Physico-Chemical Characteristics, Zooplankton Diversity And Fish Biodiversity Of Kakinada Bay And Coringa Mangrove Ecosystem, Andhra Pradesh, India

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Abstract
The present study investigated the water quality parameters, zooplankton diversity, and fish biodiversity of the Gautami Godavari estuarine system and mangrove ecosystems of the Kakinada Bay and Coringa Wildlife Sanctuary region, Andhra Pradesh, India. Monthly sampling was conducted from July 2013 to June 2014 at six selected stations namely Kakinada Bay, Chollangi, Matlapalem, Ramanapalem, Coringa, and Bhairavapalem. Important physico-chemical parameters such as temperature, pH, dissolved oxygen, salinity, alkalinity, carbon dioxide, and hardness were analyzed using standard methods. Zooplankton samples were collected using plankton nets and fish diversity was assessed from fishermen catches and field collections.

The study revealed considerable seasonal and spatial variations in water quality characteristics under the influence of tidal fluctuations and monsoonal freshwater influx. Temperature varied from 26°C to 36°C, while pH remained slightly alkaline throughout the study period. Dissolved oxygen showed marked fluctuations with comparatively lower values during summer months. Salinity exhibited significant seasonal changes due to freshwater discharge during monsoon and marine water intrusion during dry periods. Higher alkalinity and hardness values were observed in Kakinada Bay owing to tidal influence and dissolved mineral content.

Zooplankton diversity was dominated by copepods followed by decapod larvae, chaetognaths, gastropod veligers, polychaete larvae, bivalve veligers, appendicularians, ostracods, and cladocerans. Seasonal abundance indicated that mangrove ecosystems provide highly productive nursery grounds supporting rich planktonic populations. Fish biodiversity analysis recorded 31 species belonging to 26 genera, 16 families, and 7 orders. Perciformes formed the dominant group followed by Cypriniformes and Clupeiformes. Commercially important fishes such as Mugil cephalus, Sardinella longiceps, Glossogobius giuris, and Oreochromis mossambicus were commonly observed.

The present investigation highlights the ecological significance of the Kakinada Bay and Coringa mangrove ecosystems in maintaining estuarine productivity, fishery resources, and biodiversity conservation. The study also provides baseline scientific information for future environmental monitoring, conservation planning, and sustainable management of the Godavari estuarine ecosystem.

Keywords: Kakinada Bay; Coringa Mangroves; Gautami Godavari Estuary; Water Quality; Zooplankton; Fish Biodiversity; Physico-Chemical Parameters; Mangrove Ecosystem; Estuarine Ecology; Coastal Biodiversity.

Interdiction

The Coastal habitats in India mainly include Mangroves, lagoons and Estuaries, besides, brackish waters and associated ecosystem like mudflats. The Mangroves, wetlands, lagoons sea grass beds, coral reefs and shallow bays are nursery or feeding grounds for most of the coastal and oceanic species. The zones are the highest biological diversity as compared with any part of the sea. These diverse coastal ecosystem on the coastal and waters not only highly productive but are put under tremendous pressure due to increasing urbanization, economic activities and other strategic installations setup in and around close proximity to coastline. Estuarine and coastal zones comprise only 8% of ocean surface but account for about 14% of ocean production [IGBP 1994].not only do these ecosystem support a huge variety of life, many also serve as nurseries for much of the biodiversity of the entire oceanic system. These ecosystems also help protect coastal land from erosion due to storm surges and other large waves such as tsunamis.

Mangroves

Mangroves are the tidal forests of coastal wetlands, existing in the interstellar zones tidal creeks, backwaters, lagoons marshes and mudflats of the tropical and sub – tropical region of the world. Mangrove forests develop only in shallow water and inter- tidal areas and are thus strongly influenced by tides. Full development of mangroves forests is thus found

in areas of high rainfall or in areas where. Rivers furnish enough fresh water to preclude the development of hyper saline conditions. Tidal range is also an important factor wherever the tidal rang is small inter tidal zone is restricted and formation of mangrove forests is also restricted. The most extensive forests are developed on shores that have a substantial vertical tide range [Nybakken, 1988] FAO 2003.
The origin of the name mangroves is not certain. It could be a combination of the portage use “mange”, meaning an individual mangrove tree, with the English “grove”, although early versions were “mangrove” and “mangrave”. It may have been derived from the Malay “manggi-manggi” or “mangin” kathirsan.k and Bihgham, B.L. [2001]. The shorter oxford dictionary describes the word as obscurely connected with the Portuguese word “mange” and the Spanish word “mangle” and the English word and it dates its origin as 1613. Martha vannucci in her book “The mangrove and us” points out that the word is neither Portuguese nor Spanish and after an exhaustive search, she concludes that the word “mange” derives from the national language of Senegal. She comments that it was probably adopted by the portuguse, and later modified by Spanish as a result of exploration of the coast of West Africa.

Mangrove forests are extremely productive ecosystems that provide numerous good and services both to the marine environment and people, these goods and services are conservatively estimated to be worth US $ 186 million each year. Mangrove forests are home to a large variety of fish, crab, shrimp, and mollusk species. These fisheries from an essential source of food for thousands of coastal communities around the world. The forests also serve as nurseries for many fish species, including coral reef fish. A study on the Mesoamerican reef for example, showed that there are as many as 25 times more fish of some species on reefs close to mangrove areas than in areas where mangroves have been cut down. This makes mangrove forest vitally important to coral reef and commercial fisheries as well. Mangroves stabilize the coastline and prevent erosion from waves and storms. Mangroves wood is resistant to rot and insects, making it extremely valuable. Many coastal and indigenous communities rely on this wood for construction material as well as for fuel. These communities also collect medicinal plants from mangroves ecosystems and use mangrove leaves as animal fodder. Recently, the mangrove forests have also been commercially harvested for pulp, wood chip, and charcoal production.

