

## Assessment of the ecological health of Vellar and Ennore estuarine ecosystems using health indices

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Coastal and marine environments face various perturbations which include a variety of industrial wastes and other toxic compounds accruing from shore line industries. Dumping of fly ash slurry and coolant water from thermal power plant is known to affect the physico-chemical nature of the estuarine environment and thereby cause severe damage to the benthic organisms. To combat this, the European Water Framework Directive (WFD) developed a suite of health indices, of which, the AMBI (AZTI- Marine Biotic Index) index is proved to be efficient in assessing the ecological status of marine environment by using the macro benthic communities. In this backdrop, the present study was made to ascertain the ecological health of Vellar and Ennore estuarine regions using AMBI and M-AMBI (Multivariate- AZTI Marine Biotic Index) indices. The AMBI values (0.391 to 1.13) and M-AMBI (0.92 to 0.96) calculated for the Vellar estuary indicated relatively undisturbed nature and high ecological quality while the values calculated for Ennore estuary (AMBI: 2.032 to 4.146 and M-AMBI: 0.27 to 0.76) signaled moderately disturbed nature and poor ecological quality of the system. The present study proves that there is an immense scope for application of AMBI & M-AMBI in ecological health assessment studies.

**[Keywords:** Benthos; Polychaetes; Ecological quality; AMBI; M-AMBI]

### Introduction

In recent years, the coastal and marine environments have been subjected to various anthropogenic activities, which include a variety of industrial wastes and other toxic compounds accruing from shoreline industries, thermal power plants besides agricultural run-off and finally it mixes and settled into the marine environment through estuaries<sup>1</sup>. These anthropogenic effects cause damage to health of soft bottom benthic groups such as polychaetes, gastropods, bivalves, amphipods, etc., which resulted in alteration in the composition and community structure of macro invertebrate assemblages<sup>2</sup>. Of the various benthic taxa, macrobenthos especially polychaetes constitute more than 60 % of the total benthic community. As most of the benthic organisms are sedentary in nature and their movement is limited, it is very difficult for them to avoid environmental disturbance<sup>3</sup>.

The macro invertebrate communities are the most consistently emphasized biotic component for measurement of biological integrity, compared to other organisms in the aquatic life<sup>4</sup>. And also, the macro benthic organisms are proved to be the veritable indicator for assessing the healthiness of marine

environment particularly the polychaetes which play a pivotal role in environmental monitoring purpose as they are the most abundant and dominant group in the marine environment by responding rapidly to anthropogenic effects<sup>5,6,7,8</sup>.

In this backdrop, recently various ecological health indices have been advocated for ascertaining healthiness of the marine environment<sup>9,10,11</sup>. Of these biotic indices, the AMBI (AZTI-Marine Biotic Index) is the widely used index for the said purpose<sup>12,13</sup>. AMBI developed<sup>14</sup>, has been successfully applied to different geographical areas perturbed under different impact sources. Primarily, the AMBI was designed for the establishment of ecological quality of European coastal and estuarine waters through the response of soft bottom benthic organisms to natural and man-made disturbance in the environment. Subsequently, the AMBI index applied for assessing the marine environment perturbed by 38 different impact sources, including six new case studies (hypoxia processes, sand extraction, oil platform impacts, engineering works, dredging and fish aquaculture)<sup>15</sup>. Recently, the AMBI has been successfully used to study the impact assessment on worldwide, including in the Indian situation<sup>16</sup>.

The AMBI has another advanced step using M-AMBI (Multivariate- AZTI Marine Biotic Index), which is a multi-metric index for assessing the ecological status of marine environment and it also provides detailed information on species richness and diversity on AMBI index scale on the particular marine environment. Therefore, the AMBI and M-AMBI is the robust tool for assessing the healthiness of marine ecosystem<sup>17</sup>.

The land based sources such as, domestic and industrial wastes, thermal power plant waste, and agricultural run-off are the main causes for pollution in coastal and marine environment<sup>18</sup>.

Under these circumstances, studies using AMBI-index to ascertain the healthiness of coastal and marine environments are very limited in Indian context. Considering the lacunae exist in this line, an attempt was made presently to study the ecological health of Vellar and Ennore coastal environments using the health indices. The Ennore (lat.13°13'N; long.80°19'E) coastal line, located in the north of Chennai city, Tamil Nadu, India, is considered as a major industrial hub of south India. Dumping of fly ash slurry from Ennore thermal effluents coupled with anthropogenic activity including sewage pollution is said to be the major problem in this region<sup>19, 20</sup>. As regards Vellar estuary, (lat.11°29'N; long.79°46'E) located in Parangipettai coast, south east coast of India, which is relatively pristine in nature, is known to receive mostly agricultural run-off from nearby agricultural fields.

## Materials and methods

Description of the study area is shown in Fig. 1

The details of sampling stations are as follows:

- A) VE-1 (Vellar-1) located just opposite to marine biological station (Lat.11°29'20.45"N Long.79°46'3.10"E).
- B) VE-2 (Vellar-2) located at the mouth of Vellar estuary (11°29'55.18"N 79°46'23.89"E).
- C) VE-3 (Vellar-3) located 1 km away straight from the station 2 (mouth). (Lat.11°30'30.38"N Long.79°47'9.71"E).
- D) VE-4 (Vellar-4) located 1 km away from the north of station 3 (Lat.11°31'55.26"N; Long. 79°46'44.31"E).
- E) VE-5 (Vellar-5) located 1 km away from south of station 3 (Lat.11°29'11.88"N; Long.79°47'48.55"E).
- F) EC-6 (Ennore-6) located just opposite to the discharge point of Vallur conventional thermal power plant (Lat.13°13'24.28"N; Long.80°18'52.03"E).
- G) EC-7 (Ennore-7) located at the mouth of Ennore estuary and opposite to Tamil Nadu thermal power station (Lat.13°13'57.27"N; Long.80°19'35.26"E).
- H) EC-8 (Ennore-8) located 1 km away straight from the H)station 7 (Lat.13°13'52.43"N; Long.80°20'8.87"E).
- I) EC-9 (Ennore-9) located 1 km away from north of station 8 (Lat.13°14'42.47"N; Long.80°20'34.24"E).
- J) EC-10 (Ennore-10) located 1 km away from south of I)station 8 (Lat.13°13'6.10"N; Long. 80°19'54.0"E).

## Water and sediment collection

Seasonal sampling was carried out from July 2016 to June 2017 in the selected stations of study area. In order to avoid the metal contamination, Teflon coated Niskin water sampler was used for collecting water samples in the selected stations. The physico-chemical parameters such as temperature, salinity and pH were recorded by using the standard instruments (for temperature, and handheld thermometer; salinity using Hand refractometer - ATAGO Japan, and for pH, the pH pen (Eco testr pH1). The membrane filter technique was adopted for the measurement of total suspended solids (TSS) using millipore filtration unit<sup>21</sup>. Dissolved oxygen (DO) was estimated using Winkler's method as described by Strickland and Parsons<sup>22</sup>.

