V. DISCUSSION

The physico-chemical parameters such as temperature, pH, salinity, dissolved oxygen and nutrients showed seasonal variations. The seasonal variations of the environmental features in the estuarine system is chiefly controlled by the spectacular regime of the rainfall during monsoon. In the present study area, the peak values of rainfall were recorded during the northeast monsoon periods (October-December). The rainfall was scanty during post monsoon and summer months. Commendable works are available on Vellar estuary (Nedumaran et al., 2001); Point Calimere costal water (Damothaeran et al., 2010); Parangipettai coast (Santhanam and Perumal, 2003; Sundaramanickam et al., 2008) and Muttukadu backwaters (Prema and Subramaniam, 2003).

Temperature is an universal factor in the aquatic ecosystem, which influence the physico-chemical characteristics and also influence the life of organisms. The highest value of surface water temperature was recorded in summer season and lowest in monsoon periods. The seasonal variations in the water temperature may be associated with the wind force, freshwater discharge influx of the inshore water and atmospheric temperature. The reduction in the water temperature mainly depend upon the intensity of rainfall during monsoon and the low air temperature existed at the time. Similar observations have been reported by Thangaraj (1984) in Vellar estuary; Senthilnathan (1990) in Vellar, Uppanar and Kaduviar river estuary; Bikash Saha et al. (2001) in Sundarbans brackish water; Soundarapandian et al. (2009) in Uppanar estuary; Palpandi (2011) Vellar estuary. Thus the present findings favour the earlier reports on the fluctuations of water temperature on the estuaries.

Generally low pH values were recorded during the monsoon period and slightly higher values during summer period. Similar seasonal pattern was recorded earlier by Thangaraj (1984), Palpandi (2011), Santhanam and Perumal (2003) in Vellar estuary; Murugan and Ayyakkannu (1991) and Soundarapandian et al. (2009). In Uppanar backwaters, minimum values of pH during monsoon in the study area may be controlled by the influence of freshwater discharge, rainfall and also due the decomposition of organic matter as stated by Ragothaman and Patil (1995) and Upandhayay (1998).
Dissolved oxygen (DO) contents showed well marked seasonal variations in the Arasalar estuary. It seemed to be controlled by various factors such as rainfall, temperature, phytoplankton photosynthesis and salinity. Dissolved oxygen content was high during monsoon period in the study area could be due to the influx of fresh water during the monsoon, higher solubility and low salinity. Similar observations in DO values have also been reported from the Vellar estuary (Vijayalakshmi and Venugopalan, 1973, Brinda et al., 2010; Nedumaran et al., 2001); Pichavaram mangroves (Govindasamy and Kannan, 1991); Mandovi and Zuari estuaries (Dwivedi et al., 1974); Point Calimere coastal water(Damotharan et al., 2010); Mutthkadu backwaters (Prema and Subramanian, 2003).

The salinity act as a prime factor among the most important environmental parameters in the distributions of living organisms (Chandra Mohan and Sreevanivas, 1998). The salinity variation in the exchange of ions and nutrients because of the tidal flow and low during the monsoon season in the Arasalar estuary. The intrusion of neritic water and low river discharge may be responsible for high salinity, the monsoonal rain and continuous flow of the freshwater of the rivers may be responsible for low salinity in the present study in conformity with the earlier reports from Vellar estuary (Chandran and Ramamoorthi, 1984; Palpandi, 2011; Singbal, 1976); Uppanar backwaters (Murugan and Ayyakannu, 1991; Soundarapandian, et al., 2009).

The presence of total phosphorus in an estuary can be taken as an index of total fertility in the ecosystem (Redfield, 1934). In the present study, the total phosphorus were found to be increased during monsoon periods and decreased slowly from summer onwards. High concentration of total phosphorus during monsoon season due to heavy rainfall, decomposition of particular organic matter, industrial effluents and from the agricultural discharges from the adjacent lands. Such monsoonal maximum and summer minimum in the total phosphorus concentration was also reported from Vellar estuary (Sivakumar, 1982; Chandran and Ramamoorthi, 1984; Nedumaran et al. (2001); Periyar river estuary (Sarala Devi et al., 1991), Coleroon estuary (Prabha Devi, 1986) and Mandovi estuary (Dehadrai, 1970 and Dwivedi et al., 1974).
In the present study, nitrate concentration was high during the monsoon and low during summer season. The high nitrate content observed during monsoon periods is mainly due to the river water discharge from agricultural fields containing nitrogenous particles of various origin. Low values of nitrate observed during summer seasons might be due to the lesser amount of freshwater inflow and higher salinity. Similar maximum value in monsoon and minimum in summer season were also recorded by Qasim et al. (1969) from Cochin backwaters, De Souza (1977) from Mandovi and Zuari estuaries, Sivakumar (1982) in Vellar estuary, Hari Muraleedharan et al. (2010) in Thondi coastal waters, Sundaramanikam et al. (2008) in Parangipettai and Cuddalore coast.

The seasonal average silicate content in the study area showed maximum values during monsoon and minimum during summer seasons. The peak values of silicate observed during monsoon may attributed to the heavy fresh water influx and land run off which carries slit and other silicon deposits from upper reaches of the river. Observations similar to present study were reported earlier by Qasim et al. (1969) and Ansari and Rajagopal (1974) in Cochin back waters. Nair et al. (1983) in Ashtamudi estuary, Praba Devi (1986) in Coleroon estuary. The silicate concentration also showed negative relationship ($r=-0.8919$) with salinity, which was also noted earlier in Vellar estuary (Chandran and Ramamoorthi, 1984 and Thangaraj, 1984) Kerala backwaters (Sarala Devi et al., 1983).

Generally, the natural sources of heavy metals in coastal waters are through land, heavy fresh water inflow, agricultural waste, aquaculture discharge and river run off and the mechanical and chemical weathering of rocks. Also, the components washed from the atmosphere through rainfall, wind blown dust, forest fires and volcanic particles add to the distribution of heavy metals in water (Bryan, 1984). In Arasalar estuary, investigated almost all the heavy metals (Cu, Zn, Cr, and Cd) registered high concentrations. This was mainly due to the discharge of aquacultures ponds, domestic wastes, land and agricultural drainages along with the river inputs into the estuary. Apart from these sources, aquaculture and boating activities such as loading and unloading of materials, antifouling paints from boats and fishing activities contribute to the enhanced levels of metals. In addition, increasing anthropogenic activities along this coast might certainly have a significant effect on metal concentrations in the estuarine waters.
The order of abundance of different metals at the Arasalar estuary during this study was as follows: Zn>Cu>Cr>Cd. The abundance of different metals was observed during the present study period with the essential metal (Zn) recording the maximum concentration and the non-essential metal (Cd) recording the minimum concentration. The similar trend was observed in the Bay of Bengal along the Tamil Nadu coast (Ramachandran, 1990). The similar results were observed by Marchand et al. (2006) and Elijah et al. (2008).

