Estuaries of India – their environmental status and management strategies

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India has a coastline of over 8000 km long infringed with several rivers draining a total catchment of 3.02×10^6 km^2 and their estuaries have a water-spread area of 2.7×10^4 km^2. There are 14 major, 44 medium and 162 minor rivers which together discharge 1.56×10^{12} m^3 runoff every year greatly influencing ecology of their estuaries and coastal areas to which they drain. These estuaries with their wetlands, lagoons, mangroves and sea-grass beds are rich in natural resources including fisheries. They also offer tremendous potential for recreation, aquaculture, extraction of freshwater and transport, and play a dominant role in the economy of coastal population. These very areas are the recipients of liquid and solid wastes emanating from domestic and industrial sectors apart from rampant reclamation of their intertidal segments to provide additional spaces for coastal developments. Over 300 million people living in the coastal zone of India are considered to generate 1.11×10^{10} m^3 of sewage annually, a considerable fraction; particularly from coastal cities and towns where sewage collection network exists, is released in estuaries and creeks. Large and medium industries within the narrow coastal belt of 25 km width of India are estimated to generate roughly 1.35×10^6 m^3 d^{-1} of liquid effluents and about 34,500 t d^{-1} of solid waste. Much of the liquid effluents are released to estuaries and creeks while the solid waste is generally stored in unsecured dump-sites and leachates which can be toxic, enter nearby aquatic areas via runoff during monsoon.

In the coastal zone of India estuaries and other inshore zones are the preferred destinations for developments, may it be an industry, urban settlement or a port. However, with economy often overriding environment, a good deal of such developments takes place without comprehensive scientific studies to assess probable impacts of a development on the aquatic ecology. In the absence of reliable information, the environment management plans to minimize ecological damage are inadequate and when available, the enforcement is weak. The Environmental Impact Assessment (EIA) Notifications of 1994 and 2006 make it mandatory to obtain prior approval of the competent authority for most developments in the coastal zone for which an EIA report is the primary requirement. Such reports tend to assess impacts of a particular activity on aquatic ecology in isolation without giving sufficient consideration to cumulative impacts of developments already existing in the area. Thus, with near absence of basin-level planning, regional EIAs and integrated management strategies, the estuaries are often overloaded with wastes or constructions that modify their dynamics, leading to environmental degradation. However, scientific studies in most estuaries of India to quantify the nature and extent of damage due to anthropogenic activities are far inadequate and sporadic and the assessment based on the available information can be at the most tentative.

Estuaries of the Indian subcontinent come under profound influence of monsoons and on occasions of heavy downpour in the catchment are effectively flushed of contaminants accumulated in the system over the dry period when many of them receive meagre river discharge. There are instances of occurrence of freshwater during monsoonal floods even

in estuaries such as Narmada and Tapi, which normally experience high tidal influence with spring range in excess of 5 m. Because of this efficient natural cleansing the degradation in their quality is cyclic. A chance find of freshwater in the polluted Mahim Bay (Mumbai) subsequent to high freshwater discharge through the Mahim estuary lead to unprecedented public frenzy with the belief that seawater had miraculously transformed to freshwater with thousands taking bath and even feeding infants with the 'miracle water'.

Due to wide difference in temporal freshwater inflow in most estuaries over the annual cycle, the environmental status of those receiving wastes vary from season to season with no detectable degradation in monsoon and high deterioration in summer particularly in inner segments where flushing rate decreases substantially due to meagre freshwater inflow and weak tidal influence. Sabarmati, Mahi, Tapi, Mindola, Purna, Par, Ambika, Auranga, Kolak, Damanganga, Ulhas, Mahim, Savitri, Kundalika, Vashisti, Ashatmudi and Ennore estuaries and Kochi Backwaters which receive domestic and/or industrial effluents in their weak tidal zone are some such examples. Excess organic loading, often associated with the release of untreated or partially treated domestic effluents, is largely responsible for this degradation. Their waters are frequently characterized by high and tide dependant levels of PO_4^{3-}-P and NH_4^+-N, variable DO falling to zero at low tides in some instances and high and tide-dependant populations of pathogens. In some instance, the contaminated low salinity water from the interior zone draining into the outer estuary during low tide, leads to distinct vertical stratification with the surface, less saline water having low DO, low pH, high PO_4^{3-}-P and low NO_3^--N. The concentrations of NO_3^--N and NO_2^--N decrease, while that of NH_4^+-N substantially increases when DO is depleted. Occurrence of sulphide has also been reported in a few cases.

In the absence of sufficient quality-controlled data on dissolved trace constituents such as heavy metals, pesticides and hydrocarbons, the environmental status of our estuaries with respect to these contaminants remains uncertain. The available data however indicate concentrations close to expected baseline. The estuarine sediments which are reliable indicators of trace pollutants appear to be free from anthropogenic heavy metals though the assessment is complicated due bed transport and changes in sediment character due to seasonal detritus load of inland origin associated with the monsoonal runoff settling within the estuary. A few localised estuarine sediments however have been reported to have accumulated heavy metals. Some examples are: Cr and Hg in Par estuary, Cr, Cu, Zn, Pb, Cd and Hg in Ulhas estuary and Hg in Rushikulya estuary. Hg concentrations of 60 $\mu g\ g^{-1}$ have been reported in the sediments of the interior Ulhas estuary which progressively decrease in the seaward direction and attain baseline (0.1 $\mu g\ g^{-1}$) several kilometres off in the sea. The sediment of the Ulhas estuary has been estimated to have burdened with 30.3 t of anthropogenic Hg released through the effluent of chlor-alkali industries over the years. However, there is no bioaccumulation of Hg in *Crasostrea cuculata* as much of the sediment-bound Hg is probably not bio-available.

In addition to contamination due to point sources, threat to ecology due to diffused pollution particularly due to runoff from fertilized agricultural areas is of considerable concern. But very little information is available on their influence on ecology of Indian estuaries. Excess loading of nutrients on rivers and estuaries have caused severe ecological changes resulting in significant economic losses elsewhere in the world.

Because systematic, long-term investigations of biogeochemical cycles are lacking, it is difficult to evaluate to what extent the inflow of agricultural nutrients have affected our estuarine and coastal ecology. There are indications of anthropogenic inputs manifesting in the nitrogen cycle of the western shelf of India with a shift from seasonally low-DO conditions to suboxic and even anoxic conditions with enormous accumulation of N_2O in the DO-deficient zone. This ecosystem shift is probably a consequence of increase in land-derived fluxes of nutrients.

The important requirements to manage our estuaries in a professional and integrated manner are generation of long-term and systematically collected data to explain, with a certain level of confidence, their dynamics and ecology and use the emerging results in planning developments within their assimilative capacity keeping stakeholders informed. The task, if to be achieved to a level to be useful in integrated management, will require long-term commitment of resources in terms of finances and manpower since reliable information on basic parameters such as bathymetry, tides and river discharge – vital for numerical modelling, is lacking for majority of estuaries.