For nutrients analysis, a little quantity of soil samples was collected from the grab sampler. After collection, the sediment samples were dried at 55°C and then subjected to homogenization process so as to get fine particles to analyze sediment nutrients. Soil texture was analyzed by using the standard method as proposed by Krumbein and Pettijohn<sup>23</sup>. The total organic carbon (TOC) concentration was estimated by using chromic acid digestion method<sup>24</sup>. Besides, sediment samples were also subjected to perchloric acid and nitric acid digestion for the heavy metals analysis by adopting the standard method of Topping<sup>25</sup>.

## Benthic sample collection

Benthic sampling was done in the selected locations of both the estuaries. From each station, triplicate sampling was done using van Veen grab (0.1m<sup>2</sup>). Immediately after collection, the larger organisms were handpicked and the remaining

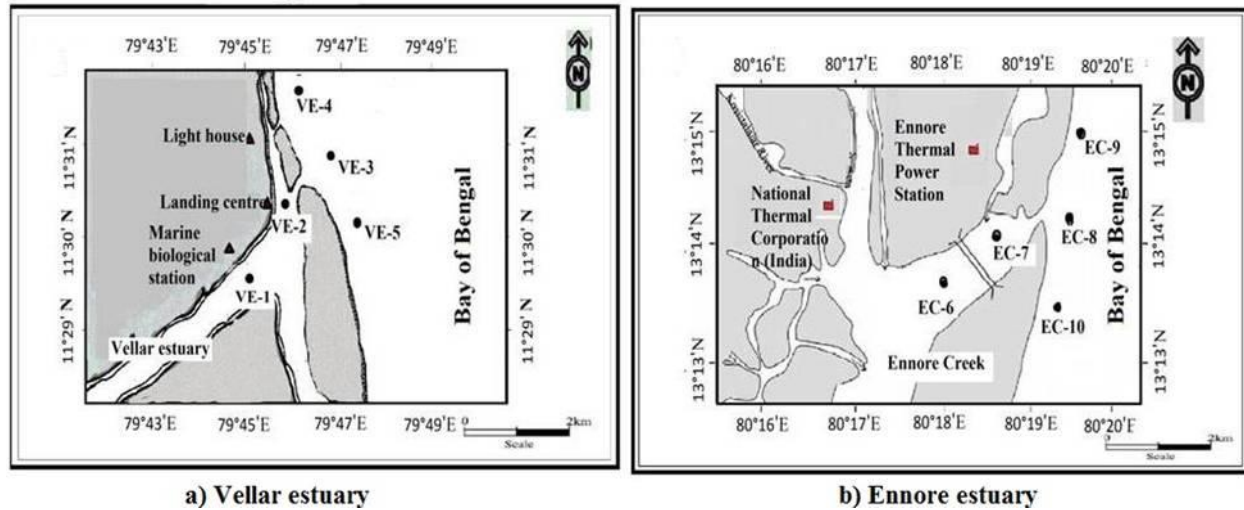


Fig. 1 — Map showing the sampling stations of study areas

sediments were sieved through a 0.5 mm mesh screen. After sieving, the sieve retains were preserved with 5-7% formalin and stained with 0.1% of Rose Bengal for better visibility during sorting and species identification. The organisms were identified by using standard references<sup>26,27</sup>.

### Data analysis

The data on environmental variables and biological variables were subjected to simple correlation and they were also treated with multivariate methods namely PCA (Pearson Correlation Analysis), CCA (Canonical Correspondence Analysis) and BIO-ENV (Biota-Environment matching) using the statistical software PRIMER (Ver.7)<sup>28</sup>. The CCA was done with the software namely PAST<sup>29</sup>.

### AMBI and M-AMBI indices

Similarly, the data on macro benthic faunal groups were subjected to AMBI index and M-AMBI<sup>14</sup> index based on the ecological groups available in AZTI Laboratory (<http://www.azti.es>). The ecological groups were classified based on their sensitivity to the pollution.

The index value was calculated using the following equation including the percentage of each ecological group and sensitive coefficient for each group<sup>30</sup>:

$$\text{AMBI} = [(0 \times \% \text{EGI}) + (1.5 \times \% \text{EGII}) + (3 \times \% \text{EGIII}) + (4.5 \times \% \text{EGIV}) + (6 \times \% \text{EGI})] / 100$$

The distributions of these ecological groups were analyzed according to their sensitivity to pollution stress which provides Biotic Index (BI) scale from 0 to 7<sup>31,32</sup>. According to Borja et al.<sup>14</sup>, each scale represents the following site pollution classification:

- 0-1 = unpolluted
- 2 = slightly polluted
- 3 = moderately polluted
- 4 - 5 = heavily polluted
- 6 - 7 = extremely polluted

M-AMBI was originally proposed<sup>12</sup> and then detailed<sup>14</sup>. This index was found to be the combination of Shannon's diversity, richness and AMBI, into (Factor Analysis) multivariate approach which appears to be a suitable method to evaluate the ecological condition using AMBI software. This method compares monitoring/ experiment results with reference conditions, in order to derive an M-AMBI value, which expresses the relationship between observed value and reference value. If the ecological status is 'high', the reference condition may be regarded as an "optimum" where the M-AMBI approaches '1'; when status is 'bad', the M-AMBI approaches '0'. The threshold values for the M-AMBI classification are based upon the following European inter-calibration (i.e.): 'High' quality, >0.77; 'Good', 0.53-0.77; 'Moderate', 0.38-0.53; 'Poor', 0.20-0.38; and 'Bad', <0.20<sup>33,34</sup>.

### Setting of reference condition

The use of AMBI and M-AMBI indices is gaining momentum in the recent years and only a few researchers have adopted these indices along the west and southeast coast of India<sup>16,48,62</sup>. The reference condition for the present study areas has been set using the values reported earlier<sup>62,48</sup>. The Reference conditions are the following: 'High' 0.820-0.999; Good, 0.690-0.846; Moderate, <0.505; Poor, 0.207-0.272; Bad, <0.168<sup>68,69</sup>.

