Benthic Foraminifera- A Promising Tool For Assessment Of Ecological Quality Of Vellar Estuary And Its Adjacent Coastal Waters, Southeast Coast Of India

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Abstract: The ecological health conditions of Vellar estuary and its adjacent coastal waters were studied by using foraminiferans as a veritable tool. A total of 49 foraminiferal species belonging to 7 orders and 41 genera were recorded. The maximum density of foraminiferal species (467 Nos/10cm²) was recorded in Parangipettai coastal waters. The common foraminifera species recorded during the present study were *Ammonia beccarii, A. tepida, Bolivina limbatam, B. tortuosa, Rosalina bertheloti* and *Triloculina tricarinata*. The maximum number of foraminifera species (18 species) was recorded in Vellar coastal stations and minimum (31 species) was recorded in Vellar estuarine stations. BIO-ENV (Biota-Environmental matching) showed that the environmental parameters such as Dissolved oxygen, Temperature, Salinity, pH, Sand and TOC manifested as best match ($\rho\omega$ = 0.964) in determining foraminiferal distributions. The maximum foraminifera species diversity was recorded (H') 3.876 at Vellar coastal stations, similarly the maximum species richness (d) 6.905 was recorded at Vellar estuarine stations and maximum species evenness (J') 0.943 was recorded at Vellar coastal stations. The results of present study throw light on the understanding on the foraminiferal distribution in relation to Physico-chemical parameters, which will form a reliable tool in bio-monitoring studies.

Keywords: Benthic Foraminifera, Density, Diversity, BIO-ENV, Vellar estuary

1. Introduction

Estuaries are transitional environments, the meeting place of land, freshwater and marine ecosystems. Coastal and estuarine ecosystems are hot spots of environmental variability, biogeochemical transformations and biological interactions, where dynamic exchanges of energy, mass and nutrients occur between benthic and pelagic habitats via diverse pathways [1], [2]. These transitional ecosystems between land and sea are often densely populated and experience multiple anthropogenic pressures including climate change, nutrient loading, and fishing, which causes adverse effects on the ecosystem and organisms living within this region [3], [4].

Benthic organisms play an important role in the detrital food cycle and it also act as prey for other fauna e.g. worms, snails, shrimps, mussels, barnacles, clams, oysters and etc. The term "meiobenthos" refers to a group of invertebrate organisms that are intermediate in size between macro and micro-fauna and includes metazoan organisms and also ecologically relevant species such as foraminifera, nematodes and ciliates inhabiting benthic environments with all sediment types in varied climatic zones [5], [6], [7]. Benthic foraminifera occur in almost all marine environments and with much higher abundances than macro-fauna, which is traditionally used in environmental monitoring studies [8]. Benthic foraminifera have been widely used as bio-indicators of several pollution sources in coastal and transitional waters such as aquaculture [9], [10], [11] oil spills [12], heavy metal pollution [13], [14] and urban sewage [15].

The ecological health of an estuarine and coastal ecosystem is demonstrated by changes in abundance, presence/absence of key taxa and species diversity of meiobenthic taxa viz., foraminifera, nematodes and copepods [16]. Considering the facts stated above, in the present study an attempt was made to investigate the influence of water and sediment quality parameters on the distribution of foraminiferans in Vellar estuary and its adjacent coastal waters.

2. Materials and methods

2.1. Study area

To achieve the objectives envisaged, water and sediment samples were collected seasonally from April 2017 - March 2018 from five different stations (Lat. 11°′25.42.66″N, Long. 79^{0}47′41.33"E) in Vellar estuary (Fig.1). The details of sampling stations are given below:

