Research Journal of Earth Sciences 1(1): 07-14, 2009
ISSN 1995-9044

Pollution Signatures of Benthic Foraminifear: A Study from the Pennar River Estuary, India

[1]B.C. Sundara Raja Reddy, [2]N. Jayaraju, [1]K.R. Reddy and [3]A.N. Reddy

[1]Department of Geology, Sri Venkateswara University, Tirupati, India
[2]Department of Geoinformatics,Yogi Vemana University, Kadapa, India
[3]ONGC Regional Labs, NH Road, Chennai, India

Abstract A detailed study on bioindicators of heavy metal contamination was carried out in the Pennar River Estuary, Nellore coast of eastern India. The estuarine sites were investigated for certain metal pollutant levels due to human activities (e.g., aquaculture, industry and harbor activities). Concentrations of heavy metals (Co, Cr, Fe, Mn, Pb, Zn, Cu, Se, Sb and Ni) were measured in sediment samples. The relative concentrations of heavy metals was Pb > Zn > Cr > Mn > Co> Fe > Cu > Ni > Sb >Se. The impact of heavy metal pollution on benthic foraminifera was very drastic. Using scanning electron microscopy (SEM), we observed morphological abnormalities such as twisted coiling, broken spines, irregular chamber arrangements, small sizes of specimens and deepening of grooves. The present density and diversity data of foraminifera were compared with the pre-pollution data.

Key words: Estuaries % Foraminifera % Test morphology % Heavy metals % India

INTRODUCTION

The Pennar River Estuary is situated on the Nellore coast in the state of Andhra Pradesh, on the east side of India. This river is represented in the Survey of India topographic sheet No. 66 B/2 in the scale of 1: 50. 000. The study area lies between longitudes 80°03'-80°06'E and latitudes 14°07'-14° 10' N (Fig. 1 and Table 1).

Some heavy metals are key to the metabolism of marine organisms and are bioaccumulated from the marine and estuarine environment. However, all metals can occur above threshold bio-available levels [1]. Metals tend to accumulate in estuarine and the continental shelf regions which are the ultimate sinks for metals coming from land-based activities [2]. The geochemical cycles of trace metals in the coastal environment are important processes regulating the present degree of metal enrichment. Deposited metals come from rivers and other industrial and domestic effluent inputs [3-15]. The heavy metal concentration of the estuaries are measured in terms of ppt in the national Geophysical Research Institute, Hyderabad, India, on the payment basis. This was measured in elemental concentration in the order of Mn> Fe > Ni > Co > Cu > Cr > Sb > Se > Pb. The environmental levels of toxicity of the metals is highly drastic in nature.

Background: The Pennar River flows through an area undergoing rapid industrial development and collects effluents discharged into the estuary. The Pennar has a large catchment area and aquacultural ponds are abundant at some points where population growth is also high. Rapid industrialization has taken place along the river course [16]. Low income housing is developed in the

Table 1: Sampling station latitudes and longitudes

Sample Station No	Latitude N	Longitude E
1	14.58392	80.17142
2	14.58367	80.17578
3	14.58461	80.18122
4	14.58614	80.19875
5	14.58864	80.19222
6	14.59311	80.19272
7	14.58742	80.193
8	14.58517	80.1932
9	14.57778	80.19289
10	14.58239	80.18761
11	14.57817	80.18464
12	14.57082	80.17479
13	14.58458	80.18475
14	14.58144	80.16983

Corresponding Author: B.C. Sundara Raja Reddy, Department of Geology, Sri Venkateswara University, Tirupati, India