## Result and discussion

### *Vellar estuary*

As regards environmental entities, the depth (m) in various stations varied from 5.37 to 14 ( $\pm 4$ ) with minimum in VE-1 (summer) and maximum in VE-4 (monsoon); temperature is an important factor that influence the life of organisms in the marine environment<sup>35</sup>. The water temperature ( $^{\circ}\text{C}$ ) ranged from 24.2 to 25.7 ( $\pm 0.3$ ) with minimum in VE-2 during monsoon period and maximum in VE-5 during summer season. The monsoonal minimum might be due to the influxes of heavy rain. Earlier reports also reported the similar seasonal range of temperature<sup>36</sup>; salinity play an important role in the regulation of marine faunal diversity<sup>37</sup>. The salinity (ppt) level varied from 34 to 36.6 ( $\pm 1.0$ ) with minimum value was recorded in VE-1 during monsoon and maximum in VE-4 during summer. It is known fact that the minimum value is due to the mixing of fresh water and maximum value due to the ingression of neritic water and high intensity of solar radiation. The similar summer maximum was reported earlier<sup>38</sup>. Water pH was in the range of 8.2 to 8.5( $\pm 0.1$ ) with minimum value in VE-5 (pre monsoon) and maximum value in VE-1 (monsoon); The Dissolved oxygen is the major factor in the coastal environs. Presently it varied from 3.6 to 4.2 ( $\pm 0.3$ ) with minimum level in VE-3 during pre monsoon and maximum level recorded in VE-1 during monsoon. Similar range of dissolved oxygen level was reported earlier<sup>39</sup> in the Nagapattinam coastal waters; total suspended solids (ppm) varied from 90.2 to 110.7 ( $\pm 9.5$ ) with minimum value was recorded in VE-5 (summer) and maximum value in VE-2 (monsoon); sediment pH varied from 8.3 to 8.5 ( $\pm 0.1$ ) with minimum level in VE-1 (pre monsoon) and maximum in VE-5 (post monsoon); the soil texture is known to play essential role in influencing the benthic faunal diversity. The sand (%) content fluctuated from 17.05 to 26.88 ( $\pm 3.9$ ) with minimum in VE-4 (monsoon) and maximum in VE-1 (pre monsoon); silt (%) varied from 34.76 to 40 ( $\pm 2.2$ ) with minimum in VE-3 (summer) and maximum in VE-1 (pre monsoon); clay (%) level from 33.11 to 46.1 ( $\pm 5.8$ ) with minimum in VE-1 (monsoon) and maximum in VE-4 (summer); the TOC (total organic carbon) also play vital role in the health of benthic faunal ecosystem. The TOC (mgC/g) ranged from 2.5 to 5.01 ( $\pm 1.05$ ) with minimum in VE-1 (monsoon) and maximum in VE-5 (summer). The level of soil texture and TOC recorded in the present study is quite

comparable with the earlier report of Muthukumar *et al.*<sup>40</sup> who worked on the sediment characteristics of Vellar estuary.

With respect to metal concentration, cadmium (ppm) level ranged from 0.002 to 0.011 ( $\pm 0.003$ ) with minimum in VE-2 (summer) and maximum in VE-1 (monsoon); copper (ppm) level was ranged from 0.117 to 0.385 ( $\pm 0.100$ ) with minimum in VE-2 (pre monsoon) and maximum in VE-1 (monsoon); manganese (ppm) level varied from 0.23 to 2.76 ( $\pm 1.070$ ) with minimum in VE-1 (pre monsoon) and maximum in VE-3 (monsoon); iron (ppm) level varied from 0.13 to 0.257 ( $\pm 0.04$ ) with minimum in VE-2 (pre monsoon) and maximum in VE-5 (post monsoon); lead (ppm) level ranged from 0.205 to 1.123 ( $\pm 0.396$ ) with minimum in VE-2 (summer) and maximum in VE-4 (post monsoon); zinc (ppm) level from 0.192 to 0.782 ( $\pm 0.217$ ) with minimum in VE-2 (pre monsoon) and maximum in VE-1 (monsoon). The values of heavy metals are in good agreement with the earlier reports<sup>41</sup> who studied the heavy metals accumulation in Vellar estuary.

### *Ennore estuary*

The depth (m) in Ennore estuary was found to vary from 3.5 to 14.2 with minimum in EC-6 (summer) and maximum in EC-10 (monsoon); water temperature ( $^{\circ}\text{C}$ ) ranged from 28 to 28.4 with minimum in EC-10 (monsoon) and maximum in EC-6 (summer); salinity (ppt) level varied from 35 to 38 with minimum value in EC-10 (monsoon) due to rain fall and maximum value in EC-6 (summer). The similar range was reported in Ennore earlier<sup>42</sup>; water pH was in the range of 8.1 to 8.5 with minimum (pre monsoon) value in EC-6 and maximum value in EC-10; Dissolved Oxygen (mg/l) level varied from 2.9 to 4.2 with minimum level recorded in EC-7 (pre monsoon) and maximum level in EC-10 (monsoon). The minimum during pre-monsoon might be due to the consumption of oxygen by other organisms (bacteria) leading to the oxidation process<sup>43</sup>; total suspended solids (ppm) varied from 70.7 to 254.2 with minimum value in EC-8 (summer) and maximum value in EC-7 (monsoon); sediment pH varied from 7.1 to 8.5 with minimum level in EC-6 (summer) and maximum in EC-9 (monsoon); sand (%) ranged from 13.5 to 57.43 with minimum in EC-6 (pre monsoon) and maximum in EC-10 (monsoon); silt (%) varied from 19.04 to 39.85 with minimum in EC-10 (monsoon) and maximum in EC-7 (pre monsoon); clay (%) level ranged from 22.81 to 50.14 with minimum in EC-8 (monsoon) and maximum in EC-6 (pre

monsoon); The similar soil composition in terms of soil texture was recorded earlier<sup>42</sup>. TOC (mgC/g) level fluctuated from 1.9 to 12.35 with minimum in EC-9 (pre monsoon) and maximum in EC-6 (summer), which might be due to the settlement of sewage waste and the fly ash from the nearby thermal power plant.

With respect to metals concentration, cadmium (ppm) level was ranged from 0.016 to 0.195 with minimum in EC-7 (pre monsoon) and maximum (monsoon) in EC-6; copper (ppm) level ranged from 0.357 to 0.597 with minimum in EC-9 (summer) and maximum in EC-6 (monsoon); manganese (ppm) level ranged from 0.88 to 7.15 with minimum in EC-7 (summer) and maximum in EC-8 (monsoon); iron (ppm) level fluctuated from 0.892 to 299.2 with minimum in EC-9 (pre monsoon) and maximum in EC-6 (monsoon); lead (ppm) level was in the range of 0.684 to 57.62 with minimum (pre monsoon) in EC-7 and maximum in EC-9 (monsoon); zinc (ppm) level varied from 0.321 to 1.856 with minimum in EC-7 (summer) and maximum in EC-6 (post monsoon). The metals (Cd, Cu, Mn, Fe, Pb and Zn) concentration in Ennore estuary showed high levels in monsoon and post monsoon season because of the settlement of industrial wastes from the nearby industries. The range of heavy metals recorded presently is comparable with the earlier reports<sup>44</sup>.

