CHAPTER I
INTRODUCTION

1.1. PRELUDE

The coastal areas by virtue of their abundant resources are among the most intensively used areas in all continents. As per United Nations Environment Programme (UNEP) estimates, almost 60% of the world’s population live in coastal areas and of the world’s 23 megacities, 16 are in the coastal zone. Over the next 100 years the world’s population is likely to double and in the year 2100, it has been predicted that 75% of the human population will inhabit the coastal areas (Karl Hofius, 1995). The above statements imply that the average population densities and other associated human activities are likely to increase manifold which may impose drastic changes in the prevailing environmental conditions of the coastal areas. However, many of the earth’s most diverse, complex and productive ecosystems are found in the coastal areas, many of which are highly sensitive to environmental changes. Already the coastal areas have been subjected to various degrees of degradation due to pollution, siltation, erosion, flooding, salt water intrusion, storm surges etc. In such a condition, the projected increase in the human population and the associated activities are very much likely to cause severe damage to the already degraded coastal zones.

India has a coastline of 7,516 km. of which the mainland accounts for 5,422 km. In the islands of the Lakshadweep and the Andaman and Nicobar, the coastlines are 132 km. and 1,962 km. (Ramachandran 2001) respectively. The coastal area in India as in other parts of the world is densely populated and this area has assumed greater importance in recent years due to accelerated developmental activities. It has been estimated that approximately 18.24 MLD (Million Litres per Day) reach the coastal waters of India and the total quantity of waste discharged by the industries is estimated to be approximately 700 million cu.m. (Department of Ocean Development Report, 1996) The marine fauna and flora of India are rich and varied and the Indian coastline
encompasses almost all types of inter tidal habitat, from hypersaline and brackish lagoons, estuaries and coastal marsh and mudflats, to sandy and rocky shores with varying degrees of exposures and profiles. But the coastal waters which support such wide variety of fauna and flora have been subjected to degradation due to intense human activities and this has led to the depletion of resources and environmental degradation (Venkataraman, 2001).

Tamil Nadu State, which is situated in the southern part of India, is endowed with nearly 1000 km. of coastline with a variety of habitats like rocky zone, coral reefs, mangroves, salt marshes, sand dunes etc. Already a number of problems have cropped up in various parts of the coastal Tamil Nadu due to human activities. These problems include coastal erosion, sedimentation, siltation of parts of river mouths, pollution, mangrove deforestation, depletion of coral reefs etc. (Natarajan et al., 1991).

Though there are a number of tools to study the degradation to coastal environment, the study of foraminifera and its sensitiveness towards the environmental modification has been recognised as one of the important tool to identify coastal pollution and degradation levels in the coastal zone. In the proposed study, ecology and distribution of benthic foraminifera and their responses to marine pollution have been carried out in detail.

1.2. AREA OF STUDY

The area under investigation is located in the southeast coast of India, forming a part of Survey of India’s topo sheets numbering 58 L/1 and 5. It lies off the coast of Tuticorin, from the Thermal plant near harbor in the South to Van island in the north, confining to the Gulf of Mannar. It is geographically situated between the latitudes N 8°45’ to N 8°50’ and longitudes E 78°10’ to E 78°15’.
1.3. CLIMATE

The area experiences two phases of rainfall one during Southwest monsoon (June to September) as occasional showers and the second phase during Northeast monsoon (October to December) when cyclones normally occur every year causing heavy down pour. The total annual rainfall varies between 1000-1200 mm of which the Northeast monsoon contributes about 50-60 percent and the Southwest monsoon contributes about 30-40 percent (Kumaraswamy, 1996). The coolest month is January with an average temperature of 25 °C and the hottest month is May with an average temperature of 37°C. During summer, the land temperature goes up to a maximum of 45° C with an average mean temperature of 40° C. The humidity is highest during the month of November with an average of 80% and is lowest during the month of June with an average of 59%.

1.4. GEOLOGY OF THE AREA

1.4.1. GEOLOGICAL AND COASTAL SETUP OF TUTICORIN COAST

The region forms the southern part of the South Indian Granulite terrain (SGT), which is a high-grade terrain metamorphosed under granulite facies. The SGT is dissected by a number of shears, which have been used to divide it in to crustal blocks. Radhakrishnan and Naqvi (1986) classified the SGT in to Northern Marginal Zone, Central Zone and Southern Zone. The Southern Zone is separated from the Central Zone by the Palghat -Cauvery shear and it is further divided in to two blocks separated by the Achankoil-Thenmalai shear (ATS). The ATS is a NW-SE trending shear terminating in the east coast 50 km south of Tuticorin.

The Gulf of Mannar receives riverine input through a number of rivers, of which the Tambraparni followed by Vaipar River, are the major sources.
1.4.2. WAVES AND CURRENTS

The sedimentary input discharged into the sea by the rivers and wind, is transported by the action of waves and currents of the sea. The turbulence caused by the waves put the sediments in suspension facilitating the currents to carry it in the direction of flow. Their dynamics is particularly important in areas subjected to pollution as they aid in the dispersal of the inputs, which otherwise will be concentrated in the near shore environment.

In the study area, the dominant wave direction is towards Southeast from March to October and changes to East-Northeast from November to January with the onset of North East monsoon and is East-Southeast during February.

According to La Fond (1957) in the Gulf of Mannar, a clockwise current pattern from January to July and anticlockwise pattern from August to December is found to exist.

1.4.3. ECOLOGICAL SCENARIO OF TUTICORIN COAST

All the coral islands situated along the Tuticorin zone are subjected to human interference and activities carried out by them. They are disturbed by the collection of coral rubble, quarrying of coral stones, operation of bottom set gills for lobsters, marine algal collection and trap fishing operations in and around the islands. Evidences are available for the removal of boulder type corals in the shallow waters, thus creating imbalances in the islands. As a result of the mining activities during the past few years, a few islands are now completely submerged during high tide. In the Gulf of Mannar, pearl oysters known as pearl banks or paars lie about 12 to 20 km away from the coast at depths of 15 to 25 m. Pearl collection was intensive during 1805 to 1961 when abundant coral reefs existed. After 1961, however, trawler fishing was introduced and has gradually intensified over the years. During a survey in
1975-76, considerable fluctuations in the pearl oyster settlement were recorded and the pearl banks were not productive at all.

As per the overall industrial scenario, many large and small scale industries have come up along the coastal zone in recent years and the large coral islands and marine community have shouldered the burden in receiving the heavy load of effluents let out in the coastal zone.

1.5. CHOICE OF THE STUDY AREA

- The study area, which includes India’s one of the important harbour and its adjoining coast, has been seriously affected by sedimentation and pollution problems, in recent years.
- The decline in pearl fishing as well as marine food production warrants environmental monitoring of the inner shelf in order to evolve strategies to control environmental degradation.
- As foraminifera are good indicators of the quality of marine ecosystem, a detailed study of the foraminiferal fauna was taken up in the present area to assess the environmental impact on them.
- Essential facilities such as motor launch etc. are available in the fishing harbour for the collection of sediment and bottom water samples.