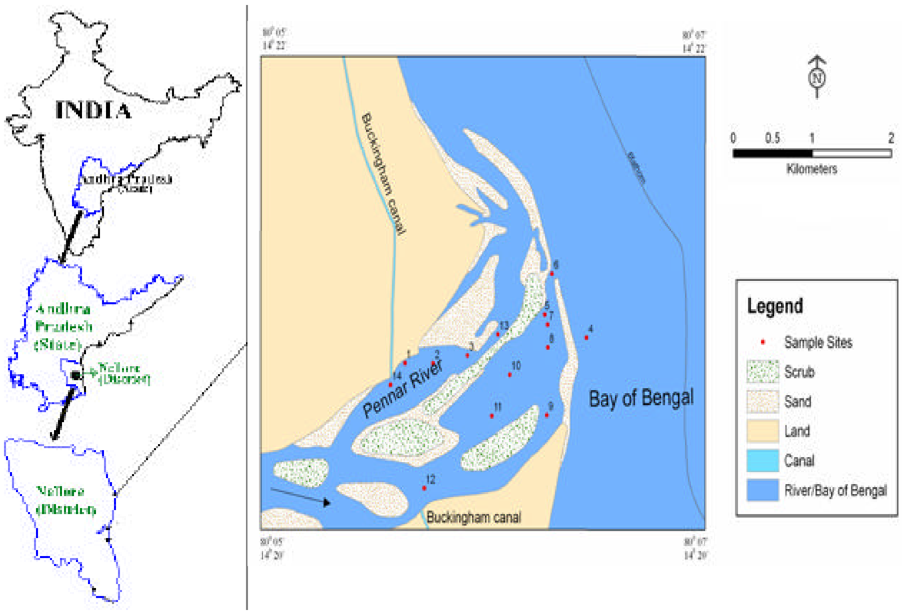

Fig. 1: Pennar River estuary with sampling stations

catchment and is associated with a constant increase in the quantity of storm water runoff. It is estimated that about 90 % of particulate matter carried by rivers settles in estuaries and coastal zones [17,18].

Estuaries tend to serve as buffer zones for domestic and industrial effluents. The highly dynamic nature of the marine environment allows for very rapid sedimentation. Effluent materials are altered by processes such as dilution, oxidation and sequestration *in situ* in estuarine sediments. Estuaries are typical environments in which human impacts have produced a large range of changes varying in severity. Their increase in attractiveness for conservation and tourism along with the simultaneous increase in anthropogenic uses results in several conflicts [19].

MATERIALS AND METHODS

A total of 14 surface sediment samples were retrieved using a hand-operated dredge in each of two seasons (pre-monsoon and post-monsoon). Sampling stations were located mainly in the central part of the estuary (Fig. 1 and Table 1). Immediately after collection, the sediment samples were preserved in polyethylene bottles for heavy metal analysis. Data pertaining to heavy metals was generated from Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the National Geophysical Research Institute, Hyderabad, India. Some of the sediment samples were subsequently dried and weighed. After soaking in water, samples were washed in a solution of water and sodium phosphate through sieves with opening of 1.0 mm and 0.1 mm. The residue on the 0.1mm mesh was dried and foraminifera were concentrated by floating on carbon tetrachloride (CCl_4) and then Bromoform [20]. The fauna was separated and identified [21]. Foraminiferan test morphology was observed using scanning electron microscopy (SEM). Abnormalities of the fauna were then related to the heavy metal data.

RESULTS AND DISCUSSIONS

Pre-Monsoon: The heavy metal concentration data was subjected for Pearson correlation (Table 2). The correlation matrix indicates particular heavy metal affinity groups given here under. There are at least seven affinity assemblages from the study area for the pre-monsoon sampling.

They Include:

Cu - Pb (0.954)
Mn - Pb- Zn (0.935: 0.924)
Fe - Pb (0.634)
Zn - Pb (0.426)
Co - Se (0.411)
Pb - Sb (0.364)
Ni - Cr (0.304)

The above assemblages indicate that Cu and Pb have a very strong affinity (0/954) followed by Mn- Pb- Zn.

