

MIXING IN VISAKHAPATNAM HARBOUR AND NUTRIENT INPUTS TO THE NEARSHORE WATERS, EAST COAST OF INDIA

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ABSTRACT

The flushing time (t) and replacement time (T) are computed for different seasons to understand mixing in Visakhapatnam harbour. Replacement times are higher than the flushing times indicating that the transverse mixing in the tidal flow in the Visakhapatnam harbour probably occurs relatively slow. The distribution curves for saline water fraction and nonconservative nutrient (phosphate) concentration in different seasons are also presented. The nutrient inputs from the Visakhapatnam harbour to nearshore waters are highest during southwest monsoon and lowest in post monsoon season.

Key - words: Mixing, Visakhapatnam harbour, nutrients.

Visakhapatnam harbour (Fig.1) extends 4 km from the northwestern arm to the outer harbour and is connected to open sea through the entrance channel. Industrial effluents enter into the harbour through western and northwestern arms and domestic sewage joins the harbour through the south lighter canal at the turning basin. Knowledge of the natural mixing characteristics of the harbour waters is essential for study of the environmental problems such as dispersion of a chemical or biological pollutant.

Studies on pollution in the Visakhapatnam harbour waters were initiated recently. The nature of the pollutants discharged and the main hydrographic features have been described earlier (Ganapati and Raman,1973). Deterioration of water quality in the Visakhapatnam harbour due to pollution (Ganapati and Raman,1979; Raman and Ganapati,1986) and tidal variations of physico-chemical characteristics and the net discharge of pollutants through the harbour mouth (Rama Raju, Sarma, Narasimha Rao and Vijaya Kumar, 1987) have been reported. This paper presents computed values of flushing time (t), replacement time (T) and nutrient inputs from the Visakhapatnam harbour into the coastal waters.

Water samples were collected at monthly intervals from stations A (Northwestern arm), B (Turning basin), C (Inner harbour) and D (Entrance channel) along the main channel of the harbour (Fig.1). Surface samples were collected with plastic bucket and bottom (10 to 15m) samples with Niskin bottles. Collections were

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made at two hourly intervals over a tidal cycle once in a month from February 1982 to January 1983. Standard analytical methods (Anonymous, 1975) were used for the determination of salinity, nitrite, nitrate, phosphate and silicate.

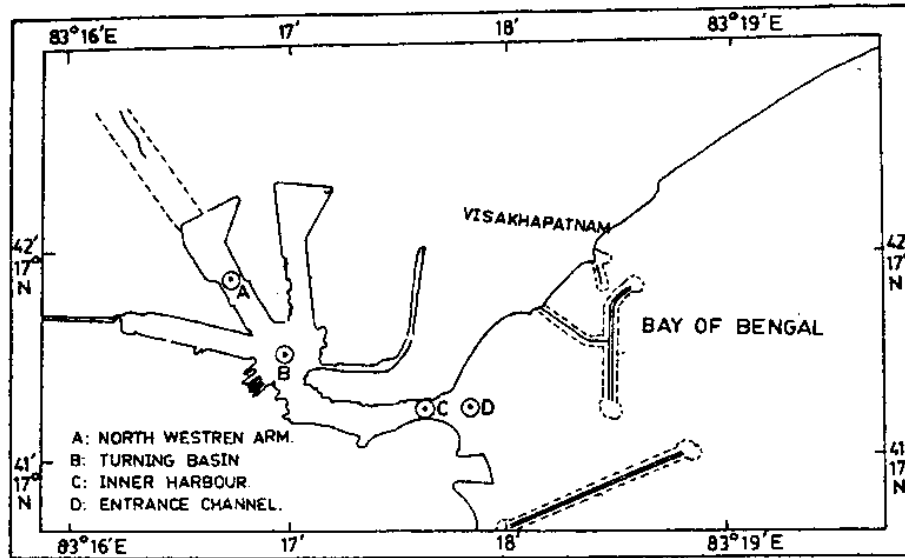


Fig.1. Station location map showing A-Northwestern arm; B-turning basin; C-inner harbour and D-entrance channel

