Assessment of ecological quality of Vellar and Uppanar estuaries, southeast coast of India, using Benthos

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Number of polychaete species identified from Vellar and Uppanar estuaries were 52 and 14 species respectively. Diversity indices were high in Vellar estuary (H' log2-4.264±0.21, d-5.782±0.65, J-0.964±0.008, Lambda'–0.02±0.004 and sPhi+ 1906±264.99) and low in Uppanar estuary (H' log2-0.941±0.27, d-1.130±0.42, J-0.418±0.05, Lambda'– 0.70±0.07 and sPhi+ 433±102.74). While the BI (AMBI–1.03±0.19) and M-AMBI (M-AMBI-0.90±0.06) values of Vellar estuary corresponded to the undisturbed nature and high/good estuarine ecological quality respectively, the above values in Uppanar showed the polluted (AMBI–4.47±0.14) and poor/bad status (M-AMBI-0.22±0.04) of estuarine ecological quality. Recently introduced tools such as AMBI & M-AMBI have clearly brought out the impaired health of Uppanar estuary and healthy nature of Vellar estuary.

[Keywords: Ecological quality, estuary, benthos, polychaetes, M-AMBI, diversity]

Introduction

Ecosystems are subjected to a wide range of anthropogenic pressures which are responsible for considerable environmental impairment1. Over the past decades water quality has been defined primarily in chemical terms. Recently, agencies managing water quality have been increasingly emphasizing the use of biological parameters as monitoring tools for better assessment of the effects of environmental stressors on biological systems2. A variety of biological assessment tools is available now, which facilitate possible interpretations and improved understanding of ecosystem health1. Biotic indices summarize in a single value the complexity of biological communities and their environment3. Macrobenthic invertebrates are considered sensitive indicators of change, integrating water and sediment quality conditions over time1 and therefore are increasingly used in health assessment of ecosystems.

The Vellar (latitude 11º 29’N; longitude, 79º 46’E) and Uppanar (latitude, 11º42’N; longitude, 79º 49’ E) estuaries are situated closely in the Southeast coast of India. In Uppanar estuary during the past few decades, industrial development has increased three times with many large and small-scale industries being established along the riverbank. These include production of fertilizers, dyes, chemicals and mineral processing plants, and metal-based industries. The effluents from the industries find their way into river Uppanar through small channels and pipelines4. Vellar estuary having artificially developed mangroves within it and lying close to the Pitchavaram mangroves is a relatively clean estuary with no major sources of pollution other than sewage and agricultural run-off5 & 6.

Polychaetes are widely distributed in the marine and brackishwater environments. They are diverse in terms of species richness and abundance. They have been successfully used as indicator taxon in long-term monitoring studies7-12. In the present study therefore, an effort has been taken to assess and compare the health of these two estuaries using the macrozoobenthic polychaetes.

Materials and Methods

In the present study, five stations each were sampled during summer season (2009) in Vellar estuary (mouth-V1, seagrass bed -V2, opposite to Marine Biological station-V3, Avicennia zone-V4 (Fig.1) and Rhizophora zone-V5) and Uppanar estuary (mouth-U1, urban discharge point-U2, Shasun Chemicals and Drugs (P) Ltd-U3, Pentasia Chemicals (P) Ltd -U4 and Spic Pharma Industries -U5) estuaries (Fig.1). The rationale for the selection of stations was:
Vellar estuary represents a relatively clean estuary having habitats such as seagrass bed and mangroves. Therefore stations were fixed up here to cover these habitats in addition to the mouth. Uppanar estuary is an impacted estuary due to the presence of polluting industrial units. Here stations were fixed up close to the major industries in the estuary for effective comparison of an impacted estuary with a relatively clean estuary.

Observations were made on the physico-chemical characteristics of the estuarine bottom water (temperature by centigrade thermometer, dissolved oxygen by Winkler’s method following Strickland and Parsons, salinity by refractometer and pH by pH meter). Sediment granulometry was done by the Pipette method as proposed by Krumbein & Pettijohn. Total Organic Carbon content (TOC) was estimated using chromic acid oxidation method followed by titration with ammonium ferrous sulfate (Walkley – Black method) as modified by Gaudette et al. Heavy metal content in the sediments was analysed following the method of Walting.