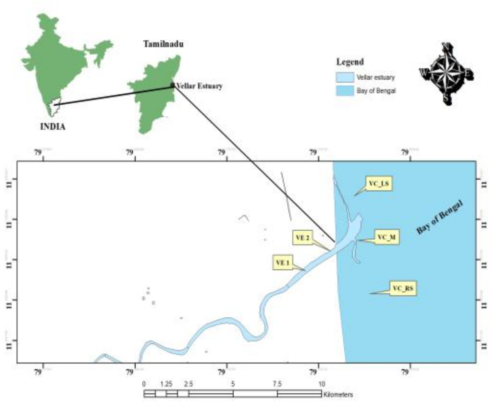

Fig.1. Map showing the sampling stations: (Vellar estuary and its adjacent coastal waters) in Parangipettai

Station-1 VE-1 - Fixed Opposite to CAS in Marine biology Institute (Lat. 11°41′25.07"N, Long. 79^{0} 45′57.57"E)

Station-2 VE-2 - Fixed near Annan Koil landing Center (Lat. 11°42′0.60"N, Long. 79^{0}46′25.14"E)

Station-3 VC-M - Near Vellar river mouth (Lat. 11°42′18.16"N, Long. 79^{0}47′17.77"E)

Station-4 VC-RS - Fixed 1km right side to the Vellar River mouth (Lat. 11°41′47. 23"N, Long. 79^{0}47′16.47"E)

Station-5 VC-LS - Fixed 1km left side to the Vellar River mouth (Lat. 11°42′50.89"N, Long. 79^{0}47′19.81"E)

2.2. Collection of Water and sediment samples

Seasonal survey (Post monsoon – January to March; Summer – April to June; Pre-monsoon – July to September and Monsoon – October to December) was carried out in the pre-determined sampling stations of the study area. Water quality parameters such as temperature, salinity, pH and dissolved oxygen were measured *in-situ* condition by following the methods described in [17].Water samples were collected by using Niskin water sampler and the undisturbed sediment samples were collected using Peterson grab and shade dried for the Soil texture and Total Organic Carbon (TOC) analysis. The Soil texture analysis was done using pipette method as described by [18]. Total Organic Carbon (TOC) analysis was done by following the wet oxidation method of [19].

2.3. Benthic foraminiferal species collection

In each station, three replicate samples were collected using Peterson Grab (biting area 0.1 m^2) by following the method of [20]. The samples collected were emptied into a plastic tray and then sieved through mesh screen (between 500 and 63µm) as described by [21]. The sieve retains were preserved in 5-7% formalin and further stained with Rose Bengal solution and the stained samples were left for two days. The foraminiferans were sorted, counted and identified up to lowest possible taxonomic level using light microscope (KL-300LED Carl Zeiss microscope) by consulting the standard works of [22], [23] [24], [25], [26] for foraminiferans.

2.4. Data analysis

The data collected were approached to various univariate and multivariate methods using various statistical packages PRIMER (Plymouth Routines In Multivariate Ecological Research, Ver. 7.0) [27], [28] and PAST (Paleontological Statistics) [29].

3. Results

3.1. Environmental variables

The mean with SD values of Physico-chemical parameters recorded at each sampling station is summarized in Table 1. Water temperature varied from 26.48 - 30.64°C with minimum at VE-1 during monsoon and maximum at VC-RS during summer; water pH showed minimum of 7.74 at VE-1 during monsoon and maximum of 8.32 at VC-LS during summer; salinity showed a wide range of fluctuation with minimum (18.5ppt) at VE-1 during monsoon and maximum (36.39ppt) at VC-LS during summer. Dissolved oxygen ranged between 5.93 mg/l at VE-1 during monsoon and 4.73 mg/l at VE-M during summer. As regards sediment parameters, pH showed minimum (7.94) at VE-1 during monsoon and maximum (8.53) at VC-LS during summer; TOC content varied from 4.46mgC/g at VC-LS during monsoon to 12.24mgC/g at VE-2 during post monsoon. The sand content showed a minimum of 11.37% at VE-1 during monsoon and a maximum of 57.16 % at VC-RS during summer and Clay content varied from 11.61% at VC-RS and a maximum of 61.46% at VE-2 during this study.

