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Spatial and seasonal variation of macrobenthos diversity around Nuclear Power Plant site, Tarapur, Maharashtra

Priti V. Kubal[a*], Ajit A. Ambekar[a], Chandra Prakash[a*], Paramita B. Sawant[a]

ICAR - Central Institute of Fisheries Education, Mumbai, India

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Key words: Macrobenthos, Nuclear Power Plant site, Tarapur.

Abstract

The present study aimed at assessment of impact of Nuclear Power Plant site, Tarapur on macrobenthos diversity at seven locations, *viz*., TAPS 1&2, TAPS 3&4, Light house, Chinchani, Varor, Uchheli and Nandgoan for premonsoon, monsoon and postmonsoon seasons. Samples were collected for physico-chemical, hydro-sedimentological and macrobenthos study in intertidal area. The surface water temperature varied from 27.5°C - 32°C, whereas dissolved oxygen ranged from 6.2-7.5 mg l^{-1} and exceptionally low at Uchheli during monsoon season, *i.e.*, 3.2 mg l^{-1}. The sediment texture analysis indicated the dominance of sand > clay > silt at all locations and all seasons except in monsoon where it showed sand > silt > clay. 25 different groups of macrobenthos were identified among which polychaetes were most dominant and contributed numerically up to 74.3 % of total infaunal population. Shannon diversity index (*H'*) was observed maximum at TAPS 1& 2 (Premonsoon -2.88 and postmonsoon -3.00) and minimum at Uchheli (monsoon -1.03). Pearson's correlation showed that dissolved oxygen positively correlated with Shannon-Weiner diversity *H'* (p = 0.726), Pielous evenness *J'* (p = 0.7511) and total species *S* with clay (p = 0.436). During present study, biodiversity of intertidal macrobenthos around Nuclear Power Plant site, Tarapur showed temporal and spatial variations.

*Corresponding Author: Priti V. Kubal ✉ pritikubal14@gmail.com

Introduction

The burgeoning population, urbanization and industrialization along the tropical coastlines intervene the coastal habitat at alarming rate and the power plants are one among them. Currently, many countries are inclined towards the use of nuclear power energy due to possible future shortage of conventional fuels. Although the atomic power stations do not release the effluent with harmful chemicals yet the condenser cooled water coupled with enhanced temperature and leaked radioactive elements, is a cause of concern for the aquatic life. Temperature is one of the key variables responsible for distribution of organisms both on small as well as large geographical scales. Moreover, the flora and fauna at intertidal area are more vulnerable to such interventions, especially the macrofaunal communities. In India, the study related to Nuclear Power Plants (NPP) and their impacts on coastal ecosystem are scarce. The detail study was done in order to understand impact of heated effluent on benthic organism by Suresh *et al.* (1993) at Kalpakkam coastal site and Kailasam and Sivakami (2004) at Tuticorin bay, South East coast of India. The work was done on zooplankton around Tarapur Panampunnayil and Desai (1975), harpacticoid copepod in the vicinity of discharge of Kalpakkam power plant by Suresh *et al.* (1996), impact of thermal discharge on phytoplankton from tropical coastal power plant (Poornima *et al.,* 2005 & 2006), distribution of physico-chemical parameter and phytoplankton in close proximity of MAPS (Saravanane *et al.,* 1995) and recovery potential of phytoplankton after entrainment in the cooling system of power plant (Satpathy *et al.,* 2001). Balani and Patel (1994), studied accumulation of radionuclide in gastropods. It is also important to consider that each species response differently to various stressors, either it is environmental or due to anthropogenic cause. As far as the heated effluent is concerned, the impacts are seen for very limited space where heating is detectable.

The aim of research work is to find out whether the benthos biodiversity around Nuclear Power Plant (NPP), Tarapur is under stress due to heated effluent. In present study data were recorded at seasonal and spatial variations on diversity of macrobenthos around NPP which has been working successfully for more than four decades. The diversity of macrobenthos was correlated mainly with water temperature and other physico-chemical parameters.

Material and methods

Study area

Tarapur Atomic Power Station, Tarapur, Maharashtra, India (Fig. 1), has two Boiling Water Reactors (BWR) - TAPS 1&2, each producing 160 MWe electricity and two Pressurized Heavy Water Reactors (PHWR) - TAPS 3&4, each producing 540 MWe of electricity. Water with elevated temperature is released from the discharge points of TAPS 1&2 and TAPS 3&4. The warm water effluent from TAPS 1&2 and TAPS 3& 4 before coming in contact with open sea passes through the channel (14m wide x 4m depth x 1000m length) and a pond of 1 ha area respectively to enhance the resident period of water which is ultimately helpful to reduce the water temperature. Seven sampling stations were selected such as TAPS 1&2, TAPS 3&4, Light house, Chinchani, Varor, Uchheli and Nandgoan. Out of these 7 stations, TAPS 1 & 2 was at the intertidal area near to intake channel of TAPS 1 & 2. Station TAPS 3 & 4 was situated in between the intake and discharge channel of TAPS 3 & 4, close to discharge channel, because the area near the intake channel get engaged in constant dredging activity, in turn flooded at mid and low tidal level. Light House is situated 0.8 km north east, where the discharge channel of TAPS 1 & 2 terminates and gets mixed with open sea water. Varror and Chinchani, are located at a distance of 8.4 km north east and 5.4 km north east respectively. Nandgaon is located at 8.4 km south east and Uchheli 4.6 km south east. Varror and Nandgaon were considered as the reference locations for the discharge of TAPS 1 & 2 and TAPS 3 & 4 respectively, as the warming up of coastal water has not been detected at this distance. The sampling locations and their station numbers with respect to seasons are given in the Table1. All distances were measured from the fixed points, *i.e.*, intake channel of TAPS 1&2.

