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Benthic foraminifera to assess ecological quality status of Kaduvaiyar and Uppanar estuaries, Southeast coast of India

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Original Article

Abstract

In the present study, the ecological conditions of Kaduvaiyar and Uppanar estuaries and its adjacent coastal waters was studied by using foraminiferans as a veritable tool. A total of 43 species of foraminifera belonging to 33 genera, 26 families, and 7 orders were recorded in this study. The occurrence of *Ammonia beccarii, Ammonia tepida, Bolivina hantkeniana, Elphidium subevolutum* and *Rosalina globularis* was relatively higher. Among the Orders, Rotallida and Miliolida were found to be the dominant groups. Diversity, expressed as the effective number of species (exp H'bc) was found lower in Uppanar estuarine stations (highly polluted sites), whereas the higher values were recorded in coastal stations of Kaduvaiyar Estuary (relatively pristine quality sites). The EcoQS values ranged between 5.0 (UE-1) and 73.3 (KC-LS). This study proves that EcoQS indices are robust tool for assessing the ecological quality of the stressed ecosystem.

Keywords: *Foraminifera, EcoQS indices, heavy metal, estuaries, Kaduvaiyar, Uppanar*

Introduction

Many coastal and marine environments have been altered to a greater extent due to direct discharge of untreated sewage, industrialization, urbanization, shipping, and discharge from power plant, oil and gas recovery and other human activities, causing deleterious effects on the biodiversity potential of the coastal and marine environments (Allen *et al.*, 2012). Besides these, a suite of biotic and abiotic factors are also known to influence the distribution of marine organisms. Among these, temperature, salinity and dissolved oxygen are the major factors that either individually or in tandem influence the distribution of organisms (Górska *et al.,* 2014; Majdi *et al.,* 2017).

With respect to various biotic components, benthic communities play an important role in the re-mineralization and release of nutrients in marine ecosystems. In them, meiofauna/ interstitial fauna occurs in almost all marine environments with greater abundance equal to macrofauna (Sergeeva *et al.*, 2017; Zeppilli *et al.*, 2018). Of various meiobenthic taxa, foraminiferans, the protozoan, is known for direct recruitment in the benthic environment; it has short generation time and therefore it is extensively used worldwide in assessment of environmental health programmes (Kennedy and Jacoby, 1999) besides they are also considered as bio-indicators of several sources of pollution such as oil spills (Morvan *et al*., 2004) heavy metals (Armynot du Chatelet *et al*., 2004) urban sewage (Burone *et al*., 2006) petroleum hydrocarbons (Sunderman and Thistle, 2003) pesticides (Coull and Chandler, 1992) and antifouling paints (Dahllöf *et al.,* 2001) in coastal waters.

Under these circumstances, the European Water Framework Directive (WFD) established a framework for the protection of marine waters. The Marine Strategic Framework Directive (MSFD) aims to achieve good environmental status of the European Union’s marine waters by 2020 and to protect the resources based upon which marine-related economic and social activities depend. This initiative evinced the attention of many benthic researchers worldwide. To achieve the prime objectives of this mission, various macro and meiobenthic organisms are being used as sentinel organisms ascertaining the healthiness of an ecosystem. Of various meiobenthic groups, foraminiferans and nematodes are the dominant ones, which are extensively used in the environmental health monitoring studies. Based on the facts stated above, an extensive survey was made to ascertain the health of two estuaries *viz*., Uppanar and Kaduvaiyar of southeast coast of India using foraminiferans as a veritable tool.

Material and methods

Study area

The present investigation was carried out seasonally from July 2016–June 2017 to study the foraminiferal diversity and to assess the ecological health status of Uppanar and Kaduvaiyar estuaries and its adjacent coastal waters. In each estuary, five stations were fixed (Fig. 1). The details of sampling stations are given below:

Station-1 UE-1 - Fixed near SPIC Pharma Industries (Lat. 11°41’25.07”N, Long. 79^0 45’57.57”E)

Station-2 UE-2 - Fixed near urban discharge point (Lat. 11°42’0.60”N, Long. 79^{0}46’25.14”E)

Station-3 UC-M - Near Uppanar river mouth (Lat. 11°42’18.16”N, Long. 79^{0}47’17.77”E)

Station-4 UC-RS - Fixed 500m right side from Uppanar mouth (Lat. 11°41’47. 23”N, Long. 79^{0}47’16.47”E)

Station-5 UC-LS - 500m left side from Uppanar mouth (Lat. 11°42’50.89”N, Long. 79^{0}47’19.81”E)

Station-6 KE-1 - Fixed near Fish landing centre (Lat. 10°45’12.78”N, Long. 79^{0}50’51.51”E)

