



EDDY DIFFUSION COEFFICIENTS IN THE COASTAL WATERS OF NORTH ANDHRA PRADESH AND ORISSA

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Marine Environmental Impact Assessment (MEIA) studies help planning setting up of new industries along the coast. In dispersion studies under MEIA, eddy diffusion coefficients are used to understand the mixing of pollutants in the marine environment. Eddy diffusion coefficients (k_x , k_y , k_z) in the coastal waters are calculated using 2-D turbulent diffusion model, in six areas (I) - Mutyalammalem-Appikonda; (II) - Bhimili-Annavaram; (III) - off Mentada; (IV) - off Gopalpur; (V) - off Puri and (VI) - off Konark along the east coast in Andhra Pradesh and Orissa states. The values of k_x and k_y , in area (I) are comparable with those obtained from dye experiment, while they are one order higher in area II, compared to areas I & III. The mean values of k_x and k_y for the coastal waters of north Andhra are estimated as $4.04 \times 10^4 \text{ cm}^2/\text{sec}$ and $0.96 \times 10^4 \text{ cm}^2/\text{sec}$ respectively during winter season, while the values off Orissa coast are $2.79 \times 10^8 \text{ cm}^2/\text{sec}$ and $3.05 \times 10^6 \text{ cm}^2/\text{sec}$ respectively.

Introduction

Industrial development significantly contributes towards economic growth of the nation, but at the same time brings in environmental problems. Injudicious setting up an industry can seriously affect the environmental features such as air, water, land, flora, fauna, human settlements and health of people. Thus the entrepreneur should take necessary steps while setting up the industry to minimize the possible adverse effects on the environment. The Environmental Impact Assessment (EIA) is an useful aid for such decision making. The Regional Centre of National Institute of Oceanography at Visakhapatnam is actively engaged in EIA and pollution studies for the coastal industries along Andhra Coast and Visakhapatnam Harbour have been reported earlier (Satyanarayana et.al,1994, Sarma et.al,1996).

The Government of Andhra Pradesh declared Visakhapatnam Coast as *Special Economic Zone* and the land acquisition is in full swing. A pharma city is also proposed at Parawada. There is a possibility of rapid industrial growth along north Andhra Coast in future. Hence, the dispersion studies are desirable to understand the dispersal capacity of the coastal waters for environmental impact assessment. Such dispersion studies were more or less limited to the open ocean so far. Bahulayan and Varadachari (1985) reported the eddy diffusion coefficients k_y and k_z to have the values of $3.06 \times 10^8 \text{ cm}^2/\text{sec}$ and $0.054 \text{ cm}^2/\text{sec}$ respectively for the Equatorial Indian Ocean. Varkey et.al (1996) discussed turbulent mixing and vertical advection in the Bay of Bengal and reported a value of $8 \text{ cm}^2/\text{sec}$ for k_z in the upper 400 m layer and the order of 10^5 to $10^8 \text{ cm}^2/\text{sec}$ for k_b in the depth range 20-350 m. These values

are representative of the open ocean conditions. Using the data collected off Visakhapatnam, the value was reported as $3.0 \times 10^4 \text{cm}^2/\text{sec}$ by Sadhuram et.al (1995). Recently, mixing in the Western Bay of Bengal has been reported using Radium Isotopes (^{228}Ra and ^{226}Ra) by Rengarajan et.al (2002). In the present study, an attempt is made to estimate eddy diffusion coefficients (k_x, k_y, k_z) in the coastal waters of north Andhra and Orissa coast and supplement these values to 2-D turbulent diffusion model to obtain current speeds.

Data and methodology

For the EIA study the data on temperature and salinity profiles, currents (speed and direction) are the basic inputs that enable one to understand the mixing characteristics. The flow pattern and mixing influence the distribution and concentration of chemical parameters (nutrients and trace metals). EIA studies need to be carried out under calm weather conditions (preferably during winter, Dec-Feb). Rengarajan et. al (2002) reported the value of effective eddy diffusivity as $24.7 \times 10^6 \text{cm}^2/\text{sec}$ and $1.2 \times 10^6 \text{cm}^2/\text{sec}$ off Visakhapatnam during March and December(1991) respectively showing a higher value of eddy diffusion by one order under rough weather conditions.