Benthic faunal collections were made during high tide time in all the 10 stations using a long-armed Peterson grab, which covered an area of 0.0251 m². From each station triplicate samples were collected. Immediately after collection of samples, the larger organisms were picked out and remaining sediment was sieved through a 0.5 mm screen. Organisms retained by the sieve were preserved in 5% formalin. Subsequently, the organisms were stained with Rose Bengal solution for enhanced visibility during sorting and the polychaetes were identified up to the highest taxonomic level possible.

Data analysis
Biodiversity measures (Margalef’s species richness-d, Shannon Wiener diversity-H’ log2, Pielou’s evenness-J’, Simpson dominance index-D and Caswell neutral model-V) were calculated and multivariate tools such as MDS and PCO were done using PRIMER v6 & PERMANOVA+

AMBI
The assignment of the identified polychaete species to the five Ecological Groups (EG I: species sensitive to disturbance; EG II: species indifferent to disturbance; EG III: species tolerant to disturbance; EG IV: second order opportunistic species and EG V: first order opportunistic species) as proposed by the marine biotic index AMBI was done based on the list available in the AMBI program (http://www.azti.es). The distribution of these ecological groups, according
to their sensitivity to pollution stress, provides a BI
with eight levels varying from 0 to 7 & 19. The
threshold values for AMBI classification are based on
those proposed by Muxika et al.20.

The M-AMBI was calculated by factor analysis
(FA) of AMBI, species richness (as number of taxa)
and Shannon’s diversity index values, using AMBI
software (http://ambi.azti.es). Depending on the
reference conditions, M-AMBI values can be lower
than 0 or higher than 1 & 21 & 22. threshold values for the
M-AMBI classification are based upon Borja et al.21&23:
‘high’ quality, >0.77; ‘good’, 0.53–0.77; ‘moderate’,
0.38–0.53; ‘poor’, 0.20–0.38; and ‘bad’, <0.20.

Results

Higher temperature was recorded in the Uppanar
estuary (31.04±1.01°C) than in Vellar (30.72±0.73°C)
estuary. The same trend was noticed in salinity- higher
in Uppanar (33.7±0.8 psu) and lower in Vellar
(32.98±1.82 psu) estuary. It increased from the higher
reaches of the estuary to the mouth region of Uppanar
(32.7 psu (U5) – 34.8 psu (U1)) and Vellar (30.4 psu
(V5) –34.7psu (V1)) estuaries. The trend noticed in
organic carbon was similar to that of temperature-high
in Uppanar (18.3±1.33 mg/g) than in Vellar
(9.09±1.05mg/g) estuary. It ranged from 16.69 (U1) to
19.54 (U3) in Uppanar and from 7.58 (V1) to 10.41
(V5) in Vellar estuary. Level of dissolved oxygen was
more in Vellar (3.68±0.64 ml L–1) than in the Uppanar
(3.36 ±0.86 ml L–1) estuary. Similar patterns were
observed with pH, high in the Vellar (8.1±0.27) and
low in the Uppanar (7.78±0.34) estuary. Nature of the
sediment was sandy clay in Vellar estuary and silty
clay in Uppanar.

The ‘t’ test done showed no significant variations in
temperature and salinity (P>0.05)between the two
estuaries. However there were significant differences in
dissolved oxygen, pH and total organic carbon between
the two estuaries (P<0.05).

The concentration of all the metals was on the
higher side in the Uppanar estuary (Fe -21395.2
±1201.36 mg/kg, Mn -252.502±5.21 mg/kg, Cu –
22.2±0.83 mg/kg, Ni – 18.2±0.44 mg/kg, Co – 7±0.7
mg/kg, Pb – 29.8±2.04 mg/kg, Zn – 81.2±6.22 mg/kg
and Hg – 1.6±0.54 mg/kg) compared to Vellar (Fe -
19618±823.17 mg/kg, Mn -52.4±4.44 mg/kg, Cu -
7.6±1.14 mg/kg, Ni – 5.2±0.83 mg/kg, Co – 3.6±0.54
mg/kg, Pb – 4.6±0.54 mg/kg and Zn – 27.4±1.81
mg/kg). The ‘t’ test showed significantly higher levels
of heavy metals in Uppanar than in Vellar (<0.01).