1.6. OBJECTIVES

In order to assess the environmental and pollution impact on foraminifera from the inner shelf sediments of Gulf of Mannar, off Tuticorin the following objectives are taken up:

- to inventory the foraminifera fauna and to observe their morphological variation and quantitative composition
- to ascertain the distribution of living and total (living + dead) population of the fauna and to correlate them with observed environmental parameters
to discover the effect of environmental and pollution parameters on the seasonal and spatial variation species of the foraminiferal fauna

1.7. METHODOLOGY

1. Using motor launch, mud grab and water sampler, systematic collection of bottom sediment and bottom water at 21 sampling stations were made in the study area, once in three months for a year.

2. Each field collection was followed by a systematic study of foraminiferal population, and estimation of various environmental parameters, which include

- identification of different morphological groups.
- quantitative determination of these faunal population (both living and dead).
- assessment of the distribution and diversity of these fauna in the present area.
- estimation of dissolved oxygen, salinity, temperature, pH and nutrients of bottom water; organic matter, calcium carbonate content, sand-silt-clay ratio and other pollutants of the substrate.

3. Scanning Electron Microscope (SEM) microphotographs of the benthic foraminifera were taken to ascertain the taxonomic position and morphological characters.

4. The various physico-chemical parameters estimated were correlated with the distribution and diversity of the living fauna and thereby the ecological factors governing the population abundance have been interpreted.

5. Statistical evaluation and interpretation of all the data collected for deciphering the relative importance of ecological factors over the fauna were carried out.
6. This was followed by the identification of pollution indicator species for the effective assessment of marine pollution.

1.7.1. FIELD WORK

The sediment and bottom water samples for the foraminiferal studies were collected at 21 stations from the study area (Fig.1.1), ranging in depths from 0.7 to 9.8 metres.

The traverse of the sample collection is from thermal plant near the Tuticorin harbour in the south to Van Island in the north. The samples were collected in four traverses, once in 3 months for a period of one year, starting from July 2003. Thus the collection amounted to a total of 84 samples.

All the sediment samples were collected, taking necessary precautions, making use of Petersen grab. A unit volume of 50 ml. wet sediment was taken from the top 1 cm. of sediment in all the sample locations (making use of a plastic tube). Each of the samples was preserved in a 10% solution of neutralised formaldehyde for foraminiferal study. A small quantity of sodium carbonate was added in all the samples to maintain the alkaline condition since otherwise the formalin may become acidic with time (Walton, 1964). The remaining sediment sample was preserved in a polythene bag for further laboratory investigations. All of them were indexed. The respective depths of the water column above the sample sites were also recorded.

At each station, samples of water from the sediment water interface were collected using a Nansen water sampler. The temperature of the bottom water sample was recorded from the built-in thermometer. A portion of the sample was transferred to a 250 ml. black-coloured bottle, carefully avoiding air bubbles. The dissolved oxygen in it was fixed by adding 1 ml. each of Winkler `A' and Winkler `B' solutions, viz., manganous sulphate and alkaline potassium iodide solutions (Strickland and Parsons, 1968). The bottle was tightly fitted with a glass stopper and thoroughly shaken until the precipitated manganous
hydroxide was uniformly dispersed. Then the precipitate was dissolved using concentrated H$_2$SO$_4$. This solution was preserved for estimating the dissolved oxygen content. The remaining water sample was stored in a polythene bottle and few drops of chloroform were added to preserve it. The addition of chloroform for the preservation proved to be a satisfactory procedure and found to be better than other methods (Newcombe et al., 1939).

1.7.2. LABORATORY WORK

1.7.2.1. Faunal Studies

(i) Staining the living foraminifera

The study of living and dead population is essential in understanding the ecology of modern foraminifera (Phleger, 1969). Hence, the first step in the study of foraminiferal ecology is the differentiation of 'living' foraminifera from the 'dead'. Any specimen in a sample preserved in neutralized formalin is considered to be alive at the time of collection, if it contained protoplasm. Recognition of the presence of the preserved cell in a specimen without use of a colour aid, such as a biologic stain, is laborious and not well-suited for rapid examination of large suites of specimens (Phleger, 1960). Different staining methods have been used for distinguishing the 'living' from the 'dead' viz., Rhumbler's 'Methgreosin' method (1935), Phleger's Biuret method (1945, 1951), etc.

The most positive method for identifying living foraminifera is Walton's (1952) staining technique with rose Bengal (Phleger, 1960). The rose Bengal technique was used by zoologists for staining bacteria and cytoplasm. After conducting a series of experiments to ascertain the effect of this dye with different concentrations, Walton found that Worms, Arthropods and those foraminiferal tests containing protoplasm were stained a deep-rose, leaving the empty shells, inorganic and organic debris unstained. He originally thought that an approximate 10 minutes time would be sufficient for staining the material,
but later he (1955) found that 20 - 30 minutes gives good colouration to the protoplasm. This technique is equally applicable to calcareous and arenaceous - agglutinated forms since it does not involve treatment with any acid. Walton's technique has since been widely adopted for its obvious advantages over the earlier methods. Schafer and Sengupta (1969) employed Walton's technique with a slight modification by storing the sample itself in isopropyl alcohol, which had been mixed with rose Bengal dye. According to Ellison and Nicholos (1970), a mixture of 1 gm. rose Bengal and 5 ml. Phenol dissolved in 100 ml. distilled water gives a good stain.

In the present study, following Walton's (1952) technique, the sediment samples preserved in neutralised formalin were subjected to laboratory treatment. The preserved samples were washed over an ASTM 230 mesh sieve (0.063 mm) to remove the silt and clay. The sieve with the residue was kept for about an hour in a tray containing an aqueous solution of rose Bengal (1gm of rose Bengal dye in 1 litre of distilled water) ensuring that the residue on the sieve mesh was fully covered by the solution. Then the material on the sieve was washed to remove the excess stain and dried.

The foraminiferal tests were then separated from the residue by floatation method using carbon tetrachloride (Cushman, 1959). As a check, the residue after floatation was re-examined under a binocular stereo-microscope for the presence of any foraminiferal tests left unconcentrated. They were handpicked using `OO' Windsor Newton sable hairbrush.

(ii) Counting, Mounting and Photography

The faunal specimens thus obtained were spread over a picking tray. The different genera and species were identified. The living and dead populations were counted. Where the population size was considerably large, it was split to obtain a workable population. A total of 126 foraminiferal species belonging to 65 genera have been identified.
Selected specimens from each species were mounted on micropalaeontological slides, according to the family, genus and species, over a thin layer of tragacanth gum. Before the gum gets dried up each specimen was oriented to the desired position for further study.

The hypotypes were mounted on a double side adhesive tape over a specified stub. Making use of the same, a series of Scanning Electron Microscope photomicrographs were taken to illustrate the various views of the 126 foraminiferal taxa.