Mangrove forests play a central role in transferring organic matter and energy from the land to marine ecosystems. This matter and energy comes from detritus from fallen leaves and branches, and forms the base of important marine food chains. Mangroves and mangrove habitats contribute significantly to the global carbon cycle. Mangroves generally grow better in wet equatorial climates than they do in seasonally monsoonal or arid climates and the amount of litter they produce is negatively correlated with latitude. Global estimates of annual mangrove litter fell ranges from 130 to 1870 gaga metrion^{-2}kathiresn [2001]. Generally the litter fall is heaviest in dry summer months when thinning of the canopy reduces transpiration, and in the wet rainy season when fresh water in put increases the nutrient supplies [Roy, 1997; Wafer teal, 1997]. Bacteria break down the detritus, releasing useful nutrients into the water that can then be used by marine animals.

Mangroves are physiologically tolerant of high salt levels and have mechanisms to obtain fresh water despite the strong osmotic potential of the sediments [Ball, 1996]. Mangroves forests consist of diverse, salt – tolerant tree and other plant species, ranging from small shrubs to tall trees tens of meters high. The forests are found between 32 degrees north and 38 degrees south of the equator, in sheltered, inter – tidal areas that receive a high annual rainfall. The word’s total mangroves span over 30 countries with a total area of 99,300sq.km [FAO 2003]. Although a wide variety of plant species are found in mangrove forests, only some 54 species belonging to 16 families are recognized as “true mangroves” species that are rarely found outside mangrove habitats. The most expensive area of mangroves is found in Asia, followed by Africa and South America. The mangrove are as in India are generally categorized as deltaic, estuarine, backwater, sheltered and insular bay. The total area of mangroves in India is estimated at 6740sq.km. This covers about 7% of the world’s mangroves.

Total area covered in sundarbans is the largest mangrove forest in India with an estimated area of around 4,250 sq.km [MOEF, 2002] [FAO 2003]. The mangroves comprise 69 species under 26 genera in 20 families [Duke 1992]. Of this 20 are either rare or endemic. The deltaic environs of east coast of India support extensive mangrove forests as a result of a general intertidal slope and heavy siltation. Totally 1854 species of flora and fauna have been reported from the mangrove environs; of which, 412 are floral species, and 1442 are faunal species, contributing 23% and 77% respectively [MOEF, 2002].

Godavari Mangroves
In Andhra Pradesh the Godavari wet lands of 33,263 ha are located in the coastal plains of deltaic regions and are located in the coastal plains of deltaic regions and are located between $16^{0}30$’-$17^{0}00$’ N and $82^{0}10$’-$82^{0}23$’ E in the East Godavari District [Haddon- Guebas. et al. 2006]. The Godavari River, with a drainage basin of about 312,812km^{2}, is the second largest river system in India after the Ganges. The river originates at an elevation of 1067m about 75km inland from the west coast of India and flows in a general eastwards direction across the country, over a length of 1465km before joining the Bay of Bengal (Nageswararao, et al, 2003). The Godavari has a mean annual discharge of 11.1×10^{14} (Revtet a., 2004), of which 93-96% occurs during the wet Monsoon season, and is listed as one of the largest POC (Particulate organic

carbon) transporting rivers in the world. The Godavari estuarine system extending over approximately 316km^2 has significant annual variation of salinity due to seasonal flooding, which is mainly monsoon, fed (Chandra Mohan et al 1997).

The Godavari has two active distributaries the Gautami and Vasishta. The total average discharge of 96.5 km^3 yr^{-1}, about 64.6 km^3 yr^{-1} (67%) was through Gauthami distributary, while 31.9km^3 yr^{-1} (33%) flowed through Vasishta branch (Nageswarrao et al 2003). The Gautami Godavari opens into the Bay, the largest and most important being Coringa (total length of 26 km) and Gaderu (total length 11 km) (Bouillon et al 2002). The area between the river and Bay is dominated by the extensive Mangrove forests and tidal mudflats. A major part of the Godavari Mangroves is separated from the Bay of Bengal by Kakinada Bay. Two major shifts in the main course of the Godavari River and the formation of sand spin have occurred since the construction of the cotton Barrage at Dowleswaram flowed northwards, opening into Kakinada Bay. Between the 1930s and the 1970s the Godavari River flows eastwards (Dahdouh-Guebas et al. 2006). The density of Mangrove cover is more on the northern side (Coringa wild Life Sanctuary) of the Godavari River than on the southern side. This may be due to the fact that the northern area receive fresh water for a prolonged from agricultural runoff. The agriculture runoff through the creeks of Coringa and Gaderu canals brings dissolved nutrients to the Mangroves. The area between Gautami Godavari and Kakinada Bay has dense vegetation of mangrove forests and mudflatswhich are an extension of Coringa Wildlife Sanctuary. The shallow Kakinada Bay (area=150km2) opens into the sea on its northern side and is bordered along most of its eastern stretch by an arrow sand bar. Tides are semi diurnal and tidal amplitude in the Bay varies between 2.3 and 4.5 m, but in the Mangrove covered area the tidal amplitude is comparatively low (Sreenivas 1998). The shoreline fringing the Gautami lobe is characterized by the growth of a number of spits. The most prominent among the shore parallel, narrow, elongated sand spits is the 2km-long spit, known as Kakinada spit. The spit stretches northward there by enclosing the Kakinada Bay. The Godavari Mangroves occupy an area of about 33,263 ha in the deltaic region of the Godavari River, which includes large areas of water bodies. The digital data (2001) shows that dense Mangroves occupy 16,406 ha, degraded Mangroves occupy 3355 ha; mudflats and water bodies cover the rest at the area (Ramasubramaniam et al 2006). The Coringa Reserve Forest Block, declared as a Wild Life Sanctuary in 1978, occupies nearly 60% of the Godavari Mangroves.

An estuary is a semi-enclosed coastal body shallow mixing zone of fresh and salt water creates a unique nutrient – rich environment for plankton, small fish and shell fish. The productivity and variety of estuarine habitats foster a wonderful abundance and diversity of wildlife. Shore birds, fish, crabs lobsters, marine mammals, clams and other shellfish, marine worms, sea birds and reptiles are just some of the animals that make their homes in and around estuaries. These animals are linked to one another and to an assortment of specialized plants and microscopic organisms through complex food webs and other interactions. Many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn, giving them the nickname “Nurseries of the sea”. Hundreds of marine organisms, including most commercially valuable fish species, depend on estuaries at some point during their development.