As many as 55 species of polychaetes were
identified during the present study. Number of species
recorded in Vellar estuary was 52 and in Uppanar
estuary only 14 species were recorded. Species
decreased from the mouth towards the upstream
stations of the estuary (26 (V1) - 3 (U5). Above trend
was noticed with respect to abundance also (from 44
ind./ 0.0251 m² at V1 to 28 ind./ 0.0251 m² at V5). Among the 14 species of polychaetes recorded in the
Uppanar estuary, Prionospio cirrobranchiata was
dominant and constituted about 84.21% of the total
number of polychaetes collected. In Vellar estuary
Magelona cincta (6.77), Chaetopterus sp. (6.21%) and
Armandia sp. (5.64%) were more abundant. In this
estuary Prionospio cirrobranchiata was recorded only
at V4 forming 0.3% of the total.

Diversity indices also showed a similar trend
(Table 1). Higher values of diversity (H’log2- 4.056-
4.572), richness (d-4.984-6.606), evenness (J’ 0.954-
0.973) and total phylogenetic diversity (1600-2267)
were observed in Vellar estuary (mean values were
4.264±0.21, 5.782±0.65, 0.965 and 1906±264.99
respectively). However in Uppanar estuary, these
values were very low (H’log2-0.547-1.260, d-0.582-
1.594, J’-0.345-0.487 and 300 - 567 with mean of
H’log2-0.941±0.27, d-1.129±0.42, J’-0.417±0.05 and
433.4±102.84 respectively). Simpson dominance index
(Lambda) was low in Vellar (0.023-0.034 with mean of
0.029±0.004) and high in Uppanar (0.604-0.815 with
mean of 0.700±0.07).

The V statistic was employed to compare the
observed diversity (H’) with that predicted from the
neutral model (E[H’]) (Table 1). The values showed
that the observed diversity was more than (positive)
that of theoretical in Vellar (varied from +0.453 to +
2.134 with mean of 1.103±0.90) and less(negative) in
Uppanar estuary (varied from -1.424 to – 3.433 with
mean of -2.408±0.96).
In MDS, while the stations sampled in Vellar lie on the right hand side, the stations from Uppanar are on the left hand side. Wide gap (distance) between the stations sampled in the two estuaries showed the wide variations in polychaete assemblage (Fig. 2). Stress value of 0.01 indicated the goodness of the fit.

The one hundred and seventy seven polychaete specimens collected from Vellar estuary were assigned to various groups in AMBI. After assignment, 86 specimens (48.58% of the total) were in EG I, 66 (37.28%) in EG II, 10 (5.64%) in EG III, 14 (8%) in EG IV and 1 (0.56%) in EG V. AMBI values varied between 0.784 (V1) and 1.189 (V4-Rhizophora zone) (Table 2). Trend was opposite in M-AMBI values which varied from 0.846 (V4-Rhizophora zone) to 0.999 (mouth region) (Fig. 3). AMBI (BI) and M-AMBI values showed the undisturbed nature and high ecological status of all the stations here (Tables 2). The abundance of polychaete (35±6) was similar to Uppanar. But the number of species was very high (21±3).

One hundred and fifty two polychaetes specimens collected from the Uppanar estuary were assigned to various ecological groups. After assignment, 1 specimen (0.65% of the total) was in EG I, 7 (4.6%) in EG III, 136 (89.47%) in EG IV, and 8 (5.26%) in EG V. In this estuary, AMBI values ranged from 4.222 (U 1) to 4.596 (U 5). According to these values, one station (U1 - BI: 3) showed transitional to pollution and four stations (U2-U5, BI: 4) were found to be polluted (Table 2). The M-AMBI results also explained poor ecological status of the Uppanar estuary very clearly. It varied from 0.168 (U5) to 0.272 (U1). Based on the M-AMBI values, station U5 was in bad condition and other stations (U1-U4) in poor condition (Fig. 3 and Table 2).

