VI. SUMMARY

An investigation was carried out from January to December 2005 in Haladi-Chakra estuarine complex, Coondapur to understand the spatial and temporal variation in the physico-chemical characteristics of water and sediment features and also to know the abundance and distribution of phytoplankton, zooplankton, fish and macrobenthos. Monthly samplings were carried out at 5 selected stations, two stations in Haladi estuary (station 2 and 3) and two stations in Chakra estuary (station 4 and 5) and one located at the confluence (station 1).

The salient feature finding of the present study are presented below:

Meteorology

- The study area experienced a total of 3296.10 mm annual rainfall, over 89.52% occurred between June and September.

- Air temperature exhibited a trimodal seasonal oscillation. The maximum and minimum air temperature was noticed between 34.22°C and 25.64°C in May and September respectively. It exhibited annual range of 8.58°C.

Hydrographical parameters

- Water temperature during present study fluctuated from 23.30°C to 33.20°C with annual range between highest and lowest of 9.9°C. Water temperature exhibited bimodal seasonal oscillation.

- The water pH varied from 6.61 to 8.12. The pH was recorded maximum in May and minimum in July. The stations located away from confluence
revealed generally lower values of pH than stations located near and at confluence.

- The surface water dissolved oxygen content, ranged from 0.0 to 7.81mg/l with an annual range between highest and lowest to be 7.81mg/l. The dissolved oxygen content varied widely with space and time. The seasonal distribution of dissolved oxygen exhibited by and large bimodal seasonal oscillation with two maxima in June and December and two minima in May and September. The spatial variation of dissolved oxygen indicated that stations located at and near the confluence registered a large variation between months. Whereas the stations located away from the confluence registered a narrow range of variation between months.

- The surface water salinity fluctuated from 0.21 ppt to 34.49 ppt registering an annual range of 34.28 ppt. Based on seasonal variation the estuary can be divided into three distinct salinity regimes; a higher saline regime in pre-monsoon season, extremely lower regime during monsoon season and moderate regime during post-monsoon season. Thus, three types of brackishwater conditions such as mixoeuhaline, liminetic and mesohaline was noticed in this estuary.

**Nitrogenous-nutrients**

- The ammonia concentration fluctuated from 0.0 to 17.99 μg-at/l. The ammonia concentration during this investigation exhibited bimodal seasonal oscillation. It exhibited peaks in pre-monsoon, monsoon season and gradual stepping up trend in post-monsoon season. The pre-monsoon peak could be attributed to intense biological activity. While the monsoon peak to the increased freshwater drainage.

- The nitrite concentration varied from 0.20 to 4.23 μg-at/l in surface water. It exhibited trimodal seasonal oscillation with peaks in February, July/August and January. The spatial distribution revealed lower nitrite
concentration with peaks at and near confluence, when compare to those stations located away from confluence.

- The nitrate concentration varied from 1.40 to 20.97 μg-at/l. The nutrient exhibited trimodal seasonal oscillation with peaks in April/May, July and January respectively. The spatial variation of this nutrient revealed higher values in Haladi estuary than in Chakra estuary.

**Nutrients**

- The surface water phosphate ranged between 0.24 to 9.34 μg-at/l. This nutrient exhibited bimodal seasonal oscillation with peaks in February/May of pre-monsoon and July of monsoon season. It exhibited decreasing trend in post-monsoon season in all the stations.

- The silicate concentration during this investigation ranged between 0.19 to 91.14 μg-at/l. This nutrient did not exhibited any clear-cut seasonal oscillation. The stations located at a near confluence registered comparatively higher values than that of values recorded by other authors along the west cost and it exhibited peaks and troughs every alternative month throughout the period of study.

**Phytoplankton pigments**

- Chlorophyll-a in present investigation varied from 0.54 mg/m³ to 50.21 mg/m³. The chlorophyll-a concentration recorded in this estuary were slightly higher than that of values recorded by other authors along west coast and it exhibited a trimodal seasonal oscillation. It exhibits peaks in March, July/August and October/November respectively.

- Phaeophytin concentration fluctuated between 0.92 to 61.74 mg/m³. It exhibited trimodal seasonal oscillation. Similar to chlorophyll-a the
phaeophytin pigments were present in higher concentration, which reflects productive potentiality of Haladi-Chakra estuary.