3.2. Foraminiferal species taxa

With respect to faunal entities, as many as 49 species of foraminiferans belonging to 7 orders and 41 genera were recorded from the various sampling stations (Table 2). Among the seven orders, Rotaliida topped the list with 27 species. Of this Order, *Ammonia beccarii, A. tepida, Bolivina hantkenian* and *B. abbreviate* were found to be the common species. Second dominant order Milioidae was found with 11 species and of this, *Miliolinella Antarctica*, *Quinqueloculina agglutinans, Milliammina* sp. and *Spiroloculina* sp. were found to be the common species. Subsequently, the orders Lagenida, Astrorhizida, Lituolida, Textulariida and Spirillinida were represented by meager contributions.

The population density calculated between the regions varied from 268 to 472nos.10cm^{-2} with maximum was recorded at VC-RS during summer season and minimum at VE-2 during monsoon season. Seasonally, the maximum number (37 species) of foraminiferal species was recorded during summer season and minimum (28 species) during pre-monsoon and monsoon.

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

Variables	VE-1	VE-2	VC-M	VC-LS	VC-LS
W. Temp. (°C)	26.48 ± 0.47	26.67 ± 0.52	27.54 ± 0.42	29.35 ± 0.59	30.64 ± 0.39
Water pH	7.74 ± 0.56	7.89 ± 0.36	8.27 ± 0.51	8.32 ± 0.48	8.29 ± 0.64
Salinity (ppt)	18.5 ± 0.62	24.85 ± 0.73	28.62 ± 0.48	35.45 ± 0.57	36.39 ± 0.64
DO (mg/l)	5.93 ± 0.38	4.85 ± 0.63	4.73 ± 0.28	5.21 ± 0.38	5.29 ± 0.57
TSS (ppm)	137.54 ± 0.98	148.35 ± 1.42	194.62 ± 1.18	106.46 ± 0.67	99.74 ± 1.63
Sediment pH	7.94 ± 0.46	8.06 ± 0.33	8.39 ± 0.65	8.53 ± 0.27	8.48 ± 0.73
TOC (mgC/g)	10.08 ± 0.13	12.24 ± 0.45	7.18 ± 0.37	4.46 ± 0.58	5.36 ± 0.74
Sand (%)	11.37 ± 0.64	12.36 ± 0.43	46.30 ± 0.72	54.08 ± 0.69	57.16 ± 0.69
Silt (%)	29.36 ± 0.65	26.18 ± 0.58	34.91 ± 0.45	32.25± 0.53	31.23± 0.53
Clay (%)	59.27 ± 0.59	61.46 ± 0.76	18.79 ± 0.54	13.67 ± 0.38	11.61 ± 0.38

Table -2. Occurrence of Foraminiferal species recorded in various sampling stations of the Vellar estuary and its adjacent coastal waters (Nos/cm^2)

S.No.	Foraminifera species	S.No.	Foraminifera species
	Rotaliida (order)		Milioida (order)
1	Oridorsalis umbonatus	28	Triloculina tricarinata
2	Ammonia beccarii	29	Miliolinella antarctica
3	A. tepida	30	Quinqueloculina agglutinans
4	Asterigerina carinata	31	Q. oblonga
5	Bolivina hantkeniana	32	Triloculina sp.
6	B. abbreviata	33	Milliammina sp.
7	Brizalina striatula	34	M. oblonga
8	Cibicides pseudoungerianus	35	Ophthalmidium inconstans
9	Clavulina cylindrica	36	Spiroloculina sp.
10	Pararotalia sp.	37	S. depressa
11	Cymbaloporetta bradyi	38	S. orbis
12	Discorbinella montereyensis		Lagenida (order)
13	Discorbis sp.	39	Lagena quadrata
14	Elphidium crispum	40	L. striata
15	Eponides repandus	41	Cristellaria helicinoides
16	Globigerina rubescens	42	Siphonodosaria sp.
17	Orbulina universa		Astrorhizida (order)
18	Globigerinoides sacculifer	43	Crithionina sp.
19	Globorotalia sp.	44	Dendrophrya arborescens
20	Nonion depressulus	45	Rhabdammina abyssorum
21	Nonionella stella		Lituolida (order)
22	N. limbatostriata	46	Haplophragmoides canariensis
23	Operculina cumingii		Spirillinida (order)
24	Planulina sp.	47	Spirillina lateseptata
25	Rosalina bertheloti		Textulariida (order)
26	R. globularis	48	Textilaria quadrilatera
27	Rotalia sp.	49	Discorinopsis aguayoi

