	0	0	0
Mysids	4	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	1
Tanaids	0	5	2	5	8	5	26	4	0	0	0	0	0	0	0	0	7	0
Echinoderms	2	2	0	0	0	0	0	0	2	0	0	0	2	1	0	0	3	0

Seasonal abundance (no./m^2) of faunal groups in station 1 of Fort Cochin beach during 2009-2011

	Monsoon 1	**Post monsoon 1**	**Pre monsoon1**	**Monsoon 2**	**Post monsoon 2**
Bivalves	5	2	3	3	6
Polychaetes	1	0	0	0	0
Oligochaetes	0	0	0	0	0
Mole crabs	0	7	1	0	0
Amphipods	32	30	18	12	0
Ispopods	0	2	2	0	6
Mysids	4	4	0	2	5
Tanaids	2	1	0	0	0

Seasonal abundance (no./m^2) of faunal groups in station 2 of Fort Cochin beach during 2009-2011

	Monsoon 1	**Post monsoon 1**	**Pre monsoon 1**	**Monsoon 2**	**Post monsoon 2**
Bivalves	0	0	0	0	0
Polychaetes	8	34	20	23	15
Oligochaetes	5	2	5	0	8
Mole crabs	5	2	0	1	0
Amphipods	8	34	0	7	0
Ispopods	0	0	0	0	0
Mysids	0	4	13	2	1

Seasonal abundance (no./m^2) of faunal groups in station 1 of Dharmadam beach during 2009-2011

	Monsoon 1	Post monsoon 1	Pre monsoon 1	Monsoon 2	Post monsoon 2
Gastropods	0	4	0	0	0
Bivalves	0	0	1	0	0
Polychaetes	15	25	15	7	0
Mole crabs	0	0	11	8	0
Shore Crabs	15	7	3	2	1
Hermit crabs	0	0	0	0	0
Amphipods	0	0	8	0	4
Ispopods	12	28	2	1	2
Mysids	8	0	4	0	0
Tanaids	13	103	60	17	10
Echinoderms	0	2	2	0	0

Seasonal abundance (no./m^2)of faunal groups in station 2 of Dharmadam beach during 2009-2011

	Monsoon 1	Post monsoon 1	Pre monsoon 1	Monsoon 2	Post monsoon 2
Gastropods	42	60	25	8	3
Bivalves	0	0	0	0	0
Polychaetes	4	65	23	2	2
Mole crabs	3	36	60	0	0
Shore Crabs	2	10	20	3	1
Hermit crabs	20	12	11	13	9
Amphipods	0	68	0	0	0
Ispopods	5	2	0	9	0
Mysids	4	11	0	0	1
Tanaids	5	20	30	0	7

Long shore current (m/s) of Fort Cochin beach during 2009-2011

	Monsoon 1	**Post monsoon 1**	**Pre monsoon**	**Monsoon 2**	**Post monsoon 2**
Long shore current	0.025	0.031	0.029	0.034	0.038

Long shore current (m/s) of Dharmadam beach during 2009-2011

	Monsoon 1	**Post monsoon 1**	**Pre monsoon**	**Monsoon 2**	**Post monsoon 2**
Long shore current	0.023	0.03	0.029	0.031	0.034

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