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Estuary: A Natural Filter Emphasis on A Mathematical Model of Pollution in Mandovi River

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Abstract

An estuary is a partially enclosed coastal body of brackish water with one or more rivers or streams flowing into it and with a free connection to the open sea. These freshwater estuaries also provide many of the ecosystem services and functions that brackish estuaries do, such as serving as natural filters for runoff and providing nursery grounds for many species of birds, fish, and other animals. Estuaries are among the most productive ecosystems in the world. Mandovi River in Goa is one such important Estuary. A mathematical model is presented to protect the Ecosystem

Keywords: *Estuary, Mandovi River, Pollution.*

1. Introduction to Estuaries

Estuaries are important parts of the coastal ecosystem and are free from extreme winds and waves because of their semi-enclosed system and hence become a source of nourishment. The essential characteristic is the richness of an estuary resulting from the passage of river water through the system into the open sea. In an estuary, the dynamical conditions are established by mixing, and bring about the eventual discharge of the river water to the sea an estuary is a semi-enclosed coastal body of water having a free connection with the open sea and contains a mixture of salt water and fresh water [1 & 15] Cameron WM and Pritchard D Win 1963], classified estuaries into the following two categories 1) Positive estuary 2) Negative estuary. A study of fundamental processes in an estuary the main physical problems to be investigated in an estuary are water movements, mixing processes, and the distribution of salinity which results from their combined action. The ratio of influx of fresh water from the river varies greatly and the conditions in an estuary change with the variations in the volume of water discharged by the river flowing into it. The water within the estuary consists of a mixture of fresh water and seawater in proportions that vary from place to place. Another type of problem is concerned with the effect of the circulation and mixing processes on the movement and dispersion of substances introduced into the estuary in various ways. Fresh water is often used as an indicator since it provides information on the mixing processes. This information is used in calculating the effect on an effluent introduced at a particular point in an estuary. The circulation pattern of an estuary plays an important role in the processes of mixing and dispersion and affects the salinity and density distribution which form the basis for understanding the distribution of chemical constituents. A study of changing conditions is presented here. Varying salinity is sufficiently strong to establish density currents transporting sea water up in the estuary. In deep water counter currents or compensation currents are maintained by the redistribution of density generated by vertical mixing. The other two important factors influencing the interaction between the river flow and tidal currents are the physical dimensions of an estuary and the effect of the Coriolis force. The entrainment process increases salinity as well as the volume of water in the upper layer. As a result, the velocity of the flow increases without affecting the salinity of the deeper layer. The slow upstream movement of water from the sea compensates for the water lost by entrainment. The instantaneous distribution of velocity in its respective components can be

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expressed as

$$u_x = u'x + U_x + u''_x,$$
$$u_y = u'y + Uy + u''_y$$
$$u_z = u''_z + Uz + u''_z \quad \text{------}(1)$$

as oscillatory velocity, U varies with the tidal period. Using these equations (1) with the equation of motion, the time mean and mean longitudinal equation. The turbulence, as well as mixing salt water into the fresh layer above mix the fresh water downwards. Consequently, there is no net exchange of water and the non-advective mixing process. The energy involved in mixing is not derived from the relative motion of two stratified liquids, but from the fractional energy dissipated by the water moving across a rigid bottom and the mixing is due to turbulent diffusion. If the lower layer is static, then there is no diffusion across the interface and the mixing is entirely by entrainment. As a result, both methods of mixing may work simultaneously and their relative importance depends largely on the degree of turbulence. Considering the significance of the non-linear, frictional terms in the equation of motion, the continuity equation is examined to predict the estuarine characteristics.

2. Methodology

Basic Equations

1 The basic equations governing the hydrodynamics of estuarine water are the equation of Continuity and the equation of Motion. The forces acting on the fluid element are surface forces and body forces. Surface of forces consists of two parts

- one acting parallel to the surfaces of the element (shear)
- the other acting normal to the surfaces (pressure)

Body forces depend on the mass of fluid in the element and are caused by gravity and the Coriolis effect. Consider a long narrow coastal inlet that has a river at the inland end where the upper layer is flowing seaward and the thickness of this layer is constant from river to river, then the seaward flow is slow at the river in space to spread out in time with irregular motion gradually occupying an even larger area at initial point. It may be defined, as an irreversible (probabilistic) [2] phenomenon by which matter or groups of random particles spread out within a given space according to individual random motion. Therefore, diffusion is the process by which matter is transported from one part of a system to another Following the mathematical equation of heat conduction, derived by Fourier [8]. Fick, in 1855, first defined diffusion on a quantitative basis. The following hypothesis is based on the mathematical theory of the advection-diffusion equation. According to Fick's 1st Law, which is expressed by equation (1) when all fluxes, forces, and gradients are along one given direction. Since the rate of change in concentration in any volume equals the net flow into the volume and is given by

$$\partial c / \partial t = - \partial / \partial x \, [\partial c / \partial x] \, \ldots\ldots\ldots \, (2)$$