1.7.2.2. Sediment analysis

(i) Sand-silt-clay ratio estimation

The inner shelf, shallow water sediments are, in general, composite types consisting particles of sizes ranging from sand to clay with their different combinations. In order to find out the percentages of sand, silt and clay, firstly, each sample was completely dried in a hot air oven to eliminate the moisture content. Then a suitable quantity of each sample was dispersed overnight with sodium hexametaphosphate solution of 0.025 N for desegregation. The material thus desegregated was washed through a 230 ASTM sieve mesh (Opening = 0.063) made of Phosphor - bronze wire mesh until clear water passed through, taking care that the washings did not exceed 1000 cc. The material retained on the sieve was dried and weighed for obtaining the weight of the material coarser than 1/16 mm., i.e. sand. The fine material (silt and clay) in the washings was analysed by the pipette method in accordance with the procedure adopted by Krumbein and Pettijohn (1938). The suspension passing through the sieve was collected in a 1 litre graduated measuring jar. If the suspension collected in the jar, after complete washing, is less than 1000 cc. the already prepared sodium hexametaphosphate solution was added to make it up to 1000 cc. Then the suspension in the measuring jar was well agitated using a stirring device, in order to have a uniform distribution of the particles in suspension. As soon as the agitation stopped, the time was noted. Exactly after 2 hours and 3 minutes,
a 20 cc pipette was slowly inserted up to a depth of 10 cms. in the solution and the sample was withdrawn from the place with uniform suction. The pipetted out sample was transferred to a 50 cc beaker and dried in an oven. Care was taken to prevent boiling and splitting. After complete drying, the weight of the residue was found out. The respective weights of sand, silt and clay were converted into weight percentages and plotted on a trilinear diagram. Trefethen's (1950) textural nomenclature has been used to describe the sediments, in the present study.

(ii) Organic matter

Organic matter is the portion of sediment, which has arisen through organic activity and contains carbon in any form other than mineral carbonate (Sverdrup et al., 1942; Trask, 1939). It consists mainly of carbon, oxygen, hydrogen, and nitrogen and also several others such as phosphorous, sulphur, silica, potassium and iron in small quantities (Trask, op. cit.). It is determined indirectly by estimating its carbon, nitrogen or phosphate content. The organic matter of soils and sediments is generally estimated by determining the organic carbon. A multiplying factor 1.72 is preferred by soil chemists on the assumption that organic matter contains 58% carbon. Texture serves as an index of organic matter content, the finer sediments containing more organic matter than the coarse grained sediments.

In the direct determination of organic matter, the soil organic matter is oxidised by a concentrated solution of hydrogen peroxide and the resultant loss is considered to be a measure of organic matter. But, the organic matter is usually calculated from the content of organic carbon. This can be determined with considerable accuracy by dry combustion methods. The dry combustion methods are too expensive and cannot distinguish between the different forms of carbon such as coal, charcoal, graphite, etc. The wet combustion methods are too time consuming.
In the present study, organic matter was determined by the method of Walkley and Black as detailed out by Jackson (1967). This is a chromic acid method based on spontaneous heating by dilution of sulphuric acid. The procedure is as follows: First, the sediment sample was dried in a hot air oven to remove the moisture content. Some quantity of the sample was crushed to fine particles and from it 0.5 gm. of sediment was transferred to a 500 ml. conical flask. Then exactly 10ml. of 1 N potassium dichromate solution was added to it and the two were mixed well by swirling the flask. Later, 20 ml. of concentrated sulphuric acid containing 0.1 gm. of silver sulphate was added. The contents were mixed well by gentle rotation of the flask for one minute to ensure complete contact of the reagents with the soil containing organic matter, with care to avoid throwing up of the soil on to the sides of the flask. The mixture was allowed to cool for 30 minutes. A standardization blank (without soil) was made in the same way. This solution was diluted to 200 ml. with distilled water and 10 ml. of 85% phosphoric acid, 0.2 gm. of sodium flouride and 30 drops of diphenylamine indicator were added. The solution was blank titrated with 0.5 N ferrous ammonium sulphate solution. The colour was dull green with turbid blue as the titration proceeds. At the end point this colour shifts to a brilliant green giving one drop end point.

The organic matter was calculated by the following equation:

\[
\text{Percentage of Organic matter} = 10(1-T/S) \times 1.34
\]

Where,

\[S = \text{Standardization blank titration ml. ferrous solution.}\]

\[T = \text{Sample titration ml. ferrous solution}\]

The factor 1.34 was derived as follows:

\[
(1.0 \text{ N}) \times 12/4000 \times 1.72/0.77 \times 100/0.5 = 1.34 \text{ in which } 0.5 \text{ is the sample weight, 1.72 the factor for Organic Matter from carbon and 12/4000 the eq. wt. of carbon.}
\]
(iii) Calcium Carbonate

Determination of calcium carbonate content of the sediments was made in order to find out its influence over the fauna.

In the present study, calcium carbonate was determined by the author using rapid titration method (Piper, 1947). The carbonate determined by this method includes other carbonates such as magnesium, which is negligible, and hence for all practical purposes the total carbonate is referred to as calcium carbonate in the present investigation.

The procedure for determining the calcium carbonate content in sediments is as follows: 5.0 gm. of soil was weighed and transferred to a tall 150 ml beaker. Then 100 ml. of N hydrochloric acid was added to it making use of a pipette with an enlarged jet. The beaker was covered with a watch glass and stirred vigorously several times for a period of one hour. After allowing the mixture to settle, 20 ml. of supernatant liquid was pipetted out and transferred to a small Erlenmeyer flask. To it was added 6 - 8 drops of bromothymal blue indicator and titrated with N sodium hydroxide. With some soils, the colour of the indicator may fade as the end point - blue colour - is approached. In such cases more indicator is added and the titration completed. A blank titration is carried out to obtain the titre value of hydrochloric acid. The percentage of calcium carbonate is estimated from the following equation:

\[
\text{Percentage of calcium carbonate} = \frac{\text{Blank titration} - \text{Actual titration}}{5}
\]

(iv) Trace metals Analyses of Sediments:

The samples were analysed for trace elements study after proper preliminary treatment. All the elemental analyses were carried out on the total unfractioned sediment samples. This means that no separation of specific sediment sizes was performed prior to the chemical analyses. To determine total trace metal concentrations of collected sediment samples by wet chemical methods, the total decomposition method detailed by Loring and
Rantala (1992), has been followed.

Total decomposition method using hydrofluoric acid (HF; 48%) in combinations with concentrated oxidizing acids such as aqua regia (HNO$_2$: HCl; 1:3 v/v) has been used in the present study. Hydrofluoric acid decomposition was preferred as this method has the following advantage: (a) HF is the only acid that completely dissolves the silicate lattices and releases all the associated metals such as Al, Fe and Li used for grain size normalization, (b) accuracy can be assessed by analyzing reference materials certified for the total metal content and (c) intercomparable data, free from operationally defined bias, can be obtained.

