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RECENT ADVANCES IN SPECIFIC ASPECTS OF COASTAL OCEANOGRAPHIC STUDIES IN INDIA AND THEIR FUTUROLOGY*

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ABSTRACT

Remarkably enough, the recent studies of Indian coastal water upwelling brought to light the limitations of the existing theoretical knowledge of the coastal water upwelling. The error in the Ekman spiral-based explanation of coastal water upwelling was pointed out. Intensification of the western boundary currents of the world oceans and the formation of upwelling on the eastern boundary were intuitively coupled, probably leading to the concept of combining the 1-dimensional Ekman theory with the 2-dimensional Stommel theory for the integrated physical picture of both the conditions at the boundaries. It was also pointed out that the upward currents in upwelling would terminate at the core of the stable thermocline, instead of generally believed termination at the sea surface.

A concept of three-phase sediment particles with different viscosity properties in the suspended mud of the mudbanks was postulated to explain the tranquility of mudbanks. This concept was expected to generate interest in marine engineers to design and fabricate suitable devices for artificial creation of mudbanks for improvement in fisheries.

The recent studies in India on coastal water pollution were described and the need for dynamic studies of pollutants was stressed.

Indian efforts for making use of the remote sensing technology for coastal water information were projected and the futurology of the art of this novel technique in Indian climatic conditions was hinted.

INTRODUCTION

IN THE RECENT past interesting developments took place in the studies of oceanography. Ever since the advent of the technique of remote sensing of the sea surface temperature, the age-old method of Nansen cast system of time consuming ship-survey data is gradually getting replaced. Even on the scientific side, there are some praise-worthy contributions from the recent studies of coastal water oceanography. Some specific aspects of such recent advances in physical oceanography of the coastal waters of India were dealt with in this paper with a touch on their futurology.

UPWELLING

In the field of physical oceanographic studies of coastal water processes, the phenomenon of upwelling is very relevant to the Indian Coast, as it has very significant impact on the biological processes of primary and secondary productions and hence to fisheries of the Exclusive Economic Zone. It was established from on-board observations that the contrastingly rich pelagic fisheries of the west coast relative to the east coast is on account of prolonged and intensified upwelling off the

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former coast (Sharma, 1968; Sastry and D'Souza, 1971; Ramamirtham and Rao, 1973; Lathipha and Murty, 1978; Johannessen *et al.*, 1981, Narayana Pillai, 1982).

The theoretical explanation of the physical process of upwelling in the vertical plane at right angles to the coast draws the attention of physical oceanographers. Upwelling of the southwest coast of India is very systematic, just as the monsoon. It always follows the onset of the southwest monsoon. If the monsoon winds are from peninsular region to offshore, which is not the case, then it would have been easy to link up the process of upwelling to the clearing up of the surface waters from the coastal belt to the offshore region by the action of wind stress on the surface waters and thereby causing for the lift of the near shore subsurface waters to restore the hydrostatic equilibrium in the water columns far off and near shore. Therefore, the explanation for upwelling was sought in the coastal currents. During the southwest monsoon, the coastal surface currents along the west coast are southerly. Therefore the coastal waters at the surface flow with the coastline to the left of the flow. The subsurface currents due to Ekman drift flow to the right of the surface flow (in the Northern Hemisphere). The flow from the subsequent depths is further deviated to the right; the lower the layer, the more towards right the flow should be. And the mean flow from the Ekman spiral leads to net driving off the coastal waters from the top layers of the sea and thereby leading to the tendency to move the deeper water from offshore to the surface of the coastal region in order to restore equilibrium. This is how the coastal upwelling is explained by taking into consideration the Ekman theory of vertically spiralling currents (Ekman, 1902; Sverdrup *et al.*, 1942).

Two forces balance one another in Ekman theory and the two forces involved are the Coriolis force and the frictional force on account of differential horizontal velocities at different depths. As the Coriolis force (in the Northern Hemisphere) acts to the right of the velocity direction, the frictional force is necessarily required to act to the left of the velocity direction.