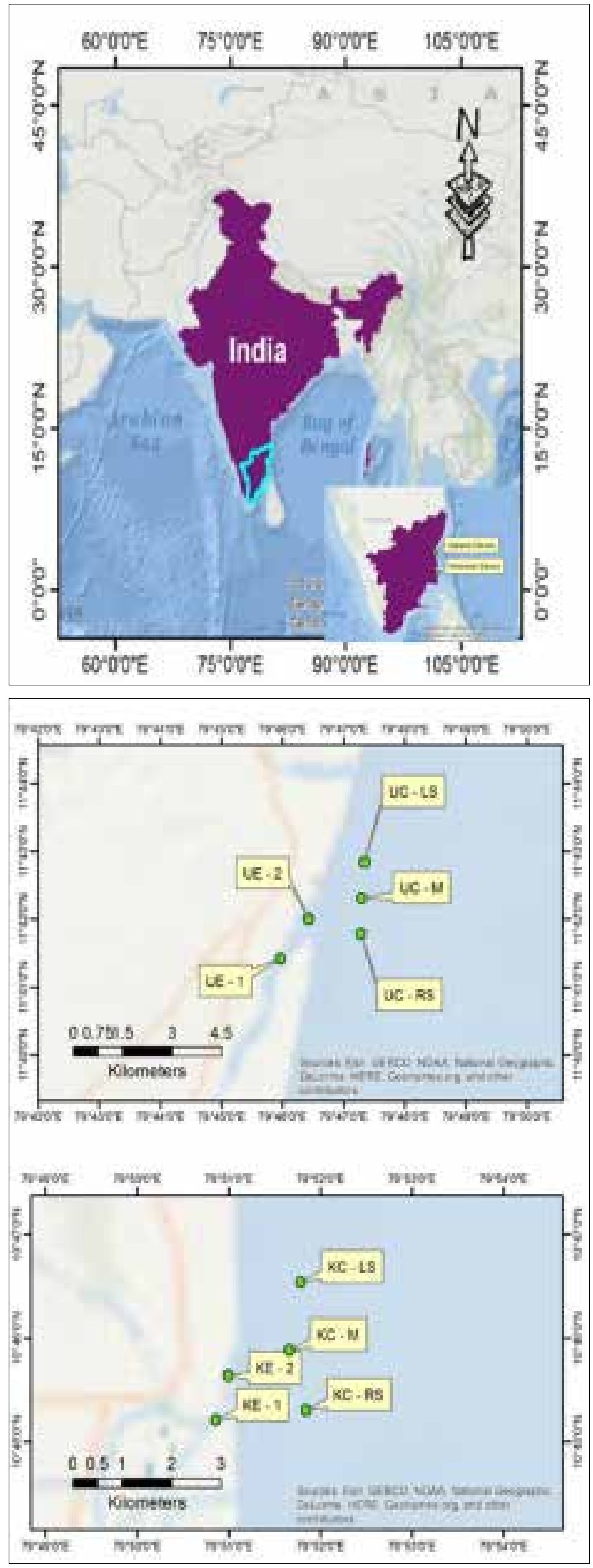

Fig. 1. Map showing the sampling stations: Uppanar and Kaduvaiyar estuaries and its adjacent coastal waters

Station-7 KE-2 - Fixed 0.5km upstream river mouth (Lat. 10°45'41.05"N, Long. 79°50'59.60"E)

Station-8 KC-M - Near Kaduvaiyar river mouth (Lat. 10°45'53.42"N, Long. 79°51'39.58"E)

Station-9 KC-RS - Fixed 500m right side from Kaduvaiyar mouth (Lat. 10°45'18.61"N, Long. 79°51'50.38"E)

Station-10 KC-LS - 500m left side from Kaduvaiyar mouth (Lat. 10°46'32.63"N, Long. 79°51'46.83"E)

(Foot note: UE- Uppanar Estuary, KE- Kaduvaiyar Estuary, UC- Uppanar Coast, KC- Kaduvaiyar Coast, M- Mouth, RS- Right side, LS- Left side)

Uppanar Estuary is known to receive municipal and domestic sewages, besides wastes from coconut husk retting grounds, and effluents from SIPCOT (Small Industries Promotion Council of Tamil Nadu) area and similarly Kaduvaiyar Estuary receives wastes from municipal and domestic sewages and agricultural run-off.

Collection of Water and sediment samples

Water samples were collected using Teflon coated Niskin (5L) water sampler. Water quality parameters such as temperature, salinity, pH, and dissolved oxygen were measured *in-situ* condition by following the methods described in APHA (1998). Sediment samples were collected by using Peterson grab and the samples were shade-dried and the same were subjected to soil texture, Total Organic Carbon (TOC) and heavy metals analysis. Soil texture was analyzed by adopting the pipette method (Krumbein and Pettijohn, 1938) and total organic carbon (TOC) content was determined by using wet oxidation method of El Wakeel and Riley (1957). For heavy metal analysis, samples were digested with concentrated perchloric acid and nitric acid (1:3) by following Topping (1973). The supernatant was analyzed to detect the level of heavy metals by using Inductively Coupled Plasma Mass Spectrophotometer (AGILENT - 7700x ICP-MS) in the Centralized Instrumentation and Service Laboratory (CISL) of Annanamalai University.

Benthic organisms

In each station, three replicate samples were collected using Peterson Grab (biting area 0.1 m^2) by following the method of Mackie (1994). The collected samples were emptied into a plastic tray and then sieved through 63 μm mesh screen. The organisms retained by the sieve were preserved in 5-7% formalin and stained with Rose Bengal and left for a day or two. Subsequently, the foraminiferans were sorted, counted and identified using light microscope (KL-300LED Carl Zeiss microscope) up to lowest possible taxonomic level by consulting the standard works (Loeblich and Tappan, 1988; Loeblich and Tappan, 2015; Thilagavathi *et al.*, 2012 and Mohan *et al.,* 2013).

Data analysis

Ecological Quality Status (EcoQS) Indices: Before experimenting the data with EcoQS Indices, they were subjected to various statistical methods namely univariate, graphical/distributional and multivariate methods available in statistical language "R software" *Version* 3.4.2., ran with package Vegan library 2.4.4 Ver. (Oksanen, 2018). Accordingly, the foraminiferan abundance data were subjected to the Shannon-Weiner species diversity index (H' log^2), Margalef species richness (d) and Pielou's species evenness (J'). Principal Component Analysis (PCA) bi-plot was drawn for physico-chemical parameters against sampling stations. Canonical Correspondence Analysis (CCA) was performed to determine the relationship between foraminiferans and the environmental parameters (Oksanen *et al.*, 2018). Classification and ordination methods (PRIMER software Ver. 7.0) were also done to find out the similarity between the samples collected in various stations by using the tree diagram or dendrogram drawn through Bray-Curtis similarity index (Bray and Curtis, 1957).