Compared to estuarine water, sediments contained very high concentrations of metals. Concentration of heavy metals in the sediments showed spatial and temporal variations at both the stations during the study period. Concentrations of dissolved metals especially Zn were high during November. Cu concentration was high during December whereas Cr and Cd concentrations were high during November. The order of abundance of different heavy metals in the sediments observed during the study period at the Arasalar estuary was as follows: Zn>Cu>Cr>Cd.

The concentration of metals observed in the sediment were compared with the levels reported elsewhere, it is obvious that the levels were higher than the values reported. In areas where higher metal concentrations have been reported (Sahu and Mukherji, 1983) were found to be influenced by the influx of industrial wastes, sewage and atmospheric fallout. The data obtained in the present investigation were well below the allowable limit.

In general, the sedimental (Cu, Zn, Cr and Cd) concentrations observed in the Arasalar estuary showed similar trend in seasonal distribution with high levels during monsoon and lower values during summer period. The higher concentration of metals observed during monsoon could be attributed to the heavy rain fall and subsequent river runoff, bringing much industrial and land derived materials along with domestic, municipal and agricultural wastes which include residues of heavy metal containing pesticides. The load of metals was found to be lower during summer months and this could be due to the meagre metal rich freshwater influx. This observation supports the earlier reports in the Pichavaram mangrove by Glory Dally (1983), in the Kodiakarai coastal area (Pragatheeewarun et al., 1986) and in the French Guiana coastal line (Marchand et al., 2006).
The concentration of zinc in sediments varied from 12.9 to 17.4 μg/g during pre-monsoon, from 17.2 to 20.61 during monsoon, from 14.6 to 16.8 during post monsoon and summer from 12.1 to 14.1. The range and average values of zinc in sediments in the present study is slightly lower than those reported earlier from Godavari estuary (Srinivas, 1998), Vamsadhara estuary (Devavarma et al., 1993 and 1991), Krishna estuary (Krishna Rao and Swamy, 1991), Vellar estuary (Mohan, 1995), World river average (Martin and Maybeck, 1979), Surficial Rocks (Martin and Maybeck, 1979) and Tapti (Subramanian, 1985). Seasonal variation of zinc registered highest concentrations during the monsoon followed by pre-monsoon, post monsoon and summer seasons. High concentrations of zinc during monsoon are due to the effect of increased inputs of land derived metals due to run off. A large part of the anthropogenic discharge of heavy metals into the environment becomes part of the suspended matter in rivers. This suspended matter can act as scavenger for heavy metal in water (Burton and Liss, 1976). Similar observations were made by Srinivas (1998) in Godavari estuarine sediments and Pondicherry harbour by Senthilnathan and Balasubramanian (1999).

Concentration of cadmium (μg/g) in different seasons in sediments varied from 1.2 to 2.7 during pre-monsoon, from 3.1 to 3.7 during monsoon, from 2.66 to 3.5 during post-monsoon and summer 1.1 to 2.3. The range and average values obtained in the study is slightly low when compared with that reported earlier from Vellar estuary (Mohan, 1995). Seasonal variation of cadmium was the highest during monsoon period followed by post monsoon, pre-monsoon and summer. Higher values during monsoon could be due to higher organic matter content in both the estuaries. This is also supported by significant positive correlation exhibited between cadmium and organic carbon during post-monsoon season in the Mandovi estuary (Singh, 2000). Senthilnathan and Balasubramanian (1999) while studying heavy metal distribution in Pondicherry harbour reported high concentration of cadmium in sediments during monsoon and low in summer. This was attributed to land runoff and influx of metal rich water.

Concentration of copper (μg/g) varied from 4.9 to 8.9 during pre-monsoon, 12.9 to 14.4 during monsoon, 8.2 to 11.6 during post-monsoon and summer 4.6 to 5.7. The range and average values of copper obtained in the present study broadly agree with those reported earlier from Mandovi estuary (Bukhari, 1994 and Alagarsamy, 1988), Vamsadhara estuary (Devavarma et al., 1993, 1991), Cauvery
estuary (Ramanathan et al., 1988), Vellar estuary (Mohan, 1995), Indian river average (Subramanian et al., 1985), Surficial Rocks (Martin and Maybeck, 1979). However, they are lower than with those of Godavari estuary (Srinivas, 1998), Krishna estuary (Krishna Rao and Swamy, 1991) and World river average (Martin and Maybeck, 1979). Seasonal variation of copper showed maximum values during monsoon followed by pre-monsoon, post monsoon seasons and summer. This slight increase in the concentrations of copper in the sediments during the monsoon period may be due to down stream transport along with the monsoonal discharge. Settling of trace metals at the area of confluence between river and seawater could lead to such effects. Senthilnathan and Balasubramanian (1999) also reported higher concentration of copper in sediments from Pondicherry harbour during monsoon and lower in summer. This was attributed to land run off and influx of metal rich water. Similarly, higher concentrations of copper in sediments were reported from Godavari estuary during monsoon season (Srinivas, 1998).