The data was collected in winter during the period 1997 and 2002 to estimate k_x, k_y, k_z at three areas(I - Mutyalammapalem-Appikonda; II - Bhimili-Annavaram; III - off Mentada) for north Andhra Coast (Fig.1). RCM-7 Current Meter (make : Aanderaa Instruments, Norway) and SBE 19 Seacat Profiler (make : Seabird Electronics, USA) have been used to obtain data on currents and CTD respectively. The data off Orissa Coast(areas IV,V,VI) were collected on board CRV Sagar Purvi by using on board CTD and vessel mounted ADCP(Acoustic Doppler Current Profiler) during 14-15 Dec, 2000. The diffusion coefficients k_x, k_y, k_z and vertical velocity component (w) were computed using 2-D turbulent diffusion model of Bahulayan and Varadachari (1985).

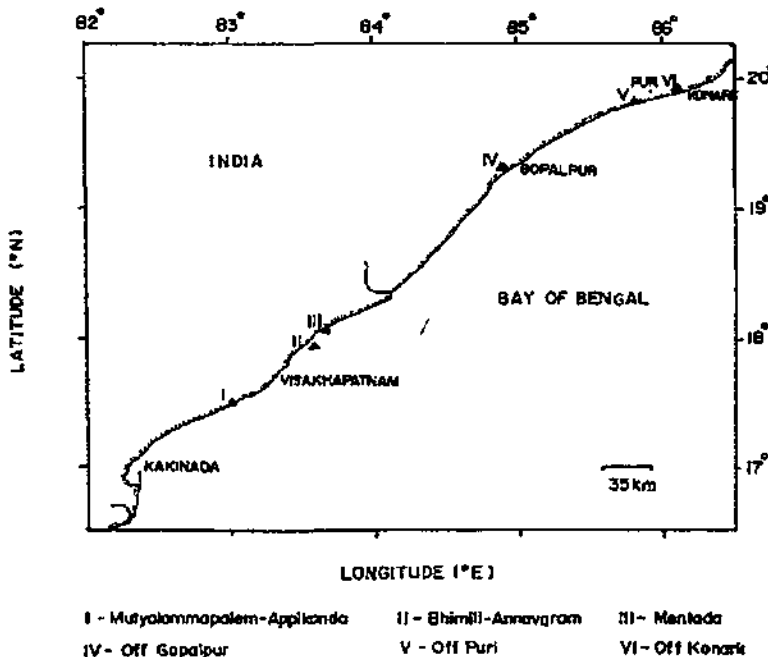


Fig.1 : Areas of study (I-VI)

Mathematical Formulations:

The two-dimensional turbulent equations of heat and salt are given below:

$$V \frac{\partial T}{\partial y} + W \frac{\partial T}{\partial z} = \frac{\partial}{\partial y} \left(k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial T}{\partial z} \right)$$

and

$$V \frac{\partial S}{\partial y} + W \frac{\partial S}{\partial z} = \frac{\partial}{\partial y} \left(k_y \frac{\partial S}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial S}{\partial z} \right),$$

where T and S are time-averaged temperature and salinity of seawater respectively. v,w are current speeds along y and z axes, y-pointing north and z-positive downwards from sea surface. If k_y and k_z the turbulent diffusion coefficients, remain constant in the respective directions, then $\partial(k_y)/\partial y = 0$ and $\partial(k_z)/\partial z = 0$. Hence

$$V \frac{\partial T}{\partial y} + W \frac{\partial T}{\partial z} = k_y \frac{\partial^2 T}{\partial y^2} + k_z \frac{\partial^2 T}{\partial z^2} = C_1 \quad (\text{say})$$

$$V \frac{\partial S}{\partial y} + W \frac{\partial S}{\partial z} = k_y \frac{\partial^2 S}{\partial y^2} + k_z \frac{\partial^2 S}{\partial z^2} = C_2 \quad (\text{say})$$