In this method (Rantala and Loring, 1989; Loring and Rantala, 1990), hydrofluoric acid and aqua regia were used to release the total metal content from coastal marine sediments into solution in a sealed Teflon vessel (Teflon bomb). This method was also recommended by ICES Inter Calibration Exercise on trace elements in Sediments (Loring, 1987). The main advantages of the Teflon bomb decomposition are: (a) rapid decomposition, (b) reduced risk of contamination, (c) small volume of acid required and (d) no loss of volatile elements. The Teflon bomb in which the sediment sample was decomposed was heated in a boiling water bath. In the present study, 1.0 g sample was used for trace metal determinations. All reagents used in this method were analytical reagent grade of high purity hydrofluoric acid (HF; 48%), nitric acid (HNO$_3$; 70%), hydrochloric acid (HCl; 37%), boric acid crystals (H$_3$BO$_3$) and high purity distilled water (HPDW). To an accurately weighed 1.0 ml of aqua regia (HNO$_3$: HCl; 1: 3 v/v) was added and followed by 6 ml of HF added very slowly to avoid excessive frothing. Then the beaker was closed tightly and kept in hot plate and cooled to room temperature in cold water. The Teflon beaker was rinsed several times with HPDW and the rinsing were added to the flask. The flask was shaken to complete the dissolution and made up to 100 ml with HPDW. The solution was transferred to a 100 ml polypropylene bottle,
which was pre-cleaned by diluted HCl followed by HPDW for storage. The solutions were analysed for selected major and trace elements by flame AAS (Varian Spectra jAA 200, Department of Geology, University of Madras)

1.7.2.3. Bottom Water analysis

(i) Dissolved Oxygen

In the present study, Winkler's method (Strickland and Parsons, 1968) was employed, in which, any dissolved oxygen present (fixed during the time of sample collection) rapidly oxidises an equivalent amount of divalent manganese to basic hydroxide of higher valency states. When the solution was acidified in the presence of iodide, the oxidised manganese again reverts to the divalent state and iodine, equivalent to the original dissolved oxygen content of water, which was titrated against sodium thiosulphate solution.

\[
\begin{align*}
\text{Mn}^{2+} + 2\text{OH}^- & \rightarrow \text{Mn(OH)}_2 \\
2\text{Mn(OH)}_2 + \text{O}_2 & \rightarrow 2\text{MnO(OH)}_2 \\
\text{MnO(OH)}_2 + 4\text{H}^+ + 3\text{I}^- & \rightarrow \text{Mn}^{2+} + \text{I}_3^- + 3\text{H}_2\text{O} \\
\text{I}_3^- + 2\text{S}_2\text{O}_3^- & \rightarrow 3\text{I}^- + \text{S}_4\text{O}_6^2- 
\end{align*}
\]

The procedure adopted is as follows:

100 ml. of sample (already fixed for dissolved oxygen in the field) was taken in a conical flask and to it was added 2 or 3 drops of starch indicator. This was titrated with N/40 sodium thiosulphate till the colour was discharged.

By calculation,

\[
\frac{1 \text{ ml. of N/40 Na}_2\text{S}_2\text{O}_3}{0.2\times1000} = \frac{0.2\times1000}{\text{Vol. of fixed solution}} \text{ ml/l of dissolved Oxygen}
\]

So, burette reading x 2 = ml/l of dissolved oxygen when 100 ml. of fixed solution was taken.
(ii) **Salinity**

Salinity is a measure of total salt content of water. To determine the salinity of water, chlorinity has to be estimated. Salinity and chlorinity are related by the equation.

\[
\text{Salinity} = 0.33 + 1.805 \text{ cl. where,}
\]

\[
\text{cl} = \text{chloride content in 1 ml. of water.}
\]

Chlorinity can be estimated both by chemical and physical methods. Physical methods are based mainly upon the determination of either density, RI or conductivity. Presently, conductivity salinometers are widely employed. This is based on the principle that conductivity of sea water is proportional to the salinity.

**Procedure**

In the present study, chlorinity was estimated employing the standard titration method. After the correction of the titration value to obtain chlorinity, the salinity value was estimated.

Exactly 10 ml. of sea water sample was taken in a conical flask and 3-4 drops of potassium chromate indicator solution was added to it. The solution will become yellowish in colour. This was titrated with standard AgNO\(_3\) with vigorous shaking of the conical flask. Appearance of a definite pale red colour indicates the end point.

\[
\frac{\text{Volume of AgNO}_3 \text{ used} \times 1000}{\text{Volume of sample taken}} = \text{Mg/L (ppt. of Chloride)}
\]

(iii) **pH (Hydrogen ion concentration)**

pH of the water sample was measured by a glass electrode and electrometer type pH meter after making necessary precautions in sampling and standardisation.
(iv) **Nutrients**

All estimations of dissolved nutrients in sea water were carried out in filtered water samples. The analyses were made almost immediately after bringing the sample to the laboratory to avoid any possible bio chemical changes in the stored water. A UNICOM 500 spectrophotometer was used for the purpose.

**a) Reactive silicate**

The reactive silicate was estimated by adopting the method described by Mullin and Riley (1955) in which the filtered water sample was allowed to react with molybdate under conditions which result in the formation of silicomolybdate, phosphomolybdate and arsenomolybdate complexes. The interference from phosphate and arsenic was eliminated by adding reducing solution containing metal and oxalic acid which reduces the silicomolybdate complex alone to give a blue reduction compound. The extinction of the resulting solution was measured as 812 μm.

**b) Inorganic Phosphate**

For the estimation of inorganic phosphate, sea water sample was allowed to react with a composite reagent containing molybdic acid, ascorbic acid and trivalent antimony. The resulting complex heteropoly acid was reduced in situ to give a blue solution. The extinction of this blue solution was measured at a wavelength of 885 μm (Strickland and Parsons, 1968).

**c) Nitrate**

Nitrate of sea water was determined by the method described by Strickland and Parsons (1968). A copperised cadmium column was used in reducing nitrate as given by Wood *et al.* (1967). The nitrate present was reduced quantitatively into nitrite when the water sample was run through the column containing cadmium fillings loosely coated with metallic copper. The
nitrite produced was then determined by the method of Bandschneider and Robinson (1952).

1.8. REVIEW OF LITERATURE

1.8.1. RECENT FORAMINIFERA FROM THE EAST COAST OF INDIA

(i) Shelf and slope regions

Gnanamuthu (1943) illustrated and described 47 species of foraminifera from the littoral zones of Kurusadai Island in the Gulf of Mannar and pointed out the similarity of the assemblages to those of Laccadive and Maldive Islands. Ganapati and Satyavati (1958) reported about 103 species of foraminifera belonging to 65 genera from the samples collected from three stations scattered in the littoral zone along the east coast extending from Calcutta in the north to Chennai in the south, with a concentration of stations off the coast of Visakhapatnam. In the subsequent year, Ganapati and Sarojini (1959) made some quantitative study of the foraminifera from the same material and reported 57 additional foraminiferal species. Subba Rao and Vedantam (1968) examined sediment samples from 22 stations located off Visakhapatnam. They dealt mainly with the distribution of 32 commonly occurring species giving more importance to the distribution pattern and their relation to the different sedimentary size fractions.