Diversity of macrobenthos

Samples were collected during three different seasons, *i.e.*, premonsoon, monsoon and postmonsoon during the year 2012 (Table No.1). Samples for macrobenthos were collected in quadruplicate using a quadrate of 20 cm x 20 cm. Samples were passed through a sieve of 0.5 mm mesh size and the organisms retained in the sieve were preserved with 5% formalin mixed with Rose Bengal stain. Organisms were sorted in the laboratory, counted (individual m^{-2}) and weighed (wet weight method gm^{-2}). The organisms were first segregated into different groups and then identified up to lowest possible level. As the taxonomy of the benthic fauna in the region was not yet explored, the above method minimized the time taken to sort them out.

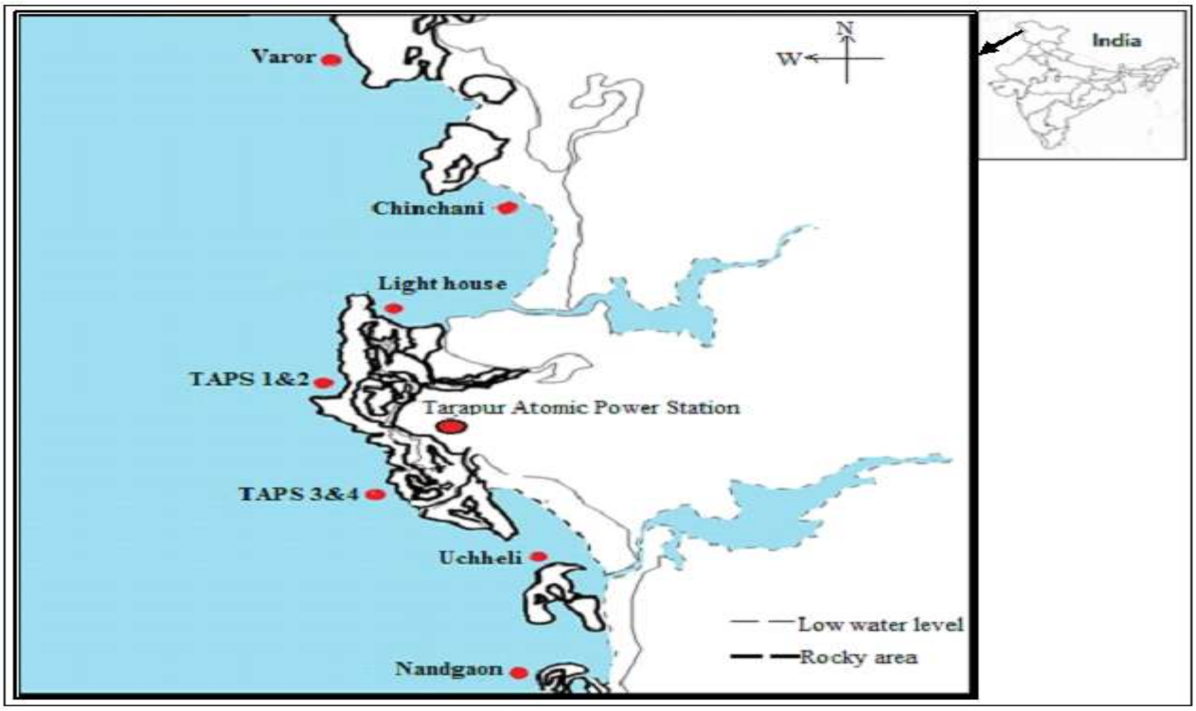

Fig. 1. Map showing sampling location around Tarapur Atomic Power Station (TAPS).

Sediment samples were treated for the analysis of texture by the hydrometer method (Kim, 1996) and organic carbon content was analyzed by the titration method (Walkey and Black, 1934). Water samples were analyzed for pH, salinity, dissolved oxygen (DO), ammonia (NH_4^+-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), inorganic phosphate (PO_4^{+3}). The temperature was recorded with digital thermometer for accuracy of ± 0.1°C. pH was observed by the pH meter (TOSHCON pH meter CL 54+). Salinity (ATAGO handheld refractometer, SMILL- E salinity 0-100, Made in Japan 505967), nutrients and dissolved oxygen were analyzed by following the standard procedures described in 'A Practical Handbook of Seawater' (Strickland and Parson, 1972).