Since T and S are known against y and z, all the partial derivatives in these equations can be calculated. Further,

$$k_y = \bar{U} \frac{\partial S}{\partial x} \left(\frac{\partial^2 S}{\partial y^2} \right)^{-1}, \quad k_z = \bar{U} \frac{\partial S}{\partial x} \left(\frac{\partial^2 S}{\partial z^2} \right)^{-1} \quad \text{and} \quad k_x = \bar{U} \frac{\partial S}{\partial x} \left(\frac{\partial^2 S}{\partial x^2} \right)^{-1},$$

where U is the average zonal component of current. Finally the simultaneous equations are transformed to the following matrix form :

$$\begin{bmatrix} \partial T / \partial y & \partial T / \partial z \\ \partial S / \partial y & \partial S / \partial z \end{bmatrix} \begin{bmatrix} V \\ W \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \end{bmatrix}$$

The unknown variables v and w can be found by solving the matrix. In the present work, the method of generalized inverse is used to solve the matrix to avoid any indeterminacy.

Results and discussion

Temperature and Salinity. Temperature and salinity- profiles in the areas I - VI at 10 m water depth are presented in Fig.2. In area I, the temperature profile shows that it is almost constant with depth around 27.2° C . The salinity at surface is 31.15 psu and increases to 31.7 psu at the bottom. In general, the horizontal gradients are small in the study area. In area II, located north of Bhimili, both the temperature and salinity fluctuated around 26.6° C and 32.25 psu respectively. In area III, the temperature was constant (~24.3°C) and salinity fluctuates around 27.5 psu. Off Gopalpur (IV) strong inversion of 1.87° C was observed during the observational period. Temperature profiles at areas V and VI indicate

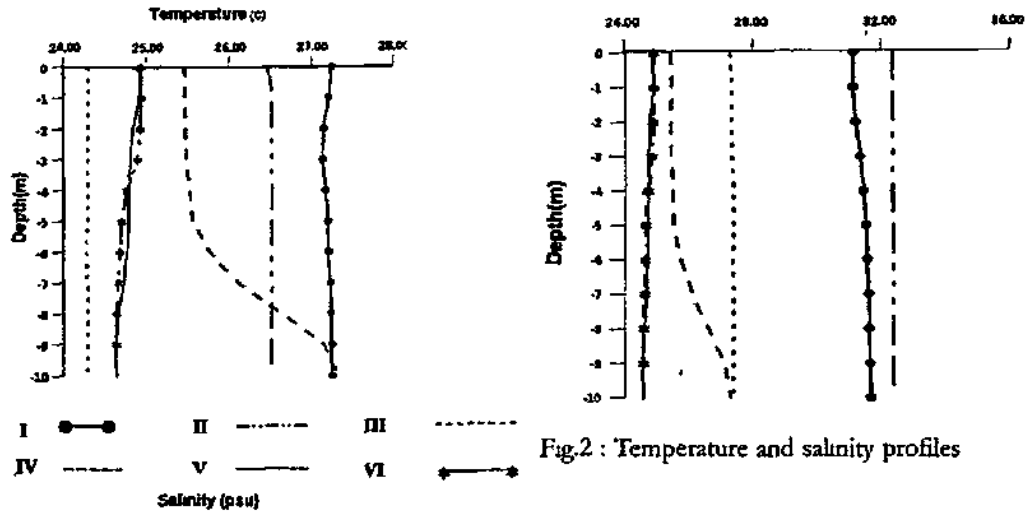


Fig.2 : Temperature and salinity profiles

more or less isothermal structure. The salinity at surface at areas V and VI is about 26 psu increasing towards south, and at area II the salinity was more than 32 psu. This large spatial gradient in salinity at surface is quite obvious due to the influence of fresh water discharge in the northern Bay of Bengal. There is not much variation in the salinity of the water column except in area III where a slight increase is noticed from 6 -10 m (Fig.2).