The role played by 18 agglutinated foraminiferal species in a depth zone of 35.22 m. off the east coast of India in terms of lithology and faunal assemblage was given by Almeida and Setty (1972). Rasheed and Ragothaman (1978) recorded the occurrence of 70 foraminiferal species from off Porto Novo and discussed their distribution in relation to various ecological factors. Narappa et al., (1981) related the distribution of living foraminifera with different ecologic factors of Gautami and Nilarevu distributaries of River Godavari. Subba Rao et al., (1979) gave the distribution and ecology of 124 species of benthonic foraminifera from the sediments of Visakhapatnam shelf. Rajasekar
(1981) recorded and described 59 foraminiferal species from the inner shelf of Tuticorin, Tamil Nadu. Ragothaman and Manivannan (1985) have given a detailed account of 56 foraminiferal species from off the coast of Mandapam, Tamil Nadu. Nigam (1987) has described the distribution, factor analysis and ecology of benthic foraminifera of the inner shelf of Vengurla Bhatkal sector, Andhra Pradesh.

Rao et al. (1990) studied the distribution of foraminifera from Nizampatinam Bay, Andhra Pradesh and determined four important assemblages by means of Q.mode factor analysis. Kaladhar et al. (1990) recognised 42 foraminiferal species, devoid of agglutinated forms, from inner shelf ranging in depth from 3 to 10m south of Visakhapatnam. Manivannan et al. (1996) observed that calcium carbonate content of the bottom sediments governs the foraminiferal population from 48 sediment samples collected in the Gulf of Mannar, off Tuticorin, Tamil Nadu. Kumar et al. (1996) studied spatial and temporal variations of 108 foraminiferal species and their relation to substrate characteristics in the Palk Bay, off Rameswaram, from 52 samples collected during four seasons of a year. Rao et al., (1998a) recorded 30 species of lagenid foraminifera from inner shelf sediments of Karikattukuppam, near Chennai and discussed the distribution in relation to depth and nature of substrate. Later they (1998b) also identified and reported 15 foraminiferal taxa belonging to 3 genera Bolivina, Bolivinella and Brazalina from off Karikattukuppam, near Chennai with a note on their seasonal distribution.

Rajeswara Rao et al., (1999) in their study relating to the Recent foraminifera of the inner shelf sediments of Bay of Bengal (off Karikattukuppam), near Chennai reveals the presence of rare foraminifera species, viz., Glandulina spinata. Jayaraju and Reddi (1999) discussed the relationship between the substrate and the benthic foraminifera of the southern most coast of India. Sanjeeva Raj (1999) in his study has brought out the impact of the developmental activities on the coastal environment of
Chennai. Kumar and Priya (2000) in their study of the benthic foraminiferal ecology of the Palk Bay area off Rameswaram, have found that most of the foraminifera of the area are epiphytic and thrived on the algae.

The relationship between the distribution and abundance of recent foraminifera to the trace elements concentration in the area from Marina beach to Ennore have been brought out by Nagendra and Dayamalar (2000). Rajeshwara Rao and Periyakali (2001) recorded a new foraminiferal species *Cocoarota madrasensis* off Karikattukuppam, near Chennai.

The benthic foraminiferal responses to bottom water characteristics of the Palk Bay area off Rameswaram, southeast coast of India were brought to light by Kumar and Manivannan (2001) and have found that the living as well as the total foraminiferal population is higher during March. Kathal (2002) has discussed in detail the distribution and ecology of recent foraminifera from the littoral sediments of 2500 km long stretch of the east coast of India.

A systematic study of benthic foraminifera was made by Gandhi et al. (2002) on 42 sediment samples collected between Mandapam and Kodiyakkarai, off Palk Strait, Tamil Nadu, India. In all, they identified 102 benthic foraminiferal species belonging to 52 genera, 38 families, 23 superfamilies and 5 suborders.

The ecology and distribution of a rare miliolid foraminifer, *Quinqueloculina cristata* Millett, was dealt with in detail by Rajeshwara Rao et al. (2005); their study was based on 56 bottom sediment samples collected from the inner shelf of the Bay of Bengal. Rajeshwara Rao et al. (2005) also discussed the importance of benthic foraminiferal signatures in the deposits laid down by the December 26, 2004 tsunami on the coast of North Chennai for deciphering their provenance.

Temporal variations in abundance and mean proloculus diameter of the benthic foraminiferal species, *Epistominella exigua*, was reconstructed over the
last ~50,000 yr B.P. by Saraswat et al. (2005), from a core collected from the distal Bay of Bengal fan. Down core variations showed significant changes in the abundance of *E. exigua* during this period. In view of the present-day abundance of this species from areas with strong seasonal organic matter supply, they postulated that mean proloculus diameter can also be used to infer increased seasonality in organic matter production, and thus variations in the strength or duration of monsoon. Saraswat et al. (2005) reconstructed the sea surface temperature (SST) for the central equatorial Indian Ocean, over the last ~137 Ky, from Mg/Ca of the planktonic foraminiferal species, *Globigerinoides ruber*. They opined that the equatorial Indian Ocean SST was approximately 2.1° C colder during the last glacial maximum as compared to present times.

Recently, Rajeshwara Rao et al. (2006) have reported benthic foraminiferal species – *Glandulina glans* – from the inner shelf sediments of the Bay of Bengal, with a brief discussion on its taxonomy, ecology and distribution off the east coast of India.

(ii) Beaches, estuaries and other marine marginal water bodies

In 1959, Bhatia and Bhalla described 14 foraminiferal species from the beach sands at Puri, Orissa. Bhalla (1968) illustrated 16 species from Visakhapatnam beach sands. Ramanathan (1969) conducted a study to find out the relationship between the substrate and the foraminiferal population sampled from the Vellar river estuary of Tamil Nadu. Bhalla (1970) has also reported the occurrence of 15 foraminiferal species from the Marina beach sands, Chennai.

Venkata Rao and Subba Rao (1971) described the ecology of living foraminifera from a tidal creek at Pudimadaka, near Visakhapatnam. The first biocoenoses study of foraminifera based on constant volume sediment samples in the Bay of Bengal was made by Rao and Rao (1972) from the Kakinada Channel. A total of 105 foraminiferal species from different marginal marine environments between Visakhapatnam and Kakinada was identified by Venkata


Jayaraju et al., (2000) analysed the relative abundance of 35 living foraminiferal species of Pulicat lake, East coast of India was using Q-mode factor. Hema Achyuthum et al.,(2000) studied the trace metal concentration in
the sediment cores of estuarine and tidal zones between Chennai and Pondicherry along the East coast of India. Kumar and Manivannan (2000) have conducted studies relating foraminifera to the bottom water and sediment parameters of the Cauvery river estuary. Kumar and Sivakumar (2001) have studied the influence of estuarine environment on the benthic foraminifera of the Uppanar river estuary of Tamil Nadu.