3.3. Percentage contribution

The percentage composition of revealed that Rotaliida as dominant group with 47% of the total foraminifera species collected; orders Milioida, Lagenida, Lituolida, Spirillinida, Textulariida and Robertinida contributed to 14%, 12%, 12%, 9%, 3% and 3% respectively to the total foraminiferans species samples collected in different Station of Vellar estuary and its adjacent coastal waters (Fig. 2).

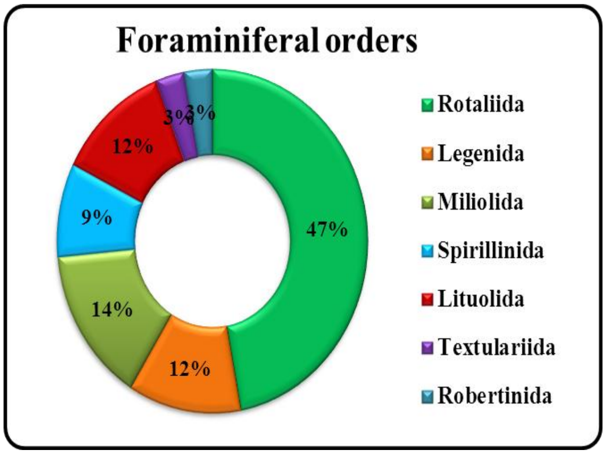

Fig. 2. Percentage contribution of foraminiferal orders recorded in various sampling stations of the Vellar estuary and its adjacent coastal waters

3.4. Diversity indices

The Shannon diversity (H') index calculated for foraminifera abundance data showed minimum (3.016) value at VE-2 during monsoon and maximum (3.876) value at VC-RS during summer season; Margalef species richness (d) showed minimum (4.959) value at VC-M during pre-monsoon and maximum (6.905) value at VE-2 in summer; Pielou's species evenness (J') varied between 0.728 and 0.943 with maximum value at VC-LS during summer and minimum value at VE-2 during monsoon and Simpson dominance varied from 0.716 to 0.886 with maximum at VC-LS during Summer season and minimum at VE-1 in monsoon (Fig. 3).

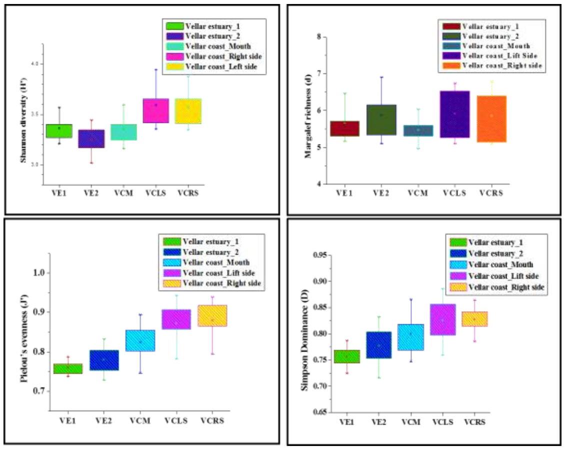

Fig. 3. Diversity indices a-Shannon diversity (H'); b-Margalef richness (d) c- Pielou's evenness (J') and d-Simpson Dominance (D) calculated for the benthic foraminifera species abundance data collected in various sampling stations of the Vellar estuary and its adjacent coastal waters