The concentrations of chromium (μg/g) in different seasons varied from 3.4 to 5.7 during pre-monsoon, from 7.12 to 8.37 during monsoon, from 4.1 to 6.21 during post-monsoon and summer 3.2 to 4.3. The ranges and averages values of chromium in the present study are slightly lower when compared with those reported earlier from Godavari estuary (Srinivas, 1998), Vamsadhara estuary (Devavarma et al., 1993 and 1991), Krishna estuary (Krishna Rao and Swamy, 1991), Cauvery estuary (Ramanathan et al., 1988), Vellar estuary (Mohan, 1995), Narmada (Subramanian et al., 1985), Tapti (Subramanian, et al., 1985), Indian river average (Subramanian et al., 1985), World river average (Martin and Maybeck, 1979) and Surficial Rocks (Martin and Maybeck, 1979). But, the range is found to be in broad agreement when compared with the earlier values reported from Mandovi estuary (Bukhari, 1994). Seasonal variation in the concentrations of chromium registered highest values during the monsoon period followed by those in pre-monsoon, post-monsoon and summer. High concentrations observed during monsoon can be attributed to the land runoff and influx of metal rich fresh water. The increased particulate matter along with suspended sediment load brought in by the river would also be a possible reason for the abnormally higher values during monsoon (Senthilnathan and Balasubramanian, 1997). Similarly, Srinivas (1998) reported higher concentrations of chromium in sediments from Godavari estuary during monsoon season.
Zn plays an important role in the composition of approximately 90 enzymes in animal metabolism (Carvalho et al., 1993). In the present study, zinc concentration showed the maximum during monsoon and minimum during summer season. The higher concentration of zinc during monsoon season is mainly due to the influence of sewage outfalls and land drainage and also due to the entrance of chemicals from the agricultural lands without and specific industrial influence. The usage of zinc block in the fishing vessels would have resulted in enhanced zinc concentration in coastal waters (Black et al., 1952). In Arasalar estuary also hundreds of vessels have been used for fishing, this may also be another reason for the higher concentrations in coastal waters. In the present study, the concentration of zinc in selected tissues ranged from 8.4 to 56.2 μg/g in the Arasalar estuary, Whereas the zinc Concentration was reported as 950 μg/g – 2760 μg/g at marine zone and from 1290μg/g – 2820 ug/g at tidal zone of Vellar estuary in Anadara rhombea (Shanthi, 1987); 589 to 2098 μg/g and 487 to 1898 μg/ g in male and female Donax cuneatus in Parangipettai coast (Rajan, et al., 1991); 92.75 μg/g in Nerita lineata in Peninsular Malaysia (Ya Pand heng, 2008); 10.37±4.60 ug/g in Patella piperata in Canary Island, Spain (Bergasa and Ramirez, 2007). Comparatively, in the present study, Zn concentration (8.4 to 56.2 μg/g) is lower than that of all the previous studies from other areas. In the present study, the zinc concentration also showed its peak during monsoon and minimum during summer. The higher concentration of zinc during monsoon was mainly due to the influence of sewage out falls and land drainage and also due to the entrance of chemicals from the agricultural lands without and specific industrial influence.

Metal storage may differ according to the species. Further copper and zinc values are low when compared with that of the previous studies cited above which may be due to low concentrations of these metals in the estuarine water. In the present study, Zn concentration of tissues showed negative correlation (r = -0.485) between the salinity. Salinity was thus found to have a profound effect on the accumulation characteristics of metals in the tissues of M. casta. This was evidenced statistically with a negative correlation. It was supported in the earlier (Rajan, 1989) studies from Donax cuneatus in Parangipettai coasts.

Cadmium and some of its compounds are considered carcinogenic and may cause damage to all types of body cells. In the present study, the mean cadmium concentration was 0.6 to 7.3 μg/g. The mean concentration of Cd as 1.3 μg/g in C. glomerata, 3.9 μg/g in Ostrea lutaria and 0.17 μg/g in Haliotis from New
Zealand waters (Nielson and Nathan, 1975); Cd concentration ranged from 1.5 to 11.1 μg/g from *Megapitaria squalida* (Mendez *et al.*, 2006). The Cd concentration as 2.65 to 13.5 μg/g at Uppanar, Kaduviar & 10.5 μg/g in Vellar and 2.5 & 12.5 μg/g at Kaduviar from *C. madrasensis* (Senthilnathan, 1990). In the present study the cadmium values are very low when compared to that of the previous studies.

Copper is an essential and potentially toxic element. Ferreira *et al.* (2005) recorded a significant-spatial difference (p<0.05) for Cu in *O. equestris* in Ponta do Retiro (86 μg/g) when compared to Buena (50 μg/g) and Barra do Furado (39 μg/g). The copper concentration found fluctuated from 5.4 to 18.7ug/g in *Megapitaria squalida* (Mendeze *et al.*, 2006; 1.361±0.01 ppm in the body tissues of *Cymbium melo* (Shanmugam *et al.*, 2007); 40.0 μg/g in *C. glomerata* and 11.0 μg/g in *O. maria* (Nielson and Nathan, 1975); 2.05 ± 0.91ug.g⁻¹ in *Patella piperata* (Bergasa and Ramirez, 2007) and 2.65 μg/g in the soft tissues of *Nerita lineata* (Yap and Cheng, 2008). In the present study the mean concentration of Cu was found to be 5.2 to 43.1 μg/g which is comparatively lower than that of the earlier studies.

Accumulations of metals were generally found to be species specific and may be related to their feeding habits and the bio-concentration capacity of each species (Fariba *et al.*, 2009; Ahmed and Naim, 2008; Agoes and Hamami, 2007; Huang, 2003). The heavy metal concentrations in fish tissues from Arasalar estuary were compared with other studies and guideline values (Table).

The copper concentrations were similar to other studies (Rejomon *et al.*, 2010; Olowu *et al.*, 2010; Yilmaz, 2009; Kamaruzzaman *et al.*, 2010; Dural and Bickici, 2010; Raja *et al.*, 2009; Turkmen *et al.*, 2008; Ahmed and Naim, 2008; De *et al.*, 2010) and fishes from Gresik coastal waters of Indonesia (Agoes and Hamami, 2007). The higher accumulation of copper may be due to its relationship with molecular weight proteins (metallothionein-like). The observations on zinc were similar to other studies (Dural *et al.*, 2007; Ahmed and Naim, 2008; Turkmen *et al.*, 2008; Raja *et al.*, 2009; De *et al.*, 2010), although, Malaysia (Kamaruzzaman *et al.*, 2010), Turkey (Dural and Bickici, 2010), and Lagos Nigeria (Olowu *et al.*, 2010), south west coast of India (Rejomon *et al.*, 2010), Indonesia (Agoes and Hamami, 2007) and Iran (Fariba *et al.*, 2009).
The ability of bivalve molluscs tested in the present study to concentrate heavy metals at very high levels in different tissues and yet to survive and apparently to reproduce normally indicates that they might have evolved control or tolerance mechanisms at cellular levels. These mechanisms include the immobilization of heavy metals in membrane bound vesicles prior to their excretion from the kidney (Bryan, 1973; Carmichael, 1980; Viarengo et al., 1981; Simkiss et al., 1982) and by binding to wandering leucocytes, polysaccharides, aminoacids and proteins eg. Metallathioneins (George et al., 1978 and Roesijadi, 1980).

Seasonal changes have a decisive influence on the rate of metal uptake in both the fresh water mussel and the estuarine clam. The present study indicated the rate of metal uptake was maximum during monsoon months and minimum during summer months. The obvious reason is the variation in bio-availability of these metal in the medium. Similar seasonal variations in metal concentrations was observed in Crossostrea madrasensis from the Pitchavaram Mangrove (Subramanian, 1981) from Vellar estuary (Senthilnathan et al., 1988) Uppanar, Kaduviar and Porto Novo waters (Senthilnathan, 1990); in Villorita cyprinoids, Meretrix casta and in Pernaviridis from Cochin back water (Laksmanan and Nambisan, 1983) in Crossostrea virginica from Rhode river of the Chesapeake Bay (Frazier, 1975); in Scrobicularia Plana from the Tamar estuary (Bryan and Uysal, 1978); in Mytilus edulis from the estuaries of the coastal area of North sea and Baltic sea from South San Francisco Bay (Luoma et al., 1985; Cain and Luoma, 1985); in Mytilus edulis from Bay of Bourgeneuf, France (Amiard et al., 1986); Mytilus galloprovincialis from Gulf of Trieste (Majori et al., 1978); in mussels and Oysters from the Bay of Bourgneuf (Brethret et al., 1986).