In order to assess the pollution status of sampling stations, EcoQS indices were adopted using benthic foraminifera as bio-assessment tool. These EcoQS indices were calculated using "R statistical software" with entropy version 1.1.5 (Hausser and Strimmer, 2010). The results of Shannon-Wiener index (H', log^2) (Shannon and Weaver, 1963), Hurlbert index ES (100) (Hurlbert, 1971) and Exponential (H'bc) bias-corrected Shannon Index were considered as metrics to characterize the EcoQS indices. Accordingly, the reference value for the Ecological Quality Status (EcoQS) of an environment is classified as the following categories based on the European intercalibration (www.ec.europa.eu/environment/water/marine.htm):

High quality	:	>20
Good	:	>15-20
Moderate	:	>10-15
Poor	:	>5-10
Bad	:	<5

Shannon-Wiener diversity index (H') is biased when there are unobserved species in the community, a common problem during sampling (Chao and Shen, 2003). Chao and Shen (2003) introduced a bias-corrected version of Shannon's index (H'_{bc}), which has little bias (Beck and Schwanghart, 2010), and it was used for this study. Shannon's index is entropy rather than diversity. The entropy gives the average uncertainty of the identity of an individual picked from the community, not the number of species in the community (Hayek and Buzas, 1997; Jost, 2006). It can be converted to true diversity, the effective number of species, with the exponential function (N1 = exp (H' bc), Hill, 1973). Exp (H'_{bc}) which gives the number of species that would, if each were equally common, produce the same H'_{bc} as the sample. Correlations between the bias-corrected exponent of Shannon of different fractions of the foraminiferal community, as well as of their microhabitat and the environmental variables are calculated. All data represent the pooled counts from three replicates per station.

Results

Environmental data

Physico-chemical characteristics of water samples: The average values of physico-chemical parameters recorded at each sampling station is summarized in Table 1. Water temperature varied from 23.2-26.5°C with minimum at UE-1 and maximum at KC-RS; water pH showed minimum (7.7) at UE-1 and maximum (8.2) at KC-LS. Salinity showed a wide range of fluctuation with minimum (27.5 ppt) at UE-1 and maximum (36.3ppt) at KC-LS. Dissolved oxygen ranged between 4.8 mg/l (UE-1) and 3.3 mg/l (KC-RS).

Sediment samples: As regards sediment samples, the pH showed minimum (7.8) at UE-1 and maximum (8.3) at KC-LS. The TOC content varied from 4.6mgC/g (KC-LS) to 13.6mgC/g at UE-1. The sand content showed a minimum of 7.1% at UE-1 and maximum of 63.8% at UE-LS and similarly the silt values were from 6.8% at KE-1 to 52.2% at KE-M. Clay content varied from 6.5% (UE-LS) to 83.4% (KE-1). The heavy metal concentration also varied significantly in both the estuaries; the level of Copper (Cu) showed minimum (8.8ppm) in KE-LS and maximum (26.4 ppm) at UE-1; Cadmium (Cd) varied from 1.5ppm (KE-RS) to 9.9ppm (UE-1) and the Lead (Pb) level ranged from 5.1ppm (KE-RS) to 57.74 ppm (UE-1) and Zinc (Zn) concentration varied widely from 12.8ppm at KE-RS to 76.6 ppm at UE-1 (Table. 1).

Principal component analysis: The physico-chemical parameters in water were subjected to Principle component analysis to set a well-defined relation between the environmental parameters against the surveyed stations (Fig. 2) and the PCA plot drawn indicated that parameters such as depth, DO, salinity, water temperature, water pH and sediment pH were highly correlated with stations KE-2, KE-2, KE-M, KE-RS, KE-LS in Kaduvaiyar and UE-M, UE-RS and UE-LS in Uppanar whereas total organic carbon, clay, zinc, cadmium, sand and silt correlated with UE-1and UE-2 in Uppanar Estuary. The heavy metals such as lead and copper significantly correlated with KE-1 located in Kaduvaiyar Estuary.

Biological entities: With respect to faunal entities, as many as 43 species of foraminiferans belonging to 7 orders, 26 families, and 33 genera were recorded from the surveyed stations

Table 1. Physico-chemical characteristics (mean and SD) recorded in various sampling stations of the Kaduvaiyar and Uppanar estuaries and its adjacent coastal waters