Comparing two regions, water temperature, salinity, PHC and TSS showed elevated levels in Ennore stations, which might be due to the influence of coolant water from thermal industries. Similar range of water temperature, salinity, PHC, TSS values were also reported by Kailasam and Sivakami<sup>45</sup> in Tuticorin bay, south east coast of India<sup>46</sup> in the Tuticorin bay, south east coast of India<sup>47</sup> in the Kalpakkam Coastal Area, southeastern coast of India. The Vellar estuary registered higher DO level than Ennore estuary, as reported earlier<sup>48</sup> who studied the assessment of ecological quality of Vellar and Uppanar estuaries. The sediment nature of the estuary is also known to modify by the discharge of fly ash slurry from the thermal power plant<sup>49</sup>, since it contain high amount of non degradable toxic metals and fine sediment particles<sup>50</sup>. Maximum level of TOC (12.35 mgC/g) was recorded in station EC-6. Similar maximum was reported earlier<sup>51</sup> in the Ennore area. The results obtained from the soil texture analysis showed the high percentage (50.1%) of clay in stations EC-6 and EC-7, which might be due to dumping of fly ash slurry from the discharge point.

However, the report<sup>52</sup> that the higher percentage of silt in the stations are near to the Ennore thermal discharge point. The high level of metals namely Zn (1.8 ppm), Fe (299.2 ppm), Cd (0.155 ppm), Cu (0.597 ppm), Mn (2.0 ppm) were recorded in the stations EC-6, EC-7 and EC-8 which might be due to the location of these stations as they receive quantum of fly ash slurry from the thermal power plant. Similar results were also observed<sup>53</sup> who reported that pool bay has received elevated amount of Mn and Cr from U.K cool fired power station<sup>54</sup> found that Korampallam creek in Tuticorin coast is highly polluted with trace elements (Cd, As, Zn, Hg and Pb) due to the discharge of effluents from thermal power point. Similarly, the present study area (Ennore Creek) also got polluted with these metal as represented earlier<sup>55</sup>. The average value of physico-chemical parameters recorded during the year 2016-2017 at each station is summarized in the Table-1.

#### Biological entities

With regard to faunal components, four benthic taxa viz., polychaetes, bivalves, gastropods and amphipods were recorded. Of these, in terms of overall species, polychaetes were found to be the dominant group with 66 %, bivalves formed the next dominant group with 18 %, gastropods with 9 % and amphipods with 7 %. Vellar estuary registered with maximum with 52 species and Ennore with 12 species. Of these, polychaetes namely *Terebellides stroemi*, *Onuphis quinequendens*, *Nephtys dibranchis*, *Eunice* sp., *Maldane sarsi*, *Ancistrosyllis parva*, *Cossura coasta*, *Cirriformia tentaculata*, *Magelona cincta*, *Euclymene oerstedii*, *Cirratulus cirratus* were found to be the dominant species in Vellar estuary while species namely *Eunice siciliensis*, *Cirratulus* sp, *Capitella capitata*, *Glycera unicornis*, *Prionospio cirrobranchiata*, *P. pinnata* were dominant species in Ennore estuary.

#### PCA (Principle component analysis)

For PCA analysis, the environmental variables were given as input parameters to ascertain the influencing parameters in the sampling locations. The results revealed that the physico-chemical variables of water and sediment samples explained 70.3 % variance of total axis with 41.9 % of PC1 (Principle component axis-1) and 28.4 % of PC2 (Fig. 2). Among the parameters, dissolved oxygen (DO), water pH, sediment pH, got positively correlated with stations located in the Vellar estuary (VE-1, VE-2,

VE-3, VE-4 and VE-5); while sand, Mn and Pb, were strongly correlated with stations EC-7, EC-8, EC-9 and EC-10 in Ennore. The water temperature, salinity, PHC, Cu, Cd, and Fe were positively

correlated with the station EC-6 in the Ennore Creek. The remaining parameters such as TSS, TOC, Clay and Silt were negatively correlated with the stations EC-8, EC-9 and EC-10. Similar variable

Table 1 — Physico-chemical characteristics (Mean and standard deviation (SD)) recorded in various sampling stations of Vellar and Ennore estuaries

	VE-1 (Mean ± SD)	VE-2 (Mean ± SD)	VE-3 (Mean ±SD)	VE-4 (Mean ±SD)	VE-5 (Mean ± SD)	EC-6 (Mean ± SD)	EC-7 (Mean ± SD)	EC-8 (Mean ± SD)	EC-9 (Mean ± SD)	EC-10 (Mean ± SD)
Depth (m)	5.37 ± 1.37	6.5 ± 1.29	11.5 ± 0.57	14 ± 0.81	13.7 ± 0.95	3.5 ± 0.40	4 ± 0.47	12.7 ± 0.64	13.8 ± 0.62	14.2 ± 0.64
Water tem (C)	25.2 ± 2.21	24.2 ± 0.95	25 ± 1.41	25 ± 1.15	25.7 ± 0.95	28.4 ± 2.1	28.1 ± 1.6	28.2 ± 0.95	28.3 ± 0.95	28 ± 1.15
Salinity (ppt)	34 ± 2.5	35 ± 2.4	36.5 ± 2.8	36.6 ± 1	36 ± 0.81	38 ± 0.81	37 ± 1.9	35.2 ± 2.9	35.25 ± 2.7	35 ± 2.0
Water pH	8.5 ± 0.5	8.4 ± 0.4	8.3 ± 0.4	8.4 ± 0.3	8.2 ± 0.3	8.1 ± 0.5	8.2 ± 0.3	8.5 ± 0.2	8.4 ± 0.2	8.5 ± 0.1
DO (mg/l)	4.2 ± 0.4	3.8 ± 0.2	3.6 ± 0.4	3.7 ± 0.4	4.1 ± 0.7	3.0 ± 0.2	2.9 ± 0.4	3.9 ± 0.3	4.1 ± 0.35	4.2 ± 0.2
TSS (ppm)	106.7 ± 31	110.7 ± 43	91.7 ± 28	102 ± 15.3	90.2 ± 6.9	133.2 ± 49	254.2 ± 127	70.7 ± 46	76 ± 29.5	91.7 ± 46.4
Sediment pH	8.3 ± 0.4	8.3 ± 0.3	8.4 ± 0.3	8.5 ± 0.3	8.5 ± 0.4	7.1 ± 0.1	7.2 ± 0.2	8.4 ± 0.2	8.5 ± 0.4	8.3 ± 0.1
Sand (%)	26.88 ± 20.43	24.2 ± 8.24	21.64 ± 12.7	17.05 ± 12.1	19.02 ± 8.8	13.5 ± 4.5	18.85 ± 7.2	41.52 ± 14.8	56.42 ± 5.1	57.43 ± 9.6
Silt (%)	40 ± 4.6	38.69 ± 6.1	34.76 ± 14.1	36.84 ± 16.2	35.01 ± 9.4	34.59 ± 5.4	39.85 ± 10.8	32.66 ± 11.4	24.71 ± 14.03	19.04 ± 2.6
Clay (%)	33.11 ± 21.1	37.1 ± 12.2	43.6 ± 2.26	46.1 ± 1.17	45.95 ± 10.5	50.14 ± 1.90	41.39 ± 3.5	25.98 ± 21.3	22.8 ± 16.35	23.58 ± 9.6
TOC (mgC/g)	2.53 ± 2.2	3.54 ± 1.5	4.41 ± 0.6	4.96 ± 0.4	5.01 ± 0.6	12.35 ± 1.0	2.955 ± 0.8	2.3 ± 1.0	1.92 ± 0.9	2.06 ± 1.0
Cd (ppm)	0.011 ± 0.004	0.002 ± 0.001	0.009 ± 0.003	0.006 ± 0.001	0.009 ± 0.007	0.195 ± 0.096	0.016 ± 0.011	0.026 ± 0.005	0.018 ± 0.009	0.154 ± 0.001
Cu (ppm)	0.385 ± 0.14	0.117 ± 0.08	0.282 ± 0.04	0.209 ± 0.04	0.202 ± 0.05	0.597 ± 0.31	0.462 ± 0.30	0.532 ± 0.17	0.357 ± 0.08	0.537 ± 0.21
Mn (ppm)	0.23 ± 0.04	0.49 ± 0.19	2.76 ± 0.48	0.3 ± 0.09	0.5 ± 0.16	2 ± 0.43	0.88 ± 0.07	7.15 ± 1.38	4.22 ± 0.47	6.75 ± 0.67
Fe (ppm)	0.154 ± 19.3	0.13 ± 0.014	0.173 ± 0.01	0.183 ± 0.007	0.257 ± 0.027	299.2 ± 108.9	0.172 ± 0.009	167.2 ± 4.81	0.892 ± 0.04	257 ± 44.70
Pb (ppm)	0.357 ± 0.14	0.205 ± 0.21	0.592 ± 0.225	1.123 ± 0.586	0.992 ± 0.171	0.84 ± 0.06	0.684 ± 0.18	1.34 ± 0.07	57.62 ± 32.62	1.149 ± 0.72
Zn (ppm)	0.782 ± 0.105	0.192 ± 0.143	0.615 ± 0.173	0.456 ± 0.164	0.52 ± 0.120	1.856 ± 0.987	0.321 ± 0.102	1.13 ± 0.568	1.225 ± 0.605	0.568 ± 0.005