**Sediment characteristics**

- The sediment temperature fluctuated between 25.5°C to 32.9°C with an annual range of 7.4°C. During pre-monsoon season, sediment temperature exhibited the higher values during the monsoon season and showed the decreasing trend and increased slightly in post-monsoon season. The seasonal fluctuation of sediment temperature exhibited bimodal seasonal oscillation.

- The sediment pH fluctuated from 6.18 to 9.19. Sediment pH showed alkaline condition throughout the year except in August with slide acidic condition. Spatial variation indicated that the confluence region showed higher values with slight decreasing trend towards the riverine stretch. However, the sediment pH exhibited lower values in monsoon season and higher in post and pre-monsoon season.

- The sediment texture at the confluence region exhibited the dominance of sand followed by slit and clay. Whereas in Haladi and Chakra estuary, the sediment texture exhibited the dominance of sand but lesser than confluence followed by silt and clay. The proportion of clay was more in confluence region. At confluence region sand contributed more than 94.97%, silt of 1.12% and clay of 0.02%. Whereas in Haladi stretch, the contribution of sand was more than 42.70% followed by silt of 0.91% and clay of 0.01%. But in Chakra stretch sand of 53.03%, silt of 1.38% and clay of 0.01% was observed. The composition of sediment indicate that Haladi-Chakra estuarine complex is greatly dominated by sand > silt > clay.

- The organic carbon content of the sediment exhibited a trimodal seasonal oscillation with one predominant peak in monsoon season and two smaller
peaks in pre and post-monsoon season. The spatial distribution of organic carbon during the study revealed comparatively higher percentage in Chakra estuary than that of confluence and Haladi estuary and fluctuated between 0.03 to 1.67%.

Phytoplankton

- Cyanophyceae in these estuaries consisted of 7 genera such as *Anabaena*, *Lyngbya*, *Merismopedia*, *Nostoc*, *Oscillatoria*, *Spirulina* and *Trichodesmium*. Among these blue green algae *Trichodesmium*, *Merismopedia*, and *Oscillatoria* occurred more frequently. *Trichodesmium, Nostoc and Oscillatoria* occurred in pre-monsoon season at all stations except at station 3. In monsoon season, moderate numbers of *Merismopedia, Oscillatoria and Trichodesmium* were recorded. During post-monsoon season, *Oscillatoria* along with *Merismopedia* formed the bulk of blue green algae. The greater abundance of blue green algae was observed only when salinity was higher in pre and post-monsoon season. During low saline regime species of *Spirulina* and *Lyngbya* were found along with *Oscillatoria* in low numbers.

- Chlorophyceae consisted of 16 genera during this investigation. Among them *Ulothrix*, *Mougeotia*, *Closterium*, *Pediastrum*, *Staurastrum*, *Sphaerocystis*, *Dinobryon*, and *Zygnema* occurred more frequently with fairly good numbers. *Ulothrix* was found in greater numbers as well as with frequent occurrence in all stations except at station 1 located at confluence. Chlorophyceae documented with primary dominant peak in pre-monsoon season followed by a small rise in monsoon and post-monsoon season and the remaining stations located in Haladi and Chakra estuaries showed dominant peak in monsoon season followed by secondary peak in post-monsoon and small rise in pre-monsoon season.

- Bacillariophyceae was recorded with 26 genera such as *Biddulphia*, *Nitzschia*, *Coscinodiscus*, *Ditylum*, *Rhizosolenia*, *Melosira*, *Chaetoceros*, *Campylodiscus*, *Pleurosigma*, *Streptothecae*, *Fragillaria*, *Cyclotella* and *Thalassiothrix* were documented in most of stations during this
investigation. The numerical abundance in whole study revealed greater abundance and richness of diatom at Haladi estuary followed by confluence and Chakra estuary. The higher density of diatom coincided with mixoeuhaline condition of water with peaks in pre and post-monsoon season.

- Dinophyceae during this investigation was represented by 5 genera such as *Ceratium*, *Peridinium* and *Periperidinium*, which occurred frequently and in large numbers; whereas *Noctiluca* and *Dinophysis* occurred in lower numbers and less frequently. Seasonal distribution exhibited trimodal oscillation with two peaks in pre-monsoon season and small peak in monsoon and post-monsoon season. Spatial distribution revealed greater diversity richness at confluence and stations situated in Haladi estuary.

**Zooplankton**

In the present study, totally 16 different groups of zooplankton were observed.