Flushing time (t) is defined as the mean time that a particle of tracer remains inside an estuary. The flushing time is usually determined in terms of 'freshness' using the formula

$$F = (S_0 - S)/S$$

where F is the freshness, S_0 is the salinity of coastal water and S is the salinity of the estuarine water. However, in the Visakhapatnam harbour, since the salinity difference between the harbour water and coastal waters is not marked (Sarma, Raju and Bose Babu, 1982; Rama Raju, Sarma, Narasimha Rao and Vijaya Kumar, 1987), the concept of Ketchum (1955) utilising the distribution of a nonconservative nutrient has been utilised to calculate the flushing time (t). Phosphate, a nonconservative nutrient, which showed marked variations in its concentration has been used for calculating the average fractional phosphate input (f) by the formula

$$\bar{f} = (P_H - P_S)/P_H$$

where P_H and P_S are the average concentrations of phosphate within the harbour and adjoining coastal waters respectively. The flushing time (t) is calculated from equation $t = \bar{f} (V/R)$ where V is the total volume of the harbour water ($5.6 \times 10^6 \text{ m}^3$) and R is the rate of net cross sectional discharge into the sea over a tidal cycle. The values of R have been evaluated by Rama Raju, Sarma, Narasimha Rao and Vijaya Kumar (1987) as per the procedure given by Kjerfve (1979) from the current observations during different tidal cycles. The current speed at the mouth of the harbour varies between 10 and 25 cm sec^{-1} in ebb tide and 9 and 28 cm sec^{-1} during flood tide.

The replacement time (T) is defined as the time required for a slug of material initially concentrated at one end of an estuary to reach approximately uniform concentration throughout the estuary (Fischer, List, Robert, Imberger and Norman, 1979). This is given by $T = 0.4L^2 / K$, where L is the length of the estuary and K is the dispersion coefficient along it. The length of Visakhapatnam harbour is 4 km from the source point to the open sea; the calculations of flushing times and replacement times have been made by considering it as a single segment. The value of K depends on many factors such as average current speed, irregularities in the shape of the channel, variations in the topography of the channel. It makes little sense to try for too high accuracy in predicting dispersion coefficients in real streams. But an order of magnitude is useful in arriving at replacement time. For calculation of K, the net cross sectional velocity for a tidal cycle through the mouth of the harbour has been computed by dividing the net cross sectional discharges (R) with the cross sectional area at the mouth of the harbour i.e. 2750 m². The longitudinal displacement in a tidal cycle during different seasons has been obtained by multiplying the net cross sectional speed with the duration of an average tidal cycle (12.8 hrs).

Table I. Mixing parameters for Visakhapatnam harbour

Season	Net cross sectional discharge (R)m ³ sec ⁻¹	Longitudinal dispersion coefficient (K) m ² sec ⁻¹	Flushing time (hrs) t=f V/R	Replacement time (hrs) T=0.4L ² /K
Premonsoon	26.51	15.4	46	115
Southwest monsoon	47.30	27.5	28	64
Postmonsoon	19.64	11.4	70	155

The longitudinal dispersion coefficient K is then calculated assuming that the area of spread of a nonconservative effluent in a tidal cycle will be nearly half of the area covered by the slug moving at the net cross sectional velocity. Thus the K values are obtained by multiplying the cross sectional width by half the net cross sectional velocity.

The calculated values of flushing time (t) and replacement time (T) in different seasons are given in Table I. The values indicate that the postmonsoon season experienced maximum flushing time of 70 hours and the southwest monsoon season lowest flushing time of 28 hours with an intermediate flushing times of 46 hours for premonsoon season. Relatively high flushing times in the post and premonsoon seasons compared to the southwest monsoon flushing time indicate considerable reduction of the exchange of waters in and out of harbour in the post and premonsoon seasons. The flushing times in different seasons have been

calculated assuming well mixed condition, but in reality it may not be so. These values of t are expected to be lower than the real values because of the fact that part of the pollutant water will return on each successive flood into the harbour.