Table 2: Pearson correlation analysis for Pre monsoon

Variables	Mn	Fe	Ni	Co	Cu	Zn	Cr	Pb	Sb	Se
Mn	1									
Fe	0.503	1								
Ni	-0.016	0.152	1							
Co	0.279	-0.210	-0.255	1						
Cu	0.897	0.598	0.092	0.193	1					
Zn	0.924	0.526	0.171	0.071	0.941	1				
Cr	0.403	0.288	0.304	-0.326	0.524	0.618	1			
Pb	0.935	0.634	0.175	0.222	0.954	0.935	0.426	1		
Sb	0.503	1.000	0.152	-0.210	0.598	0.526	0.288	0.634	1	
Se	0.145	0.472	-0.021	0.411	0.332	0.117	-0.018	0.301	0.472	1

Table 3: Factor loading matrix for heavy metals in the pre-monsoon sampling

	F1	F2	F3
Mn	0.875	0.284	0.207
Fe	0.785	-0.402	-0.472
Ni	0.154	-0.269	0.134
Co	0.077	0.956	-0.284
Cu	0.948	0.174	0.131
Zn	0.925	0.089	0.370
Cr	0.499	-0.265	0.391
Pb	0.958	0.181	0.095
Sb	0.785	-0.402	-0.472
Se	0.347	0.172	-0.565

Factor Analysis Shows That There Are Three Factors Distinguishable in the Data:

Factor 1 = Pb-Cu-Zn
Factor 2 = Co-Sb-Fe
Factor 3 = Cr-Zn

Pb-Cu-Zn Assemblages (Factor I): This factor envelopes three variables, Pb (0.958); Cu (0.948) and Zn (0.925). Hence it may be termed as the Pb-Cu-Zn assemblage. The assemblages were named according to their most important metal constituents (Table 3).

Co-Sb-Fe Assemblages (Factor II): This factor is composed of three variables viz., Co (0.956), Sb (-0.402) and Fe (-0.402). Therefore it is called the Co-Sb- Fe assemblage.

Cr-Zn Assemblages (Factor III): This factor includes two variables viz., Cr (0.391) and Zn (0.371) and it is called the Cr-Zn assemblage. Of these three assemblages, only the Pb - Cu- Zn assemblage (factor I) is significant in the estuarine environment during the pre-monsoon season (Table 3). Correlation analysis reveled that the following metals are positively related:

1. Mn ------ Pb- Zn (0.935; 0.925)
2. Fe ------- Pb (0.634)
3. Ni ------- Cr (0.304)
4. Co ------ Se (0.411)
5. Cu ------ Pb (0.954)
6. Zn ------- Pb (0.935)
7. Cr-------- Pb (0.426)
8. Pb-------- Sb (0.634)

This data shows the positive correlation of metals with correlation variables. Pb was positively correlated with almost all other heavy metals (Mn, Fe, Cu, Zn, Cr) during the pre-monsoon season.

Post-Monsoon: The correlation matrix indicates the affinity of the heavy metals in the post-monsoon season. We distinguish seven affinity assemblages from the study area (Table 4).

1. Mn ------ Zn - Pb- Ni - Cu (0.986; 0.964; 0.949; 0.936)
2. Fe ------- Ni - Cu (0.899; 0.651)
3. Ni ------- Cu - Zn - Pb (0.986; 0.964; 0.954)
4. Co ------ Cu - Zn - Pb (0.846; 0.677; 0.645)
5. Cu ------ Zn - Pb (0.935; 0.932)
6. Zn ------ Pb (0.977)
7. Cr ----- -- Pb (0.465)

Cu concentration was found to correlate positively with almost all heavy metals (Mn, Fe, Ni, Co) during the post-monsoon sampling (Table 4).

Factor analysis reveals three factor assemblages (Table 5).

Table 4: Pearson correlation analysis for the post-monsoon

Variables	Mn	Fe	Ni	Co	Cu	Zn	Cr	Pb	Sb	Se
Mn	1									
Fe	0.421	1								
Ni	0.949	0.573	1							
Co	0.700	0.899	0.798	1						
Cu	0.936	0.651	0.986	0.846	1					
Zn	0.986	0.390	0.964	0.677	0.935	1				
Cr	0.434	-0.241	0.276	0.057	0.256	0.458	1			
Pb	0.964	0.364	0.954	0.645	0.932	0.977	0.465	1		
Sb	-0.057	0.303	0.045	0.120	0.087	0.004	0.170	0.048	1	
Se	-0.440	-0.264	-0.608	-0.317	-0.599	-0.522	-0.104	-0.597	-0.228	1