1.8.2. RECENT FORAMINIFERA FROM THE WEST COAST

(i) Shelf and slope regions

Chapman (1895) studied foraminifera from the investigator collections made off Laccadives. Stubbings (1939) recorded about 300 species from the sediments collected by the John Murray expeditions off the Arabian sea. Kurian (1953) studied foraminifera from the Travancore coast which revealed the occurrence of about 25 genera and the existence of a definite relationship between the bottom fauna and the texture of the soil in which they occur. Sethulekshmiamma (1958) recorded 114 foraminiferal species from off Travancore Coast and its backwaters. Kameswara Rao (1970a,b; 1971a) contributed to our knowledge of foraminifera, for the first time from the Gulf of Cambay, describing 84 species belonging to 34 genera. He (1971b) reported 92 species belonging to 40 genera from the northeastern part of the Arabian sea. Setty (1976) gave a report on the sensitivity of benthic foraminifera to various levels of pollution in the marine environment of Cola Bay, Goa.

Nigam et al. (1979) have reported 64 benthic foraminifera from Dabbol - Vengurla inner shore neritic environment. Graphic pattern of the foraminiferal dominance in near-shore region of central West Coast of India was given by Setty et al. (1979). Cluster analysis and ecology of living benthic foraminifera from 23 samples collected from the inner shelf off Ratnagiri, West Coast of India were explained by Nigam and Sarupria (1981). Foraminifera assemblages in the sediment and their relation to organic carbon have been studied in selected near

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shore areas of the western Indian continental shelf by Setty and Nigam (1982). Using factor analysis, Nigam and Thiede (1983) described the Recent foraminifera from the inner shelf of the central West Coast of India. Nigam (1984a) described 60 species of benthonic foraminifera from 23 samples collected from the tidal affected inner shelf of Damon-Bombay sector. Setty and Nigam (1984) described 45 species of inter-tidal foraminifera from Miramar Cananzalem shore-line, Goa. Benthic foraminifera as pollution indices in the marine environment of west coast of India were explained by Setty and Nigam (1984). Nigam (1986) has grouped the foraminifera of the shelf region off Narapur, applying factor analysis. Madabhusi (1989a) studied the distribution of benthic foraminifera in the outer shelf upper slope area off Cochin and established several paleoenvironmental zones. In the same year, Madabhusi (1989b) also studied the distribution of foraminifera from the inner shelf of the Arabian sea of Cannanore - Calicut coast, while Srinivasan (1989) recorded the same from the Continental shelf, off Tripriyar - Azhikode, Kerala. Mathur and Gupta (1989) have described the areal distribution of dominant foraminifera in sea bed samples from the Arabian sea, off Devgarh, west coast of India, and discussed three major foraminiferal biofacies.

Nigam et al. (1991) studied the surficial sediment samples collected from outer shelf from Venguria to Mangalore and proposed that the intertidal barnacle (cirripedes crustacea) growth on foraminifera can be considered as a tool to monitor palaeo-sea level changes. Nigam and Khare (1992) after their detailed study of the three sediment cores from the shallow water region off Karwar inferred that microspheric generation prefers dextral coiling and coiling in benthic foraminifera appears to be influenced by mode of reproduction. Nigam and Khare (1994) have studied the effect of river discharge on the morphology of 148 benthic foraminiferal species from 21 surface sediment samples collected from the inner shelf region off Karwar. Khare et al. (1995) studied the foraminifera from off Mangalore and concluded that the
distributional pattern of benthic foraminiferal morpho-groups can be correlated with fresh water river discharge which in turn is associated with rainfall.

Nigam and Chaturvedi, (2000), after a detailed study of foraminifera from Kharo creek, Kachchh (Gujarat), north west coast in India, stated that the fauna showed a positive relationship between angular-asymmetrical form and clay fraction in the sediments while the dominant rounded-symmetrical form of benthic foraminifera exhibit high energy environment. The foraminiferal content of 108 modern marine sediment samples off Vengurla-Cochin sector, west coast of India, ranging in water depth from 30 to 1,330 m, was classified into the two morpho-groups by Nigam et al. (2000). The distribution profiles of these morpho-groups in the surface sediments showed that the angular-asymmetrical morpho-group was more abundant in deeper regions, while the rounded-symmetrical morpho-group tends to flourish in relatively shallower regions. A comparison of Total Foraminiferal Numbers (TFN) between 1972 and 1990 by Nigam et al. (2002) revealed a decrease in foraminiferal population in Mandovi estuarine sediments, from 10-139 specimens per gram in 1972 to 2-42 specimens per gram in 1990. Similarly, there was also a reduction in Total Species Number (TSN), from 18 (in 1972) to 14 (in 1990). This was attributed to the influence of pollution caused by continuous mining activities in the region.

Mazumder et al. (2003) analyzed 128 surface sediment samples (76 grab and 52 core top samples) for benthic foraminiferal contents from the region off Goa, India, in the eastern Arabian Sea up to a water depth of 3,300 m, and identified 195 species. Species belonging to Bolivina, Cassidulina, Lernella, Uvigerina and Eponides were found to be the most abundant within the depth zone of 150 to 1,500 m, a zone considered to be the oxygen minima zone (OMZ) for the Arabian Sea. Interestingly, Bulimina marginata, which has been reported to be present in considerable numbers within the OMZ in other
regions of the world’s oceans, accounted for only about 2% of the total benthic foraminifera population in the Arabian Sea. On the contrary, *Bulimina costata*, which constituted more than 15% of the total foraminifera, has not been reported to be abundant from the OMZ of any other region of the world.

Citing several case studies from the Arabian Sea, Nigam (2005) demonstrated how environmental issues can be addressed using foraminifers, particularly climatic variations in the past. He emphasized the need for supplementing the traditional hard part foraminiferal studies with a detailed foraminiferal-culture program with a molecular biological approach.

Nigam (2006) examined the foraminifers present in the shelly sediment layers in Goa and Lothal Dockyard (Cambay) and related them to the possibility of higher sea level around 6,000 years B.P., and thereby their probable utility in archeological studies. According to Khare and Nigam (2006), foraminiferal studies on a shallow water sediment core off Karwar, central west coast of India have revealed significant changes in the monsoonal precipitation during the last around 720 years. The results hinted towards some possibility of linkage of monsoonal precipitation with solar variability during this period. Nigam *et al.* (2006) carried out culture experiments to observe the response of *Pararotalia nipponica* (Asano) to different salinities and estimate its salinity tolerance limits. They observed that specimens of *P. nipponica* kept in 33 %o saline water achieved optimum growth, while rest of the specimens maintained at either higher or lower salinities showed comparatively less growth. *Pararotalia nipponica* specimens kept at 10 and 15%o salinity started becoming opaque and later dissolved within a span of 25 days. They concluded that comparatively lower salinities are much more detrimental to foraminiferal tests than higher salinities.

In order to document foraminiferal response to various pollutants, and to develop effective foraminiferal proxies for pollution monitoring through time, Nigam *et al.* (2006) opined that culture studies need to be supplemented
with advanced crystallographic and molecular studies in order to find the actual mechanism(s) through which foraminifers respond to the pollutants. In order to understand foraminiferal response to changed oxygen conditions, Panchang et al. (2006) collected three sediment cores at 50 m water depth on the west coast of India, off Ratnagiri, and subjected them to oxygen manipulations maintaining natural temperature and salinity. The results indicated that changes in natural oxygen conditions caused lowering of foraminiferal numbers, although some species were more adaptive.