Data analysis

Univariate and multivariate analyses for macrobenthos were carried out using the statistical software PRIMER v5 (Plymouth Routines in Multivariate Ecological Analysis). The univariate techniques employed were Shanon-Wiener diversity index, *H'* (log_2); Margalef's richness index*, d;* and Pielou's evenness index *J'*. Graphical tools like *k*-dominance curve and multivariate analysis including the suitable transformation of macrobenthos abundance data, using the Bray-Curtis similarities for non-metric multi-dimensional scaling (MDS) and dendrogram plots. Pearson correlation coefficient (*r*) was estimated between diversity indices and environmental parameters, using statistical software SPSS 20. One way ANOVA was applied to macrobenthic abundance to identify significant difference between the locations and seasons. All other graphical representation was performed by software Origin 6.0 and sampling location map was prepared by using software Surfer 8.0.

Results

Physico-chemical and hydro - sedimentological parameters

Physico-chemical and hydro-sedimenotological observations of seven locations, recorded during 3 seasons are presented in Table 2. The surface water temperature of water got varied from 27.5°C - 32°C with mean value of 31.4°C ± 1.6 (premonsoon), 28.4°C ± 1.4 (monsoon) and 30°C ± 1.2 (postmonsoon). pH was observed in the range of 7.5-8.2 throughout study period. Dissolved oxygen in overlying water varied from 6.2-7.5 mg l^{-1} and exceptionally low at Uchheli during monsoon season, *i.e.*, 3.2 mg l^{-1}. Salinity was not showing much difference except slight decline during monsoon. Other parameters such as nutrients like total ammonia (NH_4^+-N, mg l^{-1}), nitrite (NO_3-N, mg l^{-1}), nitrate (NO_2-N, mg l^{-1}) and phosphate (PO_4^{+3}, mg l^{-1}) were in normal range and did not show any significant variations. The sediment texture analysis indicated the dominance of sand > clay > silt at all locations and during all seasons except in monsoon where it showed sand > silt > clay. Organic carbon (%) was in the range of 0.1 % to 1 %.

Table 1. Sampling locations and their station number.

Sl. No.	Location	Premonsoon	Monsoon	Postmonsoon
1.	TAPS 1 & 2	1	8	15
2.	TAPS 3 & 4	2	9	16
3.	Light House	3	10	17
4.	Varror	4	11	18
5.	Chinchani	5	12	19
6.	Nandgoan	6	13	20
7.	Uchheli	7	14	21

Table 2. Season wise range and average values (with SD) of hydro-sedimentological parameters around coastal site.

Sl. No.	Parameter	Premonsoon		Monsoon		Postmonsoon	
		Range	Average	Range	Average	Range	Average
1.	Water temperature [°C]	29-32	30±1.2	29.9-32	30.8±0.7	27.5-29.9	28.1±1.2
2.	pH	7.9-8.2	8±0.1	7.7-8	7.9±0.1	7.5-7.8	7.6±0.1
3.	Dissolved oxygen [mgl⁻¹]	5.5-7.5	6.7±0.7	3.2-7.5	6.5±1.5	5.8-7.5	0.6±0.7
4.	Salinity [‰]	35-36	35.6±0.5	34-35	34.9±0.7	34.5-37	35.5±0.9
5.	Phosphates [mgl⁻¹]	0.23-0.6	0.4±0.1	0.5-0.8	0.7±0.1	0.52-0.9	0.7±0.1
6.	Ammonia [mgl⁻¹]	0.6-1.03	0.8±0.2	0.7-1.3	1±0.2	0.64-1.6	1.3±0.3
7.	Nitrite [mgl⁻¹]	0.03-0.7	0.2±0.3	0.4-0.8	0.6±0.1	0.07-0.38	0.2±0.1
8.	Nitrate [mgl⁻¹]	0.4-0.92	0.7±0.2	0.2-0.5	0.3±0.1	0.78-4.52	2±1.5
9.	Sand [%]	81.4-94.6	89.7±5.1	88-93.7	91.3±2	82.7-92.8	88±4.4
10.	Silt [%]	0.9-9.6	4.2±3.4	4.3-6.9	5.5±0.9	0.5-10.5	5.2±3.7
11.	Clay [%]	2.9-7.3	6±2.2	0.3-4.6	2.6±1.4	3.18-11.32	6.9±2.4
12.	Organic carbon [%]	0.09-0.39	0.30.2	0.06-0.18	0.2±0.1	0.21-1.03	0.4 ±0.4

Macrobenthos

In total, 25 different groups of macrobenthos were identified during the study period and distribution is displayed in Table 3. Polychaetes were most dominant and contributed numerically up to 74.3 % of total infaunal population. This was followed by other dominant groups like amphipods, isopods, tanaids and gastropods. Amphipods and gastropods were present at all locations during all seasons and contributed numerically up to 13 % and 3.3 % respectively. Classification analysis using Bray-Curtis similarity followed by an ordination through MDS on macrobenthos abundance data (ind./m²) were undertaken. Fig. 2 and 3 displayed the results for hierarchical clustering and MDS ordination respectively for seven different stations during all seasons. The MDS plot indicates that the four sampling locations during monsoon season were ordinate separately than others which were in conformation to the dendrogram.