Food web

Communities within estuaries are linked by overlapping food chains as energy flows from primary producers to consumers (food web0. Many producers are first converted by bacterial decomposition into organic detritus, which serves as a major food source for the majority of consumers living in the estuarine community. An important group of primary consumers living in estuaries are zooplankton and animals that feed on plankton and these are the most abundant species of vertebrates in estuaries because of the large supply of food available to them. The carnivores (predators) occupy the highest level obtaining energy by eating animals that feed on plankton and detritus. Predators are important to the estuary because of their end position in mast consumer food chains. Part-time and full-time residents feed there. Many migrating animals stop over for refuge and food in the estuary thus exporting the energy to the other environment. One aspect of the estuary food web is that there are more different species of consumers’ than species of primary producers. A few provide nutritional need to many. Thus the usual tropic pyramid is inverted because most carnivorous species are at the top of the food web.

Plankton

As early as 1828 J.V. Thompson operated a two net and described the zoea larva of the crab. In 1833 he described the life history of the barnacle, solving an age-old puzzle. The word plankton coined by Hansen in 1887 was more precisely defined by Haeckel in 1890. The plankton community consists of organisms ranging from minute plants, 1/10,000 of an inch long to the large jelly-fish three feet in diameter. The two other communities of marine organisms are the nekton and the benthos. The existence of plankton was known vaguely for a long time. But by towing fine-meshed plankton net Muller collected plankton for the first time in 1845. Muller’s work attracted a lot of interest in plankton studies. This sudden surge of interest in marine organisms led to the famous voyage of H.M.S. Challenger in 1782 under the leadership of Sir John Murray. The Challenger navigated round the world for three and a half years, and returned with a rich. Since then many expeditions explored the seas. Special mention should be made of the plankton. The first exploration of the seas around India was made by the I.N.S. investigatory. Though many oceanographic expeditions traversed the Indian ocean’ nothing notable was done until the John Murray Expedition explored the Arabian Sea and published its scientific results. The recent International Indian Ocean Expedition studied the plankton with a view to assessing organic production. This expedition gave birth to a small research establishment at Cochin known as ocean Biological sorting center. Here plankton samples collected by several research vessels were sorted out and sent to experts all over the World, including India. Later this institution developed into the National Institute of Oceanography with headquarters at Goa, India. The well-equipped research vessels belonging to the Institute are engaged in the exploration of the seas around India.

The Indian Universities located along the sea coast, namely, Madras, Bombay, Andhra, Kerala and Cochin have done valuable work on the plankton of the respective regions. With the founding of the marine Biological Association of India marine biological research gathered momentum. A large number of studies on the plankton of the Indian Ocean got published recently in the Association's journal. It is generally accepted that the overall plankton production is richer in higher latitudes than on lower latitudes. But it should be pointed out that because of the seasons in the tropics; plankton production goes on uninterrupted in tropical waters. As the euphotic zone in over latitudes is deeper, organic production can take place over wider area. Because of the uniformly high temperature, growth of organisms in tropical waters is rapid, and life-span comparatively short Decay of dead organisms is also rapid, and this helps in the speedy recycling of nutrients. Tropical animals generally produce several broods in the course of a year, whereas in higher latitudes reproduction is restricted to a short period. Since the euphotic zone is comparatively shallow there is greater concentration of organisms in higher latitudes. Consequently in impetrate waters there are spectacular outbursts of plankton the like of which are not found in the tropic except in areas of very pronounced upwelling. Nevertheless, the overall organic production on different latitudes is not likely to be appreciably different.

Hydrological study

Water resources are of critical importance to both natural ecosystem and human development. The healthy aquatic ecosystem is depended on the physico-chemical and biological characteristics. The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem. To asses that monitoring of these parameters is essential to identify magnitude and source of any pollution load. These characteristics can identify certain condition for the ecology of living organisms and suggest appropriate conservation and management strategies. In order to assess water quality index we have carried out the physicochemical analysis of water Resources. The aim of the study is too reveled out the pollution status of River in terms of physico-chemical characteristics of water. However, very little information is available in relation to physico-chemical characteristics of water in the Gauthami-Godavari Esturies, East Godavari District, and Andhra Pradesh. Hence, the preset study was conducted to study the physico-chemical properties of water in the Gauthami-Godavari Estuaries, Ckoringa Mangroves area, East Godavari District for a period of one year from 1stJanuary 2013 to 31st December 2013.

Study Area

The present study on Plankton and Fish species diversity and commercial fish landing was taken up in the vicinity of Gautami Godavari estuarine system. The Godavari is the second longest river in India with a length of 1,465 km. it originates near Nasik (22000' N & 730 48' E) in Western Ghats located in Maharashtra state and it has 16 major tributaries. The length of river in Andhra Pradesh is 770 km; the river mouth is located on the east coast near Kakinada in the East Godavari District. The drainage area of Godavari is about 312812 km sq. and normal run of river is estimated to be around 4, 60,316 million cubic feet. The catchment area of Godavari is 1, 33,000 km sq. km and deltaic area is about 8,200 sq km (Blasco and Aizpuru, 2002), before opening in to the Bay of Bengal, river Godavari divides into two major distributaries viz. Gauthami-Godavari and Vasishta-Godavari at Dowleswaram near Rajahmundry which is about 63 km from the Bay. Gauthami Godavari to the east and Vasishta Godavari to the South between these two branches lays the Godavari delta. Vasishta Godavari again divides at Gannavaram into two branches, Vasishta Godavari proper to the West and the Vainateya Godavari to the East. The former opening in to the Bay of Bengal at Anthervedi about 25.5 km northeast to this point. Vainateya opens into Bay of Bengal near Odalarevu Gauthami Godavari over a period of century changed its main river course further south and earlier deltaic wetlands developed into Mangrove mud flats.