Variables	UE-1	UE-2	UC-M	UC- RS	UC-LS	KE-1	KE-2	KC-M	KC-RS	KC-LS
Water Temp (°C)	23.2 ± 0.36	23.7 ± 0.49	24.7 ± 0.51	25.1 ± 0.38	25.3 ± 0.53	24.2 ± 0.41	25 ± 0.47	25.3 ± 0.54	26.5 ± 0.57	26.5 ± 0.48
Water pH	7.7 ± 0.36	7.8 ± 0.31	7.9 ± 0.39	8.0 ± 0.36	8.1 ± 0.31	7.8 ± 0.30	7.9 ± 0.27	8.0 ± 0.28	8.1 ± 0.46	8.2 ± 0.27
Salinity (ppt)	27.5 ± 0.38	28.5 ± 0.41	35.3 ± 0.48	35.7 ± 0.39	35.8 ± 0.46	28.7 ± 0.37	29.8 ± .42	35.5 ± 0.38	36.3 ± 0.57	36.3 ± 0.48
DO (mg/l)	3.3 ± 0.27	3.4 ± 0.30	3.8 ± 0.26	4.3 ± 0.53	4.4 ± 0.42	3.7 ± 0.31	3.8 ± 0.31	4.2 ± 0.49	4.8 ± 0.38	4.3 ± 0.32
Sediment pH	7.8 ± 0.25	7.9 ± 0.33	8.2 ± 0.46	8.2 ± 0.31	8.3 ± 0.37	7.9 ± 0.28	8.0 ± 0.38	8.2 ± 0.36	8.2 ± 0.52	8.3 ± 0.35
TOC (mgC/g)	13.6 ± 0.62	12.8 ±0.50	10.4 ± 0.48	9.4 ± 0.63	9.5 ± 0.47	12.8 ± 0.59	12.5 ± 0.68	8.7 ± 0.42	5.1 ± 0.37	4.6 ± 0.40
Sand %	7.1 ± 0.32	7.9 ± 0.44	60.3 ± 0.36	55.3 ± 0.72	63.8 ± 0.50	9.7 ± 0.41	12.6 ± 0.37	38 ± 0.56	55.3 ± 0.48	53.0 ± 0.84
Silt %	13.8 ± 0.41	20.2 ± 0.72	31.2 ± 0.53	36.1 ± 0.58	29.7 ± 0.86	6.8 ± 0.58	19.1 ± 0.83	52.2 ± 0.91	38.2 ± 0.72	40.2 ± 0.43
Clay %	79.1 ± 0.58	71.9 ± 0.96	8.5 ± 0.76	8.6 ± 0.47	6.5 ± 0.85	83.4 ± 0.73	68.1 ± 0.61	9.8 ± 0.82	6.5 ± 0.45	6.8 ± 0.62
Copper (ppm)	26.4 ± 0.36	22.7 ± 0.75	14.6 ± 0.50	10.7 ± 0.88	10.7 ± 0.34	21.6 ± 0.64	18.4 ± 0.54	12.3 ± 0.93	8.8 ± 0.66	9.7 ± 0.54
Cadmium (ppm)	9.9 ± 0.45	7.7 ± 0.93	5.1 ± 0.64	3.3 ± 0.79	2.3 ± 0.88	4.8 ± 0.72	4.0 ± 0.81	2.1 ± 0.47	1.7 ± 0.34	1.5 ± 0.87
Lead (ppm)	19.5 ± 1.67	16.7 ± 1.09	12.0 ± 0.89	8.4 ± 1.04	8.7 ± 0.52	14.3 ±0.85	10.4 ± 0.79	7.4 ±0.78	5.1 ± 0.62	5.2 ± 0.90
Zinc (ppm)	76.6 ± 1.84	64.7 ± 0.86	51.1 ± 1.05	29.1 ± 0.95	26.6 ± 0.70	41.3 ± 0.84	28.6 ± 1.06	16.7 ± 0.89	13.5 ±0.73	12.8 ±0.81
Diversity Indices										
H'(log2) (diversity)	1.6	2.0	3.5	4.0	4.0	2.2	2.8	4.1	4.1	4.3
d (richness)	4.388	4.452	2.995	2.443	3.125	3.699	3.394	2.951	2.386	2.845
J' (evenness)	0.7609	0.6602	0.7647	0.8567	0.8687	0.7821	0.7659	0.8344	0.8399	0.8692

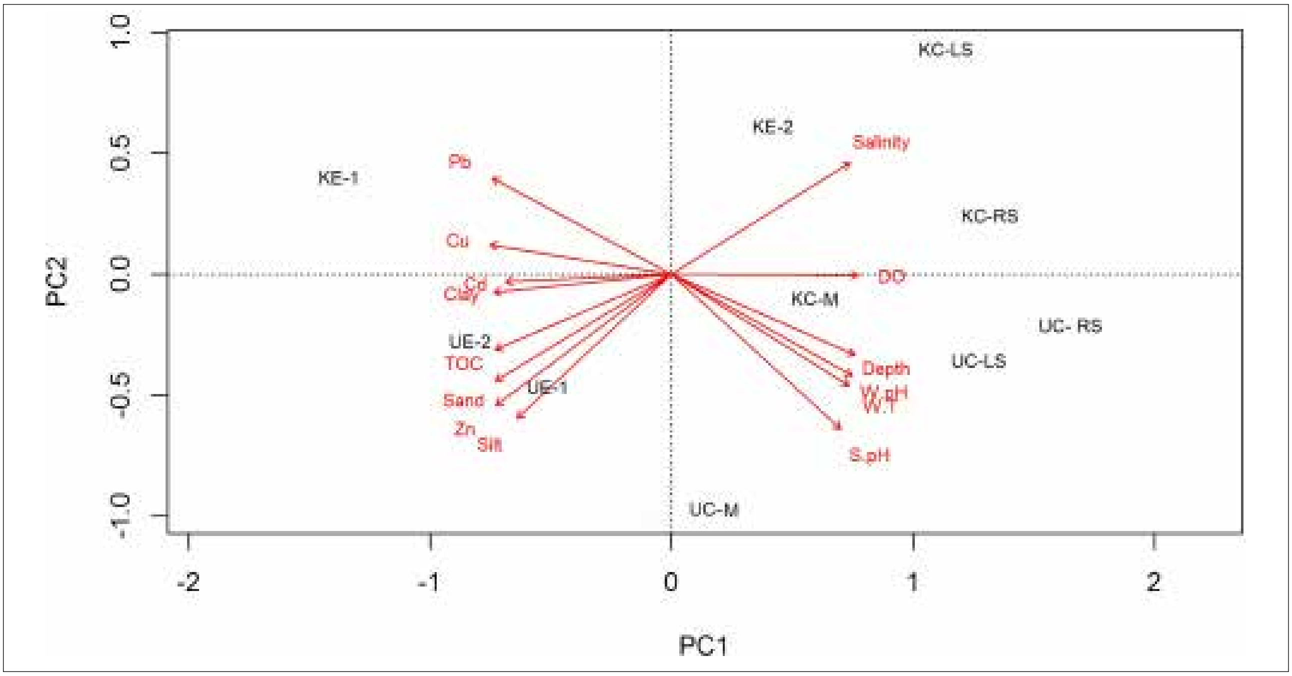

Fig. 2. Principle component analysis-biplot of physico-chemical parameters of Kaduvaiyar and Uppanar estuaries and its adjacent coastal waters