It was an Indian scientist (Murty, 1986) who pointed out that there is imbalance in the forces considered by Ekman. There would be a residual frictional force in the direction in line with the velocity direction. In support of his arguement, he said that Professor Henry Stommel's convincing theory of intensification of the western boundary currents treats the frictional force to act opposite to the direction of velocity (Stommel, 1948). Murty (1986) opined that the intensification of currents on the western boundaries of the subtropical gyres of the world oceans and the development of upwelling on their eastern boundaries are to be viewed together as a coupled system. He intuitively suggested that the essential reason for the generation of upwelling on the eastern boundary may be sought from a comprehensive study of the three-dimensional vorticity of the subtropical gyre. Prof. J. Sundermann of Hamburg University (personal communication) opined that combining both the approaches of Ekman's 1-dimensional vertical and Stommel's 2-dimensional horizontal necessarily results in Murty's intuitive findings.

It is generally assumed that the vertical currents of upwelling will cease at the surface of the sea (Hidaka, 1954). Lathipha and Murty (1987) pointed out that in view of the intensive vertical stability of the thermocline layer, the process of upwelling would not extend up far into the thermocline and the velocities of the upward moving water particles should cease before the particles reach the core of the thermocline. Chemical concentrations like the dissolved oxygen, phosphate, silicate, etc. of the waters from the depth where upwelling ceases, are exchanged with that of the top (surface) layers by eddy diffusion only. The process of diffusion is rapid if mixing is more in the subsurface waters (above the thermocline) : the greater the wind stress at the sea surface, the more would be mixing.

Attempts of mathematical modelling of coastal water upwelling require to take these physical aspects into consideration.

Tranquility of mudbanks

Mudbanks are coastal patches of muddy seawater with perfect calmness, with coastland on one side and the dynamic sea with breaking waves on the other three sides as their boundaries. Multi-disciplinary investigations with respect to physical, chemical, biological and fisheries aspects were carried out by a team of scientists of the Central Marine Fisheries Research Institute, Cochin during early seventies (Krishna Kartha, 1984) on the mudbanks of Kerala and Karnataka Coasts in general and on the Alleppey Mudbank in particular. As fishery aspects of the mudbank are important for national economy, the calmness of mudbanks with dampened waves or no waves is equally important for safe launching and landing operations with ease of the country crafts by the artisanal fishermen.

Increase of viscosity of seawater due to the presence of suspended mud in it was attributed for the calmness of mudbanks. A keen observer of the mudbanks wouldn't be satisfied with this generalised explanation of mud-rendered calmness of the mudbanks. The non-mudbank coastal stretches where the wave action is too much are equally muddy in appearance, but they are not calm unlike mudbanks. With this observation as genesis, a hypothesis of three phase sediment particles suspended in seawater was postulated (Murty *et al.*, 1984).

The particles of sediment of the first phase are those which dissolved in seawater and formed into thixotropic solution. Due to thixotropic effect, the viscosity of the seawater is increased. The second category of particles are those which are sols-like. Based on hydrodynamic considerations, Albert Einstein derived that the viscosity of the fluid is increased by at least two and a half times to the volumetric concentration of the sols in the fluid.

The second phase particles (sols) retain their physical identity while the first phase particles (thixotropic particles) lose their physical identity by dissolving into the solvent (sea water). The third category of particles which are bigger in size are those which do not contribute to the viscosity of the medium, but avail the existing viscosity as per the Stockes' law of viscosity. They are called the Stockes' particles which get afloated in the medium depending upon the viscosity of the fluid.

Therefore, the mud as a whole is the contribution of these three types of solid particles. Whatever may be the concentration of Stockes' particles, their presence cannot change the viscosity of the fluid (sea water). The more the proportion of the first two phase particles in the mud, especially the sol particles, the more would be the viscosity of sea water. If the sea water is full of Stokes' particles in its suspended mud, wave damping cannot take place, as there is no additional viscosity to the sea water on account of the presence of these suspended particles. Thus, the non-mudbank waters and the mudbank waters are differentiated in their quality of mud.

In the light of the three-phase concept of suspended sediment in sea water, Murty (1987) visualised that artificial mudbanks can be created by suitable manipulations of marine engineering devices and designs at selective coastal places. This engineering feat, if it happened, would be an excellent coastal facility for artisanal fishermen and also for coastal water mariculture and sea-ranching of commercially important marine fishes in their seed stage.