Table 3. Distribution of macrobenthic organisms around coastal area of Tarapur Atomic Power Station during the year 2012.

Faunal group	Premonsoon							Monsoon							Postmonsoon						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Anthozoan	-	-	+	-	+	+	+	-	+	+	+	-	-	-	+	-	+	+	-	+	-
Amphineurans	+	+	+	+	-	+	-	+	+	+	+	-	-	-	+	+	+	+	-	+	-
Gastropods	+	+	+	-	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
Pelecypods	+	+	+	-	-	+	+	+	-	-	-	-	+	+	+	-	+	+	+	+	+
Sipunculan worm	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	+	+	-	-	-
Nemertine worm	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Nematodes	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-
Polychaetes	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chironomus larvae	-	-	+	+	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-	+	-
Copepods	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-
Pycnogonids	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracods	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cumaceans	-	-	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-	-	+	-	-
Cirripds	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Anomurans	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-	+	+	-	-
Brachyurans	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+
Amphipods	+	+	+	+	+	+	-	+	+	+	+	+	+	-	+	+	+	+	+	-	-
Isopods	+	+	+	+	-	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Penaeids	+	-	-	-	-	+	+	-	+	+	-	-	-	-	+	-	+	-	-	+	-
Tanaids	+	+	+	+	-	+	-	-	+	+	+	+	+	-	+	+	+	+	-	+	+
Stomatopods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Mysid	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Ophiroids	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sea slug	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Decapod larvae	-	-	+	+	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-

The highest similarity locations were TAPS 3 & 4 and Light house during postmonsoon followed by TAPS 3 & 4 and Varror during monsoon. The results for different indices are represented in Fig. 4 (A-E). Shannon diversity index (*H'*) was observed maximum at TAPS 1& 2 (Premonsoon -2.88 and postmonsoon -3.00) and minimum at Uchheli (monsoon -1.03). Margalef's richness (*d*) was recorded highest at Light house (2.68) and Nandgoan (2.67) during premonsoon, followed by Varor (2.65), TAPS 1&2 (2.27) and Nandgoan (2.10) for the duration of Postmonsoon with lowest value at Uchheli (0.093) in monsoon. The *k*- dominance curve was plotted for all 7 sampling stations for three different seasons. The plot indicates that the curve for station number 1 and 15 got almost intermingled with each other and lying lowest with S shaped, indicating the highest diversity, whereas the curve for the station number 14 was lying high proving lowest diversity (Fig. 5). The *k*- dominance curve plotted for different seasons elucidated highest diversity during premonsoon followed by postmonsoon and monsoon (Fig.6). The result for one way ANOVA for all seasons gave the R = 0.181, indicating significance difference among the seasons (Fig. 7). Pearson's correlation showed that dissolved oxygen got positively correlated with Shannon-Weiner diversity *H'* (p = 0.726) and Pielous evenness *J'* (p = 0.7511). Total species *S* was positively correlated with clay (p = 0.436). Total number of organisms *N* negatively correlated with water temperature (p = -0.484), pH (p = -0.434) and nitrite (p = -0.664), whereas positively correlated with salinity (p = 0.706) and clay (p = 0.643).

Table 4. Pearson correlations between environmental variables and univariate indices.

Variable	Total species (S)	Total number of organisms (N)	Pielous evenness (*J*)	Shannon-Weiner diversity (*H'*)
Water temperature [ºC]		-0.4839		
pH		-0.4342		
Dissolved oxygen [mg/l]			+0.7511	+0.7265
Salinity [ppt]		+0.7061		
Nitrite [mg/l]		-0.6643		
Clay [%]	+0.4357	+0.6426		

*. Correlation is significant at the 0.05 level (2-tailed).

Discussion

The purpose of this study was to find out the factors responsible for diversity and community structure of macrobenthos around coastal sites of the Tarapur Atomic Power Station, the prima facie record to seasonal macrobenthic biodiversity in the study area. Precise investigation on the distribution of benthic organisms and their relation to physical and chemical ambient conditions are a prerequisite for evaluating environmental modification (Rodr´ıguez-Villanueva *et al.,* 2003).