Table 2. Foraminiferal species recorded in various sampling stations of the Kaduvaiyar and Uppanar estuaries and adjacent coastal waters (Nos/cm^2)

S.No.	Foraminifera species	S.No.	Foraminifera species
	Rotaliida (order)		**Milioida (order)**
1	*Oridorsalis umbonatus*	27	*Miliolinella* sp.
2	*Ammonia beccarii*	28	*Quinqueloculina apicula*
3	*A. tepida*	29	*Q. oblonga*
4	*Asterigerina carinata*	30	*Triloculina* sp.
5	*Bolivina hantkeniana*	31	*Milliammina* sp.
6	*B. abbreviata*	32	*M. oblonga*
7	*Brizalina striatula*	33	*Ophthalmidium inconstans*
8	*Cibicides peudoungrianus*	34	*Spiroloculina* sp.
9	*C. refulgens*	35	*S. depressa*
10	*Pararotalia* sp.	36	*S. antillarum*
11	*Cymbaloporetta bradyi*		**Lagenida (order)**
12	*Discorbinella montereyensis*	37	*Lagena quadrata*
13	*Discorbis allomorphinoides*	38	*L. striata*
14	*Elphidium subevolutum*	39	*Siphonodosaria brady*
15	*Eponides repandus*		**Astrorhizida (order)**
16	*Globigerina globularis*	40	*Diffusilina humilis*
17	*Orbulina universa*		**Lituolida (order)**
18	*Globigerinoides sacculifer*	41	*Haplophragmoides canariensis*
19	*Globorotalia* sp.		**Loftusiida (order)**
20	*Nonion depressulus*	42	*Cyclammina cancellata*
21	*Nonionella stella*		**Spirillinida (order)**
22	*N. limbatostriata*	43	*Spirillina lateseptata*
23	*Operculina cumingii*		
24	*Planulina* sp.		
25	*Rosalina bertheloti*		
26	*R. globularis*		

(Table 2). Among the seven orders, Rotaliida topped the list with 26 species belonging to 22 genera and 16 families. Of this Order, *Ammonia beccarii, A. tepida, Bolivina hantkeniana, B. abbreviate, Brizalina striatula, Globigerinoides sacculifer, Rosalina globularis* and *Nonionella* sp were found to be the common species. Next to Rotaliida, Milioida was found to be the second dominant group with 10 species belonging to 6 genera and 4 families and of this the common species were *Miliolinella Antarctica*, *Quinqueloculina agglutinans, Milliammina* sp and *Spiroloculina* sp. In the order Lagenida, 3 species belonging to 2 genera and 2 families were recorded. Subsequently, the orders Astrorhizida, Lituolida, Loftusiida, and Spirillinida were represented by meagre contributions. The population density calculated between the regions varied from 392 to 658nos.10cm^{-2} with maximum at Kaduvaiyar and minimum at Uppanar Estuary.

Similarly, when the species composition were viewed station-wise, *Ammonia beccarii, A. tepida, Bolivina hantkeniana, B. abbreviate, Miliammina* sp., *Globigerinoides sacculifer*, *Elphidium subevolutum* and *Rosalina globularis* were found common in estuarine stations. Similarly, *A. beccarii, Asterigerina carinata, Miliammina* sp., *Spiroloculina* sp., *Nonionella* sp. and *Discorbinella montereyensis* were found to be dominant in coastal stations (Fig. 3). In Uppanar Estuary, a total of 27 foraminiferal species were recorded and 32 species were recorded in Kaduvaiyar Estuary. Seasonally, the maximum number (29) of species was recorded during summer and minimum (21) during monsoon season. The dominant foraminiferal species recorded in Uppanar Estuary were *Ammonia beccarii, A. tepida, Bolivina abbreviate, Discorbinella montereyensis, Elphidium subevolutum, Eponides repandus, Quinqueloculina apicula, Q. oblonga, Rosalina bertheloti, Rosalina globularis, Spiroloculina depressa, S. antillarum* while in Kaduvaiyar Estuary *A. beccarii, A. tepida, Asterigerina carinata, B.hantkeniana, Cibicides peudoungrianus, C. refulgens, Cyclammina cancellata, Diffusilina humilis, Discorbinella montereyensis, Discorbis allomorphinoides, Elphidium subevolutum, Eponides repandus, Globigerina globularis, Lagena quadrata, Nonion depressulus, Quinqueloculina apicula, Q. oblonga, Rosalina bertheloti, R. globularis, Siphonodosaria brady, Spirillina lateseptata, Spiroloculina depressa* were found as dominant.

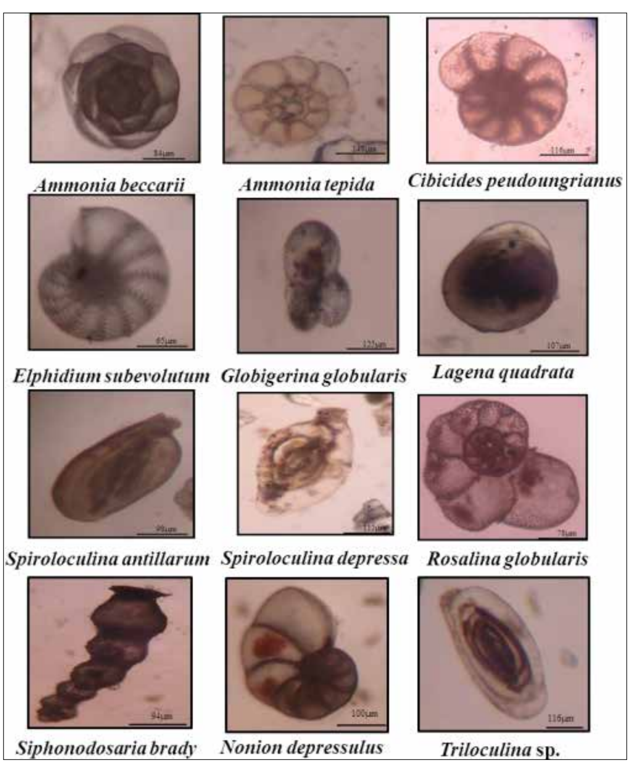

Fig. 3. Dominant benthic foraminiferans recorded in Uppanar and Kaduvaiyar estuaries