Table 1— Diversity indices of infaunal polychaetes of Uppanar and Vellar estuaries

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>N</th>
<th>d</th>
<th>J'</th>
<th>H'(log2)</th>
<th>Lambda'</th>
<th>Delta</th>
<th>sPhi+</th>
<th>V(N.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>6</td>
<td>27</td>
<td>1.517</td>
<td>0.433</td>
<td>1.121</td>
<td>0.658</td>
<td>34.093</td>
<td>567</td>
<td>-3.433</td>
</tr>
<tr>
<td>U2</td>
<td>6</td>
<td>23</td>
<td>1.594</td>
<td>0.487</td>
<td>1.260</td>
<td>0.604</td>
<td>34.519</td>
<td>500</td>
<td>-3.393</td>
</tr>
<tr>
<td>U3</td>
<td>5</td>
<td>39</td>
<td>1.091</td>
<td>0.393</td>
<td>0.914</td>
<td>0.715</td>
<td>22.447</td>
<td>400</td>
<td>-2.210</td>
</tr>
<tr>
<td>U4</td>
<td>4</td>
<td>32</td>
<td>0.865</td>
<td>0.431</td>
<td>0.863</td>
<td>0.711</td>
<td>28.830</td>
<td>400</td>
<td>-1.581</td>
</tr>
<tr>
<td>U5</td>
<td>3</td>
<td>31</td>
<td>0.582</td>
<td>0.345</td>
<td>0.547</td>
<td>0.815</td>
<td>18.494</td>
<td>300</td>
<td>-1.424</td>
</tr>
<tr>
<td>V1</td>
<td>26</td>
<td>44</td>
<td>6.606</td>
<td>0.972</td>
<td>4.572</td>
<td>0.023</td>
<td>96.828</td>
<td>2267</td>
<td>1.944</td>
</tr>
<tr>
<td>V2</td>
<td>24</td>
<td>39</td>
<td>6.278</td>
<td>0.959</td>
<td>4.4</td>
<td>0.028</td>
<td>95.906</td>
<td>2067</td>
<td>0.916</td>
</tr>
<tr>
<td>V3</td>
<td>19</td>
<td>37</td>
<td>4.984</td>
<td>0.973</td>
<td>4.134</td>
<td>0.034</td>
<td>94.994</td>
<td>1600</td>
<td>2.133</td>
</tr>
<tr>
<td>V4</td>
<td>20</td>
<td>29</td>
<td>5.642</td>
<td>0.962</td>
<td>4.159</td>
<td>0.029</td>
<td>96.387</td>
<td>1867</td>
<td>0.452</td>
</tr>
<tr>
<td>V5</td>
<td>19</td>
<td>28</td>
<td>5.401</td>
<td>0.954</td>
<td>4.056</td>
<td>0.034</td>
<td>95.943</td>
<td>1733</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Fig. 2— MDS of infaunal polychaetes collected from various stations of Uppanar and Vellar estuaries

Fig. 3— Factor wise M-AMBI values indicating the ecological status for the stations sampled in Uppanar and Vellar estuaries
Almost all the stations showed impairment, with the predominance of the *Prionospio cirrobranchiata* (Ecological group IV - opportunistic species) in the Uppanar estuary. It is important to highlight that the abundance was high (30±6/0.0251 m$^2$) even though number of species was very low (4±1) in this estuary. Comparatively low AMBI (1) and high M-AMBI (0.272) values were recorded in the mouth where the estuary is joining the Bay of Bengal. High AMBI (4.5) and low M-AMBI (0.168- 0.264) values were observed in stations U3-U5 where the discharge of industrial effluent was frequent (Tables 2). Silty clay soil, low pH and low dissolved oxygen were the characteristic features of these stations.