The higher metal content observed during monsoon in the present study might be due to low salinity that facilitated the dissolution of precipitated metals and the increase in the amount of ionic species in solution with increasing bio-availability (Sundara Raj and Krishnamoorthy, 1972; Zirino and Yamamoto, 1972; Bryan and Uysal, 1978; Subramanian et al., 1979; Lakshmanan and Nambisan, 1986.

The values of cadmium were comparable with earlier reports on heavy metals in fishes from Hooghly river (De et al., 2010). However, lower than south west coast of India (Rejomon et al., 2010), Red sea (Ahmed and Naim, 2008), the fishes from Turkey (Dural and Bickici, 2010), south east coast of India (Raja et al., 2009) and fishes from Indonesia (Agoes and Hamami, 2007).
Estuarine environments are vulnerable to stress and if a key species disappears due to heavy metal pollution, no other species can replace it. A vast number of chemicals, as well as large amount of nutrients, are released into the environment daily and transported via rivers and lakes into estuarine and marine environments. Hence there is need to monitor environmental changes, with quantitative laboratory and field investigations integrated to link ecological matrices with metal body burden in sentinel aquatic organisms.

Heavy metal contamination of the environment is recognized as a serious pollution problem. Variability in metal concentrations of marine organism depends on many factors, both environmental and purely biological (Phillips, 1995). Fish are widely used as sentinels of contamination as sufficient background knowledge enables the use of certain species as bio-indicators of heavy metal pollution (Pastor et al., 1994, 1996). Metal analyses of water samples and fish tissue have revealed that metal accumulation is inversely proportional to ecosystem changes (Birge et al., 2000).

The results presented here indicate that metal distribution in the waters of the Arasalar estuary are around the normal range, as prescribed by ISI (Anon, 1986). In the Arasalar estuary, the concentrations of metals were observed to be significantly higher during monsoon than summer. These seasonal low values may be attributed to freshwater input following rain as well as due to the release of surplus water from the surrounding environment (Murthy and Rao, 1987). In an earlier study, lower metal concentrations were observed during winter and higher concentrations in Florida Bay during the summer season (Caccio and Millero, 2003).

The influence of seasonal variations of metal concentrations at Arasalar estuary, indicated high values during monsoon. This is demonstrated by the metal concentrations, of a great difference between monsoon and summer values in the Arasalar estuary. The influence of seasonal changes on the metal concentrations of the estuary can also be explained in terms of changes in river flow and changes in the geochemistry of the dissolved metals. In the Western Scheldt estuary chemical speciation studies have shown that the distribution of heavy metals is strongly influenced by salinity, dissolved organic carbon and dissolved oxygen (Paucot and Wollast 1997; Zwolsman et al., 1997 and Gerringa et al., 1998).
During summer seasons, when the fresh water inflow in the estuary is largely anoxic, dissolved metal concentrations tend to be very low and the metal partitioning in those conditions favours adsorption to suspended particles and the sediments (Mubiana et al., 2005). Generally increased dissolved oxygen level leads to the oxidation of the bottom sediments, which when re-suspended brings metals in to the water column causing secondary pollution. However, the seasonal trends in the Arasalar estuary suggests that the seasonal changes in metal concentrations observed in fish are probably due to changes in the water quality influencing levels of metal exposure. Earlier reports suggest that metal accumulation can be increased in the presence of dissolved organic carbon (Penttinen et al., 1995; Stuijfzand et al., 1999; Winch et al., 2002).

High metal concentrations in the tissues of fish inhabiting the Arasalar estuary are probably related to a high influx of metals as a result of pollution from the surrounding industries. Nammalwar (1992) reported that the concentrations of Hg, Cd, Cu, Zn, Ni, Pb and Fe in various tissues of Liza macrolepis inhabiting the Ennore estuary were found to be above the permissible safe levels. Padmini and Kavitha (2005a) reported that the brain tissue of Mugil cephalus inhabiting the Ennore estuary is subjected to severe stress as it is surviving in highly contaminated conditions. Previous studies have indicated that the Mugil cephalus in the Ennore estuary is subjected to cytogenetic damage (Padmini et al., 2006). It has been reported that there is a gender specific interaction between Se and Cu uptake that may contribute to decreased female reproductive condition in wild yellow perch (Pyle et al., 2005).

Mohaptra and Rengarajan (1998) reported that the levels of Fe, Zn, Mn and Cu in water and sediment samples showed seasonal fluctuations in the Ennore estuary. Measurement of trace metals in Mugil cephalus at contaminated sites shows that this fish accumulates metals in response to environmental contamination. This contamination may cause oxidative stress in these fish, which in turn can lead to decreased reproduction, susceptibility to infection and sudden death of fish in large numbers (Padmini et al., 2004 and Padmini and Sudha, 2004). It has been reported that M. cephalus surviving in the polluted Ennore estuary are subjected to severe oxidative stress causing considerable DNA fragmentation, potentially leading to cell death (Padmini and Kavitha, 2005b).
The 96-h LC$_{50}$ value of aquatic organisms especially fish vary from species to species and from metal to metal. In the present study, concentration of 9.6 ppm copper caused 50% mortality in *M. cephalus* during 96 hours for zinc it was 13.4 ppm, chromium 8.24 ppm and cadmium, the sublethal effect was at 6.1 ppm. Gill and Pant (1985), Kirubagaray and Joy (1988), Veena *et al.* (1997) and Lliopoulou-Georgudaki and Kotasanis (2001) reported 96-h LC$_{50}$ values of 0.181, 0.51, 0.13 and 0.51 ppm Hg, for *Barbus conchonus, Clarius batrachus, Euproctus maculates* and *Salmo gairdneri*, respectively. Johansson Sjobeck and Larsson (1978) and Gill and Pant (1985) found 96-h LC$_{50}$ values of 20.0 and 12.65 ppm Cd for *Puntius conchonius* and *Pleuronectes flesus* respectively. Das and Banerjee (1980) reported 175.0 and 300.0 ppm Cd for *Heteropneustes fossilis* and *Lebio rohita*, respectively. However, Smet and Blust (2001) observed 100% mortality in *Cyprinus carpio* after 21-29 days of exposure to 20 ppm of Cd. Holcombe *et al.* (1976) found 4.1 and 3.36 ppm total and dissolved Pb, respectively, for the 96-h LC$_{50}$ values of *Salvalinus fontinalis*, and Srivastava and Mishra (1979) recorded 19 ppm Pb for the 96-h LC$_{50}$ of *Colisa fasciatus*. However, Hodson *et al.* (1978) found 2.4 ppm Pb for the 21 day LC$_{50}$ of *Salmo gairdneri*.

