PREAMBLE

Coral reefs are diverse and vulnerable ecosystem characterized by a complex interdependence of plants and animals. Coral reefs are massive limestone structures built up through the constructional cementing processes and depositional activities of animals of the class Anthozoa (Order Scleractinia) as well as all other calcium carbonate secreting animals and calcifying algae (Venkataraman, 2000). The value of coral reefs, both for the biosphere and human utilization are well known. Reefs are centers of high biological productivity, sites of CO$_2$ sink, ecosystem of very rich biodiversity helping in shoreline protection, sources of huge deposits of CaCO$_3$ and centers of scientific research. Additionally, they provide many natural raw materials for deriving pharmacological products especially life saving drugs (Gopinadhan Pillai, 1997).

The biodiversity of coral reefs is responsible for productivity in the sea and these coral reefs are built mainly by corals containing calcium carbonate skeleton. The reef building corals are the hermatypic corals harboring zooxanthellae and the ahermatypic corals or without zooxanthellae. Coral reefs are found in the well lighted zone of waters up to a depth of 50-70 m having salinity of 32-35ppt and temperature above 20°C. In the coral habitat a variety of fascinating animal life such as Giant Clams, Sea Cucumbers, Sea Anemones, Sea Urchins, Sea Fans, Crown of thorned star fish and variety of coloured fishes are abundant. Each of these animals has a special niche in this system (Raghukumar, 1997).

Coral reefs are highly productive with annual production rates ranging from 2,000 to 5,000g/cm$^2$/yr. Such a high rate of productivity is due to the efficient retention and recycling of nutrients with in the reef system. Such internal recycling of nutrients is greater than that of other marine ecosystems and is responsible for the higher gross productivity of coral reefs (Wafer, 1990). The potential fish yield from the world’s reefs is 6-9 million
tones/yr, equivalent to 9-12% of all marine fish catch. Indian reefs together with their shelves, Lagoons and submerged banks covering an area of 1,800km² have a potential fish yield of 0.2 million tones/yr, or about 10% of the annual marine fish production (MoEF, 2000).

The Indian Ocean coral reefs include sea level atolls, fringing and barrier reefs elevated reefs and submerged reef platforms (Johannes, 1975; Dahl, 1985; Rogers, 1985). In the Indian subcontinent, the reefs are distributed along the east and west coasts at restricted places and all the major reef types are represented here, fringing reefs are found in the Gulf of Mannar and Palk bay. Platform reefs are seen along the Gulf of Kutch. Patchy reefs are found near Ratnagiri and Malwan coasts. Atoll reefs are found in the Lakshadweep archipelago. Fringing and barrier reefs are found in Andaman and Nicobar islands (Wafar et al., 1992; Venkatraman et al., 2003). Due to the highest freshwater flow through a large number of rivers mixing with Bay of Bengal, there are no significant coral reef formations on the east coast of India (Venkatraman et al., 2003). Satellite imagery shows scattered patches of corals in the intertidal areas and occasionally at subtidal depths down to a few meters along the west coast of India, notably at Ratnagiri, Malwan, Rede Port and Vizhingam (Wafar, 1990).

Coral formation in Tamil Nadu is mainly confined to the Gulf of Mannar and Palk Bay. Some patchy growth is also found at Enayam, on the west coast of Kanniyakumari District. The Gulf of Mannar reefs extend from the Rameswaram archipelago to Thoothukudi in a north east-south west (NE-SW) direction over a distance of 140km. The formation is estimated to be 100km² in extent (Wafar, 1986). The reefs are discontinuous and are mainly found around twenty small islands, at a maximum depth of about six metres (Yogesh et al., 2010). These islands are located between latitude 8°47’N and 9°15’N and Longitude 78°12’ E and 79°14’E. The islands lie at an average distance of 8km from the mainland. They are a part of the mannar barrier reef, which are 140km long and 25km
wide between Pamban and Thoothukudi. Different type of reef forms such as shore, Platform, Patch and fringing type are observed in the Gulf of Mannar. The island has fringing reef are located mostly at a distance of 50 to 100m from the island. On the other hand, patch reefs rise from depths of 2 to 9m, extend from 1 to 2 km in length and have a width of as much as 50 meters. Reef flat is extensive in almost all the reefs in the Gulf of Mannar. Reef vegetation is richly distributed on these reefs. The total area of coral reefs in India occupied to be 2,379 sq km, respectively (D.O.D and S.A.C., 1997).