- The abundance of medusae during the study period were observed in August at confluence region. The abundance of medusae were more in post-monsoon season followed by pre-monsoon and monsoon season. Whereas siphonophores occurred in meager numbers only in May. The abundance of hydromedusae at confluence region dominant the Haladi and Chakra estuary.

- The ctenophores represented by adult and juvenile *Pleurobranchia* sp. and *Mnemiopsis* sp. They occurred sporadically during pre and post-monsoon season. During monsoon season, ctenophores consisted mainly of juvenile *Pleurobranchia* sp. which breeds in adjoining coastal waters. The abundance of *Pleurobranchia* sp. was more in the stations located in Haladi estuary and the confluence region. The numerical abundance in Chakra estuary was lower when compared to Haladi estuary.
The quality composition of chaetognath and chaetognath larvae revealed the presence of *Sagitta beloti, Sagitta setosa, Sagitta polchra, Sagitta enflata* and *Eokonia* sp. The pre-monsoon peaks of chaetognath were dominant in March except at station 4 and the post-monsoon peak was observed in October at confluence and Haladi estuary. The frequency of occurrence and the numerical abundance of chaetognath were more at confluence and Chakra estuary respectively. The pre-monsoon peak of chaetognath larvae was documented in February/ March, monsoon peak in August/ September and the post-monsoon peak in October. The distribution of these groups is influenced by topography of estuarine basin, which could possible make free flow of tidal waters to the estuarine regions.

The seasonal distribution of polychaete revealed lesser in pre-monsoon season. The monsoon peak was observed in September (station 1). The post-monsoon peak was dominant in October (station 1 and 2) and November (station 3) respectively. The moderate peak was observed in station 4. The post-monsoon peak was more dominant than pre-monsoon and monsoon peak except at station 4. The polychaete in the present study revealed more numbers at confluence.

The seasonal fluctuation of polychaete larvae indicated a peak abundance in February of pre-monsoon season at all stations. The monsoon peak was maximum in August and formed the secondary peak. The post-monsoon peak in January month. The pre-monsoon peak dominant in almost all the stations most of this larvae belong to family Spionidae and Sabellaridae. The polychaete larvae exhibited trimodal seasonal oscillation. The polychaete larvae were more dominant in stations at and near to the confluence.

The cladocera consisted of *Penilia avirosteris* and *Evadne tergestina*. The pre-monsoon peak of *Penilia* sp. were observed in April except in station 5 (March) and in station 1 (February). The monsoon peak in August/ September. The post-monsoon peak was observed in October (station 1
and 2) and December (station 3, 4 and 5). The post-monsoon peak dominant the pre-monsoon peaks. The confluence region registered more abundance than the Haladi-Chakra estuary.

The pre-monsoon peak of *Evadne* sp. were observed in February and April (station 2). The monsoon peak was not clear but attains maximum in August (station 1, 2 and 5) and September (station 3 and 4). The post-monsoon peak was noticed in October (station 1 and 2) and December (station 3, 4 and 5). The *Evadne* sp. dominant in pre-monsoon and post-monsoon season. The stations at confluence and Chakra estuary dominant the Haladi estuary.

The group cirripidea was represented by nauplius and cypris stages. The seasonal distribution barnacle nauplii revealed the presence of greater abundance in different months of pre-monsoon season at different stations. It shows peak in February/March. The monsoon peaks in August month. Whereas the post-monsoon peak was observed in October (station 1, 3 and 4) and November (station 2 and 3). During the present study, barnacle nauplii exhibited trimodal seasonal oscillation. The clear cut spatial variation could not observed during present investigation. The greater abundance were recorded in pre and post-monsoon season. The low numbers in monsoon season was due to low saline condition. During the present study, cypris larvae were present at two instances one in August (station 1) and another in September (station 4).

The copepods were most dominant form of zooplankton in the present study. Copepods were present at all the stations throughout the period of study. The greater abundance in February/May of pre-monsoon season. In monsoon season, the population density of copepods declined in all the stations and gradual increased in September. During post-monsoon season, they occurred with two small peaks in November/January at stations in Haladi estuary, during October/ January at confluence. The pre-monsoon and post-monsoon abundance was more intense than that of monsoon season. The spatial distribution revealed more abundance in stations away
from the confluence. The abundance was more in Haladi estuary. The quality composition of copepod revealed the presence of various species belonging to genera *Acartia*, *Paracalanus*, *Pseudodiaptomous*, *Centrophages*, *Microsetella* and *Eutripina*. The group Cyclopoidae consisted of species belonging to genus, *Oithona*, *Corycaeus*, *Oncia*, *Cyclops* and *Diaptomous*. Among the three different forms of copepods the Cyclopoidea and Herpecticoidea dominated the samples collected during monsoon season. While pre-monsoon samples contained copepods belong to group Calanoidae and Cyclopoidae.