The level of DNA and RNA was found to be decreased in the gills, digestive gland, liver, and muscle of test organisms due to period of exposure and different concentration of different heavy metals. Heavy metal toxicity indicates alteration in nucleic acid synthesis. Despite the importance, information on impact of heavy metals of DNA and RNA are scanty. The rapid histolysis of pesticide treated animals is the only possible reason for this. Impairment of nucleic acid metabolism the degradation of cells, resulting in the reduction in the DNA content. Furthermore, inhibition of DNA synthesis, thus, might affect both protein as well as amino acid levels by decreasing the level of RNA in protein synthesis machinery. The regulatory roles of nucleic acid metabolism as observed in the different animals when treated with the different pesticides were reported earlier (Kabeer, *et al.*, 1981; Das and Mukherjee, 2003; Asif Zaidi, *et al.*, 1990). Heavy metal appears as a potential inhibitor of DNA synthesis, which might result in reduction of RNA level. Because of toxic nature of heavy metal compounds may attack many enzymes, responsible for normal metabolic pathway (Tripathi and Verma, 2004).
RNA plays a significant role in protein synthesis; hence, depletion in RNA contents also results in depletion in protein level (Tripathi, 2002). Hence, there is a decrease in RNA level, thus reducing protein synthesis (Maruthanayagam and Sharmila, 2004), and reported similar results. This is because the animal requires more energy to overcome the stress upon exposure to the heavy metals. As a result, the animal prefers glucogenesis to protein synthesis and diverts all the metabolites for carbohydrate biosynthesis (Tripathi, 2003). Significant declines in RNA level were observed in treated fish, which might also be any obstruction in RNA synthesis. The decrease in RNA may be suggested that the daily addition of heavy metals results in the swelling and chromatolysis of Nissl bodies which are rich in RNA.

Tripathi (2003), also reported that fish exposed to Dimethoate exhibited a decrease in nucleic acid (DNA and RNA) content. The reason for decreased nucleic acids levels in liver under the influence of carbosulfan treatment in mice might caused genotoxic actin by decreased mitotic index and disturbed cell division (Topktas et al., 1996) or due to inhibitory action of pesticides on DNA and RNA synthesis (Walter et al., 1980) or by cell death due to focal necrosis (Shivanandappa and Krishnakumari, 1981). The effects of sublethal concentration of Fenvalerate on DNA, RNA, RNA/DNA ratio and protein contents were estimated in gill and kidney tissues of an air breathing fish, Clarias batrachus. Fenvalerate reduced the DNA content in gills, whereas it dose not produce any significant effect on DNA in kidney. This tissue-specific change in DNA content may be due to differential effects of Fenvalerate or its metabolite(s) on synthesis and degradation of DNA in gill and kidney cells of the fish (Tripathi et al., 2002). Toxicants that cause genetic effects may be present at very low, sub-lethal concentrations (Anderson et al., 1994). Toxicants appear as a potential inhibitor of DNA synthesis, which might result in reduction of RNA level. Because of toxic nature, the metal compounds may attack many enzymes responsible for normal metabolic pathway (Tripathi and Verma, 2004).

Thus, from the present investigation, it can be concluded that the marked decrease in the DNA and RNA content upon exposure to heavy metals may be due to decrease in protein synthesis, impairment of nucleic acid metabolism, the degradation of cells, resulting in the reduction in the DNA, most decrease was found in the liver and least in the gill. Thus, it is possible that these heavy metals will have inhibited the enzyme necessary for DNA synthesis. On compilation of the results, it appears that the disruption of DNA synthesis might have affected RNA synthesis.
Histological study of the gills showed a typical structural organization of the lamella in the normal hermit crabs (Plate 1a). The treated (Plate 1-4) however, showed progressive architectural distortion at the end of the exposure period. This corroborates with the observation of Jana and Bandopadhyaya (1987) which reported that, gill is an important tissue because of its direct contact with water and any effect or agency has to go through it to come into the fish body. The lamella epithelial lining reacts to dissolved lead creating tissue osmoregulatory imbalance.

The histopathological studies help in understanding the stress caused to the animal exposed to pollution. This is a universal method for the assessment of the impact of xenobiotics on the tissues of animal. The ability of any tissue to regulate its normal physiological function is extensively related to its structural integrity. Any damage to the tissues usually results in altered and frequently abnormal metabolic activities.

The changes in the morphology of the gill filaments, the atrophy of the ciliated epithelial cells and the damage of chitinous rods are pathological indices of the gill filaments of bivalves exposed to heavy metals and thermal stress (Sunila, 1986). Discussing the effects of these damages on general performance of bivalves, Sunila (1988) has pointed out that damage of gill filaments would have an effect either on respiration or food transport. She, however, says that the nature of damaged cells could be different, thus the endothelial cells can become granular when exposed to copper, whereas it can render cells highly vacuolated when exposed to silver. According to her, the inflammatory reaction in the gill is characterised by the dilation of brachial vessels. The findings of Sunila (1988) that nature of damage of gills by heavy metal toxicity could be different in animals living in the coastal waters and those exposed in the laboratory opens up an issue which needs further clarifications.

In general, the heavy metals selected were found to cause damage to the tissues of vital organs namely gill. In the gills, the disintegration of inter-filamenter junctions, dilation and shrinkage of branchial vein were observed. Similar branchial vein damage and breakdown of interfilamenter junctions were observed by Donde (2006) in G. divericatum exposed to WSF of crude oil. The gills are the vital organs for respiration and feeding and are exposed directly to the surrounding water. The loss of lateral cilia would affect the circulation of water through the gill filaments
and the transport of food particles to the mouth. This in turn can disturb the flow of oxygenated blood this causing anoxia which ultimately affect the normal metabolic activity of the animal.