Mean ± SD, VE-Vellar Estuary, EC- Ennore Creek

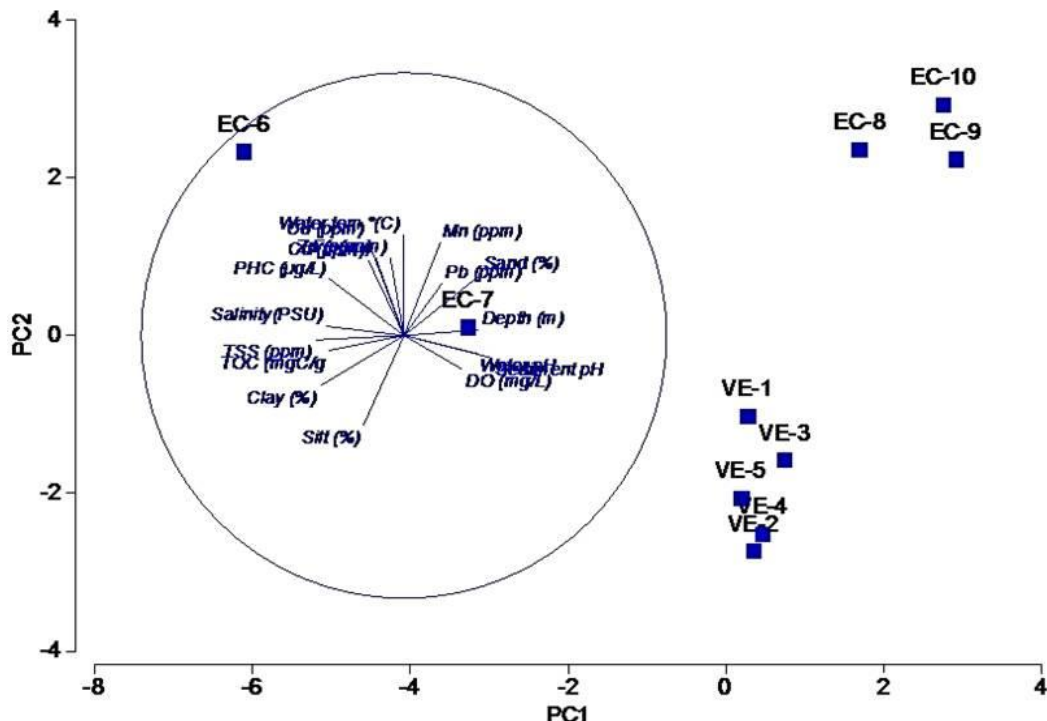


Fig. 2 — Principle Component Analysis-biplot drawn for physico-chemical parameters against stations of Vellar –Ennore estuaries.



combinations were reported earlier<sup>16</sup> who found that water temperature and salinity were positively correlated with stations located close to the thermal discharge point. PCA results also confirmed that the significant correlation of salinity, water temperature, and PHC in the stations EC-6 and EC-7. The sediment parameters viz., Fe, Cu, Cd, Zi, Mn revealed the strong correlation with stations EC-6 & EC-7. These results are in agreement with the previous report of Zhuang and Gao<sup>56</sup>.

### CCA (Canonical Correspondence Analysis) – (Dominant polychaetes against environmental variables)

The CCA plot explains the correlation between most abundant species of polychaetes and environmental parameters. The first 2 axes of CCA triplot explained 66.83 % of the variance of species-environment relationship. The first canonical axis (Axis 1) accounted for 50.41 % variance and 16.42 % for second canonical axis (Axis 2) (Fig. 3). The polychaete species such as *Capitella capitata*, *Prionospio cirrobranchiata*, *P. pinnata*, *Glycera unicornis*, *Lumbrineris magalhensis*, *Notomastus aberrans* and *Cirratulus* sp. showed strong correlation with temperature, TSS, TOC, and PHC at stations EC-6-EC-10. This indicated the tolerance of these polychaete species to survive in the moderate

environment. A similar species combination with the said parameters was reported earlier by Musal and Desai<sup>57</sup>. The rest of the polychaete species such as *Maldane sarsi*, *Magelona cincta*, and *Euclymene oerstedii* are highly sensitive to pollution. These species were correlated with stations of Vellar estuary because of higher oxygen level and lower organic content in the sediments, indicating a healthy environment for sensitive polychaete species as reported earlier<sup>58</sup>.