Among the various foraminiferan orders, Rotaliida was found to be the dominant one with 47% in Kaduvaiyar Estuary and the other orders such as Miliolida, Lituolida, Spirillinida, Legenida, Robertinida, Textulariida and Astrorhizida contributed with 24, 8, 8, 6, 4, 4 and 3% respectively to the total foraminiferan species collected. Similarly, as in Kaduvaiyar, Rotaliida continued to be the dominant group with 38% of the total foraminifera species collected and the rest like Milioida, Lagenida, Spirillinida, Lituolida Astrorhizida and Loftusiida contributed with 32, 16, 7, 3, 2 and 2% respectively to the total foraminiferan species collected from Uppanar Estuary.

Diversity indices: The species diversity index varied from 1.675 at UE-1 of Uppanar Estuary to 4.269 at KE-LS of Kaduvaiyar Estuary with maximum during dry season and minimum during wet season; species richness index fluctuated from 2.386 (KC-RS) to 4.452 (UE-2) with maximum during dry season and minimum during wet season; Pielou's evenness values varied from 0.6602 (UE-2) to 0.8692 (KE-LS) with maximum during dry season (summer) and minimum during wet season (monsoon).

Cluster analysis: To find out the similarity/dissimilarity between stations, the foraminiferal abundance data of both the regions were amalgamated and subjected to classification and ordination methods. The resulting dendrogram revealed that the stations of respective estuary (KE-1, KE-2, KC-M, KC-RS and KC-LS) were forming cluster separately based on the species composition and abundance (Fig. 4). This fact was further confirmed through MDS, which was also revealing the same pattern of groupings as observed in cluster analysis. The stress value (0.01), which is overlying on the top-right corner of the MDS plot, was also found

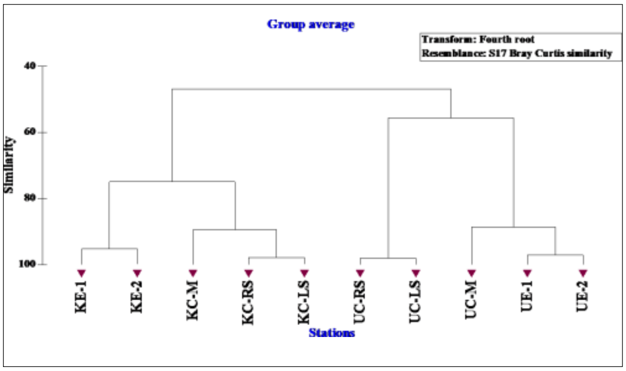

Fig. 4. Dendrogram for the benthic foraminiferal data collected in Kaduvaiyar and Uppanar estuaries and its adjacent coastal waters

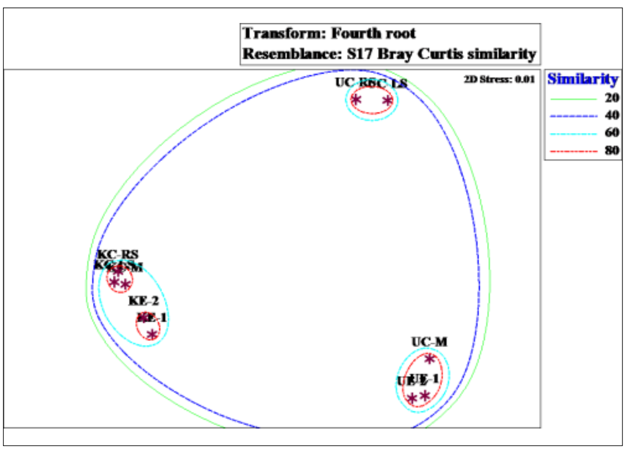

Fig. 5. MDS drawn for the benthic foraminiferal abundance recorded in various stations of Kaduvaiyar and Uppanar estuaries and its adjacent coastal waters

to be low signifying the good ordination pattern of the samples (Fig. 5).

Canonical correspondence analysis: Besides PCA, CCA (Canonical Correspondence Analysis) was also drawn to study the relationship between the physico-chemical parameters and benthic foraminiferal diversity components. The CCA plot showed total variance of 78.2% between

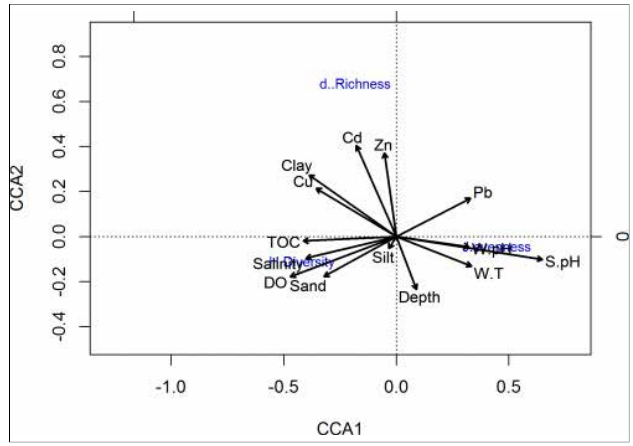

Fig. 6. Canonical correspondence analysis showing the correlation between benthic foraminiferal diversity indices and environmental variable

F1 and F2 axis and the maximum canonical values were 0.603, 0.505, 0.521, 0.487 and 0.377. The environmental parameters such as water temperature, water pH, sediment pH and lead strongly influenced evenness (J), while other parameters DO, salinity, TOC, sand, silt, clay, copper, cadmium, lead and zinc weakly influenced the richness (d) and diversity (H') (Fig. 6).