Currents' The observed data on currents at 10 m water depth at the above areas are presented in Fig.3. In area I, at the surface, the direction of the current is highly fluctuating between 90° and 270° during Dec'97 - jan'98. The speed of current is 5-10 cm/sec throughout the period except on a few occasions, when it reached a maximum (—40 cm/sec). At the bottom, direction is fluctuating with speed 10-20 cm/sec (NIO,1999). In area II, at the surface, speed of current is 5-15 cm/sec and the direction is stable around 240°. At bottom, the current speed is less than 5 cm/sec while the direction changed from 240° to 30° during the observational period. In Area III, the direction changed from 60° to 240° with speed 5-10 cm/sec at the surface and more or less same trend is observed at the bottom (Fig.3).

Table 1: Speed and Direction of current at 10 m water depth (Orissa Coast)

Depth (m)	IV		V		VI	
	S	D	S	D	S	D
0	21	170	24		14	183
5	25	170	20	179	17	175
10	17	194	29	178	18	165

S = Speed (cm/sec)

D = Direction (Degrees from North)

Table 2: Eddy diffusion coefficients (k_x k_y k_z) (Unit: cm^2/sec)

Area	k_x	k_y	k_z
I	2.27×10^4	0.95×10^3	0.30
II	9.27×10^4	1.70×10^3	1.21
III	0.57×10^4	0.24×10^3	0.15
North Andhra Coast	4.04×10^4	0.96×10^3	0.55
Orissa Coast	2.79×10^8	3.05×10^6	4.90

Eddy diffusion coefficients in coastal waters

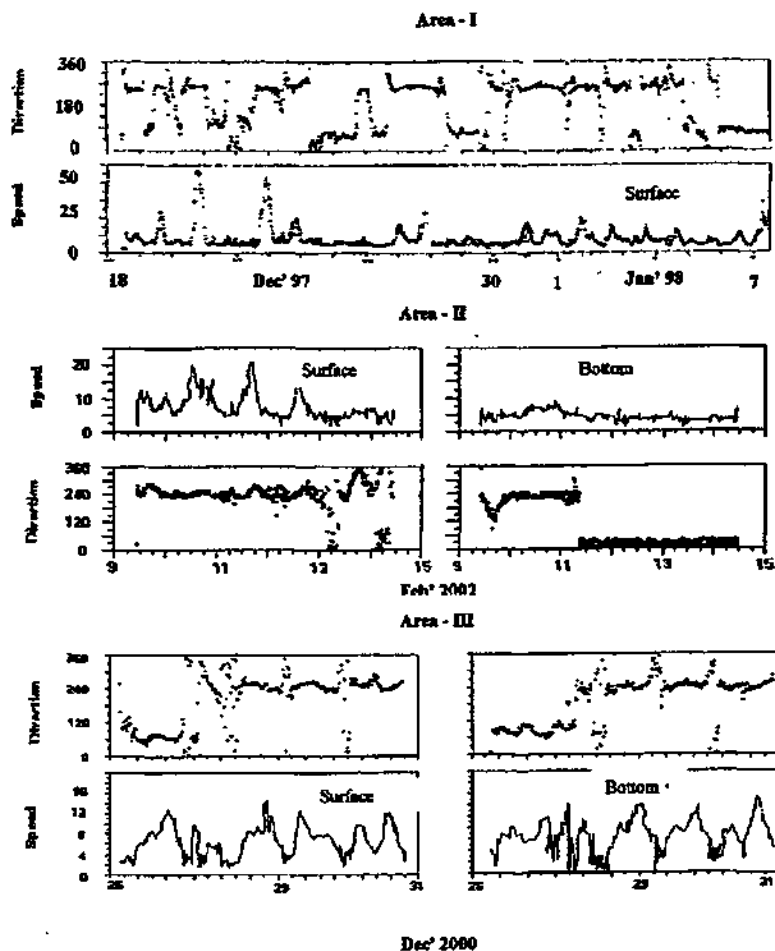


Fig.3 : Speed and direction of currents

Currents were measured by ADCP for the first time in the coastal waters off Orissa Coast (Areas IV,V,V1) on board CRV Sagar Purvi. In general, the flow is towards south with speeds varying from 14-29 cm/sec in the water column (Table-1).