The deltaic wetlands of Gautami Godavari estuarine system have many channels and creeks cris-crossing though mudflats had developed Mangrove vegetation exihibiting salt-water tolerance. Mangrove forests situated in the estuary or deltaic wetlands of river Gautami Godavari consists of coring, Kandi-kuppa, Balusuthippa, Matlapalem, Ratikalava, Magasanithippa and Kothapalem reserve forests covering an areas of 31,747 ha (Andhra Pradesh Forest Department working circle, 1974). Based on the functional classification of Mangrove (Lugo & Snedaker, 1974) they may be described as a mixture of riverine (Gaderu & Coringa), Fringe (Hope Island & South-Western Bay), and basins (towards the Island side) types. Towards the Southern side of the Kakinada Bay dense Mangrove vegetation with extensive mudflats are encountered wchich lie between 82012'-82021' E and 16031'-16054 N extending an area of over 312 sq. km (Benerjee et al, 1998).

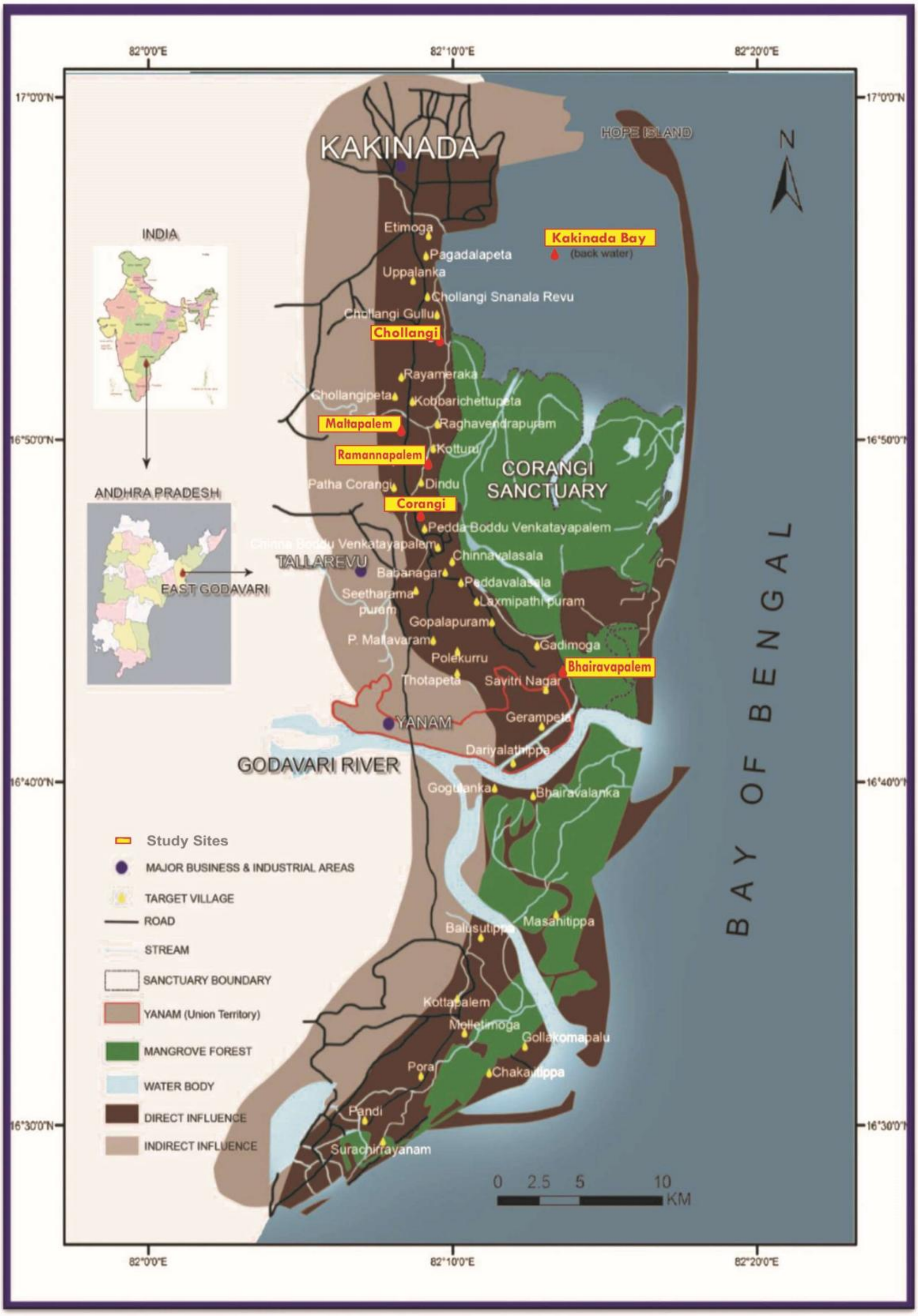

Fig. 1: Map representing study areas and sampling locations (Modified from source, Sabita Parida, EGREE, Report)

The two important distributaries the Gaderu and Coringa open into the Kakinada Bay on its Southern side. Three smaller creeks of which Chollangi and Matlapalem open into the Kakinada Bay on the Southern side and third third one pillavarava opens into the Bay its Southeast side. The Gautami River at Bhairavapalem villege, leads to Gaderu channel, which runs to a length of 14 km and finally opens into the Kakinada Bay. Similary the Coringa originates near Neelapalli (Yanam) and run aeross the agricultural lands and finally meets the Kakinada Bay after traveling a distance of 21 km Both the Coringa and gaderu rivers have dense Mangrove vegetation associated mudflats and smaller creeks, which open into the Kakinada Bay on the southern side. The back waters of Kakinada extend from Kakinada town in the south to the Gautami Godavari in the South, bordering the kakinada Bay on the East and covering an area of about 330 sq. km. a network of tidal creeks, which are directly or indirectly connected to the Kakinada Bay, traverses the entire large ones like coring and Gaderu, which can be up to six meters deep. The creeks show influence of salt water from the Kakinada Bay and Bay of Bengal from November onwards markedly high gradients in salinity, temperature and nutrient contents of the water. The bed of all the creeks and rivers in this area is muddy and very rich in the detritus and bottom fauna. All these creeks, channels and distributary are bordered with Mangroves. During annual flooding of the river Godavari coincides with monsoon (July-October) these distributaries and creeks get flooded with fresh water discharge earring lot of silt, which contain heavy loads of nutrients and minerals originating in the in the hinterland and finally heavy loads of nutrients and minerals originating in the hinterland and brackish water areas along the coast act as nursery grounds for a large number of marine organisms including the commercially important fin fishes and shell fishes (FAO 2003).