(ii) Beaches, estuaries and other marine marginal water bodies

The report of *Elphidium indicum* from the shore sands of Bombay harbour by Cushman (1936) was the earliest of foraminifera recovered from beach sands. Subsequently, Chaudhury and Biswas (1954) described 12 perforate species from the Juhu beach sands. After a systematic study of 46 species of foraminifera from the Juhu (Bombay) and Bhogat (Gujarat) beaches, Bhatia (1956) found a majority to be characteristic of Indo-pacific. Rocha and Ubaldo (1964a) studied and recorded 52 foraminiferal species from the dune and beach sands of Diu, Gogola and Shimbor of Gujarat coast.

Seibold (1971) studied the foraminiferal fauna from a lagoon of Cochin and concluded that the foraminiferal species were transport into the lagoon by the tidal currents. Venkatachalapathy and Shareef (1976) reported some smaller foraminifera from the shore sediments of Mangalore area and explained their morphologic and microstructural characteristics. Also, they (1978) made SEM studies on some rotaliid foraminifera off the Mangalore Coast. In 1979, Bhalla and Nigam studied the Calangute beach sand, Goa and reported 36 foraminiferal taxa.

Rao and Rao (1979) analysed the sediment samples from the beach and studied the pollution ecology of foraminifera belonging to 42 genera from the Trivananthapuram coast.
Shareef and Venkatachalapathy (1988) have studied the foraminifera from the shore sands of Bhatkal and Devagad islands and stated that *Edentostomina cultrata*, *Spiroloculina angulata* and *Pararotalia ozawai* are recorded for the first time from the Indian waters. Nigam and Chaturvedi (2000) have documented the distribution of foraminiferal assemblages of the Kharo creek, Kachchh; north west coast of India.

A study by Nigam *et al.* (2005) revealed drastic fall in total foraminiferal number in the lower reaches of the Mandovi River estuary, from 138/g in dry sediment sample in 1994 to 41/g in 2001. The decline was also noted in diversity from 22 in 1994 to only 5 species in 2001.

**1.8.3 HEAVY METAL POLLUTION**

In recent years, several researchers have focused on morphological abnormalities of foraminifera in response to various pollution sources, particularly heavy metal contamination (Watkins, 1961; Boltovskoy *et al.*, 1991; Sharifi *et al.*, 1991; Yanko *et al.*, 1998; Coccioni, 2000; Samir, 2000; Samir and El-Din, 2001; Geslin *et al.*, 2002). Although heavy metal concentrations directly correlate with elevated percentages of deformed tests in many case studies, there is more to consider. No variable (temperature, salinity, depth, carbonate solubility, dissolved oxygen, substrate, water motion, trace elements, etc.) acts independently on test morphologies (Boltovskoy *et al.*, 1991). A stress or such as salinity changes may cause abnormalities in one location but not in another (Sharifi *et al.*, 1991; Yanko *et al.*, 1998). Background percentages of deformed tests in unstressed conditions must be considered. Deformities are commonly found in up to 1% of total live populations, for a given species in given environmental conditions, representing the range of natural variability (Yanko *et al.*, 1998). It is, however, very difficult to find ecosystems untouched, directly or indirectly, by human impact. Geslin *et al.* (2002) found in Brazilian estuarine environments
that it was difficult to distinguish natural from anthropogenic stress; in fact, their study showed higher percentages of abnormal tests occurring in supposedly non-polluted areas than in polluted areas.

Nevertheless, a convincing amount of recent research supports the correlation between increased heavy metal concentrations and aberrations in foraminiferal tests. Elberling et al. (2003) found that abnormalities may represent a useful biomarker for evaluating trends in the biological impact resulting from submarine tailings disposal as in Western Greenland. Samir (2000) summarised that benthic foraminiferal abnormalities depend on the nature of the pollutant. Heavy metals from industrial locations were associated with test deformations in Southampton Water, England (Sharifi et al., 1991). In the pilot study of the Biscayne Bay Project, however, Hoare (2002) did not find correlation between test abnormalities and increased heavy metal concentrations. Test abnormalities were observed at several sites. Those occurrences were, however, not at sites where trace metal concentrations were highest.

Vast amount of research has quantified and analyzed total benthic foraminiferal assemblages as bioindicators of heavy metal pollution (Naidu et al., 1985; Alve and Nagy, 1986; Banerji, 1992; González-Regalado et al., 2001; Armynot du Châtelet et al., 2004). Total densities and species richness tend to decrease in areas of elevated heavy metal concentrations (Naidu et al., 1985; Sharifi et al., 1991; Armynot du Châtelet et al., 2004).

Quite often, however, one or a few taxa of foraminifers will thrive in stressed environments (Schafer, 2000). For example, in soft-bottom fauna in Norwegian fjords, 22 out of 23 species tolerant of high concentrations of copper were present at stations with very low diversity (Rygg, 1985). Debenay et al. (2001) and Armynot du Châtelet et al. (2004) found *Haynesina germanica*, a tolerant pioneer species, to be an indicator of heavy metal pollution. Sharifi et al. (1991) observed that *H. germanica, Ammonia beccarrii*,
and *Elphidium excavatum* not only dominated at all nine of their sample sites, but they also collectively constituted over 80% of the living assemblage. *Elphidium excavatum* showed the highest tolerance to heavy metal pollution, followed by *H. germanica* and *A. beccarii*.

Banerji (1992) also found *Elphidium* to be least impacted by increased heavy metal concentrations. Some researchers have noted that there are limitations to statistical analyses. In practice, it is often difficult to separate effects caused by heavy metals from those caused by organic material and consequent hypoxia, since most polluted areas are subjected to some kind of organic enrichment (Alve, 1995). Geslin (1998) attributed the abnormal wall textures and test deformation in *Ammonia* (hyaline foraminifer) to pollution such as heavy metal contamination, change of physical and chemical parameters and shortage of nutrients in the environment. Debenay *et al.* (2001) found that correlation between heavy metals and the silt and clay fraction of sediments insufficient to determine whether sediment characteristics or pollution have the stronger influence on foraminiferal assemblages, except in areas heavily affected by pollution. Cearreta *et al.* (2002) found that the occurrence of foraminifers in two industrial zones along the Bilbao Estuary in Northern Spain did not correspond to defined levels of metals. Instead, oxygen limitation was believed to be the key factor explaining the absence of foraminifers in sediment cores. In some cases, individual heavy metals or groups of heavy metals must be analyzed separately. Along the Bombay coast in India, Banerji (1992) found maximum diversity of foraminifers coupled with higher concentrations of Fe-Mn-Zn and lower concentrations of Co-Ni-Pb.

**1.8.4 FORAMINIFERS AS BIOINDICATORS**

Foraminifera are very sensitive to environmental stress and have been increasingly used for pollution studies in the last 30-40 years. They have been frequently used as biomonitors of sewage pollution since they are both
abundant and ubiquitous. Sewage outfalls have been demonstrated to have both positive and negative effects on adjacent foraminiferal populations, but it has never been shown conclusively why sewage affects foraminifera in these ways. Such information on the impact mechanisms of sewage pollution is essential if foraminifera are to be used as sewage pollution biomonitors, and also to understand the ecology of these important protists (Ward et al., 2003).