- The copepod larvae were present throughout pre and post-monsoon season with very low density during peak monsoon season and showed peak in September month. The copepod larvae exhibited trimodal seasonal oscillation with primary peak in March, secondary peak in September and post-monsoon peak in January. The copepod larvae dominant in pre and post-monsoon season. Based on the abundance of larvae with that of salinity variation, it is revealed that copepod larvae exhibit intense breeding in mixoeuhaline conditions during monsoon and moderate breeding in polyhaline condition during post-monsoon season.

- The seasonal distribution of lucifers revealed the presence of higher number in May of pre-monsoon season and completely absent in April month. The monsoon peak was observed in September. Whereas the lucifers occur in two instances in October (station 1 and 4) of post-monsoon season. It is observed that pre-monsoon abundance were more dominant than that of post-monsoon season.

- In the present study, shrimp nauplius, protozoea, the post larvae of shrimp, zoea, mysis and megalopa formed the bulk of decapod larvae. Among them, post larvae of shrimp, zoea, mysis and protozoea occurred more frequently with higher numbers.
The protozoa stages were mainly belonging to lucifers and shrimps. The seasonal distribution revealed the presence of this larvae were dominant in February and September at all the stations and absent in April, June and July throughout the study period.

The zoea was abundant in post-monsoon season. The greater abundance was observed in October/ December and second abundance was in September.

The seasonal distribution of mysis revealed the presence of moderate numbers in February/ March and secondary abundance in September. In post-monsoon season, it exhibits its maximum in November/ December. The mysis were dominated in post-monsoon season. The spatial distribution exhibited more in Haladi estuary.

The post larvae of shrimp was higher in February (station 3) and October/ November (station 2) of pre-monsoon and post-monsoon season. The abundance of this group was more in stations at confluence and Haladi estuary.

The molluscan larvae consisted of spats of gastropods, bivalves and echinoderm larvae. The gastropod larvae were more abundant in March/ September and October month. Whereas, moderate to low number are present in February/April/July and November. The stations located at and near to the confluence have registered greater numbers. The bivalve larvae occurred in greater abundance during monsoon season and moderate numbers in pre and post-monsoon season. They were found in higher numbers in March/ September and December month. They were dominant in stations at Haladi estuary and confluence, but moderate number in Chakra estuary. The echinoderm larvae were more abundant in pre and post-monsoon season. The maximum was noticed in May/ September and January month. They were dominant in stations located at confluence and Haladi estuary.
The protochordates consisted of *Oikopleura* sp., Doliolids and Salpids. Doliolids and Salpids were observed sporadically throughout the study period. They were observed in February/May/December and January month. Among the protochordates observed *Oikopleura* sp. occur during most of the months at all the stations. The abundance of *Oikopleura* sp. during monsoon season was different at different stations. They were absent in July month excepted at station 1 throughout the study period. The dominant peak was observed in February/December and January in different station. These protochordates exhibit a bimodal seasonal oscillation with peak in pre-monsoon and post-monsoon season.

In the present study, the fish eggs were observed at all the stations during most of the months except in July. The seasonal distribution of fish eggs were occurred in greater abundance in April/May of pre-monsoon season, June in monsoon season and October/November in post-monsoon season. The clear-cut seasonal distribution of fish eggs could not be recognized. The spatial distribution revealed the higher frequency of occurrence at station 1, 2 and 3 compared to station 4 and 5. The fish eggs were found to belong to family Carangidae, Engraulidae, Clupeidae and Scombridae. Among them, Engraulidae was dominant in September of monsoon season, while Carangidae during pre-monsoon season and Engraulidae, Scombridae and Clupeidae observed in post-monsoon season. They were totally dominant in pre and post-monsoon season.

The seasonal distribution of fish larvae revealed greater frequency of occurrence and abundance during post-monsoon season and it was dominated by Engraulidae, Clupeidae Scombridae and Sillaginidae. Whereas in pre-monsoon season, the fish larvae population consisted of Carangidae and Soleidae. While in monsoon season, the fish larvae were dominated by Engraulidae. The spatial distribution revealed greater numbers at station 1 at confluence.