The rate of transfer of diffusing substance through a unit area of a section is proportional to the concentration gradient. The diffusion coefficient 'D' is defined as a phenomenological coefficient that relates a net flux of atoms per unit area to an atom concentration gradient.

$$\partial c / \partial t + u \, [\partial c / \partial x] + v \, [\partial c / \partial x] + w \, [\partial c / \partial x] = \partial / \partial x \, [K_x \partial c / \partial x] + \partial / \partial y \, [K_y \partial c / \partial y] + \partial / \partial z \, [K_z \partial c / \partial x] \, \ldots\ldots \, (3)$$

The equation of mass balance for a substance is usually called the advection-diffusion equation (3). It specifies the rate at which the substance is changed by advection and diffusion phenomena and contains the terms for the time rate of addition of substance from the efficient outfall, chemical degradation, rainfall etc.

3. Studies on Pollution Analysis in Estuarine Coastal Region

The coastal regions are one of the main thoroughfares of commerce and also the principal areas for the disposition of many industrial and domestic waste products. All these demands have greatly increased the possibility of potential damage to the coastal regions by pollution. Man's increased use of coastal areas, particularly estuaries, has extensively damaged the breeding where plants, animals and other forms of life the areas are dependent. As a result, the most serious problem facing the estuary is its pollution. This problem is extremely complex because of the lack of background data. We unaware of the facts as

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to what level the estuary already polluted, and what levels of independent of man's activities, by natural weathering and erosion of rock and soil. It is conceivable that in some instances the input of a potential pollutant from natural causes may exceed man's input. [4] The principal difficulty in combating marine pollution lies in defining it. A recent investigation by renowned scientists have defined marine pollution as the direct introduction of substances into the marine environment by man, resulting in some such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fish Industrial pollutants have several ways of reaching the estuary including direct input by rivers, runoff, sewer outfall and industrial and agricultural wastes being dumped into the estuary, assuming that the ocean can easily absorb such ingredients is extremely detrimental to the environment. [16,17] Pollution of the marine environmental has three main disastrous consequences:

- It directly destroys the organisms in the polluted areas.
- It alters the physical and chemical properties of the environment.
- It introduces substances that are dangerous to higher forms of life such as human being, but harmless to lower forms of life.

It has been realized that the changes in the environment of these coastal regions will seriously degrade them by decreasing their aesthetic and economic value, endangering public health, and threatening their living re- sources. In 2022, [5] Regional Studies in Marine Science like, several initiatives to understand the tides along the estuarine channel of Mandovi Estuary, but the available studies are mostly based on the observations [18, 19] (Shetye et al., 1995; Manoj et al., 2009) and numerical approaches (Unnikrishnan et al., 1997). Researchers have also extensively studied this estuarine network's tidal propagation and freshwater influx by using a numerical model [20] (Vijith et al., 2009, 2016). However, simultaneous information from the coastal as well as in the estuary is crucial to understand the overall tidal propagation in this region.

4. Results and Discussion

In recent years there has been a rapid development in the representation of estuarine circulation and in mixing by numerical models. These may be classified into three types, the first being those that solve the equations of momentum balance and continuity to give the distribution of water movements. The second type comprises of those which solve the advection-diffusion equation to give the distribution of salinity in water, taking the current distribution to be known from observations or the output of a model of the first type. In the third type the momentum and salt conservation equations are solved simultaneously so that the change in density distribution brought about by mixing is taken into account. In formulating a model of either type the questions of scale, dimensionality and methods of averaging have to be considered. [11, 12] The present investigation is concerned not only with mathematical modelling but also with physical processes which provide an input to such models. A comprehensive review of estuarine processes and modelling has been given by Ward and (43). [9] Calibration of a mathematical model involves evaluation and modification of the supplementary relations to the basic equations and a systematic discussion the derivation of a set of governing equations. The following information is necessary to express the basic principles in order to perform the estuarine model calibration:

- Given an existing estuary what physicochemist cal changes will result from the introduction of a new waste discharge.
- What changes will occur if physical characteristics of an existing estuary is permanently changed by dredging or change in freshwater inflow.
- Distribution of currents, circulation and mixing processes in the estuary.
- Mass transport processes and hydrodynamics of estuaries.