EcoQS based on Foraminiferans: A total of 43 species of foraminiferans was recorded in the present study and the same was subjected to Ecological Quality Status (EcoQS) indices, based on the criteria set by the Norwegian Pollution Control Authority (Table.3). Of this, Exp (H'_{bc}) values for the foraminiferal species ranged between 5.0 at station UE-1 and 73.3 at station KC-LS. According to EcoQS status, estuarine stations namely UE-1 and UE-2 in Uppanar fell in the category of "Bad" & "Poor" status respectively; KE-1 in Kaduvaiyar fell in the category of "Moderate" environmental health status while the remaining stations of both the regions fell in the category of "High quality" nature (Table. 4). Correspondingly the diversity values in stations UE-1, UE-2 of Uppanar; KE-1 of Kaduvaiyar were also found to be less than 3.

Table 3. Criteria for determining EcoQS using benthic foraminiferans

EcoQS and associated color code	Bad	Poor	Moderate	Good	High
EcoQS foraminiferans derived from	<5	5-10	10-15	15-20	>20
0-2 cm (from soil surface), >62 μm,					

Table 4. The diversity of foraminiferal assemblages (H'log2, ES (100) and Exp (H' bc) EcoQS.

	UE- 1	UE- 2	UC- M	UC- RS	UC- LS	KE- 1	KE- 2	KC- M	KC- RS	KC- LS
H' (log2)	1.6	2	3.5	4	4	2.2	2.8	4.1	4.1	4.3
ES (100)	7	9	16	21	21	12	16	25	25	27
Exp (H'bc)	5.0	6.4	34.4	53.9	54.3	10.4	18.4	59.3	62.4	73.3

Discussion

Worldwide urbanization and industrialization led to widespread contamination of coastal systems and estuarine environments. Scott *et al.* (2001) reported that benthic foraminiferal can cope with highly stressed environments and among the various meiobenthic taxa, foraminiferans will be the last group to disappear at heavily impacted sites. Foraminiferans are highly sensitive marine protists, which has great potential to indicate ecological stress at a very early stage. There have been previous reports on potential impacts on the abundance and composition of the benthic foraminiferans assemblage due to various environmental disturbances, such as substrate nature and texture, bathymetry, temperature, dissolved oxygen, salinity, sedimentation rate, organic carbon, anthropogenic pollutants, and toxins (Buosi *et al.*, 2012; Magno *et al.*, 2012).

There was no pronounced variations observed in environmental parameters of both the estuaries. However, a few parameters such as TOC, sediment texture showed an elevated level in Uppanar compared to Kaduvaiyar so also the heavy metals, which could have been plausible reasons for variations in the distribution of benthic organisms as reported by Scott *et al.* (1979); Reinhardt *et al.* (2003) and Woodroffe *et al.* (2005). Understandably, the range in environemental entities of the present investigation is comparable to the results obtained by Gandhi and Nathan (2014) in the Uppanar Estuary; Balasubramanian and Kannan (2005) in Gulf of Mannar and Sankar *et al.* (2018) in Nagapattinam coastal waters.

Among the sedimentary nutrients, total organic carbon is known to play an important role in the accumulation and release of different micro-nutrients, which reflects more accurately in the organic matter content. It is a well–known fact that the sediment texture determines the level of total organic carbon, which in turn influences the abundance of benthic fauna in any given environment. During the present study, maximum TOC was recorded at estuarine stations of Uppanar Estuary and minimum at Kaduvaiyar coastal stations. The higher TOC level in the estuarine stations might be due to transport of increased anthropogenic organic matter from the terrestrial environment, coupled with degradation of mangrove litter fall and the discharges from aquaculture activities (Bao *et al.*, 2013). Untreated municipal sewage is yet another potential source of TOC entering into the estuary (Herbeck *et al.*, 2011). The values obtained in the present study are in agreement with reports made by Murugesan (2002) in Vellar Estuary; Karthikeyan *et al.* (2004), Pugazhendy *et al.* (2008) in Uppanar Estuary.

Bottom sediments cannot be considered as a permanent sink of pollutants. That way, the metal mobilization in the sediment environment may take place, depending on the physico-chemical changes. In the present study, heavy metal concentration also varied significantly in both the estuaries. Of these, the level of Copper (Cu), Cadmium, Lead and Zinc accumulation was found maximum at estuarine stations of Uppanar Estuary and minimum at Kaduvaiyar coastal stations (KE-RS and KE-LS). The higher concentration of metals in estuarine stations could be attributed to the heavy rainfall and subsequent river runoff, bringing much industrial and land derived materials along with domestic, municipal, and agricultural wastes, which include residue of heavy metal containing pesticides (Ananthan *et al.*, 2006; Karthikeyan *et al.*, 2007). Saleshrani and Prabhahar (2013) also reported similar trend of heavy metal distribution in Kaduvaiyar Estuary; Jeshma *et al.* (2016) in Karaikal coastal waters. The values recorded in the present study are comparable to the reports made by Kesavan and Ravi (2013); Gandhi and Nathan (2014) and Ayyamperumal *et al.* (2006) from Uppanar Estuary.

The principal component analysis was performed using physico-chemical parameters as input data to set a well defined distinction between stations and parameters. In the present study depth, DO, salinity, water temperature, water pH and sediment pH were positively correlated with coastal stations of Uppanar and Kaduvaiyar whereas TOC, clay, lead, zinc, cadmium, copper, sand and silt were negatively correlated with the estuarine stations of Uppanar and Kaduvaiyar. Similar variables combination was reported earlier (Sivaraj *et al.*, 2015; Janakiraman *et al.*, 2016).

