

## PHYSICAL CHARACTERISTICS OF THE COASTAL WATERS BETWEEN NAVAPUR AND UMBHARAT, WEST COAST OF INDIA — PART III: STABILITY AND DISPERSION

G. NARAYANA SWAMY AND C. V. VIJAYAKUMAR \*

*National Institute of Oceanography, Dona Paula, Goa-403 004.*

### ABSTRACT

Vertical profiles of currents of the coastal waters between Navapur and Umbharat were analysed. Dynamic stability as well as the diffusion capacity of the water columns were estimated from the vertical distribution of temperature, salinity and current. Considering the physical behaviour, the coastal waters of this highly industrialised region were found to possess high instantaneous dilution capacity. However the spatial and temporal variability of the parameters calls for better understanding of the environment for long-term effluent disposal schemes.

*Key words:* Physical characteristics, coastal waters, vertical profile, dispersion, diffusion, stability.

### INTRODUCTION

Most of the factories situated along the Maharashtra-Gujarat Industrial Belt make use of the streams and rivers in the vicinity for the disposal of their effluents. Only a few industrial complexes discharge the effluents into the water bodies after systematic studies of the environment. But the possibility of exponential growth of industries based on Bombay High natural gas, warrants better management of the environment. This paper is intended to form a general study of the physical characteristics of these coastal waters with reference to pollutant dispersion. The circulation pattern and the distribution of temperature and salinity in this region have been described by Swamy, Sarma and Suryanarayana (1982) and Swamy and Sarma (1982), respectively.

Effluent mixing characteristics of a water body depend on the static and dynamic properties of the water column. However, considering the variability of oceanographic parameters in the coastal waters, it is considered to be more pragmatic to describe the mixing characteristics in terms of the dynamic properties coupled with the static properties. Thus the current distribution and the dynamic stability factors along with the eddy diffusion become the key to the understanding of the physical behaviour of pollutants in the coastal waters. This paper analyses these dynamic parameters and hints at the pollutant dispersion capacity of the water body under study.

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\* Regional Centre of National Institute of Oceanography, Sea Shell Building, Seven Bungalows, Versova, Bombay-400 061.

## METHOD OF STUDY

The general features of the area under study have been described by Swamy, Sarma and Suryanarayana (1982). In all, five stations viz., Navapur, Daman, Umbhergaon, Tithal and Umbharat were considered for diffusion estimates. The data from a representative station viz., Tithal was considered for the computation of the vertical profile of the currents, and the stability of the water columns.

Using the temperature and salinity data and the simultaneous current values, the dynamic stability factor defined by the Richardson Number,

$$Ri = \frac{N^2}{\left| \frac{\partial u}{\partial z} \right|^2}$$

was calculated for every hour over a tidal cycle (Fig. 1).

Here,

$$N^2 = \frac{g}{\bar{\rho}} \left[ \frac{\rho - \rho'}{z - z'} \right]$$

$\rho$  = Density of water at depth  $z$

$\rho'$  = Density of water at depth  $z'$

$\bar{\rho}$  = Mean density of the water column

$g$  = Acceleration due to gravity

$u$  = Current speed.

The vertical current profile at the station off Tithal was elicited by plotting the dimensionless parameters  $\log \bar{U}/\bar{U}_0$  versus  $\log z/H$ , where  $\bar{U}_0$  is the tidal average of the surface current,  $\bar{U}$  is the corresponding value at a given depth,  $H$  is the total depth of the water column and  $z$  the depth of observation reckoned positive upward from the bottom (Fig. 2). Tidal averaging was resorted to, since the vertical distribution varied drastically during the tidal march. The curve in Fig. 2 was fit by linear regression. Average of the depth mean velocity, mean water depth, tidal current average, maximum depth mean velocity, and maximum current at the surface, mid-depth and near-bottom levels were also calculated (Table I).

It was assumed that the vertical mixing time is small (of the order of 1 hr) compared to the tidal periods. For values giving the vertical mixing time much less than the tidal period the vertical shear process described by Bowden (1965) would be dominant. Hence the model for the computation of the longitudinal mixing coefficient suggested by Talbot and Talbot (1974), incorporating the depth mean velocity over a tidal cycle was used (Table II). However the averaging of the current speed was carried out irrespective of the directionality of the current vector, for the sake of comparison of the relative mixing potential of various stations.

## RESULTS AND DISCUSSION

*Stability of water column*

The dynamic stability factor defined by the Richardson Number ( $R_i$ ) computed for the representative station Tithal, varied over a wide range between positive

Table I. Current averages and extremes (cm s<sup>-1</sup>) in the coastal waters between Navapur and Umbharat.