Increasing human population and anthropogenic pressures have severely affected coral distribution and biodiversity. Natural calamities also cause considerable damage to the coral reef structures through direct and indirect means (Paul et al., 2005). Further, global warming leads to increase in volume of sea water due to melting of ice sheets (Robert et al., 2004). Global warming increases the sea surface temperature. It is alarming to note that sea surface temperature is rising by 0.1°C every year. The satellite measurements confirm the present sea level raise (SLR) at the rate of 2mm/yr. Further, the increase in the concentration of green house gases in the atmosphere, the average earth surface temperature would rise between 2 and 5°C over the next 100yrs. But it should be noted that the coral reefs are stenotypes requiring constant environmental conditions. The rising sea level due to global warming would favour the vertical extension of the fast growing species, while slow growing species will die due to shading effect and also by the limited availability of resources (Robert et al., 2004). Increasing UV radiation is also harmful to a wide variety of corals and associated organisms (Wafer, 1990). Various activities such as fishing gear operations, anchoring of boat, collecting corals for ornamental purposes, algal collection, shell collection, illegal quarrying of corals for industries, use in house building, promotion of tourism and activities like mariculture would add to the complexity of management of coral reef ecosystem in India (Ramaiyan et al., 1995). One island has disappeared below the
surface due to anthropogenic and coral mining activity in Thoothukudi group of island, Gulf of Mannar (Venkatraman et al., 2003).

The supremacy of man and his mismanagement of natural wealth, has very much affected these precious ecosystems. Discharging untreated waste water and industrial effluents into surface water bodies often results in serious water pollution at Thoothukudi coast. In Thoothukudi there are several industries like Thoothukudi Alkali Chemical and Fertilizers Ltd. (TAC), Southern petrochemical industries Corporation Limited (SPIC), Tuticorin Thermal Power Station (TTPS), Heavy Water Plant (HWP), Dharangadhara Chemical Works Limited (DCW), Sterlite Copper industry and a huge SIPCOT industrial complex. All these are bordering the coast of Thoothukudi and also discharging their wastes directly into the sea. In addition, the domestic sewage of near by towns and villages further aggravates the status of pollution in this ecosystem (Easterson et al., 2000; Asha, 2002; Patterson Edward et al., 2004; Asha et al., 2009). These industrial wastes contain different concentrations of heavy metals and other chemicals. Deposition and sedimentation of these on coral reef ecosystem definitely has an impact. Knowledge on the distribution of heavy metals in the aquatic environment is important in studying environmental pollution (Johnels et al., 1967; Irukayama, 1961; Jenson and Jernelov, 1969; Kobayashi, 1971; Fernandez and Jones, 1987).

**REVIEW OF LITERATURE**

Extensive studies have been conducted on the heavy metals contamination and toxicity in water, sediment and biota of coastal regions and estuary (Badri and Aston, 1983; Fernandez and Jones, 1987; Nair et al., 1987; Fernandez et al., 1995; Fernandez and George Thomas, 1996; George Thomas and Fernandez, 1996). Antagonistic behaviors of zinc and copper has been worked out by Athalye and Gokhale, (1989), Fernandez and Jones, (1989) and nickel and copper by Jamila and Fernandez, (1995). The toxicity of heavy metals and their effects to fish and seaweeds have been extensively documented by
Instances of hazards to human health caused by high concentration of heavy metals in aquatic environment have been reported by Johnels et al., (1967); Jenson and Jernelov, (1969) and Kobayashi, (1971). Even though the aquatic environment consists of three main reservoirs, water, sediment and biota (Philips, 1977), the sediment is the ultimate recipient of nearly all trace metal pollutants introduced into aquatic system by various human activities. It appears that a large proportion of the metallic substances discharged into the aquatic environment are ultimately incorporated into the sediments (Duursma and Gross, 1971; Lowman et al., 1971; James, 1978; Fernandez and Jones, 1987).