Numerical models of estuaries are being constructed primarily to aid in the studies of water quality and environmental degradation by industrial pollution. The procedures involve certain simplification in the tuarine hydrodynamics are to assess the variations in

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quantity which may be associated with changes in observed estuarine topography, river flow, salt intrusion and effluent discharge, etc. To examine the extent of the vertical the dispersion of effluents the variation above model in is applied to the Mandovi estuary in Goa. [13] During ebb tides quantity of fresh water discharge the pre-monsoon and the post-monsoon is very different. During these seasons the flow is regulated by of mixed semi-diurnal type. Since maximum of saline water is 60 km upstream. Its penetration gets reduced to a minimum of 20 km during the onset of monsoon. The mean river runoff during wet season is 150 m/sec The vertical variation in salinity undergoes marked changes from season to season. In the Mandovi estuary, it was observed that there is less than 0.1 ppt during average of salinity variation from surface the pre-monsoon season. to During monsoon bottom the vertical salinity difference is about 20 ppt and at the end of September it be was observed 5 ppt (Cherian et al., [6]; and Quasim Gupta [36]). The average annual river discharge is 6004 Mm3 (Manoj, 2012). Runoff into the estuary varies from ∼1000 m3 s−1 in the wet season to ∼1 m3 s−1 at end of the dry season (Vijith et al., 2016). During dry season, tidal circulation dominates and saline waters penetrate ∼45 km upstream from the river mouth [7] (Shynu et al., 2015). It is obvious that vertical exchanges are significant during the monsoon and post-monsoon seasons, considerable vertical the shear acts as a stretching agent these layers and decrease in the thickness. The vertical diffusion effluents effluent thickness two mean the son of increases an approximate balance between mechanism is visualized. The decrease concentration is attributed to advection diffusion. The vertical diffusion seems possible that this concentration, after observed over release, are layers, with considerable preferably situated layers where the turbulence is This is due to, either gradient to weakly in de an enhanced or a weak vertical shear layer and is possible to establish, if in the observations are made small enough on vertical scale. The present model is an attempt to determine the effects of diffusion from small scale, in short term conditions. The vertical exchange is not continuous but by using a process, we can obtain a measure of this mean vertical exchange, which may be related to the surrounding conditions. The estuary, under the influence of the southwest monsoon, experiences a spell of heavy precipitation to the tune of 250 cm. during June July. As a result, the salinity value drops to < 1 x 10-3 upstream of 20 Km. The inter tidal volume of water (volume of water between high and low level) in the estuary is around 90 x 106 3. The fresh water contribution to this volume is thus <0.5% during the dry season when the runoff is m^3/ Sec-1 [3] (Cherian et al. []). tion is < 10 Hence the runoff contributes- > 7% of inter tidal volume. It is the intertidal volume removal of which is available for the dilution and contaminants, out of the estuary and this intertidal volume is taken for calculation. It is concluded that the Mandovi estuary is vertically mixed during the dry season and experiences a temporal increase of salinity throughout its length. The transport processes controlling the salt budget of the estuary is the runoff induced advection of salt out of the estuary, and the tidally induced diffusion into the estuary, The tidal diffusion is about 20% larger of the two processes and leads to a net upstream movement of salt. During the wet spell of monsoon, the runoff in the estuary increases rapidly. As a result, the estuary dilutes about 75% of its salt approximately in two months [10 & 18] (Shetye and Murthy) During the following two months, when the runoff decreases, about 2/3rd of the diluted salt is recovered. To examine the extent to which the present model is applicable for contaminants and the abatement of pollution due to the introduced, we assume the discharged effluents as conservative and behave like that of saline water. The observed salinity at 45 the mouth, i.e. [14] at X=0 km. and at X=65 km., at the head of estuary, are used as boundary values. These are substituted in equation to compute exchange ratios that express the amount of non-advective salt transfer into and out of the boxes at the grid points. This is not possible when the combined longitudinal dispersion coefficient term is calculated from analytical methods. As the exchange ratio increases in a particular box there will be a rapid mixing within the box. The numerical model of the dispersion of contaminants from a distant source of fresh water and the change in concentration cat the surface following the discharge of the effluent emission with initial concentration. A pollutant, when introduced, is transported down- stream by fresh water discharge and upstream by a tidal exchange process. The up-estuary exchange is the distance traveled by a water particle during a tidal cycle, when observed in the coordinate frame moving with mean motion. As a result, the effluents are dispersed in both the directions i.e., down-estuary and up-estuary. The discharge emission, considerably of contaminants, that continues sustained the concentrations at the surface decreases as it moves toward the mouth of the estuary, at which the contaminant is lost into the ocean. As an example of practical use of the numerical model a study was made of a continuous discharge of pollutant in the Mandovi estuary. Two cases were considered, the first case in which the pollutant is discharged at far upstream or injected, at the head of the estuary at constant rate. In the other case the location of an input source of pollutant is moved to- wards the mouth of the estuary. The peak concentration of the effluent decreases as it is introduced with the input flux W. The peak concentration reduces everywhere along the distance if the location of input source is moved towards the mouth. The diffusion coefficient, ex- pressed as exchange ratio, was found to have application in the effluent dispersion. a direct distant source concentration.