The studies on histology and histopathology have been proved to be a very useful tool in assessing pollutant induced injury to whole animals. It is known that there will be structural and functional alterations in individual cell types or group of cells at an early stage of response before alteration in cellular structure could manifest at organism level (Moore, 1980). Normally injured cells undergo structural alterations. These alterations can have at least two phases, the reversible alterations are leading to total disruption of cellular function and hence death of cell which can be called as irreversible change (Trump and Arstilla, 1975). Viarengo et al. (1982), evaluating the general and specific stress indices in mussels inhabiting an environment with a definite pollution gradient found that the digestive gland of animals sampled from heavy metal polluted area had a high concentration of low molecular weight thioneine like copper binding protein. It is possible that accumulation of cellular secretions of intra cellular origin is a response of increased activity by those intrusions responsible for such secretions. High vacuolization of digestive cells is known to be one of the manifestations of stress response which is indicative of the increased lysosomal number.

The cells of the digestive epithelium belonging to the tubules have shown degeneration and structural alterations at various degrees. Workers on histopathology have identified structural changes in digestive cells involving atrophy or epithelium thinning. There is a tendency in the case of workers to generalize such changes to stressor effects mainly xenobiotics or prolonged starvation (Bayne et al., 1978; Pipe and Moore, 1985; Moore et al., 1987). The structural assay of cellular damage has shown that there was enlargement of cells of digestive tubules resulting in bulbous epithelial structure or total atrophy resulting in thinning. The enlargement of cells results in overall increase in volume of cells because of formation of enlarged or giant lysosomes. This subsequently leads to atrophy of digestive cells. The functional aspect being confined to autolytic or autophagic activity brought in by the enlarged lysosomes.

The digestive gland is the centre for metabolism and detoxification in molluscs (Thompson et al., 1974). On the chronic exposure to heavy metals, the
hepatopancreas exhibited several pathological changes including shrunken of digestive and secretory cells, vacuolation, rupturing of cell membrane, atrophy of digestive cells and necrosis. These changes were linearly proportional to exposure period.

The present study closely agrees with a similar report by Muley and Mane (1986) in the hepatopancreas of lamellibranch molluscs, *Lamellidens corrianus* and *L. marginalis* exposed to pesticide endosulfan. The histopathological alterations observed, were the ruptured basement membrane and muscular layer and shrunken of digestive and secretory cells. The vacuolation, atrophy and rupturing of cell membrane in *L. marginalis* by Amanulla Hameed et al. (2005) due to copper toxicity have been reported. Tubular damage and heavy vacuolization in tubules in *Perna viridis* (Sreekala Pillai and Menon, 1998) and reduction in the size of digestive cells of *Mactra violacea* (Shah et al., 2003) have been reported. Auffret (1988) observed that *Mytilus edulis* exposed to high concentrations of diesel oil and copper mixture showed severe degenerative changes in the epithelium of the digestive gland. Epithelial cell shrinkage, erosion of cells and large vacuoles in the digestive tubules noticed in the present work have suggested as the effects of copper and cadmium by Mathew and Menon (2005) in the mussel *Perna indica*.

The digestive gland of mollusc is one of the target organs in toxicological prospects regarding its role in detoxification bio transformation and excretion of xenobiotics. Thus, the present study reveals the impact of heavy metals on the histology and ultra structural of digestive gland cells of *M.casta*. The digestive cells showed severe cytoplasmic vacuolization, necrosis and atrophy especially after 30 days of metal exposure. This results confirmed the investigation in the digestive gland of snails *B. dissimilis* exposed to endosulfan, methyparathior, quinalphos and Nuvan (Jonnalagadda and Rao, 1996), *M. obtucta* exposed to lannate (Zedan et al., 1999) *E. vermiculata* exposed to oxamyl (Aioub et al., 2000) *Planorbarius corneus* exposed to endosulfan, (Otludil et al., 2004), *Galba truncatula* exposed to thiodan (Cengiz et al., 2005).

According to Cladwell (1997), the end result would be reduced flow of oxygen-enriched water to lamellar tissues and ultimately, a reduction in the
performance capacity of the fish. The change in physiological property was evident in the shrinkage and fusion observed at the lamella thus, suggesting that lead intake mostly occurs via gills. In cadmium treated gill marked hyperplasia of bronchial arch, pilaster cell vacuolization and congestion of blood vessels were well marked. The results are in parallel with the works of Kapila and Ragothaman (1999) who reported for *Boleopthalmus dumeric* exposed to sublethal concentrations of cadmium. Histopathological changes in the gill of *Labeo rohita* were reported by Vijayalakshmi and Tilak (1996) which included epithelial proliferation, congestion of blood vessels and hyperplasia. Tilak *et al.* (2005a) subsequently reported dropsy, vascular degeneration, cloudy swelling and necrosis in epithelial and pillar cells of the gills upon chlorpyrifos intoxication.

The high accumulation of heavy metals in the liver, which Gbem *et al.* (2001) also noted in their findings, is related to the fact that liver plays a role in accumulation and detoxification. It appears to be a general feature of the liver of intoxicated fish that the degree of structural heterogeneity is enhanced with increasing concentrations of the toxicant (Hawkes, 1980). Although, according to Friberg *et al.* (1971), fishes are known to possess sequestering agent (metallothionein) and the bioaccumulation of these trace elements in the liver tissue reaches a proportion in which the function of the liver is impeded, thus resulting in gradual degeneration of the liver and syncytial arrangement. The surface area of the liver cell is also decreased, which may be due to increase in intrabiliary fibre-connective tissue. The vacuolization observed are zones of total cell degeneration. Similar degenerating changes were observed in liver of both sexes of *Cyprinus carpio* after exposure to HgCl$_2$ at 0.1 ppm for 45 and 60 days (Masud *et al.*, 2001 & 2003).

The normal histology and the remarkable histopathological changes in the gill and hepatopancreas of the estuarine hermit crab, *C. infraspinatus* exposed the sublethal concentration of the heavy metals Cu, Zn, Cr and Cd were depicted in the Plate 1-4. In the present investigation, a number of histopathological conditions have been observed in the gills and hepatopancreas of the Cu, Zn, Cr and Cd treated hermit crabs. The damage was found to be severe in hermit crabs exposed to 30%
sublethal concentrations than 10% of heavy metals. These reflects the time and dose dependent nature of metals toxicant. Histological lesions of gill of *C. infraspinatus* heavy metals exposure shows swelling and fusion of the lamellae, disintegration of epithelium, accumulation of haemocytes in the haemocoelic spaces, necrosis and malformations of the tips of the gill lamellae. These finding fall in line with cadmium exposed *Penaeus duorarum* (Couch, 1977), copper exposed *Macrobrachium* sp. (Ghate and Leela Mulherkar, 1979), Crude oil exposed *Scylla Serrata* (Chandy and Kolwalker, 1984), Cu and Zn exposed *C. longitorsus* (Lyla, 1991) and lead exposed *Liza parsia* (Pandey et al., 1997). They suggested that those histological changes were primarily due to interaction between mucous secretion and heavy metal ions and secondarily due to destruction of respiratory system because of the damage caused to the gill epithelium. Establier et al. (1978) have reported the fusion of gill lamellae in *Discentrarchus labrax* after heavy metal treatment also they have suggested that the fusion of lamellae might have been due to the sticky nature of the mucous film formed over the gill.