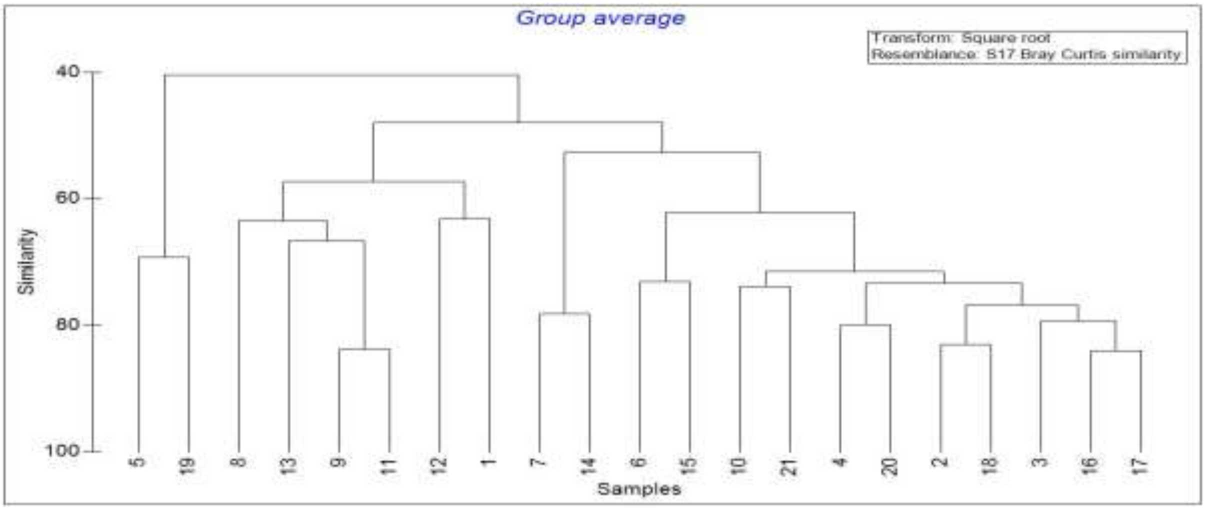

Fig. 2. Dendrogram for hierarchial agglomerative clustering of square-root transformed macrobenthos data using group average linking of Bray–Curtis similarities for intertidal stations around Tarapur Atomic Power Station for the year of 2012.

Taking these aspects into consideration, 25 groups were observed after analyzing 240 different sediment samples, along with hydro-sedimentological parameters. In the present investigations, lower water temperature during monsoon and subsequent increase in postmonsoon and premonsoon revealed a seasonal change. As discussed by Luis and Kawamura (2003), dropdown in the temperature due to cold water spread at the entire shelf during the summer monsoon, with a faster rate of Sea Surface Temperature (SST) cooling dominated the Kerala coast, where Ekman pumping and upwelling promoted by the dominant alongshore air current overwhelm the surface heat loss. Apart from this, TAPS 3&4 showed consistently high water temperature (°C) throughout the study and these increased water temperature coupled with a decrease in dissolved oxygen. This phenomenon of decreased dissolved oxygen with elevated temperature was very well explained by Badran (2001).

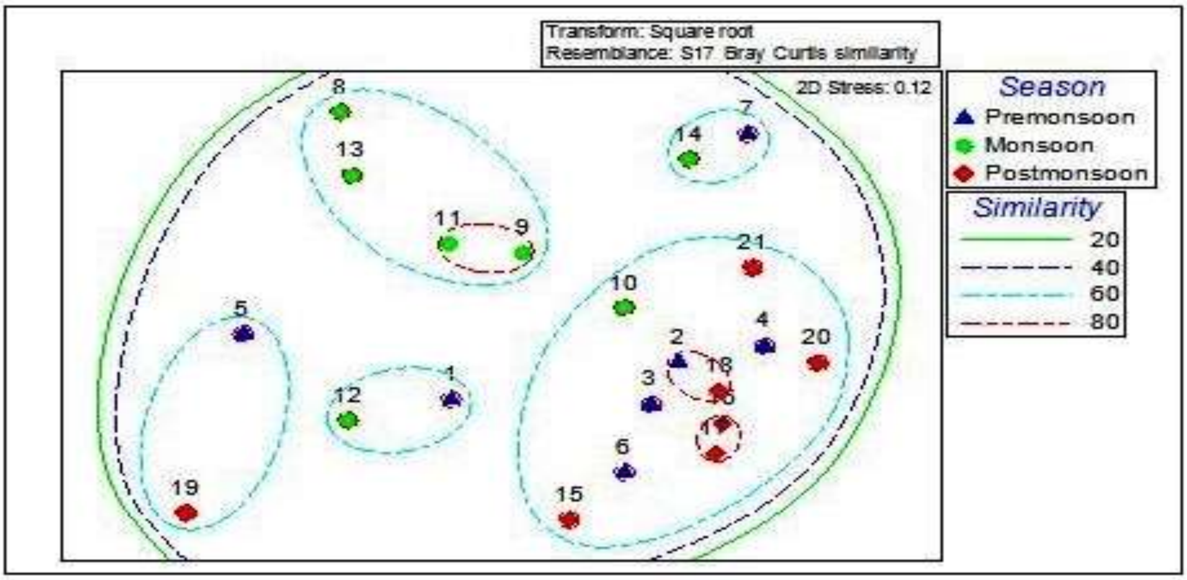

Fig. 3. Non-metric multidimensional scaling of square transformed macrobenthos data using similarities around Tarapur Atomic Power Station of three seasons, *viz.*, premonsoon, monsoon and postmonsoon.