Materials and Methods

Water, plankton and fish samples were collected monthly between July 2012 – June 2013 from six stations of coring wild life sanctuary area 1. Kakinada Bay 2.Chollangi 3.Matlapalem
4. Ramanapallem 5. Koringa and 6.Bhairavapallem.

Water Samples for the Determination of Physico-chemical properties

Parameters were ply key role in the development and growth of the Aquatic organic forms. For the determination of physic chemical properties of the water one litter of surface water was collected from each of the three stations. Sampling was usually done in the morning.Standard methods of for analysis were used. Temperature was measured with a mercury Thermometer and PH was pH-meter, Dissolved oxygen samples were collected in BOD bottles and analyzed by a modified Winkler method[Welch, 1948] and Salinity was estimated by Mohr's method were used to determine Alkanity, Hardness (with EDTA) and $CO_2$was titration (NAOH).

Sampling of Plankton

Monthly surface zooplankton samples were made out at the selected six stations in the coring wild life sanctuary area. Surface zooplankton samples were collected by employing a 120 m mesh sized net of 40 cm diameter. As soon as the net was hauled the contents in the cod end collector of the net were gently transferred in to a clean polyethylene container and fixed with 5% formaldehyde solution. In the laboratory biomass was measured by the displacement method (WICKSTEAD, 1965). For the enumeration of Zooplankton aliquot method was employed (Wickstead, 1965), where the total sampled was sub sampled and 10 ml. aliquot, was taken in to a Petridis provided with a grid, and the major groups of zooplankton were enumerated according to the illustrations given by Wickstead (1965). Prior to the sub sampling larger forms like Hydromedusae, Siphonophores were separated from the sample and counted separately.

Fish sampling

Fish samples were collected from the catch of fishermen from all six stations. Samples were preserved in 10% Formalin. The samples were identified by reference to Day (1878). As soon as the fish were brought to the laboratory the measurements were taken. The total length, standard length, height and weight of the fish.

Total length: The length from the up of the snout to the end of the dorsal fluke of the caudal fin.
Standard length: The length from the tip of the snout to the end of the silvery area on the caudal peduncle.

The length of the each fish was measured to the nearest millimeter morphometric characters and meristic characters are given in the plate. The fishes were subsequently wiped and dried between folds of filter paper and weighted to the nearest gram on the platform balance after taking body measurements. The guts were carefully removed and preserved in 5% formalin. Later the stomach was slit open and the contents were washed into a Petridis and this material was then transferred into the measuring jar to measure the volumes of the gut contents. These measurements were made by settling method.

In the settling method the stomach contents should be taken in a measuring jar along with formalin. The jar should be kept aside 10 to 12 hour without any disturbance to enable the contents to settle at the bottom. Then the volume of the gut contents was noted for that particular fish. After taking the gut volumes the material was examined under the binocular microscope. Numerical counts were made of the different groups encountered their percentage of occurrence was calculated.

Results

Temperature

Recorded temperature during the study period ranged from high tides 27^0C to 36ºC in the month of May, July and low tides 26^0C to 36^0C in the month of May and March at Kakinada and from high tides 26^0C to 33^0C in the month of May, July and low tides 27^0C to 35^0C in the month of May and June at Chollangi and from high tides 27^0C to 34^0C in the month of May, July and March and low tides 29^0C to 35^0C in the month of May, July and March at Matlapalem. From high tides

28^{0}C to 34^{0}C in the month of May, March and low tides 29^{0}C to 35^{0}Cin the month of May and March at Ramanapallem. From high tides 27^{0}C to 33^{0}C in the month of May, July and March and low tides 28^{0}C to 34^{0}C in the month of February, July and March at koringa. From high tides 28^{0}C to 34^{0}C in the month of May, August, September, October, November, April and June and low tides 27^{0}C to 35^{0}C in the month of May, July and March at Bhairavapallam. From selected six stations the high tides maximum temperature was reached 36^{0}C at Kakinada and the minimum temperature was reached in 26^{0}C at Chollangi. Low tides maximum temperature was reached 36^{0}C at Kakinada and the minimum temperature was reached in 26^{0}C at Kakinada.

pH

Kakinada high tides the minimum value of pH 8 in the month of August, October, November, April and June and maximum value 8.71 in the month of Julyand low tides minimum value of pH 8 in the month of August, October, November, April and Marchand maximum value 8.79 in the month of July, March. At Chollangihigh tides the minimum value of pH 7.1 in the month of February and maximum value 8.3 in the month of August, October and Apriland low tides minimum value of pH 7.4 in the month of July, March and maximum value 8.2 in the month of January. At Matlapallem high tides the minimum value of pH 7 in the month of November, June and maximum value 8.1 in the month of July, November, March and May and low tides minimum value of pH 7.5 in the month of November, June and maximum value 8 in the month of July. At Ramanapallem high tides the minimum value of pH 7.2 in the month of June and maximum value 8.1 in the month of March, May and low tides minimum value of pH 7 in the month of November, June and maximum value 8.1 in the month of March. At Corangi high tides the minimum value of pH 7.4 in the month of Januaryy and maximum value 8.2 in the month of August, February and May and low tides minimum value of pH 7.2 in the month of November, December and May and maximum value 8 in the month of July, September, February, March and May . At Bhairavapallem high tides the minimum value of pH7.8 in the month of October, June and maximum value 8.69 in the month of April and low tides minimum value of pH 8 in the month of September, October, June and maximum value 8.4 in the month of July, December and March. The high tides maximum pH was 8.71 at Kakinada and the minimum pH was 7 at Matlapalem. Low tides maximum pH was 8.79 at Kakinada and the minimum pH was 7 at Ramanapalam. The pH value was affected by temperature, salinity and alkalinit.