MARINE POLLUTION

A systematic work on marine pollution of the seas around India was done with National Institute of Oceanography as the base of undertaking sea voyages. The state of various pollutants such as domestic sewage, heavy metals, pesticides and oil along the length and breadth of the Indian coastline was summarised by Qasim *et al.* (1988). The problem of oil pollution in Indian waters was projected by them in the form of counted number of trips in each 5° square when slicks were observed. When compared to total number of observations in each 5° square, the observations with slicks were 50 to 60% off Indian Coast which is in contrast to East African Coasts (Soudi Arabia and Somali) where it is only 30 to 40%. A number of instances were reported when fishes were killed due to contamination by toxic chemicals in the coastal waters and connected estuaries, especially off large cities like Bombay, Cochin, Madras and Calcutta (Pillai *et al.*, 1981). A strange, harmful and unwarranted method of chemical fishing by use of some industrial waste product which was determined to contain 3.8% of cyanide off Madras was noticed in October 1983 by the scientists of the Central Marine Fisheries Research Institute, Cochin (Rao and Girijavallabhan, 1984) and it was immediately brought to the notice of the state authorities to ban such ignorant activity.

It is to be admitted that scientific approach to marine pollution in our country is at the threshold, as it still remains with survey and identification of various pollutants. The dynamical aspects of pollutants require more attention. Space and time processes of diffusion of pollutants, determining their effective harmfulness which in turn offers remedial measures to be taken, require properly evaluated.

The problem of oil pollution off the metropolitan cities like Bombay, Madras and Vizag deserves special attention. Efforts are needed to identify the strains of bacteria and culture them which can consume and convert the mineral oil into some other substance which sinks to the bottom instead of remaining afloated at the surface and subsurface. Our approach to marine pollution problem should be to strike a balance between good industrial and commercial growth with clean beaches and healthy coastal fisheries. This balanced approach is a must for any developing country, not only to our country.

REMOTE SENSING

All the world over in the last decade, exploration of the oceans took the shape of exploiting its wealth fully for the benefit of mankind, at the same time carefully managing it for its preservation for the future (Robinson, 1985) for example, extraction of offshore minerals (oil and gas), deep-sea mining for metals (manganese nodules) and fishing industry by continued improvements of craft and gear. All these developments required a preliminary survey of a wider area within a short interval of time. The primary advantage of remotely sensed data by satellite is the wide synoptic view of the sea surface which is otherwise not possible.

Indian Space Research Organisation at Bangalore, Space Applications Centre at Ahmedabad and National Remote Sensing Agency at Hyderabad are keenly concentrating their efforts in the field of application of remote sensing technology to the physical processes of the coastal waters of the seas around India and thereby to apply to the marine living resources (Gopalan and Narain, 1985; Pranav Desai, 1985; Manikiam, 1988). Certain bands of wavelengths in the visible and infrared regions of the electromagnetic radiation were found suitable for remotely sensing from satellite some physical properties of the sea water, especially sea surface temperature. Some of the landsat sensors have been found useful in the study of coastal processes like turbidity and longshore transport of sediment. However, it may be admitted that the sensors are not optimized for ocean studies (Manikiam, 1988). By determining the colour of the sea surface by radiometer technique, the chlorophyll content which brings characteristic changes in the colour of the waters was determined.

As the radiation from sea surface travels through the atmosphere, it is partially absorbed and scattered before it reaches the sensor carried by the satellite. Therefore, the information given by the sensor about a parameter contained within the radiation band required correction for its true value at its origin, the sea surface. The coefficient of correction even for a single waveband is not the same for all the seasons for a given sensor, as the atmospheric conditions change. The presence of cloud cover creates more problem for the atmospheric correction.

The main hurdle for advancement in this field is to evolve a suitable correction technique of the infrared radiometer response, under the varying interference of the ever-modifying monsoon cloud cover over the enormously long coastline of our country. The breaks in monsoon add to the cumbersome nature of the correction problem (Murty, 1989; Visweswara Rao, 1977). Even though empirical solutions may not stand the test of time, various models based on multi-channel system have to be evolved in this direction so that the error would be minimised. It is, however, to be remarked that as long as collection of sea truth data is required every time for calibration of the satellite imagery data, so long the basic idea of getting the snap-shot (synoptic) picture of the parameter from the sea surface loses its significance. We look forward to ISRO for resolving the specific problems in order to evolve the required synoptic oceanographic data of the coastal waters.

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