Benthic foraminiferal assemblages have been used to determine the effects of pollution on the marine environment. Many of these studies focused on the environmental change caused by organic pollution from sewage outfalls (e.g., Watkins 1961; Schafer, 1970; Nagy and Schafer 1970). Ecological studies of recent foraminifera by Watkins (1961) around the Orange County ocean sewer outfall, California, revealed that higher proportion of abnormal specimens were present near polluted areas. This phenomenon was noticed by Lidz (1965) in the Nantucket Bay, Massachusetts, by Seiglie (1971) in two Puerto Rican bays, and Seiglie (1975) in the Guayanilla Bay. He (1973) had earlier observed that more than 90% of the living pyritized specimens were from polluted areas in the Jobo? Bay, Puerto Rico. He could not, however, explain this apparent connection between pollution and pyritization.

Yanko et al. (1994) made a detailed study of foraminiferal populations at three contaminated sites along the Mediterranean coast of Israel, using the unpolluted coast of Nitzanim as a natural baseline. They observed that species diversity and population density were highest in areas of domestic sewage disposal where highest percentage of agglutinated foraminifers was also found. In contrast, the lowest species diversity and population density occurred near the Hadera Power Station, where coal was the major source of pollution in the sediment. Another interesting observation made by them was the presence of stunted and aberrant tests in a part of Haifa Bay, an area contaminated by variety of heavy metals.
The response of foraminiferal assemblages to industrial and municipal wastewater was documented in San Francisco Bay (van Geen et al., 1993).

According to Samir and Eldin (2001), the Alexandrian coast is contaminated by wastes chiefly heavy metals, as well as agricultural and domestic effluents resulting in low species diversity and population density associated with an increase in tolerant or opportunistic species. According to them benthic foraminifera reflect human-induced environmental perturbation and they can be used as bioindicators for monitoring coastal pollution.

According to Debenay (2001), the foraminiferal assemblages were dominated by miliolids, mainly *Trioculina oblonga*, and rotaliids, with *Ammonia tepida* and the less abundant *Cribroelphidium excavatum* var. *selseyense*, in the hypersaline Araruama Lagoon, Brazil. Textularids were almost absent. Anthropogenic stress did not seem to be responsible for morphological abnormalities, which were attributed to high salinity conditions and to changes in salinity. The higher proportion of *Ammonia tepida* in the more affected northern part of the area was, however, probably due to human impact in the lagoon.

The response of foraminiferal assemblages to industrial and municipal pollution has been documented in San Francisco Bay (van Geen et al., 1993) and in many other areas, including Southern California (Watkins, 1961; Bandy et al., 1964a, 1964b, 1965a, 1965b; Seiglie, 1968), the eastern United States (Ellison et al., 1986), and in many other countries (e.g., Canada, Norway, England, the Mediterranean, and the Caribbean). These and other studies have shown that the distribution of benthic foraminifers is affected by organic enrichment of the sediments, increased heavy metal loading and other anthropogenic contamination. Foraminiferal response to heavy metal pollution, in particular, has been well documented with local extinctions resulting in barren zones where contamination levels are high, and in transitional to less polluted levels with assemblage modifications due to loss of diversity,
disturbance of live activities and test deformation (double or enlarged apertures, twinning, protuberances, reduced chamber size, or twisted chamber arrangements (Alve, 1995).

A study of foraminiferal assemblages was carried out at two Egyptian Nile Delta lagoons by Samir et al. (2000). Analysis of surficial sediment samples from Manzalah Lagoon showed enrichment in heavy metals (Pb, Zn, Cu, Cr and Cd). The environment had become so lethal to foraminifera that no species could survive. Samples from Edku Lagoon, which receives only agricultural drainage water, showed heavy metal concentrations close to natural baseline levels, and yielded living foraminifera. The frequent occurrence of deformed specimens in Manzalah Lagoon, comparable to Edku Lagoon, revealed that: (1) benthic foraminifera are more sensitive to industrial wastes containing heavy metals; (2) agricultural wastes do not significantly harm benthic foraminifera; (3) *Ammonia beccarii* forma *parkinsoniana* is less resistant to pollution than *A. beccarii* forma *tepida*; (4) morphological abnormalities for the foraminiferal tests depend upon the nature of the pollutant; and (5) benthic foraminifera are less tolerant to pollution than ostracods and molluscs.

Foraminiferal species and heavy metal concentrations were investigated Coccioni, (2000) using bivariate (correlation matrix) and multivariate techniques of principal component analysis (PCA) and cluster analysis. The analysis has shown a possible control of pollutants both on the taxonomic composition of the benthic foraminiferal assemblages and the development of test malformations. He has opined that increasing heavy metal contents have led to an increase in relative abundances of *Ammonia tepida*, *A. perlucida*, *Nonionella turgida* and *Eggerella scabra*, a relative concurrent decrease in the relative abundance of *Ammonia parkinsoniana*, and higher percentages of deformed specimens and species in the Adriatic Sea.
Nigam et al. (2004) recorded the presence of *Ammolagena clavata*, an agglutinated benthic foraminiferal species for the first time from the Indian Ocean region, in the depth range of 1,650-2,050 m, compared to the depth range of 684-2,503 m in the Pacific and 553-4,500 m in the Atlantic regions. They observed this species to be attached to the planktonic foraminiferal species, *Globorotalia menardii*, in addition to large quartz grains or on some other larger benthic foraminiferal species.

In order to develop a viable foraminiferal proxy for heavy metal pollutants, juvenile specimens of *Rosalina leei* were subjected to different mercury concentrations (0 -180 ng/l) in growth experiments conducted by Saraswat et al. (2004). They observed that total growth achieved was significantly lower in case of specimens kept at relatively higher mercury concentrations then those maintained in normal saline water. The most significant result of this experiment was the addition of abnormal chambers in the specimens kept at higher mercury concentrations.

Nigam et al. (2005) have opined that the ever-increasing suspended load in Mandovi Estuary, probably due to mining activities in the catchment area of the river, was suggested as the plausible reason for the decline of foraminiferal fauna.

Panchang et al. (2005) noted a substantial increase in the maximum total foraminiferal number (TFN) in the Zuari River estuary, from 1,143 specimens in 1972 to 3,057 specimens per gram sand in 2003; there was also a corresponding increase in the total species number (TSN) from 24 in 1972 to 50 in 2003, in compliance with considerable decrease in total suspended matter TSM over the years. Their study demonstrated the potentiality of foraminifera in detecting mining pollution.

Kumar et al., (2006) have stated that the deformities observed in the tests of foraminifera in the Palk Bay off Rameswaram may be caused by an
increase in the concentration of heavy metals or even by the additional mechanical forces and predation.

Sivakumar et al., (2007) in their review article summarised that the abnormalities of the foraminifera from various locations are caused by stressed ecological and pollution parameters and hence foraminifera can effectively be used as a tool for environmental and pollution monitoring.