Table 5: Factor loading matrix for heavy metals for the post-monsoon sampling

	F1	F2	F3
Mn	0.950	-0.224	0.218
Fe	0.600	0.800	0.007
Ni	0.989	-0.027	0.005
Co	0.820	0.478	0.170
Cu	0.994	0.062	0.002
Zn	0.959	-0.261	0.113
Cr	0.306	-0.479	0.090
Pb	0.954	-0.287	0.008
Sb	0.098	0.160	-0.223
Se	-0.605	0.091	0.791

Factor 1: Cu - Ni - Zn - Pb - Mn.
Factor 2: Fe - Co
Factor 3: Se - Mn

Cu - Ni - Zn - Pb - Mn Assemblage (Factor 1): This factor covers almost all major metals including Cu (0.944); Ni (0.989); Zn (0.959); Pb (0.954) and Mn (0.950). Hence this factor is called Cu-Ni-Zn-Pb-Mn assemblage.

Fe - Co Assemblage (Factor 2): Factor II includes Fe (0.800) and Co (0.478) and is thus called the Fe- Co assemblage.

Se - Mn Assemblage (Factor 3): This factor includes Se (0.791) and Mn (0.218) and it is called the Se- Mn assemblage.

Foraminiferal Test Abnormalities / Proxies: A total of 20 species for pre-monsoon and 14 species for post-monsoon samples were identified from the study area. During the pre-monsoon sampling, *Ammonia beccarii* was ubiquitous and cosmopolitan and remaining genera is decreasing order are *Quinqueloculina, Cibicides, Elphidium, Roishusenia* etc., However., post monsoon also reported *Ammonia beccarii* as the dominant species among all other reported. The decreasing order of the other genera are *Elphidium, Quinqueloculina, Cibicides and Nonionellla.* Unfortunately, Some of the sampling stations viz., no 3, 6 -14 in pre monsoon and nos 1,4,13 and 14 during post monsoon are devoid of fauna (Table 6a, 6b). The species richness of abundance in pre monsoon may be because of the luxurious nutrient supply in to the estuary owing to floods during monsoon. The nutrient abundance is directly related to faunal abundance [20].

Comparative Studies: The present work was compared with the post pollution data [22] for both the seasons viz., premonsoon (Tab.7a and Fig.2) and post monsoon (Tab.7b and Fig.3). The comparison revealed the following:

- The total crop during pre monsoon of post pollution period was higher (1270) at station .6 and low (1) at station 13. But the present work noticed high crop (639) at station .2 and absent in station 3, 6-14 (Tab.7a and Fig.2). There has been substantial decrease in the TFN from 1270 in 1973 to 635 in 2007 during pre monsoon.
- During post monsoon, the post pollution data recorded a high crop (2340) at station 5 and low (15) at station 14 (Tab.7b and Fig.3). However, the present investigation have recorded high crop (763) at station 8 and absent at stations 1, 4, 13and14. The data shows that there is phenomenal fall in the TFN from 2340 in 1973 to 763 in 2007 during post monsoon. Huge fluctuations in faunal crop from station 8 to stations 1,4,13 and 14 may be attributed to the metal pollution.

Table 6a: Faunal distribution at sampling stations during pre-monsoon

	Sampling stations					
Species	1	2	3	4	5	6-14
Ammobaculites exiguous	1	4		1	-	-
Ammonia beccarii	665	620	-	210	1	-
Ammonia dentate	5	-	-	40	-	-
Cibicides lobatulus	11	-	-	1	-	-
Elphidium advena	4	-	-	-	--	-
Elphidium excavatum	-	7	-	9	-	-
Elphidium hispidulum	-	3	-	2	-	-
Elphidium norvangi	2	-	-	2	-	-
Hanzawaia nipponica	4	-	-	-	1	-
Miliolinella subrotunda	1	-	-	2	-	-
Nonion grateloupi	2	4	-	-	-	-
Quinqueloculina lamarckiana	-	-	-	1	1	-
Quinqueloculina milletti	-	-	-	2	-	-
Quinqueloculina seminulum	4	-	-	-	1	-
Quinqueloculina sp	-	-	-	4	2	-
Quinqueloculina stalkeri	29	3	-	-	-	-
Quinqueloculina tropicalis	1	-	-	-	-	-
Rolshausenia rolshauseni	15	-	--	2	-	-
Rosalina globularis	-	1	-	-	-	-
Textularia agglutinans	2	1	-	-	-	-
Total (# Specimens /10 grams of dry sediment)	750	639	-	276	6	
Diversity (absolute number)	14	7	-	12	5	