With regard to biological entities, 43 species of foraminiferans belonging to 33 genera, 26 families, and 7 orders were recorded from the surveyed stations. Among them, the most dominant species were *A. beccarii, A. tepida, B. hantkeniana, B. abbreviate, E. subevolutum* and *R. globularis.* Similar species compositions have also been reported in earlier studies: Thilagavathi *et al.* (2011) from the Gulf of Mannar; Kelmo and Hallock (2013) from northern Bahia, Brazil. The population density recorded in the present study is comparable with the observations made by Muthuvelu *et al.* (2013) in Parangipettai and Cuddalore coastal waters.

Seasonally, summer registered maximum number of species and monsoon the minimum. In their study, Stouff *et al.* (1999) and Berkeley *et al.* (2007) reported that salinity is an important factor in regulating distribution and growth of foraminifera, since they are typically stenohaline in nature. True to their sense, in the present study also summer season favored a higher density of foraminiferans in both the estuaries. The reason for the low desnity during monsoon and pre-monsoon might be due to unfavorable conditions i.e., low salinity, which could be attributed to the copious freshwater flow into the estuary which led to reduction in salinity (Orabi *et al.*, 2017).

The variation in species distribution of foramaniferan species in Uppanar and Kaduvaiyar estuaries could be due to the overall geographical distributional range of a group of species and environmental factors, which regulates the occurrence and distribution as has been suggested by Tsuchiya *et al.* (2015). As indicated above, the abundance, diversity and composition of foraminiferan assemblages in coastal and sublittoral environments are controlled largely by a combination of physical and chemical parameters (temperature, salinity, currents, substrate, sediment grain size), food resources and biotic interactions (Culver and Buzas, 1999, Murray, 2006).

In the present study, foraminiferan species, *A. beccarii*, *A. tepida* and *E. advenum* were reported as highly tolerant species and the density of these species was found higher in the stations (UE-1 & UE-2). Correspondingly the level of heavy metals and TOC content were high in those stations. Martins *et al.* (2016) reported *A. teptida* and *E. subevolutum* as the bio-indicator species for lower salinity, high concentration of metals and TOC from Ria de Aveiro, west zone of Portugal and they also recommended benthic foramniferal as valuable bio-indicator species to study the environmental health.

Diversity is a measure of the complexity of the community structure and it increases or decreases due to physical, chemical and biological factors. In the present study, a marked variation in the Shannon diversity was noticed between the surveyed stations. The species richness value was found maximum at industrial discharge zone of Uppanar Estuary. With respect to evenness (J'), the maximum value was found at Kaduvaiyar coastal stations. The minimum diversity was recorded in UE-1, UE-2 in Uppanar and KE-1 in Kaduvaiyar. This might be due to the locations of the stations as these stations are quite close to discharge point of industry. True to this fact, the density was found less in these stations. The diversity indices values recorded in the present study was found similar to the reports made by Murugesan (2002) in Vellar Estuary and Kumar and Khan (2013) in Pondicherry.

The cluster analysis showed unequivocally distinct variation in species composition and abundance in the surveyed sites. The dendrogram drawn for the abundance of benthic foraminiferans in estuarine and coastal stations showed two major clusters. The estuarine and coastal stations of both the regions formed clusters indicating variation in species composition and abundance. Samir *et al.* (2003) and Martins *et al.* (2016) also reported similar trend of benthic foraminiferan distribution. This fact was further confirmed through MDS, which also revealed the similar grouping of estuarine and coastal stations. The stress value recorded in the present study is comparable with the studies made by Khan *et al.* (2005). Investigation similar to this was carried out by Sivaraj (2014) who made a comparative study of Vellar-Coleroon estuarine system using macrobenthic communities through cluster analysis.

Canonical Correspondence Analysis (CCA) was done to ascertain the relationship between the physico-chemical parameters and benthic faunal density which revealed that the parameters such as water temperature, pH, sediment pH and lead correlated with evenness (J), while DO, salinity, TOC, sand, silt, clay, copper, cadmium, lead and zinc correlated with the richness (d) and diversity (H') components of foraminiferans. Sivaraj *et al.* (2015) in Vellar–Coleroon estuaries and Martins *et al.* (2016) also used the similar variables combinations as input parameters and found that the salinity, sediment pH, silt, clay and TOC showed significant relationship with benthic faunal distribution.

Besides PCA and CCA, the Ecological Quality Status (EcoQS) indices set by the Norwegian Pollution Control Authority were adopted in the present study to know the ecological health condition of surveyed estuaries and its adjacent coastal waters. This is the first attempt defining criteria to determine "EcoQS" using benthic foraminifera as a tool in environmental monitoring in the Indian context. The range of EcoQS recorded was found to vary between 5.0 at station UE-1 (Uppanar) and 73.3 at station KC-LS (Kaduvaiyar) indicating the former station in the category of "Bad" and latter being pristine nature. However, the remaining stations such as UE-2 of Uppanar fell in the category "Poor"; KE-1 of Kaduvaiyar in moderately disturbed and good categories respectively and the rest of the stations such as KE-2, UC-M, UC-RS, UC-LS, KC-M, KC-RS, & KC-LS were in pristine category.

The EcoQS values estimated presently for two estuaries unequivocally suggest that the stations near industrial zone in Uppanar Estuary were found to fall in the category of "Bad", whereas the stations of Kaduvaiyar in the category of Good to High. Doubtless, the results of the present study would certainly supplement to the existing knowledge on seasonal variation in foraminiferal assemblages in tropical estuaries. Not only is that, benthic foraminifera was used for the first time as a bio-monitoring tool by using Ecological Quality Status Indices (EcoQS) and this will go a long way in environmental monitoring programs worldwide. Nevertheless, it needs a long term study temporally and spatially experimenting in coastal and estuarine ecosystems with various types of pollutants, so as to have a holistic view.

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