### CCA (Canonical Correspondence Analysis) – dominant polychaetes against heavy metals

As done for polychaete abundance with physico-chemical variables, CCA was also drawn for polychaete abundance against heavy metals. The results of the CCA plot revealed about 68.15 % of total variance with 48.15 % of axis 1 and 20.75 % of axis 2 (Fig. 4). Here as well, the CCA plot showed the close association of polychaete species namely *Eunice sciliensis*, *Capitella capitata*, *Glycera unicornis*, and *Cirratulus* sp. with heavy metals Cu, Cd, Zn, Mn, Fe in stations EC-6, EC-8 & EC-10 as these polychaete species belong to the pollution tolerant groups. The CCA results of the present study clearly showed the impact of different variables on the biota of various stations of Ennore estuary. These results are in agreement with the findings of Gurerra-Garcia and

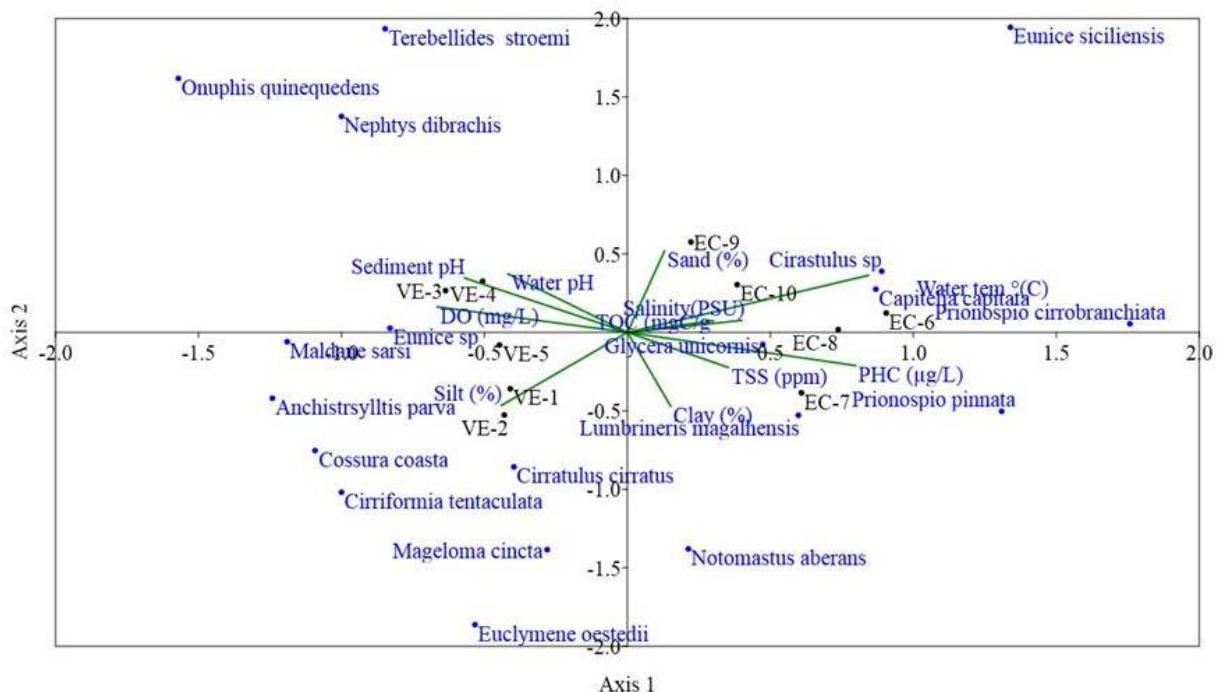


Fig. 3 — Canonical correspondence analysis drawn for correlation between dominant species of polychaetes and environmental variables against stations.

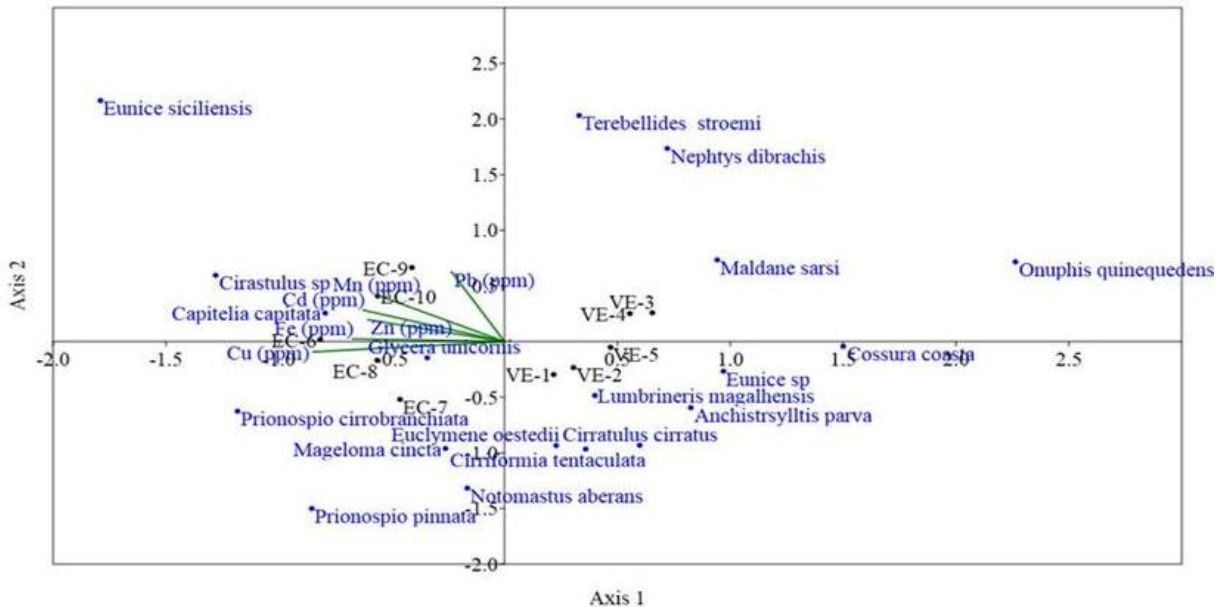


Fig. 4 — Canonical correspondence analysis drawn for correlation between dominant species of polychaetes and heavy metals against stations.

Garcia and Gomez<sup>59</sup> who reported that the polychaetes species namely *Capitella capitata*, *Potamilla reniformis*, *Pseudomalacocerose tridentata*, *Platynereies dumerilii*, *Cirriformia tentaculata* had strong correlation with Cu, Zn, Pb and Mn.

#### BIO-ENV (Biota-Environment matching)

The BIO-ENV was employed to measure the correlation between polychaete species abundance (Bray- Curtis similarity) and environmental parameters (Euclidean distance). A total of 18 environmental variables were used as the input parameters for BIO-ENV analysis. Of this, the results clearly indicated that the combination of five variables such as DO, Water pH, Cd, Cu, and Zn explained the best match ( $\rho = 0.693$ ) influencing the polychaete distribution.