Table 6b: Faunal distribution at each sampling station during post-monsoon

	Sampling stations												
Species	1	2	3	4	5	6	7	8	9	10	11	12	13- 14
Adelosina semistriata	-	-	-	--	-	-	-	-	1	-	-	-	-
Ammonia beccarii	-	33	4	-	176	-	124	638	13	40	86	3	-
Ammonia dentata	-	3	1	-	9	13	5	37	1	-	-	-	-
Elphidium advena	-	3	-	-	11	-	5	48	-	6	6	-	-
Elphidium excavatum	-	-	-	-	-	-	2	4	-	-	-	-	-
Quinqueloculina sp	-	3	-	-	4	-	-	-	-	-	-	-	-
Triloculina tricarinata	-	-	-	-	-	1	-	2	-	2	-	-	-
Total (# Specimens /10 grams of dry sediment)	-	42	5	-	200	14	132	729	16	48	72	3	-
Diversity (absolute number)	-	4	2	-	4	2	4	5	3	3	2	1	-

Table 7a: Comparison of Foraminiferal biota in pre monsoon

	1973 (after K.R.Reddy)		Present work	
Sampling stations	Total crop	Diversity	Total crop	Diversity
1	578	11	750	14
2	292	6	639	7
3	351	13	0	0
4	768	9	276	12
5	558	8	6	5
6	1270	9	0	0
7	337	3	0	0
8	628	5	0	0
9	309	2	0	0
10	26	2	0	0
11	7	1	0	0
12	17	6	0	0
13	1	1	0	0
14	3	1	0	0

Table 7b: Comparison of Foraminiferal biota in post monsoon

	1973 (after K.R.Reddy)		Present work	
Sampling stations	Total crop	Diversity	Total crop	Diversity
1	136	10	0	0
2	1720	6	42	4
3	214	6	5	2
4	1240	6	0	0
5	2340	6	200	4
6	1540	4	14	2
7	70	3	132	4
8	1020	5	729	5
9	40	4	16	3
10	165	3	48	3
11	254	5	72	2
12	109	4	3	1
13	164	2	0	0
14	15	2	0	0