3.5. Cluster/MDS Analysis and BIO-ENVI

Further, to study the similarity/dissimilarity between stations, the replicate data of foraminiferans abundance of five different stations were approached to cluster analysis and MDS (non-metric Multi-Dimensional Scaling) ordination (Fig. 4). The dendrogram showed that the replicate of station VE-2 formed separate cluster with similarity percentage of 54%; similarly the coastal stations VC-LS and VC-RS grouped together with similarity percentage of 75% and the remaining stations VE-1 and VC-M grouped together at the next level with 63%. The MDS plot also confirmed the groupings observed in the cluster analysis. The stress value, which is overlying on the top-right corner of the MDS plot is also very minimal (0.16), signaling a good ordination pattern of foraminiferal abundance (Fig. 5). Biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices were allowed to match the biota. Among the parameters, a combination of six environmental parameters (pω = 0.964) namely Dissolved oxygen, Temperature, Salinity, pH, Sand and TOC got manifested as best match in determination of benthic foraminiferal distributions followed by Dissolved oxygen, Salinity, TOC, pH, Sand and Silt in the next level (Table 3).

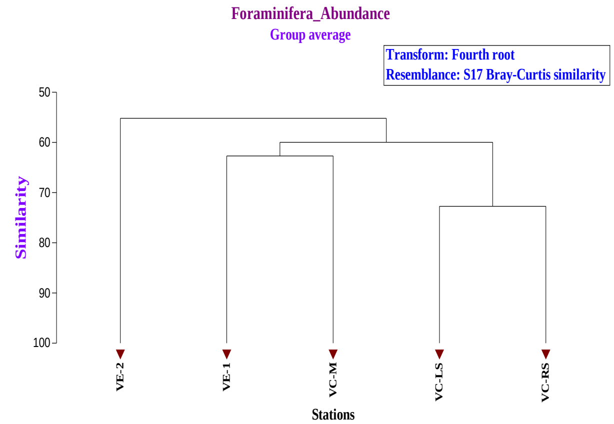

Fig. 4. Dendrogram for the benthic foraminiferal species data collected in various sampling stations of the Vellar estuary and its adjacent coastal waters

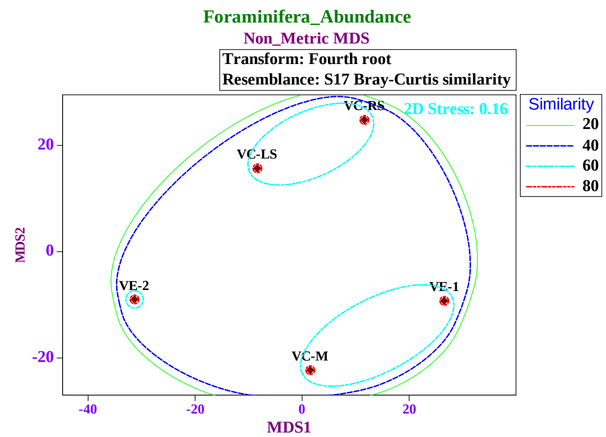

Fig. 5. MDS drawn for the benthic foraminiferal abundance recorded in various stations of Vellar estuary and its adjacent coastal waters

3.6. Principle component analysis

The PCA plot was drawn to set a well-defined relation between the environmental parameters (DO, water temperature, water pH, salinity, TSS, Sand, Silt, Clay, TOC) and diversity components [richness (d), diversity (H') evenness (J) and dominance (D)] against the surveyed different stations (Fig. 6). The plot revealed that, among the stations, the VE-1, VC-LS and VC-RS showed high correlation with parameters such as Salinity, Water pH, TOC, Clay, Sand, Sediment pH, diversity and evenness; while VC-M and VE-2 got highly correlated with other parameters such as W. T., DO, TSS, Silt, dominance and richness.