#### AMBI and M-AMBI indices

AMBI indices have been in use recent years with a view to assess the ecological health of the marine ecosystem using macro benthic species experiencing various anthropogenic activities<sup>60,61</sup>. In the present study, totally 59 macro benthic species were identified and three taxa (shrimp larvae, foraminifera and sea urchin) were excluded as it did not fall in to the benthic macro invertebrates. Based on the AZTI classification, 51 macro benthic species were fit in the five ecological groups and the remaining 5 species were not assigned. Of 51 species, 21 species (42.6 %)

fell into EG -I (Ecological Group); 12 species (24.5 %) into EG-II; 5 species (9.3 %) in to EG-III; 10 species (16.2) in to EG-IV and three species (4.6 %) in to EG-V. The percentage compositions of various five ecological groups are shown in Figure 5.

After assigning the species, AMBI software was ran and when we looked at the AMBI values in Vellar estuary, it ranged from 0.391 to 1.13 which clearly indicated the undisturbed nature of the Vellar stations (VE-1, VE-2, VE-3, VE-4 and VE-5), due to the fact that the Vellar estuary has the optimum nutrients, sea grass bed, and mangroves which provide conducive habitat of many macro benthic organisms. Further high dissolved oxygen and lower organic matter offered a healthy environment for the occurrence of sensitive organisms as reported by Khan<sup>48</sup>. While the AMBI values of Ennore creek were viewed, it varied from 2.032 to 4.146 which evidently revealed polluted nature of the stations of Ennore creek. Among the stations, EC-6 showed the maximum (4.146) value of AMBI indicating moderately polluted nature due to the thermal discharges (Fly ash slurry) from National Thermal Power Corporation of India. And the AMBI value of EC-7 (3.512) also indicated moderate pollution in Ennore creek due to vicinity of the site at the cooling water discharge point of Ennore Thermal Power Station (Fig. 6). The AMBI values of remaining stations in Ennore creek (EC-8, EC-9 - EC-10) ranged from 2.032 - 2.232 indicating the slightly



polluted condition of the sites. Similar study was also carried out<sup>62</sup> in Vellar and Coleroon estuaries of southeast coast of India and they found higher AMBI values in the stations studied and they also attributed

the higher values to discharges from nearby fish landings and municipal sewages. In light of this statement Liu et al<sup>63</sup> worked on the ecological status assessment in Chang jiang estuary located in the

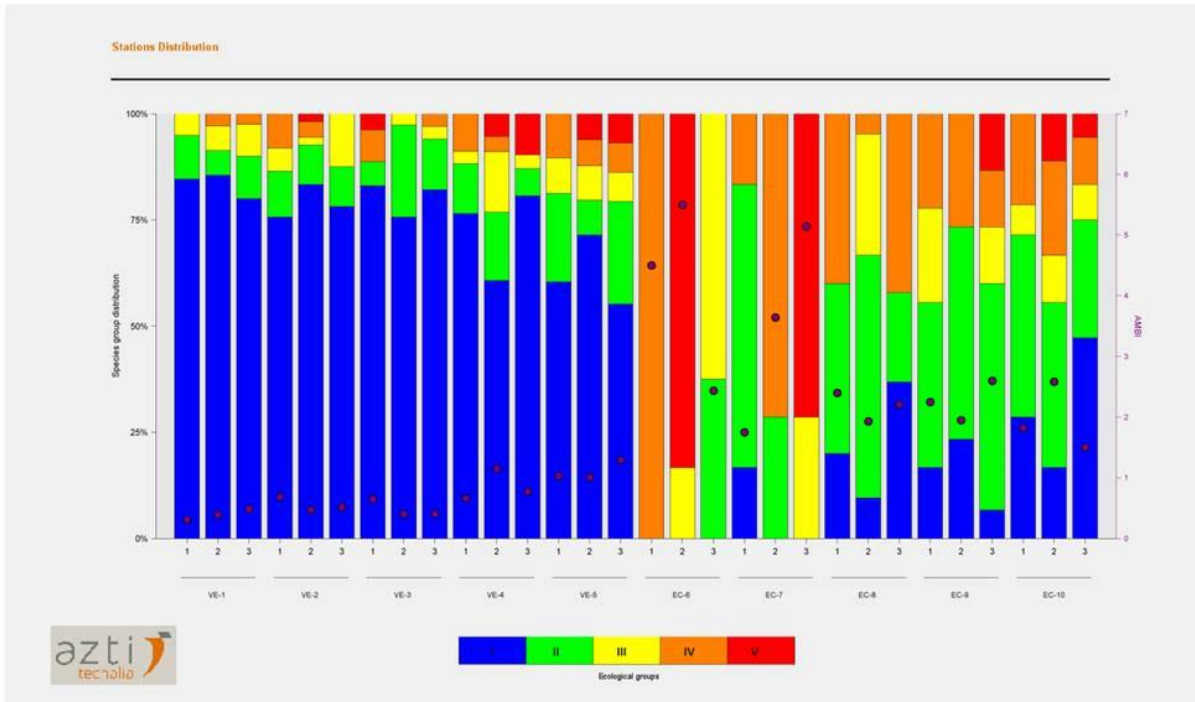


Fig. 5 — Percentage compositions of various ecological groups recorded at various stations in the Vellar and Ennore estuaries