Many studies relating to heavy metal pollution have been reported from India. Seaweeds are efficient organism in accumulating metals dissolved in sea water (Fernandez et al., 1995; Fernandez and George Thomas, 1996; Zingde et al., 1976). Trace metal level in marine water have been studied in detail by Singbal et al., (1977), Sankaranarayan et al., (1978); Nair et al., (1985); Venugopal et al., (1982). Seasonal variation of heavy metal concentration in sediment samples of Kodiyakkari coastal environment was reported by Pragatheeswaran et al., (1986).

A few reports are available on the heavy metals distribution in the sediments of the mangrove environment in India (Seralathan, 1987; Athalye and Gokhale, 1989; Borgaonkar and Gokhale, 1992; George Thomas and Fernandez, 1996). Trace metals in plant and animals of the Sunderban Mangrove areas have been reported by Chakrabarti et al., (1993). The distribution of heavy metals in plant, animals and sediments in mangrove areas of kerala have been studied in great detail by George Thomas, (1995) and George Thomas and Fernandez (1996). Kurieshy et al., (1983) reported the content of mercury, Cadmium and Lead in different tissues of fishes collected from Andaman Sea. Depledge and Rainbow,
(1990) reported on the significance of trace metals levels in regard to the well being of marine invertebrates and their use in biomonitoring studies.

Trace metal level in fishes from Marmara and Black sea was studied by Topeuoglu et al., (1990). Vas and Gordon, (1993) studied the trace metals in the deep sea sharks from Rockall Trough. Depledge et al., (1993) reported the distribution of copper, zinc, iron and cadmium in the tissues of the benthic crab. Distribution of zinc in different body tissues of Nereis was studied by Fernandez, (1983). Turner et al., (1992) carried out an in situ experimental techniques using radioisotope for studying trace metal behaviour in coastal waters. Niencheski et al., (1994) reported that high excess metal fluxes observed for copper and lead reflected the industrial activity occurring in the watershed of Patos Lagoon. Dalal et al., (1999) reported the detailed nutrients, trace metals and organic contaminants in the area of Polar Island, Maryland. Distribution of trace elements in the coastal sea sediments and water of Maslinica Bay south Adriatic reported by Mikulic et al., (2008). The impact of industrial and human activities in the coastal area of Soudi Arabia was reported by Nadia Badr et al., (2008). Chad Hammerschmidt et al., (2006) reported the Bioaccumulation of Methylmercury, in microeston, Zooplankton, Crustacean and fin fish in Long Island Sound, north eastern United States. The ionic composition of total suspended particulate and fine fractions was investigated from Jeju Island, Korea by Nguyen et al., (2009). Franklin Berandah Edward et al., (2009), was assessed variation of heavy metal concentrations in different species of bivalves in Malaysian coast. Macrophytic brown algae are used as indicator for heavy metal pollution by Kozhenkova et al., (2000). Quantitative identification and sources of anthropogenic interference for heavy metals in marine sediment of Hong Kong by Feng Zhou et al., (2007). Paulo Pedrosa, (2007) was investigated and the relationships between major nutrients and trace metals from lake and lagoon system in Southern Brazil. Enfeng et al., (2005) reported sequential core sediments from north western Taihu Lake in China. The content of heavy metals has been analyzed in

The metal concentration in coral skeleton was analyzed by McConchie and Harriott, (1992) and Esslemont, (1999). Heavy metal concentration in some algae, sediment, and water and reef sediments from the Gulf of Mannar was well documented by Kumaresan et al., (1998); Vinithkumar et al., (1999); Palanichamy and Rajendran, (2000); Palanichamy et al., (2002).

Sedimentation is a major controlling factor in the distribution of reef organisms and overall reef development (Hubbard, 1986; Macintyre, 1988; Randall and Birkeland, 1978; Bak and Engel, 1979; Birkeland et al., 1981; Morelock et al., 1983; Rogers et al., 1984; Hubbard et al., 1987) The growth of a coral skeleton is the end result of several physiological processes which can be altered by environmental condition (Barnes and Crossland, 1982; Gladfelter, 1982; 1983; Dodge and Brass, 1984).