Table 1. Comparative Analysis of Physico-Chemical Parameters among Six Sampling Stations.

Physico-Chemical Parameter	Kakinada Bay	Chollangi	Matlapalem	Ramanapalem	Coringa	Bhairavapalem
Temperature (°C)	26-36	26-35	27-35	28-35	27-34	27-35
pH	8.0-8.79	7.1-8.3	7.0-8.1	7.0-8.1	7.2-8.2	7.8-8.69
Dissolved Oxygen (mg L^{-1})	2.3-9.0	1.9-9.8	1.6-8.1	1.4-6.3	1.5-7.2	1.8-8.2
Salinity (%)	2.5-36.8	0.0-4.1	0.0-1.6	0.0-4.2	0.0-2.7	0.17-24
Alkalinity (mg L^{-1})	104-225	45-116	30-125	40-135	80-146	50-165
Carbon Dioxide (mg L^{-1})	0.89-1.99	0.99-5.99	0.99-5.99	0.99-5.99	0.99-5.99	0.89-3.99
Hardness (mg L^{-1})	350-6600	140-460	98-270	120-560	120-350	198-1760

Dissolved Oxygen

The concentration ofdissolve oxygen ranges between high tides 9 -2.4 mg L^{-1} in the month of June and March and low tides ranges between 8.5 – 2.3 mg L^{-1} respectively in the month of June and July, March at Kakinada. Maximum 9.8 mg L^{-1} was observed November, December, May and June and minimum 2 mg L^{-1} was recorded during July and March and low tides ranges between 9.8 – 1.9 mg L^{-1} respectively in the month of May, June and June at Chollangi. At Matlapallem high tides maximum content of dissolve oxygen was 8.1 mg L^{-1} in December, May and minimum 1.6 mg L^{-1} was in month of May and low tides ranges between 7.8– 1.8 mg L^{-1} respectively in the month of December, May and March. At Ramanapallem high tides maximum content of dissolve oxygen was 6.3 mg L^{-1} in December, May and minimum 1.6 mg L^{-1} was in month of February and May and low tides ranges between 5.2 – 1.4 mg L^{-1} respectively in the month of August, October, November, December and March. At Corangi high tides maximum content of dissolve oxygen was 7.2 mg L^{-1} in February and minimum 1.5 mg L^{-1} was in month of May and low tides ranges between 6.5 – 1.6 mg L^{-1} respectively in the month of November, May and March. At Bhairavapallem high tides maximum content of dissolve oxygen was 8.2 mg L^{-1} in December, May and minimum 2 mg $L^{-1}$was in month of May and low tides ranges between 7.9 – 1.8 mg L^{-1} respectively in the month of December, May and March. However high tides maximum dissolved oxygen was 9.8 mg L^{-1} at Chollangi and minimum 1.5 mg L^{-1} at Corangi and low tides maximum dissolved oxygen was 9.8 mg L^{-1} at Chollangi and minimum 1.4 mg L^{-1} at Ramanapallam during present study.

Salinity

Salinity was variable throughout present study period. High tides the minimum salinity of 36.8% was observed in

September, and a maximum salinity of 2.7% were observed in February and low tides the minimum salinity of 35.6% was observed in September, and a maximum salinity of 2.5% were observed in February at Kakinada. High tide minimum salinity of 4.1% was observed in December and a maximum salinity of 0.6% was observed in August, October and April low tides the minimum salinity of 3.82% was observed in October and June a maximum salinity of 0.0% were observed in August, November and April at Chollangi. High tides the minimum salinity of 1.6% was observed in November, June and a maximum salinity of 0.24‰ were observed in September and low tides the minimum salinity of 1.3% was observed in December and a maximum salinity of 0.0% were observed in August, October, February and April at Matlapalem. High tides the minimum salinity of 4.2% was observed in December and a maximum salinity of 0.2% were observed in July and low tides the minimum salinity of 4.1% was observed in December and a maximum salinity of 0.0% were observed in August, October, February and April at Ramanapallem. High tides the minimum salinity of 2.7% was observed in December and a maximum salinity of 0.13% were observed in September and low tides the minimum salinity of 2.3% was observed in December and a maximum salinity of 0.0% were observed in August, October, February and April at Corangi. High tides the minimum salinity of 24% was observed in January and a maximum salinity of 0.17% were observed in September and low tides the minimum salinity of 22% was observed in January and a maximum salinity of 0.28% were observed in September at Bhairavapallem. However high tides maximum Salinity was 36.8%at Kakinada and minimum 0.13% at Corangi low tides maximum Salinity was 35.3% at Kakinada and minimum 0.0% at Chollangi, Matlapalem, Ramanapalem and Corangi during present study.