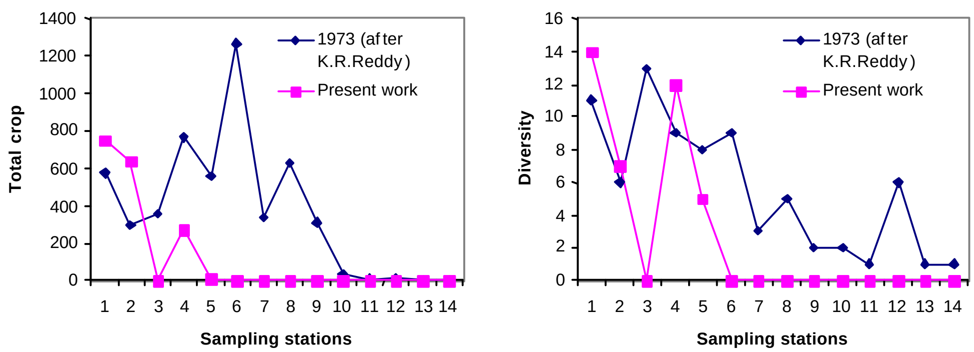

Fig. 2: Faunal density and diversity verses sampling stations in pre monsoon

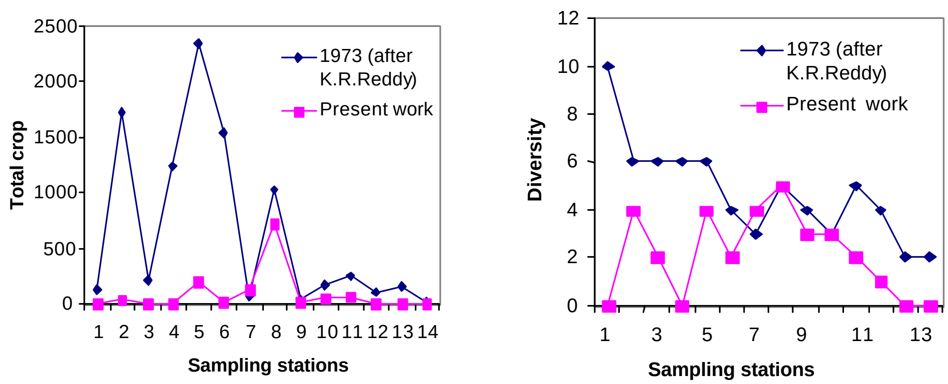

Fig. 3: Faunal density and diversity verses sampling stations in post monsoon

- The diversity of fauna is from 1-13 (stations 13,14 and3) respectively during pre monsoon as reported by Reddy [22]. However the present data shows 0-11 (stations 6-14 and 3) respectively. This drastic variation may be due to metallic pollution in the estuary.
- During post monsoon Reddy [22] noticed the diversity from 2-10 (13,14 and1) respectively. Where as we have noticed 0-9 (stations 13, 14 and 4). Usually stations 13 and 14 have no diversity and density represented of the crop. This is because these stations are highly polluted and hence the absence of data.

Abnormal test morphology in benthic foraminifera is well known from the geological record [23,24,25]. Here are some of the abnormalities noted in the study area.