Sediment chemistry and its impact on biology of near shore regions has been worked out by several authors at several locations (Anto, 1971; Murthy and Veeraya, 1972; Ansari, 1974; Pillips, 1977; Sankaranarayanan and Panampunnayil, 1979; Sarala Devi et al., 1979; Remani et al., 1980; Mallik and Suchindan, 1984; Ansari et al., 1994). Rate of sedimentation and characteristic of sediments were assessed in Thoothukudi coast by Mathews and Patterson, (2006). Thanikachalam and Ramachandran, (2002) was reported the role of wave and wind direction that lead to the sedimentation in Gulf of mannar region using the remote sensing method.

Impact of Seasonal variability and anthropogenic activities on coastal region was well documented by several workers (Peter Barile., 2004; Antony Joseph et al., 2005; Hui Fan et al., 2006; Simone et al., 2007; Mohanty et al., 2008; Assefa Melesse et al., 2008). Anthropogenic and natural disturbances have been linked to vast majority of decreases in coral cover and general health (Wilkinson and Buddemeier, 1994). Reports on coral
bleaching are also available in plenty (Rohan Arthur, 2000; Patterson et al., 2004; Venkatraman et al., 2003)

Early studies on corals and coral reefs of Gulf of Mannar area are available in plenty (Brook, 1893; Thurston, 1895; Matthai, 1924; Gravely, 1927a and b; Sewell, 1932, 1935). Previously 94 coral species under 37 genera were recorded in Gulf of Mannar and Palk Bay (Gopinadhan Pillai, 1971; 1973). Of this 18 species of stony corals were recorded from Thoothukudi (Santhanam and Venkataramanujam, 1996). After that Patterson et al., (2004), reported 22 species under the 8 genera and 53 species belonging to 22 genera in Thoothukudi.


The literature survey showed that there are several unexposed area for the field of research in Gulf of Mannar area. Most of the work carried out in this region related with the assessment of coral mass, coral organisms and so on. But the status of corals, impact of pollution on corals, sedimentation on corals, and sedimentation impact on corals are lacking. There are also no reports available regarding the impact of pollution on the distribution of corals and coral associated biota of islands of Gulf of Mannar. Hence this proposed study was planned.
STUDY AREA PROFILE

The Gulf of Mannar Biosphere Reserve (GoMBR) encompasses 21 islands. The 21 Islands between Rameshwaram and Thoothukudi as well as the entire Gulf of Mannar were declared as marine national park in 1986 for the purpose of protecting marine Wildlife and its environment (Upreti and Shanmugaraj, 1997). These are uninhabited islands, ranging in size from 0.25 to 130ha, along the coast for 170km, with the closest being 500 meters from shore and farthest, over 4km. The island and their shallow waters form the core of the reserve. This core area is in turning surrounded by a 10km wide buffer zone.

Study area map (Thoothukudi and Vembar group of islands)

The Gulf of Mannar consists of three important ecosystems viz. Mangrove, Seaweed and seagrass and coral reef. The entire three highly productive ecosystem harbour a rich biodiversity of fauna and flora (3,600 species) making it biologically one of the richest
coastal region in India. It has become significant because of the luxuriant growth of coral reefs and its associated fauna.

The Gulf of Mannar is bordered on the west by the southeast coast of India, on the east by the north west coast of Srilanka and enclosed with in 8°35’N-9°29’N lat and 78°08’E -79°30’E long. There are 21 islands of coral based origin, which are lying as a string of chain parallely opposite to the mainland coast. Each island has its unique characteristics, surrounded by coral reefs with rich faunal and floral diversity. The islands in the Gulf of Mannar are classified into 4 major groups.

1. **Mandapam Group** (7 islands): Musal, Manoli, Manoliputti, Poomarichan Pullivasal, Krusadai and Shingle.


4. **Thoothukudi Group** (4 islands): Van, Koswari, Kariyachalli and Velanguchalli (Submerged).