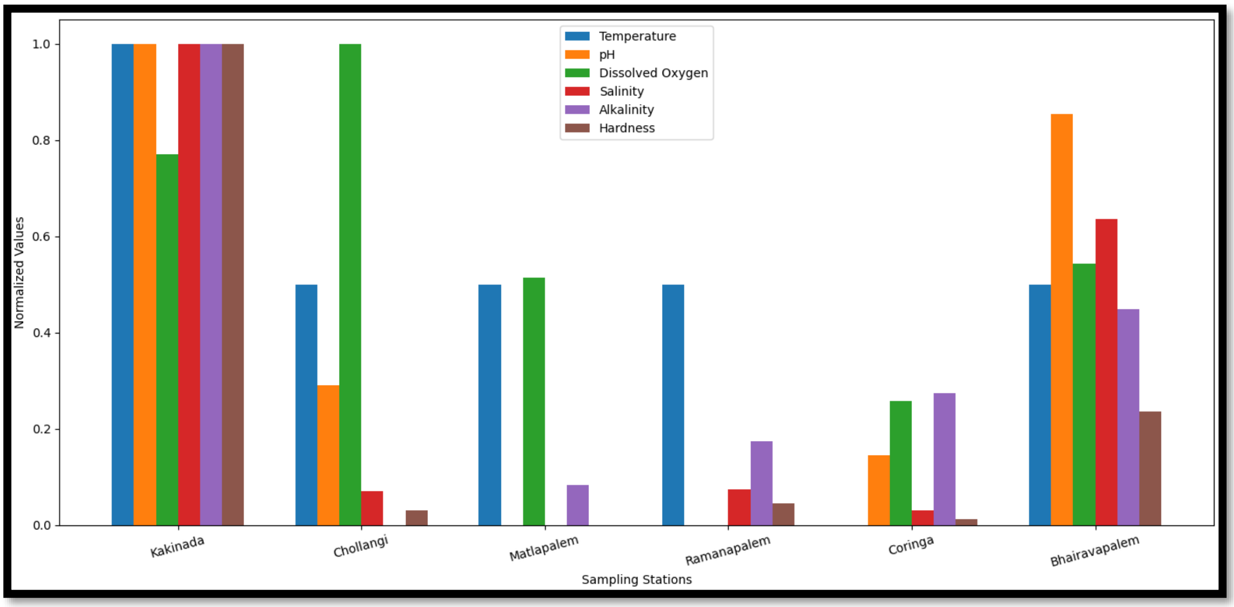

Fig. 2 Comparative visualization of physico-chemical parameters among the six sampling stations.

Alkalinity

Alkalinity varied between high tides 225 mg L^{-1} in September and 104 mg L^{-1} in July and March varied between low tides 215 mg L^{-1} in September and 105 mg L^{-1} in July and March at Kakinada. At Chollangi high tides range was from 116 mg L^{-1} in July and March to 70 mg L^{-1} in September and low tides range from 114 mg L^{-1} in July and March to 45 mg L^{-1} in September. At Matlapalem high tides range was from 125 mg L^{-1} in August, October and April to 75 mg L^{-1} in September and low tides range from 120 mg L^{-1} in August, October and April to 30 mg L^{-1} in September. At Ramanapalem high tides range was from 130 mg L^{-1} in August, October, November, April, May and June to 40 mg L^{-1} in July, September and low tides range from 135 mg L^{-1} in March and May to 40 mg L^{-1} in July and September. At Corangi high tides range was from 144 mg L^{-1} in July and March to 82 mg L^{-1} in January and low tides range from 146 mg L^{-1} in July and March to 80 mg L^{-1} in September. At Bhairavapalam high tides range was from 155 mg L^{-1} in May to 56 mg L^{-1} in November and June and low tides range from 165 mg L^{-1} in May to 50 mg L^{-1} in November and June. However high tides maximum Alkalinity was 225 mg L^{-1} at Kakinada and minimum 56 mg L^{-1} at Bhairavapalam and low tides maximum Alkalinity was 215 mg L^{-1} at Kakinada and minimum 30 mg L^{-1} at Matlapalem during present study.

Carbon dioxide

The concentration of Carbon dioxide ranges between high tides 1.99 – 0.99 mg L^{-1} in the month of September, October, February, April and July and low tides ranges between 1.89 – 0.89 mg L^{-1}respectively in the month of November and June at Kakinada. Maximum 5.99 mg L^{-1} was observed December, May and June and minimum 0.99 mg L^{-1} was recorded during October, January, February andApril and low tides ranges between 5.6 – 0.99 mg L^{-1} respectively in the month of November, December, May, June, July, August, September and February at Chollangi. At Matlapallem high tides maximum content of Carbon dioxide was 5.99 mg L^{-1} in November, June and minimum 0.99 mg L^{-1} was in month of October, January, May and April low tides ranges between 5.99 – 0.99 mg L^{-1} respectively in the month of November, June, August and January. At Ramanapallem high tides maximum content of Carbon dioxide was 5.99 mg L^{-1} in November, June and minimum 0.99 mg L^{-1} was in month of December, February and May and low tides ranges between 5 – 0.99 mg L^{-1} respectively in the month of November, June, August, October, December, January, February, April and May. At Corangi high tides maximum content of Carbon dioxide was 5.99 mg L^{-1} in November, June and minimum 0.99 mg L^{-1} was in month of October, January, and February and May low tides ranges between 5.33 – 0.99 mg L^{-1} respectively in the month of November, June, July, August, September, January and February. At Bhairavapallem high tides maximum content of Carbon dioxide was 3.99 mg L^{-1} in November, June and minimum 0.89 mg L^{-1} was in month of March and low tides ranges between 3.51 – 1 mg L^{-1} respectively in the month of November, June and May. However high tides maximum Carbon dioxide was 5.99 mg L^{-1} at Chollangi, Matlapalem and Corangi minimum 0.89 mg L^{-1} at Bhairavapalam and low tides maximum Carbon dioxide was 5.99 mg L^{-1} at Matlapalem and minimum 1 mg L^{-1} at Bhairavapalem during present study.

Hardness

Hardness varied between high tides 6500 mg L^{-1} in November and 370 mg L^{-1} in December and varied between low tides 6600 mg L^{-1} in August, October and April and 350 mg L^{-1} in December at Kakinada. At Chollangi high tides range was from 380 mg L^{-1} in November and December to 153 mg L^{-1} in September and June low tides range from 460 mg L^{-1} in September to 140 mg L^{-1} in April. At Matlapalem high tides range was from 250 mg L^{-1} in February and March to 105 mg L^{-1} in September and low tides range from 270 mg L^{-1} in May to 98 mg L^{-1} in September. At Ramanapalem high tides range was from 550 mg L^{-1} in May to 120 mg L^{-1} in July, September and June low tides range from 560 mg L^{-1} in May to 120 mg L^{-1} in November. At Corangi high tides range was from 350 mg L^{-1} in February to 127 mg L^{-1} in August, October and April low tides range from 300 mg L^{-1} in February to 120 mg L^{-1} in August, October and April. At Bhairavapalam high tides range was from 1760 mg L^{-1} in July and March to 198 mg L^{-1} in November and low tides range from 1750 mg L^{-1} in Julyand May to 200 mg L^{-1} in August, September and April. However high tides maximum hardness was 6500 mg L^{-1} at Kakinada and minimum 105 mg L^{-1} at Matlapalam and low tides maximum hardness was 6600 mg L^{-1} at Kakinada and minimum 98 mg L^{-1} at Matlapalem during present study.