Normally during monsoon season, oxygen level in water got increased due to dissolution of atmospheric oxygen in rain water (Kundu *et al.,* 2010) but there was noticeable low dissolved oxygen found at Uchheli for the period of monsoon (3.2 mgl^{-1}) and higher during postmonsoon (5.8 mgl^{-1}) respectively. Moreover, this place is surrounded by villages having anthropogenic activities such as release of domestic wastewater and repairing of fishing boats and fishing gears, which ultimately result in depleted dissolved oxygen contents (Anirudh *et al.,* 2014). pH mainly depends on the concentration of hydrogen ion and fixing of carbon dioxide by marine fauna (Kundu *et al.,* 2010), has also followed the trend of seasonal variation as, 8.0 ± 0.1 (premonsoon), 7.9 ± 0.1and 7.6 ±0.1 (postmonsoon).

In addition to that, salinity is having an ecological impact of considerable significance, influencing the composition and diversity of life in the marine environment. In the present study, salinity ranges showed a normal trend except during monsoon which was due to rainfall and fresh water input from the surrounding areas. Nutrients value showed normal patterns throughout the study period. Macrobenthic organisms are sediment dwelling organisms, therefore, texture and organic carbon play the major role in their habitat (Jayaraj *et al.,* 2008.). During the present work, sediment texture showed pattern of sand> clay > silt for both premonsoon and postmonsoon periods but only monsoon was having a pattern of sand >silt > clay. This was accompanied by low concentration of organic carbon during monsoon which revealed that rain water washed down clay as well as organic carbon (Chollet and Bone, 2007).

Among all organisms, polychaetes were 74.39 % and dominated in total biomass during the study period except monsoon season as gastropods were recorded with high biomass. It was due to rainfall during monsoon season causing reduction in their population by altering the seabed pattern (Sukumaran *et al.,* 2011). Highest numbers of groups were recorded at Light House, Nandgaon, TAPS1&2 and Varor during premonsoon and Varor, TAPS 1&2, light house and Nandgaon during postmonsoon season. However, lesser number of groups were recorded during monsoon season illustrating temporal variation due natural condition (Harkantra and Rodrigues, 2004).