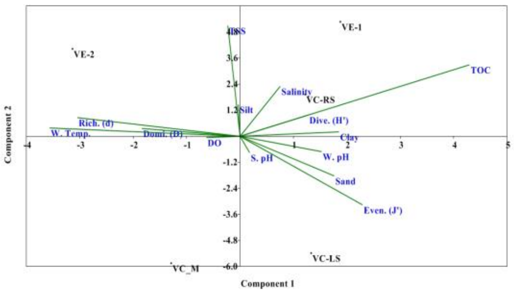

Fig. 6. Principle Component Analysis for environmental parameters and Foraminifera species diversity in various

3.7. Pearson-Correlation matrix

Further, Pearson correlation (r) was also done to ascertain correlation between the Physico-chemical characteristics and meio-fauna diversity components. The correlation matrix revealed that a positive significant correlation (P < 0.001) was found for the following combination of parameters: Evenness vs Diversity (0.997); Fora. Ab. vs Sand (0.993); TOC vs Clay (0.968); Richness vs Salinity (0.971); W. Temperature vs W. pH (0.912); W. pH vs W. Temperature (0.870) as evidenced in Table 3. Besides, a significant negative correlations (P < 0.05) were found between diversity vs Salinity (-0.918); Richness vs Diversity (-0.884); Sand vs TOC (-0.843) and DO vs Salinity (0.829) in various stations of Vellar estuary and its adjacent coastal waters.

Table 3. Correlation matrix between the Physico-chemical characteristics in various stations of Vellar estuary and its adjacent coastal waters

	W. Temp.	W. pH	Salinity	DO	S. pH	TOC	Sand	Clay	(H')	(d)	(J')	For. Ab.
W. Temp.	1											
W. pH	0.870*	1										
Salinity	0.912**	0.899*	1									
DO	0.599	-0.085	0.829*	1								
S. pH	0.788*	-0.816**	0.920**	-0.142	1							
TOC	0.403	0.297	0.659	-0.650	0.443	1						
Sand	0.891*	-0.787*	0.446	-0.015	0.675	-0.843*	1					
Clay	0.966***	0.949***	-0.940**	0.039	-0.994***	0.968***	-0.692	1				
(H')	-0.780*	0.845**	-0.918*	0.969***	-0.100	0.508	-0.109	0.201	1			
(d)	-0.872*	-0.667	0.971***	-0.062	0.992**	0.458	0.904**	-0.843**	-0.884**	1		
(J')	-0.735	0.936**	-0.974***	0.016	-0.774*	-0.487	-0.527	0.978**	0.997***	-0.830	1	
For. Ab.	0.856***	0.948**	0.967***	0.759*	0.896*	0.787*	0.993**	0.716	0.783*	0.847	0.891*	1

*P < 0.05 significant correlation
**P < 0.01 strong significant correlation
***P < 0.001 very strong significant correlation

(Footnote: W. Temp - Water Temperature; W. pH - Water pH; DO - Dissolved Oxygen; TSS - Total Suspended Solid; S. pH - Sediment pH; TOC - Total organic carbon; (H') - Diversity; (d) – Richness; (J') – Evenness and For. Ab. – Foraminifera Abundance)

4. Discussion

Worldwide urbanization and industrialization led to widespread contamination of coastal systems and estuarine environments. As observed above, the distributions, abundance, diversity, and composition of benthic foraminiferal assemblages in coastal and sub-littoral environments are controlled largely by a combination of physical and chemical parameters (temperature, salinity, currents, substrate, sediment type and vegetation cover), food resources and biotic interactions [30]. Among the estuarine and coastal waters, the high water temperature, salinity and pH values were observed in VC-RS and VC-LS, which might be due to proximity to the marine zone and lower values were recorded in estuary zones. Among the seasons, the maximum values were recorded during summer which might be due to low rain fall and the rise in atmospheric temperature [31], [32].