Zooplankton

A total of 16 species of Zooplankton comprising Copepods constitute the bulk of the plankton at the present station Kakinada, Chollangi, Ramanapalem and Bhairavapalem. The decapods larval abundance in stationMatlapalem, Ramanapalem, KoringaandBhairavapalem. The abundance of the chaetognaths in station Matlapalem, RamanapalemandKoringa. The abundance of the lucifers is the Cholangi, Matlapalem, Koringa and Bhairavapalem. The abundance of the gastropod veligers ranged in station Cholangi, Matlapalem, Ramanapalem and Koringa. The polychaete larval abundance varied in station Kakinada, Cholangi, Ramanapalem and Bhairavapalem. The bivalve veligers abundance varied in the station Cholangi, Matlapalem, Ramanapalem, Corangi and Bhairavapalem. Abundance of the appendicularians varied in station Cholangi, Matlapalem, Ramanapalem and Corangi. The abundance of Ostracodsranged from station Kakinada, Matlapalem, Corangi and Bhairavapalem. Cladocern abundance varied station Cholangi, Matlapalem and Corangi. The miscellaneous groups include hydromedusae, ctenophores, siphonophores and other larger plank tonic groups.

Fishes

During the study period different fish varieties have been observed in the Gowthami Godavari and vasistavainateya River, Coringa Mangroves area. East Godavari dist, Andhra Pradesh, India. The results showed that the area was rich in fish biodiversity. Fishes belonging to seven orders and sixteen families were collected during course of the study period. Many collected fishes having economic importance sold after collection in the local fish market. In the present fish biodiversity study 31 species of 26 different genera 16 families and 7 orders were recorded from the Gowthami Godavari and vasista vainateya River, number of catches carried out during July 2012-Juny 2013. The members of Order Perciformes were dominated by 11 species followed by Cypriniformes 8 species Clupeformes 6 species Siluriformes, Tetraodontiformes and Mugiliformes with2 species, each Elopiformes with one species.

Discussion and Summary

The present investigation demonstrated significant seasonal and spatial variations in the physico-chemical characteristics of the Kakinada Bay and Coringa mangrove ecosystem. Temperature fluctuations observed during the study period were mainly influenced by seasonal climatic conditions, tidal mixing, and freshwater inflow from the Godavari River. Similar seasonal variations in estuarine temperature were earlier reported by Nybakken (1988), Chandra Mohan et al. (1997), and Sreenivas (1998), who emphasized the influence of monsoonal hydrology on tropical estuarine systems.

The pH values remained alkaline throughout the study period, indicating favorable conditions for estuarine and mangrove biota. Comparable alkaline conditions were reported by Welch (1948) and Kathiresan and Bingham (2001), who observed that estuarine waters generally maintain slightly alkaline conditions due to buffering effects and seawater intrusion. The observed fluctuations in pH may be attributed to variations in salinity, photosynthetic activity, decomposition processes, and tidal influences.

Dissolved oxygen concentrations exhibited considerable fluctuations among stations and seasons. Higher dissolved oxygen levels during monsoon and post-monsoon seasons may be associated with freshwater inflow and increased water circulation, whereas lower values during summer may be due to elevated temperature and organic decomposition. Similar observations were documented by Laybourn-Parry et al. (1992), who explained that estuarine oxygen dynamics are strongly controlled by organic matter decomposition and microbial activity.

Salinity showed pronounced seasonal variation, with higher values during dry seasons and lower values during monsoon periods. This variation clearly reflects the influence of freshwater discharge from the Godavari River and seawater intrusion from the Bay of Bengal. Similar findings were reported by Chandra Mohan et al. (1997), Nageswara Rao et al. (2003), and Dahdouh-Guebas et al. (2006), who studied the Godavari estuarine system and reported strong salinity gradients associated with tidal and monsoonal conditions.

The alkalinity and hardness values observed in the present study indicate the nutrient-rich nature of the estuarine environment. Elevated hardness and alkalinity at Kakinada Bay may be associated with higher mineral content and marine influence. Comparable results were reported by Roy (1997) and Wafer et al. (1997), who emphasized that mangrove and estuarine waters are enriched by nutrient recycling and decomposition of organic matter.

Zooplankton abundance and biomass were comparatively high throughout the study period, indicating the highly productive nature of the mangrove ecosystem. Copepods constituted the dominant zooplankton group, which agrees with earlier observations by Wickstead (1965) and Laybourn-Parry et al. (1992). The dominance of copepods in tropical estuarine ecosystems is generally associated with high detrital productivity and nutrient availability. The present findings also support the observations of FAO (2003), which recognized mangrove ecosystems as important nursery grounds for planktonic organisms and juvenile fishes.

The abundance of decapod larvae, chaetognaths, appendicularians, gastropod veligers, and polychaete larvae further confirms the ecological richness of the Coringa mangrove ecosystem. Mangrove-derived detritus and organic matter provide ideal feeding and breeding conditions for zooplankton communities. Similar ecological roles of mangroves were discussed by Ball (1996), Kathiresan and Bingham (2001), and FAO (2003).

Fish diversity analysis revealed that the estuarine and mangrove ecosystem supports a rich assemblage of commercially important fishes. Perciformes was the dominant order followed by Cypriniformes and Clupeiformes. Similar fish diversity patterns in estuarine and mangrove habitats were reported by Day (1878), Blasco and Aizpuru (2002), and Ramasubramaniam et al. (2006). The presence of economically important fishes such as Mugil cephalus, Glossogobius giuris, Sardinella longiceps, and Oreochromis mossambicus indicates the ecological and fisheries importance of the Kakinada Bay ecosystem.

The present study also indicates that mangrove ecosystems play a significant role in sustaining fishery resources by functioning as spawning, nursery, and feeding grounds. Similar ecological functions of mangroves were highlighted by Duke (1992), MOEF (2002), and FAO (2003). However, increasing anthropogenic activities such as aquaculture expansion, industrialization, and pollution may adversely affect the ecological balance of the estuarine ecosystem. Therefore, continuous monitoring and conservation measures are essential for sustainable management of the Kakinada Bay and Coringa mangrove ecosystem.

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