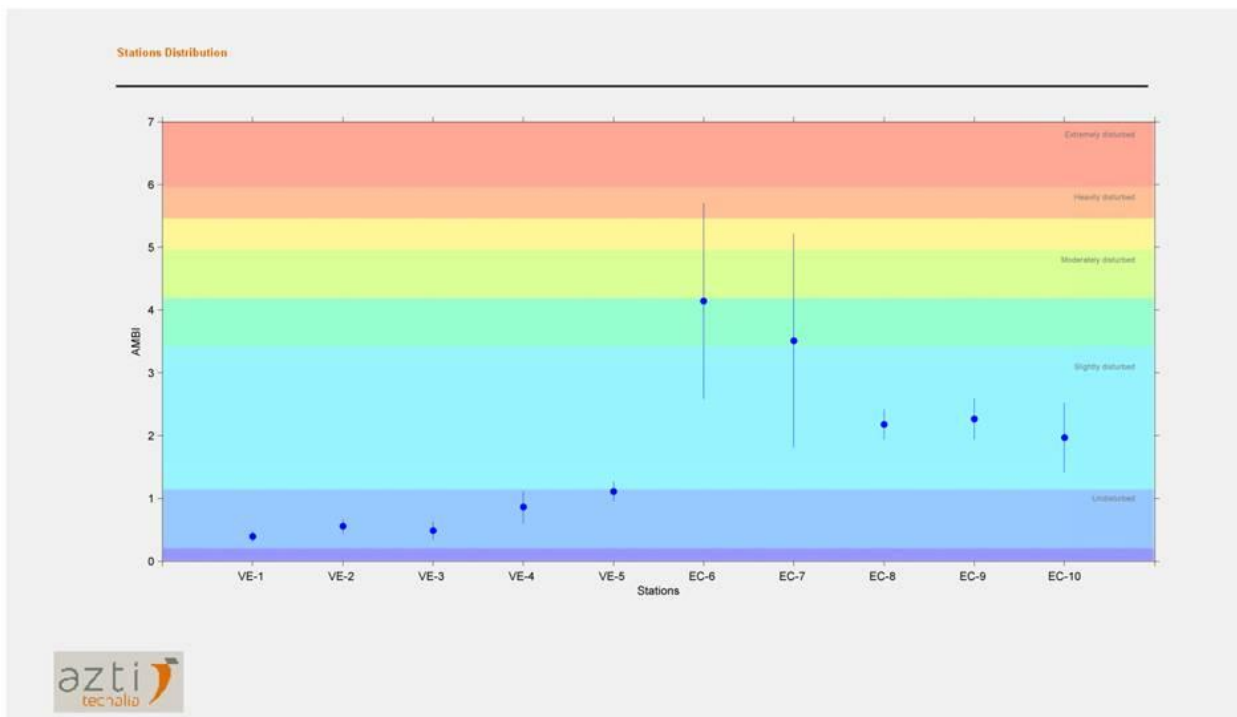


Fig. 6 — AMBI disturbance classification values for various stations of Vellar-Ennore estuaries.

China and they described the high AMBI values might be due to the prevailing anthropogenic activities. Several researchers have reported that the organic pollutants from the thermal power plants are known to alter the composition of benthic fauna where the AMBI indices were used<sup>64, 65, 66</sup>.

As regards M-AMBI, the values varied from 0.27 to 0.95 with ecological status, from “Poor” to “High”. Based on the M-AMBI values, the stations VE-1 - VE-5 belonged to “High” ecological status in Vellar estuary whereas the values for Ennore, the station EC-6 and EC-7 belonged to the “Poor” ecological status and the remaining stations (EC-8, EC-9, EC-10) fell in the “Good” ecological status (Fig.7). Similar

ecological status of Vellar estuary was earlier represented<sup>48</sup>. Also, assessed the ecological status of Eo estuary in Spain and observed the similar range of M-AMBI values in the study area located nearby oyster farm<sup>67,68,69</sup>. M-AMBI results also explained the “Diversity” and “Richness” values of macro benthic organisms from all the station. The diversity values of Vellar estuary ranged between 4.70 and 4.96, while in Ennore creek the diversity values were varied from 1.78 to 4.42. The species richness is varied from 36 to 40 in the station of Vellar estuary. But in the stations from Ennore has the very low richness values from 4-26. The diversity (0.27 to 0.76) and richness (4 to 26) values of Ennore stations are given in Table 2.

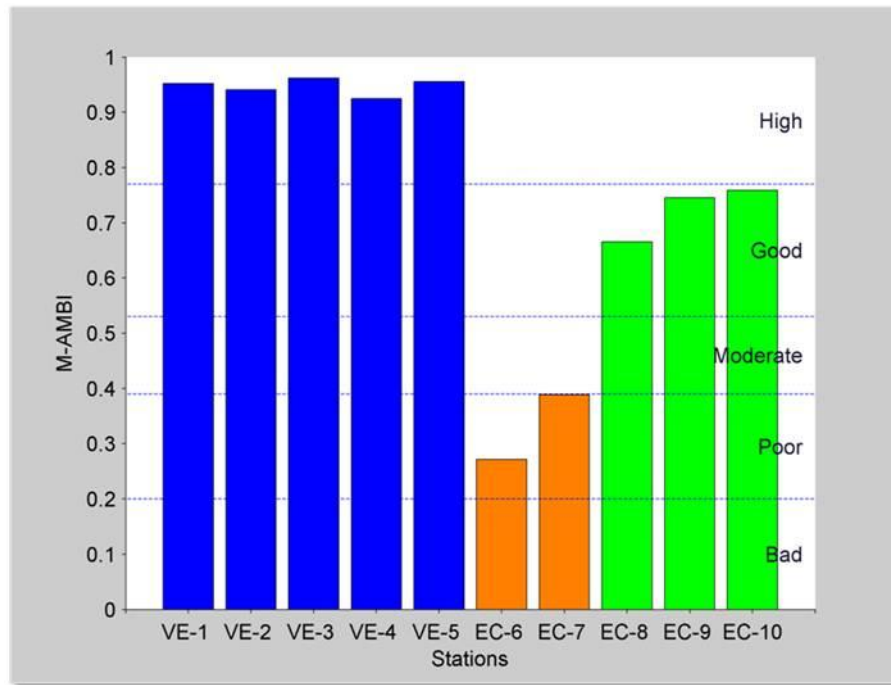


Fig. 7 — M-AMBI values indicating the ecological status for the stations in Vellar and Ennore estuaries.

Table 2 — AMBI site disturbance classification and M-AMBI values in the various stations of Vellar and Ennore estuaries.

Stations	EG-I (%)	EG-II (%)	EG-III (%)	EG-IV (%)	EG-V (%)	%-Not assigned	AMBI	BI	M-AMBI	Diversity	Richness	Disturbance classification
VE-1	83.2	9.2	5.3	2.3	0	11.5	0.391	1	0.95	4.70	36	Undisturbed
VE-2	77.5	12.6	4.5	4.5	0.9	14.6	0.673	1	0.94	4.69	36	Undisturbed
VE-3	79.6	12.9	2	4.1	1.4	14.5	0.62	1	0.96	4.81	37	Undisturbed
VE-4	72.1	14.4	3.6	4.5	5.4	8.3	0.837	1	0.92	4.83	35	Undisturbed
VE-5	63.6	19.1	3.6	9.1	4.5	14.7	1.13	1	0.96	4.96	40	Undisturbed
EC-6	0	20	40	6.7	33.3	0	4.146	3	0.27	1.78	4	Moderately disturbed
EC-7	5	30	10	30	25	0	3.512	3	0.39	2.56	7	Moderately disturbed
EC-8	18	44	12	26	0	0	2.232	2	0.67	4.02	19	Slightly disturbed
EC-9	12.9	51.6	9.7	22.6	3.2	3.1	2.362	2	0.74	4.38	27	Slightly disturbed
EC-10	29.3	40.2	8.5	17.1	4.9	2.4	2.032	2	0.76	4.42	26	Slightly disturbed

EG-Ecological Group, VE-Vellar Estuary, EC- Ennore Creek, BI-Biotic index.

## Conclusion

In the present study, the ecological status of Vellar and Ennore estuaries was assessed by biotic indices (AMBI, M-AMBI). The results of this study suggested that AMBI and M-AMBI is the sufficient tool for assessing the estuarine ecosystem. The findings clearly showed the moderately/slightly disturbed nature and poor ecological status of Ennore estuary owing to the thermal pollution. In respect of Vellar estuary, lower AMBI and higher M-AMBI values clearly signaled the undisturbed nature and “high” ecological status. Therefore, continuous pollution monitoring program is needed to assess the health of environments undergoing severe anthropogenic effects.

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