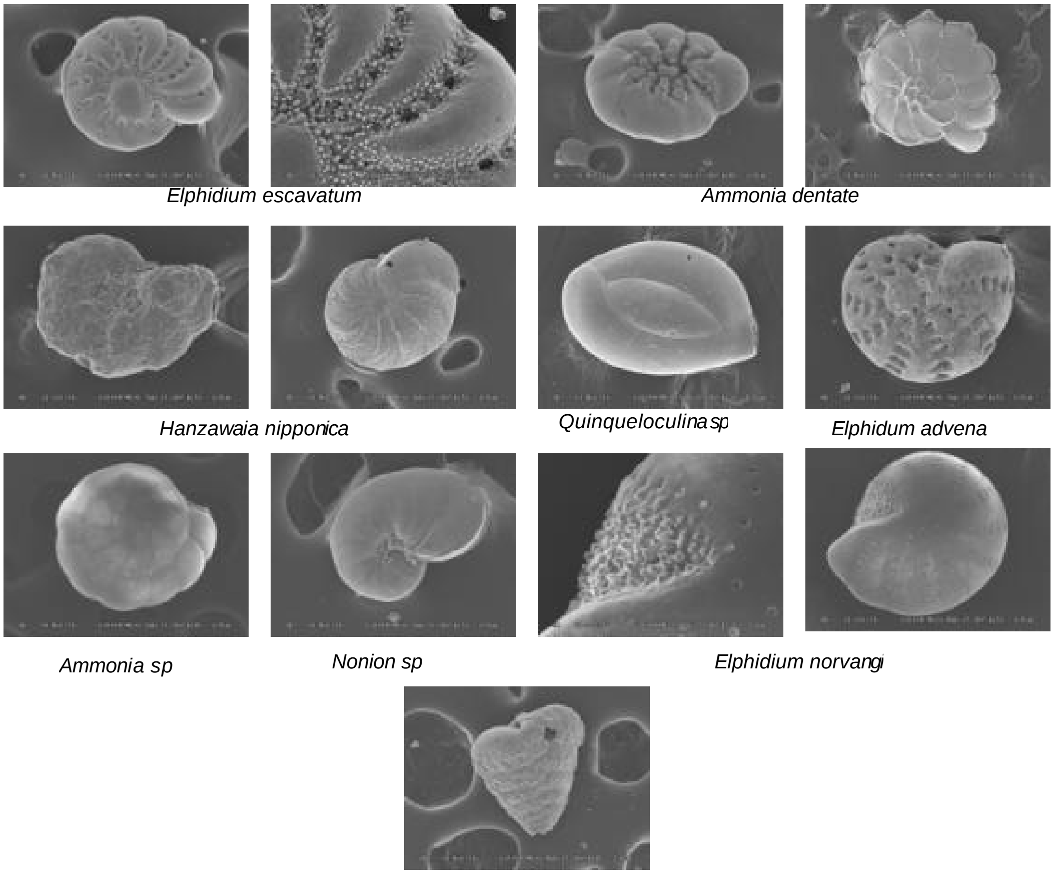

Plate 1: Morphological Abnormalities on Foraminifera

1. Reduced test	-	*Elphidium escavatum* Plate1. Fig. 1, 2
2. Reduced size of chambers	-	*Ammonia dentate* Plate1. Fig. 3, 4
3. Twisted chambers	-	*Hanzawaia nipponica* Plate1. Fig. 5, 6
4. Distorted chamber arrangement	-	*Quinqueloculina sp* Plate1. Fig. 7
5. Reduction of spine and keel	-	*Elphidium advena* Plate1. Fig. 8
6. Deepening of grooves	-	*Ammonia sp* Plate1. Fig. 9
7. Thinning effect	-	*Nonion sp* Plate 1. Fig. 10
8. Small size of specimen	-	*Elphidium norvangi* Plate .1. Fig. 11, 12
9. Pyritised shells	-	*Textularia sp* Plate1. Fig. 13

The foraminiferal test abnormalities displayed in these photomicrographs, along with others we observed, were taken as bioindicators of pollution by metal pollutants such as Fe, Cr, Cu, Co, Mn, Pb and Zn released as industrial effluents dotting the Pennar River course. Efforts were made to relate specific metal pollutants to specific test abnormalities. However, it was realized that numerous lab and field culture studies, in which particular foraminifera would be subjected to specific pollutants, would be necessary in order to document their responses to the pollutants and to develop effective foraminiferal proxies for heavy metal pollutant monitoring.

ACKNOWLEDGEMENTS

BCS and KRR thank the DST for financial assistance (ES/11/591/2001 date 09-08-2004). We thank Dr. Raymond L. Kepner, Jr, USA, for improving the quality of English language of the paper.