The dissolved oxygen (DO) was found maximum in VE-1 during monsoon season and minimum at VE-2 during summer season. The relatively minimum DO values observed in the summer/post monsoon are attributed to the entry of high saline waters in to the estuarine region, as well as fluctuations in temperature and salinity, which in turn affect the dissolution of oxygen. Similar observation was made earlier by [33] in Iranian coast and [34] from Uppanar Estuary, Tamil Nadu Coast, India.

TOC content varied from 4.46mgC/g to 12.24mgC/g and the maximum was recorded at VE-2 during postmonsoon and minimum at VC-LS during monsoon. The maximum TOC might be attributed to clayey nature of sediment (sandy loams, sandy clay, clay loams and clays). Estuarine ecosystems are able to store large amounts of organic matter (TOC) contents using the PERSE procedure (Procedure to Establish a Reference State) for estuaries and coastal ecosystems [35]. Organic matter, as a food source, plays a key role in determining the foraminiferal distributions [36]. Similarly, [37] also opined that the sediment characteristics and the total organic carbon (TOC) contents influenced the distribution of foraminiferans in Lake Varano, Southern Italy.

A total of 49 foraminiferal species belonging to 7 orders and 41 genera was identified during this study. In Vellar estuarine stations, totally 18 benthic foraminiferans species belonging to 4 orders and 14 genera were recorded and similarly in Coastal stations, a total of 31 benthic foraminifera species belonging to 6 orders and 28 genera were recorded. *Ammonia beccarii, A. tepida, Bolivina hantkeniana, Elphidium crispum* and *Rosalina globularis* was found dominant in estuarine stations and *A. beccarii, A. tepida, Asterigerina carinata,* and *Discorbinella montereyensis* in coastal stations. The density of foraminifera was more at coastal stations than the estuarine stations. The lower diversity of foraminifera in Vellar estuary might be due to the freshwater influx and shallow depth, leading to unfavorable environment for foraminiferal population. Similar findings were also made by [38] from Puravadaiyanar and Vettar estuaries, India and [39] from northern Bahia, Brazil.

Species diversity can be an expression of the environmental stress on benthic foraminiferal assemblages, with higher diversity in more stable environments. Species diversity and evenness value was found minimum in Vellar estuarine stations during monsoon and maximum in coastal stations during summer season, which might be due to the influence of freshwater influx, temperature and low salinity as reported by [40]. Similar range of foraminiferal diversity values were also reported by [41] from Conero coast, Adriatic. Species richness and dominance showed minimum value at Vellar coastal stations during pre-monsoon and higher value in Vellar estuarine stations in summer Similar trend was also observed by [42] from Dongsha Atoll Lagoon, China.

The dendrogram/cluster analysis showed that the replicate of estuarine station formed separate cluster with similarity percentage of 54% and similarly the coastal stations grouped together with similarity percentage of 75%. Similar groupings with coastal and estuarine stations separately was reported by [43] from Guanabara Bay, Brazil and [44] from the Kharrar Lagoon, Saudi Arabia. The PCA and Correlation coefficients results displayed a good correlation of salinity, temperature and pH to the distribution and composition of foraminifera in the surveyed stations. Similar trend was also observed by [45] from the Moorea, French Polynesia and [46] from Aveiro Lagoon, Portugal.

5. Conclusion

Benthic foraminifera facilitate biological characterization of a variety of estuarine and coastal environments; they react quickly to environmental stress, either natural or anthropogenic. Because of their small size, they occur in large numbers in small-diameter core samples. The findings of the present study form the base line information pertinent to biodiversity changes in spatial distribution of foraminiferans in relation to seasonal changes in physico-chemical parameters. The benthic foraminifera reflect human-induced environmental perturbation and they can be used as bio-indicators for coastal pollution monitoring. Therefore, the present study paves way for the posterity to specifically focus on the role of foraminifera in the ecological health assessment studies.

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7.1 Conflict of interest statement

Authors declare that they do not have any conflict of interest.

7. References

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