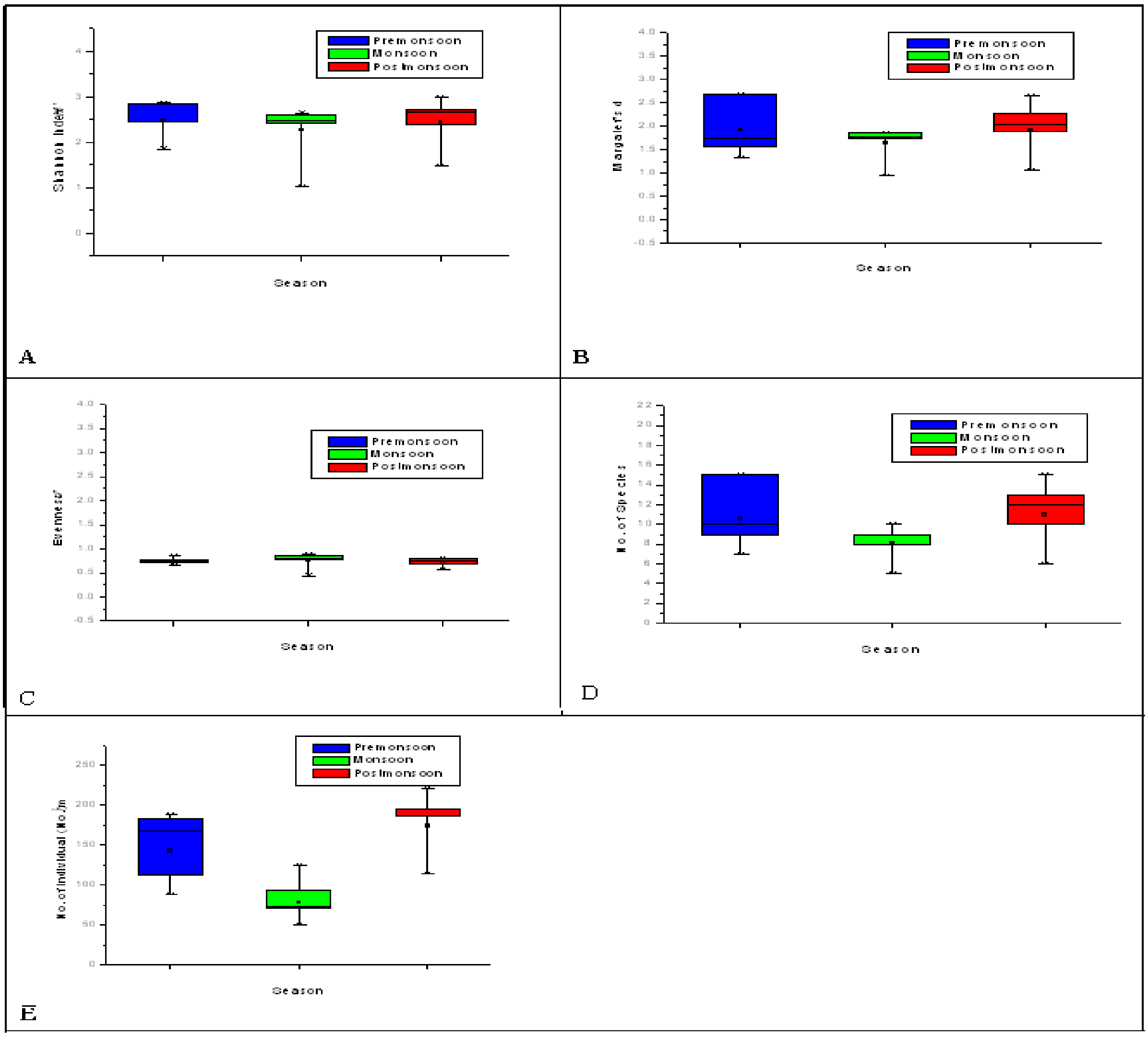

Fig. 4. Box plot of diversity indices univariate measures for macro-benthic infauna around Tarapur Atomic power Station: A No. of species, B No. of individuals, C evenness *J'*, d Shannon–Wiener index *H'*, E Margalef's richness. Data presented as mean (*squares*), ±1 SE (*boxes*) and ±1 SD (*whiskers*). *Upside-down triangles*: minimum; *right-side-up triangles*: maximum.

Low numbers of groups observed at Uchheli for all seasons showed spatial variation of macrobenthos as described by Bone *et al.,* (2011) and this evidenced that creek area always got disturbed due to fishing activities. Shannon diversity '*H*' was highest at TAPS 1&2 (postmonsoon and premonsoon) and lowest at Uchheli (monsoon), since, TAPS 1&2 area is prohibited by 'Nuclear Power Corporation India Limited' for human interruptions whereas Uchheli is heavily disturbed by anthropogenic activities. Maximum numbers of organisms were observed during postmonsoon followed by premonsoon and monsoon respectively.

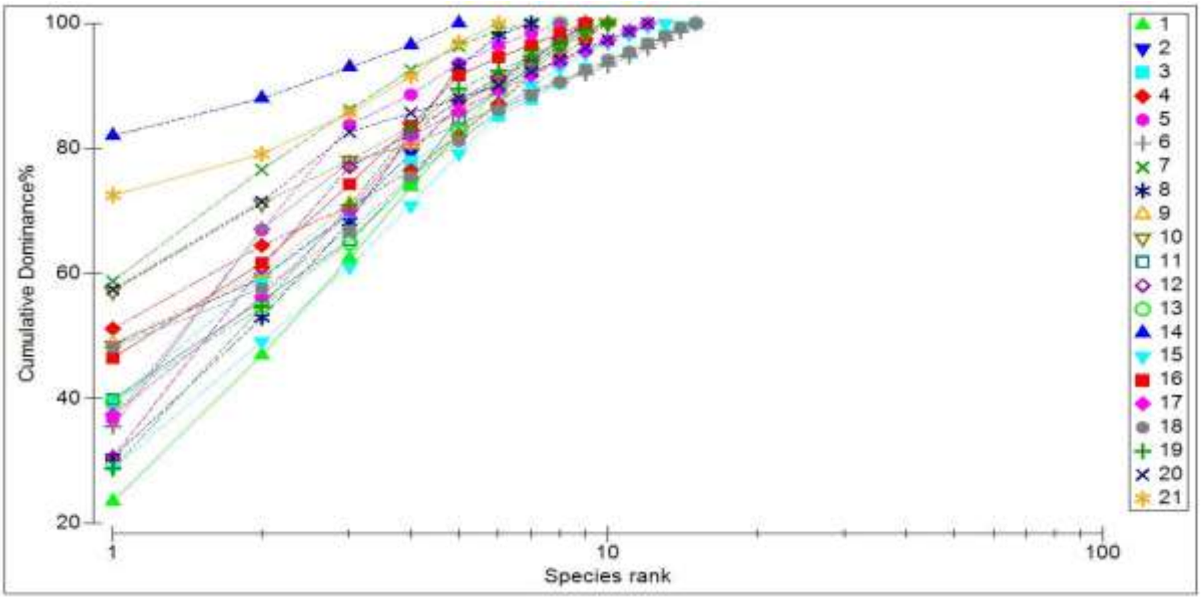

Fig. 5. K – dominance curve for all stations around TAPS.