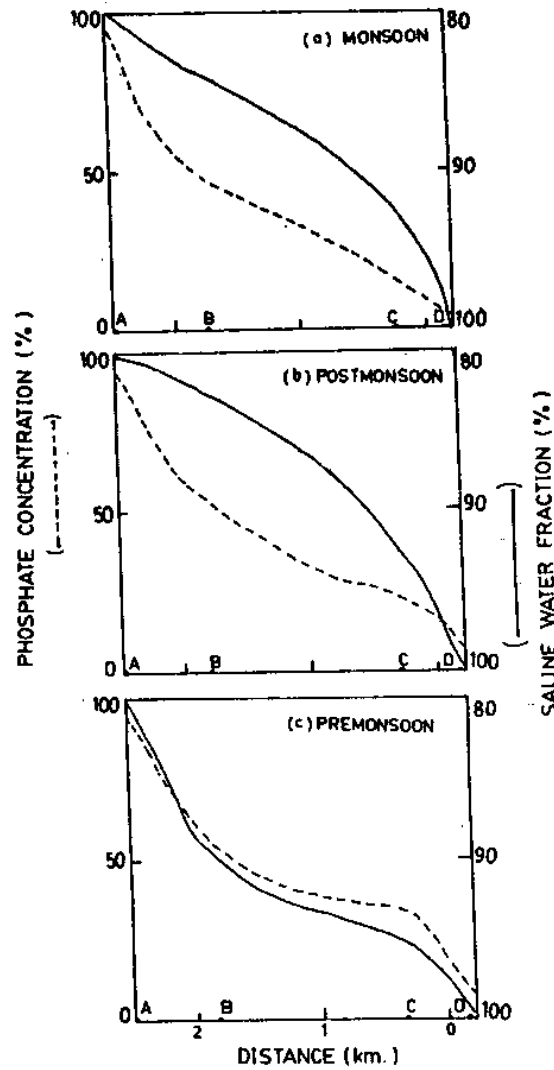


Fig.2. Distribution of phosphate (%) and saline water fraction (%) with distance

Table II. Estimated input of nutrients from harbour (tons day^{-1}) into the coastal waters

Season	Nitrate	Phosphate	Silicate
Premonsoon	4.67	1.67	2.05
Southwest monsoon	5.85	2.19	4.42
Post monsoon	3.14	1.14	1.93

It is evident that the replacement times (T) are more than the flushing times (t) indicating that the transverse mixing in the tidal flow through the Visakhapatnam harbour probably occurs relatively slow and hence transverse concentration gradients persist. With this simple analysis we infer that within the harbour region extending approximately 4 km from the nutrient loading point appreciable transverse concentration gradients might prevail.

Mixing: In an estuary, since the distribution of a conservative parameter or pollutant varies with distance from the source in the same manner as the distribution of fresh water fraction, we can determine the concentration of pollutant from salinity distribution (Charles, 1976). In the present study, an attempt has been made to understand the mixing in Visakhapatnam harbour through the distribution of salinity (Saline water fraction) and nutrient concentration. Fig.2 represents the variation of saline water fraction and phosphate concentration (expressed in percentage) with distance from the mouth of the harbour. The distribution of nonconservative nutrient i.e. phosphate in the harbour follows the distribution of saline water fraction during the premonsoon (Fig.2 c) and is inversely related. Further the similarity of the two curves (Fig. 2 c) imply that the ratio of dp/dx to ds/dx from the source point is the same throughout the harbour channel in premonsoon season. Thus the changes of the individual parameters along the length of channel bear the same ratio to one another in premonsoon season. But this is not the case with the other two seasons (SW and post SW monsoon seasons) probably because mixing in the harbour results from a continuation of small scale turbulent diffusion and large scale variation of the field of advective mean velocities. The dissimilarities in the curves (Fig. 2a & b) may also be explained as due to the variations in external inputs from the industrial discharges from increased surface run-off during postmonsoon and southwest monsoon seasons.

Nutrient Inputs: From the net cross sectional discharges over a tidal cycle (R) through the mouth of the harbour and the concentrations of the nutrients, the average quantities of various nutrients discharged in the nearshore waters are calculated and the data is presented in Table II. The estimated inputs of the nutrients showed higher values in the southwest monsoon season and lower values in postmonsoon season. The concentrations of nutrients in the nearshore waters of Visakhapatnam (Sarma, Narasimha Rao, Rama Raju, Vijaya Kumar and Suguna, 1988) are relatively low compared to the harbour waters showing rapid mixing within a few kilometers from the harbour mouth. Thus the impact of nutrient input from the urban and industrial waters discharged through the harbour channel into the nearshore waters does not appear to be alarming at present.

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