Station	Date	$\bar{U}_o$	$\bar{U}_m$	$\bar{U}_b$	$\bar{U}$	$\bar{U}_d$	$\bar{U}_{dm}$	U	U'	U''
Daman	29.6.78	53.1	43.8	40.8	45.4	46.9	73.3	80	80	60
Navapur	21.8.78	105.0	102.8	99.0	104.6	102.1	162.0	160	160	160
Umbergaon	10.11.78	67.2	66.9		59.1	66.2	120.3	125	120	116
					70.4					
Umbergaon	13.12.78	89.5	86.0		55.0	85.7	119.0	130	125	138
					76.8					
Umbergaon	24.8.78	89.3	72.8	67.8	73.9	70.0	103.3	100	110	110
					64.8					
Umbharat	15.11.78	80.2	83.4	79.6	60.8	77.0	122.0	126	130	125
					83.1					
					93.7					
					75.6					
Tithal	1.4.78	50.6	50.2	42.3	40.2	48.0	83.3	90	90	80
					56.6					
					48.3					
					46.4					
Tithal	11.4.78	63.6	73.3	65.4	65.2	67.3	126.7	120	140	120
					50.1					
					62.0					
					82.0					
Tithal	17.4.78	32.5	36.0	29.8	22.5	31.1	50.0	60	50	50
					36.1					

$\bar{U}_o$  : Tidal Average at surface

$\bar{U}_{dm}$  : Maximum depth mean velocity

$\bar{U}_m$  : Tidal Average at middle depth

U, U', U'' : Maximum current at surface,

$\bar{U}_b$  : Tidal Average at bottom

middle & bottom respectively.

$\bar{U}_d$  : Average depth mean velocity over half a tidal cycle

$\bar{U}$  : Average depth mean velocity over a tidal cycle

Table II. Dispersion characteristics of the coastal waters between Navapur and Umbharat.

Station	Average Station Depth (m)	Date	Tide	Average Surface Current (cm s <sup>-1</sup> )	Horizontal Diffusion Coefficient (10 <sup>3</sup> cm <sup>2</sup> s <sup>-1</sup> )
Daman	15	29.6.78	N	53.1	624
Navapur	17	21.8.78	S	105.0	1506
Umbergaon	17	10.11.78	N	67.2	1145
Umbergaon	17	31.12.78	S	89.5	1133
Umbharat	16	24.8.78	S-N	79.3	897
Umbharat	16	15.11.78	N-S	80.2	1093
Tithal	10	1.4.78	S-N	50.6	452
Tithal	12	11.4.78	S	63.6	858
Tithal	12	17.4.78	N	32.5	1033

N — Neap, S-N — Spring to Neap, S — Spring, N-S — Neap to Spring

and negative values corresponding to perfect stability and complete instability respectively, through the value of zero corresponding to the neutral condition.

Various cases of the combined stability of the surface and bottom layers and their percentage frequency are given below: % frequency

- Case (a) : The entire water column stable throughout the depth ... 18
- Case (b) : The surface layers neutrally stable and the bottom layers stable ... 7