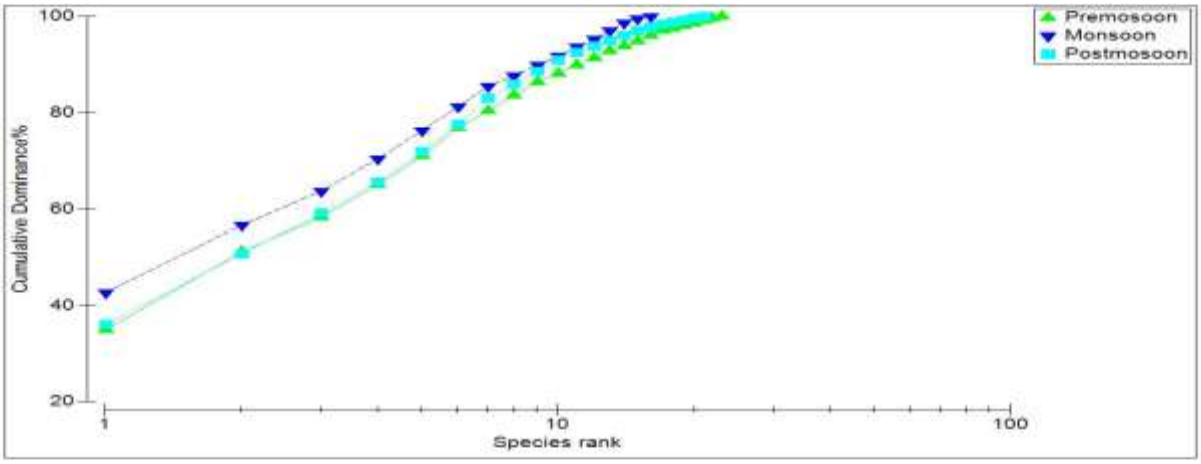

Fig. 6. K – dominance curve of seasonal variations around TAPS.

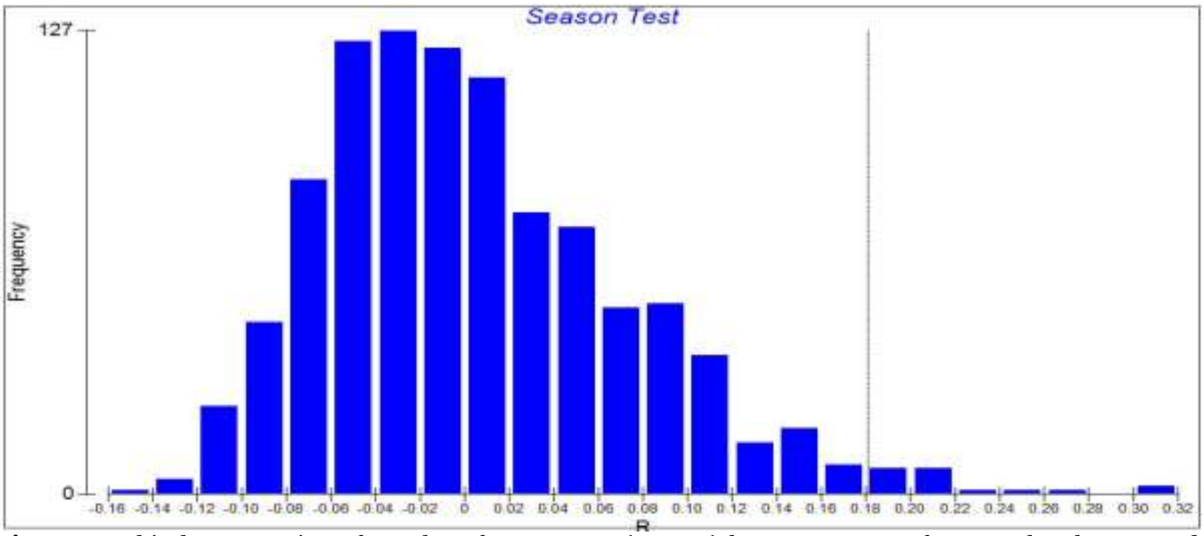

Fig. 7. Graphical presentation of R values for ANOSIM (R=0.18) between seasons for macrobenthos around TAPS.

Increased number of organisms has a major share of polychaetes which showed recovery of the organisms after monsoon period. Sivadas *et al.* (2011), observed that the community showed high abundance, biomass and number of family during postmonsoon, which was mainly due to the recruitment process. Similarly, in the present study, highest diversity was observed at TAPS 1&2 during postmonsoon and premonsoon which showed undisturbed area due to restricted zone of Nuclear Power Plant Site. This was also accompanied by low organic carbon which was negatively correlated with diversity '*H*', Margalef's richness'*d*' and pielous evevness '*j*'. High organic carbon adversely affects the abundance and diversity of macrobenthos (Musale and Desai, 2011).

Conclusion

Biodiversity pattern of intertidal macrobenthos around Tarapur Atomic Power Station showed temporal and spatial variations. Along with hydro-sedimentological parameters, monsoon season played significant role on the community structure and abundance of macrobenthic organisms. All the locations shared similar geographical pattern of rocky substratum dominated by sandy texture except at Uchheli, which showed spatial variation in terms of high organic carbon, low dissolved oxygen and heavily disturbed by anthropogenic activities.

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