REFERENCES

1. Blackmore, G., 1998. An overview of trace metal pollution in the coastal waters of Hong Kong. The Science of the Total Environment, 214: 21-48.
2. Yeats, P.A. and J.M. Brewers, 1983. Potential anthropogenic influences on trace metal distribution in the North Atlantic. Can J. Fish and Sci., 40: 124-131.
3. Campbell, J.A. and D.H. Loring, 1980. Baseline levels of heavy metals in the waters and sediments of Baffin Bay. Mar Pollut Bull, 11: 257-261.
4. Chester, R. and F.G. Voutsinou, 1981. The initial assessment of trace metal pollution in coastal sediments. Mar Pollut Bull, 12(3): 84-91.
5. Voutsinou, F.T. and J. Satsmadjis, 1983. Distribution of heavy metals in sediments of the Patraikos Gulf (Greece).Mar Pollut Bull, 14(1): 33-35.
6. Abu-Hilal, A.H., 1987. Distribution of trace elements in near shore surface sediments from the Jordan Gulf of Aqaba (Red Sea). Mar Pollut Bull, 18(4): 190-193.
7. Ergin, M. and R. Yo¨ru¨k, 1990. Distribution and texture of the bottom sediments in a semi-enclosed coastal inlet, the Izmit Bay from the Eastern Sea of Marmara (Turkey). Estuar Coast Shelf Sci., 30: 647-654.
8. Szefer, P., A. Kusak, K. Szefer, H. Jankowska, M. Wolowicz and A.A. Ali, 1995. Distribution of selected metals in sediment cores of Puck Bay, Baltic Sea. Mar Pollut Bull, 30(9): 615-618.
9. Szefer, P., A. Kusak, K. Szefer, H. Jankowska, M. Wolowicz and A.A. Ali, 1998. Evaluation of the anthropogenic influx of metallic pollutants into Puck Bay, Southern Baltic Sea. Appl Geochem, 13: 293-304.
10. Coccioni, R., 2000. Benthic foraminifera as bioindicators of heavy metal pollution: A case study from the Goro Lagoon (Italy). In: R. Martin, (Eds.), Environmental Micropaleontology. Kluwer Academic/Plenum Publishers, New York, pp: 71-103.
11. Soyla, M., U. Divrikli, S. Sarac¸oðlu and L. Elci, 2002. Monitoring trace metal levels in Yozgat-Turkey: copper, iron, nickel, cobalt, lead, cadmium, manganese and chromium levels in stream sediments. Polish J. Environ. Stud, 11: 47-51.
12. Jonathan, M.P., V. Ram-Mohan and S. Srinivasalu, 2004. Geochemical variations of major and trace elements in recent sediments, off the Gulf of Mannar, southeast coast of India. Environ Geol, 45: 466-480.
13. Mostafa, A.R., O.A. Barakat, Y, Qian , L.T. Wade and D. Yuan, 2004. An overview of metal pollution in the western harbour of Alexandria, Egypt. J. Soil Sediment Contam, 13: 299-311.
14. Selvaraj, K., V. Ram-Mohan and P. Szefer, 2004. Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: geochemical and statistical approaches. Mar Pollut Bull, 49: 174-185.
15. Jayaraju, N., B.C. Sunder Raja Reddy and K.R. Reddy, 2008. The response of benthic foraminifera to various pollution sources: A study from Nellore coast, East Coast of India . Environ Monit Assess., 142: 319-323.
16. Sundara Raja Reddy, B.C., 2006. Estuarine pollution signatures on the Benthic foraminifera: A study from Nellore coast, East coast of India. Unpublished Ph.D thesis. S.V. University, Tirupati, A.P., India.
17. Martin, J.M. and M. Whitefield, 1983. The significance of river input of chemical elements to the ocean. In C.S. Wongs, E. Boyle, K.W. Druland, J.D. Burton and E.D. Goldberg (Eds.), Trace metals in sea water. New York: Plenum, pp: 265-296.
18. Karen, B. and D. Barid, 2001. Survey of heavy metals in the sediments of Swartkops River estuary. Port Elizabeth South Africa. Water SA,27, 4: 461-466. South Africa.
19. Del valls, T.A. and I. Ribs, 2007. A weight of evidence of approach to asses sediment quality in the Gudalquivir estuary, Aquatic ecosystem Health and Management, 10(1): 101-106.
20. Jayaraju, N., I. Surya Kumar and K.R. Reddi, 2007. Foraminiferal species densities and environmental variables of Pulicat Lake, South east coast of India, JGSI, 70: 829-836.
21. Lobeblich, A.R. and H. Tappan, 1988. Foraminiferal genera and their classification. Van Nostrand reinhold, New York.
22. Reddy, K.R, 1973. Ecology of recent foraminifera: Pennar estuary. Andhra Pradesh, India. Unpublished Ph.D thesis, S.V. University, Tirupati, AP, India.
23. Alve, E., 1995. Benthic foraminiferal responses to estuarine pollution: A review. J. Foraminiferal Res., 25: 190-203.
24. Jayaraju, N. and K.R. Reddi, 1996. Impact of pollution on Coastal Zone monitoring with benthic foraminifera of Tuticorin, South east coast of Inida. Indian J. Marine Sci., 25: 376-378.
25. Nigam, R., R. Saraswat and R. Panchang, 2006. Application of Foraminifera ecotoxicology: Retrospect, prospect and prospect, Envi Inta, 32: 273-283.