Eddy diffusion coefficients (k_x , k_y , M_z) : The values of k_x , k_y and k_z for the study areas are presented in Table 2. The values of k_x and k_y are $2.27 \times 10^4 \text{ cm}^2/\text{sec}$ and $0.95 \times 10^3 \text{ cm}^2/\text{sec}$ respectively. Dispersion study was also carried out in this area by using Rhodamine-B dye under calm weather conditions. Based on the dilution of the dye patch, k_x and k_y are estimated at $3.0 \times 10^4 \text{ cm}^2/\text{sec}$ and $0.14 \times 10^4 \text{ cm}^2/\text{sec}$ respectively (NIO,1999). Another study close to this location reported the value of k_x as $1.3 \times 10^4 \text{ cm}^2/\text{sec}$ (NIO,1981). The present values of k_x and k_y are comparable with the above. In area II, for a current speed of 5 cm/sec, k_x was $9.27 \times 10^4 \text{ cm}^2/\text{sec}$ and k_y was $1.7 \times 10^3 \text{ cm}^2/\text{sec}$. In area III, the values of k_x and k_y are one order less ($k_x = 0.57 \times 10^4 \text{ cm}^2/\text{sec}$; $k_y = 0.24 \times 10^4 \text{ cm}^2/\text{sec}$) compared with those observed in areas I & II. The average values of k_x and k_y for the coastal waters of north Andhra Coast are $4.04 \times 10^4 \text{ cm}^2/\text{sec}$ and $0.96 \times 10^3 \text{ cm}^2/\text{sec}$ respectively during winter season. The present value of k_x ($4.04 \times 10^4 \text{ cm}^2/\text{sec}$) is close to the value ($3.0 \times 10^4 \text{ cm}^2/\text{sec}$) reported by Sadharam et.al.(1995) for the coastal waters from Gangavaram to Visakhapatnam Harbour. The value of k_z varied from 0.15 - 4.9 cm^2/sec in the study areas.

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The values of k_x and k_y off Orissa Coast are of the order of $2.79 \times 10^8 \text{ cm}^2/\text{sec}$ and $3.05 \times 10^6 \text{ cm}^2/\text{sec}$ respectively which mostly represent open ocean conditions. Rengarajan et.al (2002) reported k_x and k_y as $1.3 \times 10^7 \text{ cm}^2/\text{sec}$ and $2.1 \times 10^8 \text{ cm}^2/\text{sec}$ for Western Bay of Bengal which represent open ocean conditions. They reported effective eddy diffusivities varying from 5.1 to $56 \times 10^6 \text{ cm}^2/\text{sec}$, from 228 Ra and 226 Ra with a characteristic scale length of 114-323 km. The scale length is much smaller (~1km) in the areas I, II, III and larger than 10 km in case of Orissa Coast. The value of vertical velocity component (w) varied from -0.28 to -0.56 cm/sec for north Andhra coast which indicates sinking. The present values of the model appear to be reasonable. In the present study the values of eddy diffusion coefficients are computed at a few selected locations based on a limited data. However, a model study covering the coastal waters of Andhra Pradesh is desirable to understand the impact of the coastal industries on marine environment, which will help to plan the establishment of industries in future.

Conclusions

(1) Strong inversions off Orissa coast and isothermal layer off north Andhra coast are noticed during winter season (Dec-Feb). There is not much gradient in temperature and salinity in the horizontal in the study areas I, II & III.

(2) The values of k_x and k_y are comparable with those estimated from dye experiment in area I. They are one order higher in area II compared to those in areas I & III.

(3) The values of k_x & k_y are of the order of $2.79 \times 10^8 \text{ cm}^2/\text{sec}$ and $3.05 \times 10^6 \text{ cm}^2/\text{sec}$ respectively off Orissa coast which are comparable with the values reported from 228 Ra and 226 Ra in western Bay of Bengal (Rengarajan et.al, 2002).

(4) The negative values of vertical velocity component w (-0.28 to -0.56 cm/sec) obtained through 2-D turbulent diffusion model indicates probably the sinking in the coastal waters.

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