**Macrobenthos**
The Macrobenthos of Haladi-Chakra estuary were mainly represented by Polychaeta, Crustacea, Mollusca and miscellaneous forms. Mollusca formed the major benthic community followed by Crustacea, Polychaeta and other forms.

The Polychaeta was represented by individuals belonging to seven different families such as Nepthidae, Nereidae, Onuphidae, Glyceridae, Arenicola, Maladanidae and Sabellaridae were dominant and present throughout the study period. The percentage contribution of polychaetes to the total macrobenthos varied from 0.56 to 50.63%. The seasonal distribution of polychaetes revealed greater abundance during monsoon season followed by pre-monsoon and post-monsoon season. The spatial distribution indicated that increased abundance with increased distance from the confluence. The higher polychaetes population coincided with increased silt percentage in the sediment.

The Phylum Crustacea was represented by individuals of crabs, juveniles of shrimps, amphipods, barnacles and few numbers of Squillidae. The class amphipods represented by Gammaridae, Caprellidae and Orechastredae dominant the Crustacea. Whereas, barnacles were represented by only one species that is Balanus balanoid occurred more frequently with greater abundance. They were found settled on pebbles, leaves and twigs. The seasonal variation exhibited that the crustacean population were abundant in monsoon season followed by post-monsoon season and pre-monsoon season. The spatial distribution revealed greater diversity of crustaceans are recorded in Chakra estuary than that of Haladi estuary and confluence region. The percentage composition of crustacean to the total macrobenthos varied between 0.37 to 76.50%.

The Phylum Mollusca were represented by most dominant group in the marcobenthos throughout the study period. The class Gastropoda was represented by Umbonidae, Cerithidae, Turritellidae, Telescopium, Trochidae, Olividae, Conidae, Littorinidae and Babelonia. The class Bivalvia was represented by Donacidae, Archidae, Mytilidae, Ostreidae, Ophimeda, Trigonia and spats. The class Scaphopoda was represented by
family Dentallidae. The percentage contribution of molluscans to the total macro benthos varied from 13.89 to 97.62%. The seasonal variation of molluscans revealed greater abundance almost throughout the post-monsoon and pre-monsoon season. The lower percentage was observed during monsoon season. The spatial distribution exhibited the greater numbers and diversity of molluscans in the confluence region followed by Chakra and Haladi estuary. This variation is due to higher percentage of sand in sediment at confluence region.

- Miscellaneous forms include egg cases, sand tubes, dead annelida tubes and fishes. The percentage contribution of this group varied from 0.0 to 34.66%. The seasonal variation of miscellaneous group exhibited greater abundance in pre-monsoon and monsoon season followed by post-monsoon season. The spatial distribution revealed the greater numbers and diversity of miscellaneous forms in Chakra estuary followed by Haladi estuary and confluence region.

**Statistical analysis**

**Phytoplankton**

- It was found that there is a significant difference in total phytoplankton numbers due to months and no significant difference due to stations.

- At station 1, a significant positive correlation was observed between nitrite and phytoplankton. A significant positive correlation between salinity and water temperature, salinity and pH, nitrate and ammonia, phosphate and ammonia, phosphate and nitrate and phaeophytin and nitrate respectively was observed at station 2. At station 3, a significant positive correlation was exhibited between salinity and pH, nitrate and water temperature and phosphorous and ammonia. A significant positive correlation was observed between salinity and water temperature, salinity and pH, phosphate and ammonia and chlorophyll-a and nitrate respectively at station 4. At station 5, a significant positive correlation coefficient was
noticed between salinity and water temperature, nitrite and pH, salinity and pH, nitrate and ammonia, phosphate and ammonia and silicate and phosphate respectively. But the significant positive correlation coefficient between phaeophytin and chlorophyll-a were observed at all the stations throughout the study period.

Zooplankton

- Copepod and copepod larvae showed significant difference due to months and stations. However, polychaete larvae showed significant difference due to months, but no significant difference due to stations.

Macrobenthos

- It was found that there is a significant difference in total macrobenthos numbers due to stations, but no significant difference due to months has been observed during present investigation.

- The correlation co-efficient between macrobenthos with salinity at station 1 showed positive correlation. However, the correlation co-efficient between macrobenthos with silt and clay at station 5 and 4 showed positively correlated.