### Discussion

Soft bottom benthic communities, specifically, polychaetes are considered as good indicators of environmental quality because they are the most abundant and species-rich component among the marine benthic organisms, often comprising more than one-third of the total number of macrobenthic species. Results of the present study based on the latest tools which are used extensively in the European and American waters in relation to Water Framework Directives indicated high level of disturbance in the Uppanar estuary. These tools take into consideration the sensitivity of each and every species to disturbance. That way these are more efficient.
Principal Coordinate Analysis was done (Fig.4) in the present study to visualize patterns in response to the whole set of variables. The first two axes combinedly explained 97.1% (first axis-88.9% and second axis-8.2%) of the variability. While axis 1 separated the two estuaries (Vellar estuary on the right hand side and Uppanar estuary on the left hand side), axis 2 separated the stations sampled in each estuary. Higher values of salinity, temperature, Toc, Co, Cu, Ni, Pb, Fe, Zn, Mn and Hg were found in the Uppanar estuary (vectors represent only Fe, Zn, Mn and Hg in the Uppanar to avoid cluttering) and higher values of oxygen and pH in the Vellar estuary (vector represent only oxygen).

In the present study (U1-U5), Uppanar estuary showed less diversity. In Mumbai Port, also low diversity to moderate diversity (0.06-2.6) was reported due to environmental deterioration25. Quadros et al.26 also reported low diversity in the anthropogenically stressed tropical creek of Thane (H': 0.4 to 1.5 and d: 0.4 to 1.1) indicating poor quality.

Number of species (21±3), species richness (5.782±0.65), diversity (4.264±0.21) and total phylogenetic diversity (1906±264.99) were all high in Vellar estuary (V1-V5) having artificially developed mangroves and situated close to the Pitchavaram mangroves5 & 27. In a healthy environment, the Shannon diversity is higher in the range of 3-4 28. Average Shannon diversity value of 3.21 has been reported from the marine zone of Vellar estuary earlier 27.

The use of AMBI and M-AMBI has significant advantages viz., they permit visualization of both spatial and temporal gradients 29, no need to have reference sites in the area under study 30 and not getting affected by sampling effort 31. In the Uppanar estuary, high AMBI values were recorded in all the stations due to impairment arising out of discharges from industries and municipality (U1-U5). These results agree with those of diversity indices and MDS. In this estuary, anthropogenic stressors from Cuddalore urban area in addition to those from industries produce an organic enrichment which in turn induces changes in the structure of macrobenthic communities. These changes got reflected in the AMBI (BI) and M-AMBI values which corresponded to the disturbed nature of the environment (transitional to pollution to higher level of pollution & poor to bad condition). The opportunistic species which belong to groups IV (Prionospio cirrobranchiata and Cirratulus sp.) and V (Capitella capitata) of AMBI are capable of proliferating in reduced sediments. Species from these groups can also tolerate toxic conditions32. In South American Atlantic region, the highest AMBI value (AMBI = 5.2; BI = 5) showed the dominance by the first order opportunistic polychaete Ficopomatus enigmaticus and by second-order opportunistic species such as Heteromastus similis and Heleobia australis33.

The polychaetes community of Vellar estuary belonged to groups of high ecological quality. In this estuary, higher oxygen level, high percentage of sand and lower organic content in the sediments, presented a healthy environment for the predominance of species of the Ecological groups I (Armandia sp., Chaetopterus sp., Diapatura neapolitana, Euclymene annandalei, Magelona cincta, Pectinaria sp. and Poecilochaetus serpens) and II (Polynoe sp.). Sousa et al. 34 (2007) reported high nutrient concentrations and high levels of some metallic elements in more sensitive areas subjected to eutrophication and harbor activity. In such areas high densities of the opportunistic species Capitella capitata were also observed. Dias et al.1 also stated that all the impacted sites revealed higher AMBI and lower M-AMBI values. The Vellar estuary showed lower AMBI and higher M-AMBI values. In the Uppanar estuary, the reverse was the case. Present study which used many biotic tools including the latest AMBI has clearly brought out the disturbed nature of the Uppanar estuary. As more number of industries is coming up in the vicinity, effective strategies have to be evolved for balanced development and ecological upkeep of the estuaries and nearby coastal waters.

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References