**THOOTHKUDI GROUP OF ISLANDS**

There are four islands in this group, among this one Villanguchalli Island, now lies 1m below mean low water level as a result of soil erosion caused by excessive coral mining activity.

**Van Island**

The total area of this island is 16.0ha and the circumference is 2015m. It is 6km away from Thoothukudi sewage river mouth and very closed to Vellapatti fishing village. This island is covered with sparse vegetation of low bushes mostly grasses and xerophytic plants. The mangroves and up rooted plants are absent. Fringing reefs are present on the eastern side of the Island at a distance of 500m.
**Koswari Island**

The total area of this island is 19.50ha and the circumference is 2160m. Recently this island was eroded and the area became 15ha only. It is 7km away from Thoothukudi and very close to Tharuvikulam fishing village. This island has small sand mounds and Mangrove plant and bushes here and there. The whole island is covered with xerophytic vegetation. Coral reefs are found at the southwest corner of the island at a distance of 500m.

**Kariyachalli Island**

The total area of this island is 16.46ha and the circumference is 1610m. Recently some portion of the island got eroded and hence area become reduced to 12.70ha. It is 15 km away from Thoothukudi and very close to Keelavippar fishing village and Vippar River. It is a sandy island, thickly set with tall bushes in the center and western side. The whole island is covered with grasses and small plants the island at a distance of 500m to 1km from the shore.

**Villanguchalli Island**

The total area of this island is 0.95ha, and the circumference is 614m. It is 15km away from Thoothukudi and very close to Sippikulam fishing village. This island is submerged now. There are isolated patches of thin reef of corals along southeastern side of the island.

**VEMBAR GROUP OF ISLANDS**

**Upputhanni Island**

The total area of this island is 29.94ha and the circumference is 2292m. It is 8km away from Vembar River and very close to Mookiyour fishing village. It is a big sandy island with plenty of coral rubble all over. There are a few trees, Mangroves, tall bushes and grass present in this island. Fringing reefs are found in the mid- eastern portion rounding south up to the western middle portion at a distance of 150 to 300m from the island.
Pulivinichalli Island

The total area of this island is 6.12ha and the circumference is 1372m. It is 18km away from Vembar and very close to the Mookiyour and Mela Munthal fishing village. This island has a good sandy beach, and thick vegetation. This island is surrounded by live coral reef all round except for a small stretch on the eastern side.

Nallathanni Island

The total area of this island is 110ha and the circumference is 2700m. It is 2km away from Keela Mundal a place near Valinokkam. It is the large island of Vembar group containing about 4000 coconut trees, palmyrah and other woody trees. Coral reef and coral boulders are present all around the island at a distance of 0.5km on the southern side and very near to northern shore.

The coast between Thoothukudi to vembar is the most environmentally stressed area in the Gulf of Mannar mainly due to various human activities such as destructive fishing, coral mining and dumping of sewage from the industries along the entire coastal belt. The various unwanted operations and anthropological activities going on in the study area becomes a serious threat to the corals and coral biota. The corals are illegally collected for the lime industry involving many poor fishermen. Also, cyanide fishing is used to catch reef fishes, particularly groupers and ornamental fishes. Various types of destructive fishing nets such as beach seine nets, trawl nets, causing considerable damage to the benthic environment in Thoothukudi and Vembar coast. Further a small section of fishermen are also involved in dynamite fishing using gelatin sticks to blow up the reef and kill shoaling fishes near the study area. Another major problem in Thoothukudi coast is the discharge of untreated and partially treated effluents from industries that are bordering the coast of Thoothukudi. In addition, dumping of domestic sewage and salt pan wastes, further aggravates the pollution status of this ecosystem. Hence the present study was planned to assess the impact of pollution in this ecosystem concentrating on the following objectives.
Objectives of the study

- Assessment of physiographic status of the study area.
- Assessment of the hydrographic parameters and its impact on the coral fauna of the study area.
- Assessment of the rate of sedimentation and its impact on the coral fauna of the study area.
- Assessment of the accumulated volume of heavy metals in the water, sediment and coral organisms in the study area.
- Assessment of coral population and its distribution in the study area.