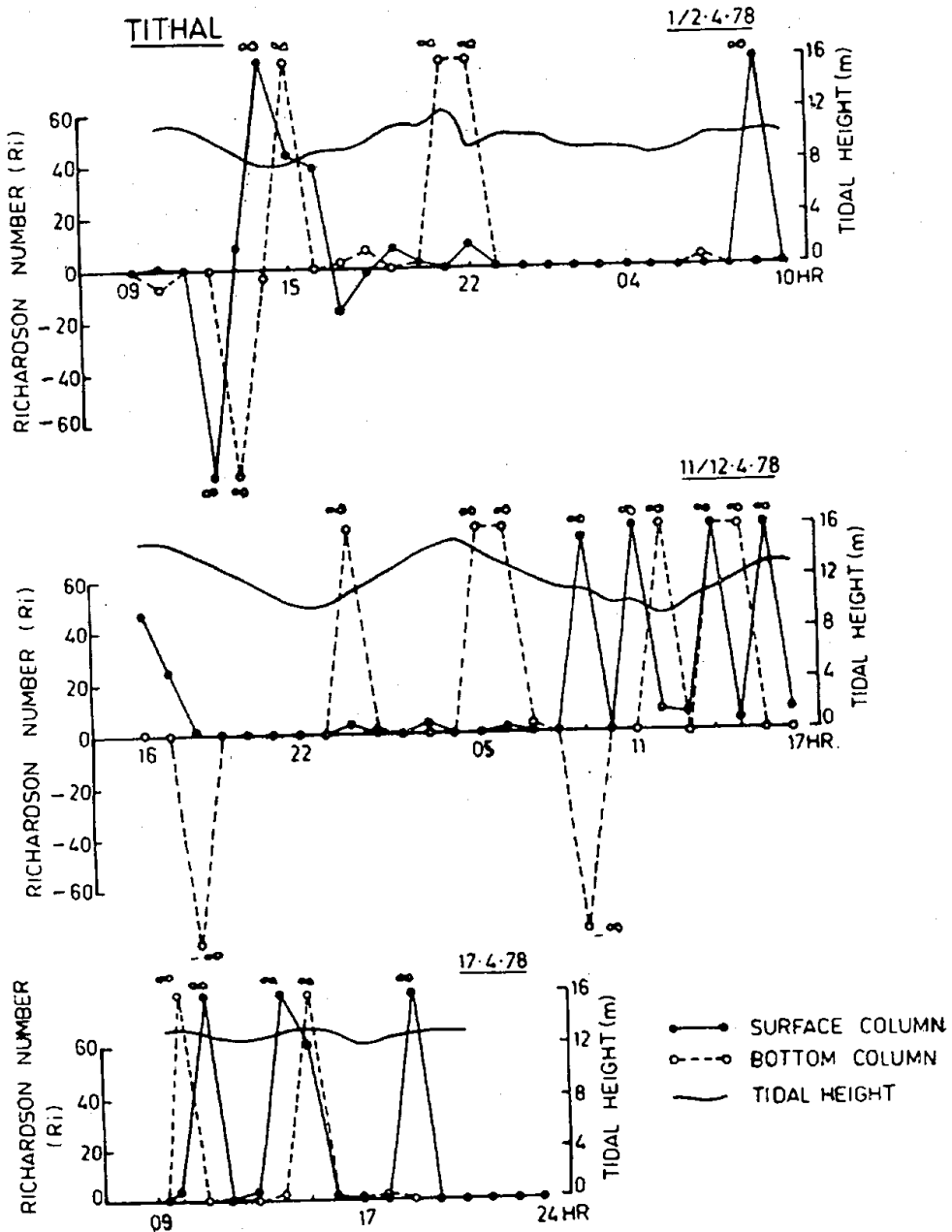


Fig. 1. Dynamic stability criteria.

Case (c) :	Unstable layers riding over stable waters	...	...	3
Case (d) :	The entire water column neutrally stable	...	...	43
Case (e) :	The surface layers in stable equilibrium and the bottom layers in neutral equilibrium	...	...	21
Case (f) :	The surface layers unstable and the bottom waters in neutral equilibrium	...	...	2
Case (g) :	The entire water column completely unstable	...	...	0
Case (h) :	The surface waters in stable equilibrium and the bottom waters in unstable equilibrium	...	...	4
Case (i) :	Neutral waters riding over unstable waters	...	...	3

The frequency of occurrence of these different cases during the present study, indicate that most of the time, the waters of this area are thoroughly mixed to produce a vertically homogeneous body (Case d). Rest of the time, mainly the stable surface layers ride over the neutral bottom layers (Case e), or the entire water column