The hepatopancreas of decapod crustaceans is involved in several functions, namely absorption of food, synthesis and secretion of digestive enzymes, storage of lipid, glycogen and minerals Smith et al. (1975). In addition, it is the principal site of accumulation of heavy metals such as lead, copper and zinc (Loizzi, 1971).

The histopathological studies revealed the structural alterations in the cells that were wrought by exposure to heavy metals. The hepatopancreas of Cu, Zn, Cr and Cd exposed hermit crabs were characterised by disorganisation of hepatopancreas tubules, modification of epithelial cell nuclei which become irregular, flat and pycnotic, atrophy of digestive cells, necrosis and vacuolisation of the digestive tubules. These findings fall in line with zinc intoxication of *C. longitorsus* reported by Lyla (1991), copper in *Metapenaeus dobsoni* reported by Manisseri and Menon (1995). Virginia popescu-Marinescu et al. (1997) have also reported disorganisation and destruction of hepatopancreas tubules, disappearance in the epithelial cell, modification of epithelial cell nuclei and disintegration of connective tissue in *Astacus lepodactylus* when exposed to copper.

In the present investigation, heavy tubular damage and more vacuolisation of cells, in the hepatopancreas were observed in the hermit crabs exposed to 30%
sublethal concentrations of heavy metals. Similar observations were made by Sreekala Pillai and Menon (1998) and concluded that the high vacuolisation of digestive cells is known to be one of the manifestations of stress induced response, which is an indication of increase in lysosomal number.

Gills are the major respiratory organs and all metabolic pathways depend upon the efficiency of the gills for their energy supply and damage to these vital organs cause a chain of destructive events, which ultimately lead to respiratory distress. Pronounced secretion of mucus layer over the gill lamellae has been during malathion stress. Secretion of mucus over the gill curtails the diffusion of oxygen (David et al., 2002), which may ultimately reduce the oxygen uptake by the animal.

Gills are the major route for the entry of heavy metals into the fish (Olsen and Fromm, 1973) and they also accumulate significant amount of metals as compared to other tissues. Epithelial cells of the secondary gill lamellae of Cr treated O.mossambicus showed an initial hypertrophy and vacolization. These alterations appear to be a general response of the gill to heavy metal pollution (Kumar and Pant, 1981; Pandey et al., 1996). The Oedematous changes observed at the base of primary and secondary gill lamellae of O.mossambicus could probably due to the increased capillary permeability or lowered efficiency of the epithelial cells in maintaining normal water balance (Roberts, 1989; Pandey et al., 1996). They progressive hyperplasia, necrosis and degeneration of epithelial cells were observed in the gill of O.mossambicus on prolonged Cr treatment. Similar findings have been reported in Puntius sophore (Khangarot and Somani, 1980), Liza parsia (Pandey et al., 1996) Mystus guilio (Amanulla Hameed et al., 2004) and in O.mossambicus (Amanulla Hameed et al., 2005) may be due to heavy metals intoxication.

Histological structures of liver of the freshwater fish O.mossambicus are almost similar to those described for a number of fresh water teleosts namely Salmo clarkii (Eisler, 1971), C.punctotus (Anees, 1976; Dubale and Shah, 1979; Bhattacharya et al., 1985) Carassinus auratus (Sultan and Khan, 1983), Salmo Salar and S.gairdeneri (Roberts, 1989).
Helmy et al. (1979) and Krishnakumari et al. (1983) have demonstrated the toxicity of Hg in the estuarine fishes Liza marolepis and Therapan jarbua respectively. Present study revealed that chromium induced pathological changes in the liver of O.mossambicus Jackim et al., (1970) have shown that the salts of Pb, Hg and Cu caused detrimental effects on the hepatic enzymes in Fundulus heteroclitus. Dubale and Shah (1979) reported degenerative changes like vacuolization of cytoplasn and shrinkage in nuclei of channa punctatus exposed to varying concentrations of cadmium nitrate. Destruction of cytoplasmic materials and vacuolization of hepatocytes of Carassius auratus in response to acute and chronic exposures of copper sulphate were observed by Sultan and Khan (1983). Liver of Sarotherodon mossambicus exhibited engorged blood sinusoid, vacolication, granular degeneration of hepatocytes, oedema focal necrosis and proliferation of fibroblasts to lethal and sublethal HgCl₂ treatments (Naidu et al., 1983). Recently, Bhattacharya et al. (1985) also noticed clumping of cytoplasmic materials, displacement of nuclei towards periphery and coagulation of blood sinusoids of C.punctatus treated with 0.60 ppm of HgCl₂. The observed progressive degenerative changes in the liver of O.mossambicus in response to chromium intoxication supports the findings of O.mossambicus (Naidu et al., 1983) and C.punctatus (Bhattacharya et al., 1985). Present results on the histopathological changes in O.mossambicus to 10% sublethal concentration of chromium intoxication correspond well with the observations made in 1.0 mg/L malthion treated. C.punctatus (Dubale and Shah, 1979b) and DDT and mercuric chloride treated Liza parsia (Pandey et al., 1996).

The SEM is a technique that allows the study of the damage of surface ultrastructure of the gill epithelium that can not be revealved by light or TEM (Devos et al., 1998). The scanning electron micrographs of the gill epithelium also revealved that rohu of untreated group showed normal architecture. In contrast the present study showed that the gills of Mugil cephalus exposed to heavy metals during thirty days presented a higher occurrence of histopathological lesions such as hypertrophy, fusion of secondary lamellae, edema and mucus openings. These pathological changes may be a reaction to toxicants intake or an adaptive response to present the entry of the pollutants through the gill surface (Mohamed, 2009). The damages observed in the gills in terms of hypertrophy, fusion of secondary lamellae and necrosis could cause a decrease in free gas exchange, thus affecting the general
health of fish (Skidmore and Tovell, 1972). Similar of these changes in gill epithelia of *Oreochromis niloticus* were ultrastructurally observed by Nath and Kumar (1989). Crespo (1982) in the dog fish, *Scyliorhinus canicula* subjected to zinc sulphate; Temmink *et al.* (1983) in rainbow trout, *Salmo gairdneri* exposed to chromate; Gupta and Dua (2002) in the *Channa punctatus* intoxicated with mercury. Pane *et al.* (2004) in *Oncorhynchus mykiss* treated with nickel. Acharya *et al.* (2005) in *Labeo rohita* treated with sublethal acidic (HCl) and alkaline (NaOH) pH. In the study of Muthukumaravel *et al.* (2008), copper exposure resulted in marked ultrastructural damage to the respiratory epithelium of gill in *Oreochromis mossambicus* including swelling and fusion of secondary lamellae. Palaniappan *et al.* (2008) observed hypertrophy, hyperplasia, alteration of lamellar surface and fused lamellae in pb exposed *Catla catla*. In fishes, the gills play vital roles, since they are the main site of gaseous exchanges. Further more, they are involved in osmoregulation acid – base balance (Mc Donalh *et al.*, 1991 and Goss *et al.*, 1992) and excretion of nitrogenous compounds (Goldstein 1982; Evans and Cameron, 1986; Sayer and Daven Post, 1987).
VI. SUMMARY AND CONCLUSION