Conclusion

A distinct feature that the concentration is not reduced to zero during the monsoon season, as the effluents move towards the mouth they move like a plume. This may be attributed to the dominance of mass transfer by advection due to high river discharge resulting in the highly stratified conditions with two-layer flow. The comparison shows how much reduction in the peak concentration of pollutants result from the different discharge location. Hence it may be concluded that the most feasible discharge location during high tide is the midpoint of the estuary i.e. 35 Km. upstream when the penetration is 65 Km. has the estuary acts like a natural filter.

References

[1]. Cameron W. M. and Pritchard D.W., 1965: Estuaries', in 'The Sea', II, John Wiley, NY6. Cherian T., Rao L.V.G. and Verma K.K., 1975: Variations in physical characteristics waters of Zuari estuary', Ind Jr Mar Sc,4, p. 5-10.
[2]. Carpenter W., 1960: 'The Chesapeake Bay Institute study of the Baltimore Harbor', Proc 33rd An Conf. Maryland Delaware water and Sewage Assoc, 62-78.
[3]. Cherian et al., 1975, Variations in physical characteristics of waters of Zuari Estaury, Ind Jr Mar Sc 4.
[4]. Dorrestein R., 1960: A method of computing the spreading of matter in the water of an estu-ary', Disposal of Radioactive Waste (Inter Atom En Agen), 2, p. 163 166.
[5]. Dyer, K. R. and Taylor, P. A., 1973, A simple segmented prism model of tidal mixing in well-mixed estuaries, Estuarine and Coastal Marine Science, 1, p. 411-418.
[6]. Elder, 1959: The dispersion of marked fluid in turbulent in turbulent shear flow', Jour Fluid Mech, 5, p. 544 560.
[7]. Fischer H.B., 1972: 'Mass transport mechanisms in partially stratified estuaries', Jr of Fl Mech, 53, p. 671-688.
[8]. Fourier, 1922:in 'Mathematics of diffusion', by Crank J, Clarendon Press, Oxford,
[9]. Gehre J, 1909: 'Beirag zur hydrographic des finnischen meerbusens', Finn Hydrogr Waters, vol 3. Biol
[10]. Murthy C.S. et al, 1976: in 'Enviromental charac teristics of the Mondovi-Zuari estuarine system in Goa', Estuaries and Coastal shelf Sc, 13, p.557-578.
[11]. Neumann, Gerhard, and Willard J. Pierson Jr. "Principles of physical oceanography." (1966).
[12]. Officer C. B., 1983: The Revised Box-model', in Estuarine and Wetland processes with emphasis on modelling, by Hamilton P and McDonald K, Plenum Press, New York, p. 67.
[13]. Okubo A, 1962: 'Equation describing the sion

e ISSN: 2584-2854
Volume: 02
Issue: 05 May 2024
Page No: 1276-1281

of an introduced pollutant in a dimensional estuary', in Studies on phy, Univ of diffu one-Ocean'- Washington Press, p. 216-266.
[14]. Preddy W.S., 1954: 'The mixing and movement of water in the estuary of the Thames', Jr of Marine Biol Assoc, U. K., 33, p. 645-662.
[15]. Pritchard D.W., 1952a: 'Salinity distribution and circulation in the Chesapeake Bay estuarine system', Jr Marine Res, 11, p.106-123., p. 306 324.
[16]. Carpenter W., 1960: 'The Chesapeake Bay Institute study of the Baltimore Harbor', Proc 33rd An Conf. Maryland Delaware water and Sewage Assoc, 62-78.
[17]. Quasim Gupta. & Sen Gupta 1981, Environmental characteristics of the Mandovi - Zuari Estuarine system in Goa, Estuarine, Coastal and Shelf Science 13.
[18]. Shetye and Murthy C S. 1987, ‘Seasnal Variation of the salinity in the Zuari Estuary, Goa. Proc Ind Acad Sc vol 96-3.
[19]. Fernandes, S. O., Gonsalves, M. J., Nazareth, D. R., Wong, S. K., Haider, M. N., Ijichi, M., & Kogure, K. (2022). Seasonal variability in environmental parameters influence bacterial communities in mangrove sediments along an estuarine gradient. Estuarine, Coastal and Shelf Science, 270, 107791.