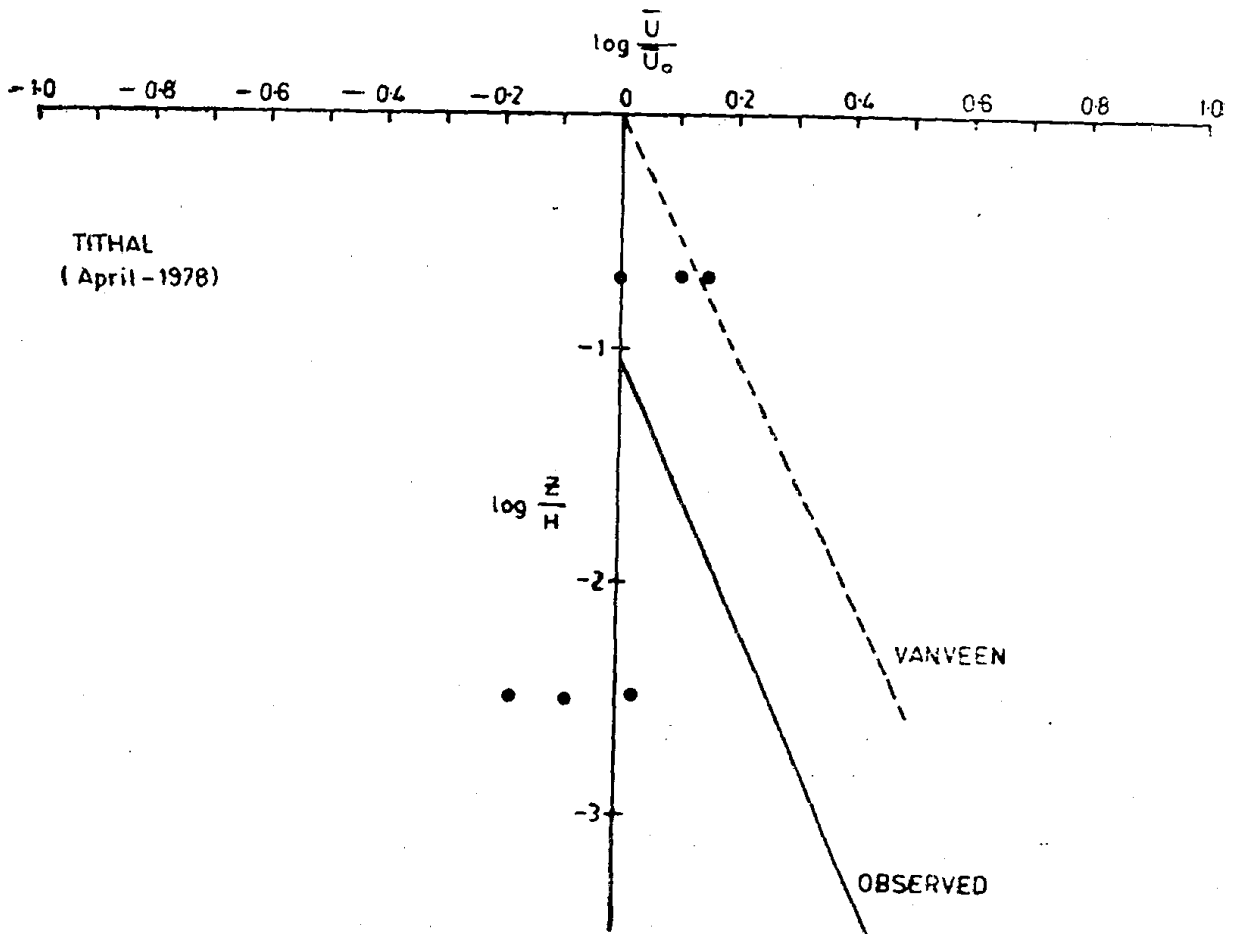


Fig. 2. Vertical profile of current speed.

is stable throughout the depth (Case a). These two cases are normally possible when partial or complete stratification is brought out by insolation or river influx. The last few cases were observed prior to or soon after the change in the tidal phase implying the tidal influence causing drastic imbalance in the water column.

It was also evident that the tide and the associated tidal currents influenced the stability of the water column. For example, the waters were found to be stable throughout the depth for a short while during the slack period associated with the changing phases of the tide. The water column was found to undergo considerable mix-up tending towards neutral stability, presumably due to higher current velocities occurring at mid-tides.

It can be seen from Fig. 1 that the waters were in neutral equilibrium most of the time indicating thorough vertical mixing. The layers were rarely unstable; and highly stratified events were not infrequent.

#### *Vertical profile of currents*

Vertical current profile plays a major role in effluent mixing in the coastal marine environment. Vertical distribution of the currents in all the five stations at different tidal stages has been described earlier (Swamy, Sarma and Suryanarayana, 1982). The essential feature was that the current velocity systematically varied at different levels during the tidal march (Table I).

The plot  $\log \bar{U}/\bar{U}_0$  vs.  $\log z/H$  in Fig. 2 reveals that the slope of the curve corresponds fairly well with the empirical fit suggested by van Veen (Swamy, 1980). However a y-intercept was noticed. This could be due to the observation error in either the surface current or the water depth, resulting in a constant shift of the straight line fit from that of van Veen. Besides, the disturbance caused by the wind, waves, and the eddies might have contributed to the minor deviation. Eventhough the slope of the curve was very close to that of van Veen, the regression coefficient was found to be only 0.5. However for practical purposes the vertical distribution of currents could be assumed to be van Veen in this area. The empirical relation obtained for these data was

$$\log \frac{\bar{U}}{\bar{U}_0} = \frac{1}{5.52} \log \left( \frac{z}{H} \right) - 1.04.$$

#### *Diffusion characteristics*

Table II indicates that the horizontal diffusivity is generally of the order of  $10^5$ - $10^6$   $\text{cm}^2 \text{s}^{-1}$  at all the stations considered. The values are remarkably high favouring efficient mixing of the effluent with the receiving body. However, the local and seasonal variability are pronounced.

These results lead to the following conclusions :

(i) The dynamic stability of the water column appears to be neutral most of the time in the highly changing physical environment in the area of study.

(ii) The vertical profile of the currents in the area approximate the van Veen distribution.

(iii) The coastal waters considered have high degree of dilution capacity arising out of the dynamics of the medium.

(iv) But the local variation in the circulation pattern and the related parameters have to be taken into account while planning major effluent disposal schemes of long-term nature.

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