Heavy metals have the tendency to accumulate in various organs of estuarine organisms, especially fish which may in turn enter into the human metabolism through consumption causing serious health hazards. Hence, the present study was initiated to assess the level of heavy metals in different tissues of hermit crab, clam and fish collected form Arasalar estuary at Karaikal and their seasonal variations from July 2010 to June 2011 to know the extent of heavy metal pollution probably due to industrial waste water discharge by using as a biological indicator.

Physico-Chemical parameters in Arasalar Estuary

Physico-chemical parameters such as temperature, salinity, pH and dissolved oxygen were studied. They were influenced by rainfall and water discharge. North East monsoon (October – December) brought maximum rain to this region. Rainfall was scanty during post monsoon (Jan - March) and summer (April - June). Data on temperature, salinity, pH and dissolved oxygen of the present study showed significant difference with respect to seasons. Maximum dissolved oxygen and nutrients such as total phosphorus, nitrate and silicate were recorded during monsoon months and minimum values were recorded during summer months similarly maximum temperature, pH and salinity were recorded doing summer months and minimum values were recorded during monsoon months. pH of the water showed alkaline range throughout the study period.

Heavy metal concentration in water and sediments

Heavy metal concentrations in estuarine water and sediments showed higher values during monsoon and lower during summer. Among the four metals (copper, zinc, cadmium and chromium) studied, zinc concentrations were found to be maximum.

Bio accumulation of heavy metals in Clibanarius infraspinatus, Meretrix casta, and Mugil caphalus

The accumulation was observed in tissues of gill, hepatopancreas and muscle (hermit crab), gill, digestive gland, and foot (clam) and gill, liver, and muscle (fish). The analysis of the selected metals in the present study revealed an order of Zn > Cu >Cr > Cd in almost all the species.
Heavy metals accumulated as per order *Meretrix casta*, *Clibanarious infraspinatus* and *Mugil Cephalus*. The results revealed that the Zn and Cu concentrations were highest in all tissues analysed followed by Cr and Cd in almost all the three species.

The order of metal accumulate ability of these organs had been hepatopancreas > gill > muscle (Hermit crab); digestive glad > gill > Foot (Clam) and liver > gill > muscle (Fish). The general pattern of metal accumulation in different organs remains the same in all three species

**Effect of Toxicity of heavy metals on Clibanarius infraspinatus, Meretrix casta and Mugil caphalus**

The acute toxicity bioassays (96 h LC$_{50}$) were conducted for heavy metals zinc, cadmium, copper and chromium. The degree of toxicity was greater in cadmium. The degree of toxicity was in the order of Cd> Cr> Cu> Zn. Sub lethal concentrations namely 1/10 and 1/30 of the 96h LC$_{50}$ values were selected for these heavy metals for studying their effects on nucleic acids and histological aspects.

**Effect of the heavy metals on the nucleic acids (RNA and DNA) Meretrix casta Clibanarius infraspinatus and Mugil caphalus**

The effect of sub lethal concentrations of heavy metals on RNA and DNA content were studied in the hermit crab, clam and fish up to 30 days at an interval of 10 days. The exposed organisms exhibited various changes in nucleic acid composition. The changes were dependent on the period of exposure and concentrations of toxicants. The effect of cadmium was found to be more pronounced than that of zinc, copper and chromium.

**Effect of the heavy metals on the histology of various organs of Meretrix casta, Clibanarius infraspinatus and Mugil caphalus**

Histopathological lesions in the gill, hepatopancreas and muscle of *C. infraspinatus*; gill, digestive gland and foot of estuarine clam *M. casta*; gill, liver muscle of *M. cephalus* were assessed by 10% and 30% sublethal concentrations for 30 days exposure to the different heavy metals
Histological changes in the gill, hepatopancreas and muscle of *C. infraspinatus* induced by heavy metals

The main histopathological changes observed in the gill were disintegration of epithelium, accumulation of haemocytes, fusion of gill lamellae and abnormal gill tips. The hepatopancreas of hermit crab exhibited a normal structural pattern while the hermit crab exposed to heavy metals showed vacuoles, necrotic digestive cells and abnormal lumen. The findings in muscle exhibited the presence of atrophy and degeneration of muscle bundles. The damage was more severe and progressive after 30% sublethal concentrations of heavy metals for 30 days exposure.

Histological changes in the gill, digestive gland and foot of *M. casta* induced by heavy metals

Histopathological examination of gill revealed vacuolation, hypertrophy, loss of inter lamellar junction and enlargement of gill filament. Pathological changes of digestive gland exhibit exhibit atrophy of digestive cells, vacuolization and degeneration of digestive tubules; vacuoles and degeneration of muscle bundles in foot.

Histological changes in the gill, liver and muscle of *M. cephalus* induced by heavy metals

Fish exposed in the heavy metals the most common lesions were fusion of gill lamellae, degeneration of gill epithelium, necrosis and hypertrophy of respiratory epithelium in the gills; dilation of blood sinusoids, vacuolization, hypertrophy and disintegration of cell boundaries in the liver; atrophy and degeneration of muscle bundles in the muscle.

Effect of heavy metals on the ultrastructure (SEM) studies of the gill:

Scanning electron microscopic studies revealed that the fusion of gill filament, erosion of gill epithelium, mucus secretion and vacuolization in the architecture of heavy metal exposed gill of hermit crab, clam and fish.
Conclusion

The results obtained in the present study from the Arasalar estuary were well below the tolerance limit (Cu-3mg/g; Zn-5 mg/g; Cd-0.1mg/g; Cr-0.05 mg/g) for industrial effluents prescribed by ISI (1994). Trace element levels in analysed tissues were acceptable to human consumption at nutritional and toxic levels. This study indicated that the Arasalar estuary are not highly contaminated but at the same time there is a possibility of gradual addition of heavy metals in due course.