STUDIES ON THE NUTRIENT CHEMISTRY OF MUDBANKS

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C E R T I F I C A T E

This is to certify that the thesis bound herewith is an authentic record of the research carried out by SRI. S. MURALEEDHARAN NAIR, under my supervision and guidance in the Chemical Oceanography Division, School of Marine Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Ph.D. degree of Cochin University of Science and Technology and no part thereof has been presented before for any other degree in any University.

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PREFACE

Coastal environments exhibit varied characteristics influenced by a broad range of conditions. An extensive knowledge of these complex environments is essential in order to maximise the utility of these areas for shelter, transport, food and recreation. This study attempts to describe the unique annually occurring event namely "Mudbank" (Chakara) or better known as "Zones of Bio-Rhythm",confined to the southwest coast of India. A manifestation of coastal zone processes during the southwest monsoon season, this phenomenon has wide ranging implications on fisheries and allied aspects. Thus, the socio-economic status of fishermen and the fisheries resources of India are largely influenced by the presence of the rich aquatic life in these mudbanks. Further, the presence of mudbanks has varied effects on the shore stability and induces coastal accretion/ erosion processes in adjacent areas.

Studies relating to the physical and biological aspects of mudbanks are available but chemical features have not been explained. This thesis attempts to quantify the extent, rate and pattern of nutrient cycling in the mudbank region. The investigations, significant from the view point of both theoretical and practical aspects of nutrient sorption and fractionation processes, are supplemented by data sets on hydrochemical parameters. The study is believed to make a major contribution to the understanding of coastal processes highlighting various aspects of environmental chemistry.

Additionally, research work in mudbank regions have been substantially supported by investigations in nearshore waters and adjoining backwaters; the following papers incorporate the findings from the main study as well as spin-off(s) from subjacent works.

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1. Anirudhan, T.S., Balchand, A.N., Nair, S.M. & Nambisan, P.N.K. 1987 Distribution pattern of salinity and silicon and their inter-relationship in Cochin backwaters. Proceedings of the National Seminar on Estuarine Management, Trivandrum. 26-31.

2. Sathyanathan, B., Nair, S.M., Chacko, J. & Nambisan, P.N.K. 1988 Sublethal effects of copper and mercury on some biochemical constituents of the estuarine clam Villorita cyprinoides var. cochinensis (Hanley). Bulletin of Environmental Contamination and Toxicology. 40, 510-516.

3. Nair, S.M., Balchand, A.N. & Nambisan, P.N.K. 1988 On the determination and distribution of hydroxylated aromatic compounds in estuarine waters. Toxicological and Environmental Chemistry. 22, 203-213.

4. Balchand, A.N., Nair, S.M. & Nambisan, P.N.K. 1990. A survey of the protein content in estuarine waters. Toxicological and Environmental Chemistry (in press).

SYMPOSIUM PRESENTATIONS

1. Nambisan, P.N.K., Balchand, A.N. & Nair, S.M. 1987 Chemical Oceanographic Aspects of Mud Banks - A unique coastal phenomenon along southwest coast of India. XIX IUGG Symposia, Vancouver, Canada. Proceedings - IAPSO OPS9A-P7.

2. Balchand, A.N., Nair, S.M. & Nambisan, P.N.K. 1987 Occurrence of unique seasonal phenomenon along western south coast of India - Theories and perspectives of Mud Banks. XIX IUGG Symposia, Vancouver, Canada. Proceedings - IAPSO OPS7-P18.

3. Nair, S.M., Balchand, A.N. & Nambisan, P.N.K. 1987 Transport of sediment - associated nutrients in a tropical fluvial system. XIX IUGG Symposia, Vancouver, Canada. Proceedings-IAHS HW 6d - P5.

4. Nambisan, P.N.K., Balchand, A.N. & Nair, S.M. 1988 Particulate related processes controlling trace metal distribution in tropical estuaries. Presented in the Symposium "Fate and effects of toxic chemicals in large rivers and estuaries", Quebec City, Canada.

5. Nair, S.M., Balchand, A.N. & Nambisan, P.N.K. 1988 Metal levels in recently deposited sediments of Cochin backwaters. Presented in the Symposium "Fate and effects of toxic chemicals in large rivers and estuaries", Quebec City, Canada (under publication in Science of the Total Environment).

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CHAPTER - 1

INTRODUCTION

The coasts, the confluence of land, sea and atmosphere are most susceptible to environmental changes on the earth. This region is generally reckoned as a strip of land of variable width that extends from the low-tide line on land to the first major change in landform features.

King (1979) on the basis of tectonics, classified coasts into three main types, viz, the trailing margin (eg: the coasts of western Europe and Africa), the marginal sea coast (eg: coast of eastern Asia) and collision margin (eg: coast of western South America). While Inman & Nordstrom (1971) based on morphology, classified them as mountain coasts, narrow shelves coasts and wide shelves coasts, Davies (1964) classified them into storm wave coasts, west and east coast swell wave coasts and low energy coasts. However, the most widely known and accepted classification is that of Shepard (1963) who classified them into two principal categories, namely primary coasts and secondary coasts.

West coast of India

The west coast of India is believed to have been evolved during the Mesozoic era. However, the sub-continent seems to have acquired its outline only the end of the Cretaceous period. The Quilon Beds indicate that a marked marine transgression seems to have taken place in the southwest coast of India during Burdigalian time (upper part of Lower Miocene). The elevation of the Tertiary sequence of formations known as the Quilon Beds & Warkalli Beds and their forming cliff sections as at Varkala, Cannanore etc. point out that the Kerala coast line took its present shape during post - Pliocene (Quaternary) times.

The present day south west coast of India (Figure 1) is characterised by broad strand plains intercoupled with cliffed shorelines with or without beaches. It is highly irregular, cliffed and wave eroded. Nearly 360 km out of 560 km of Kerala coast is vulnerable to

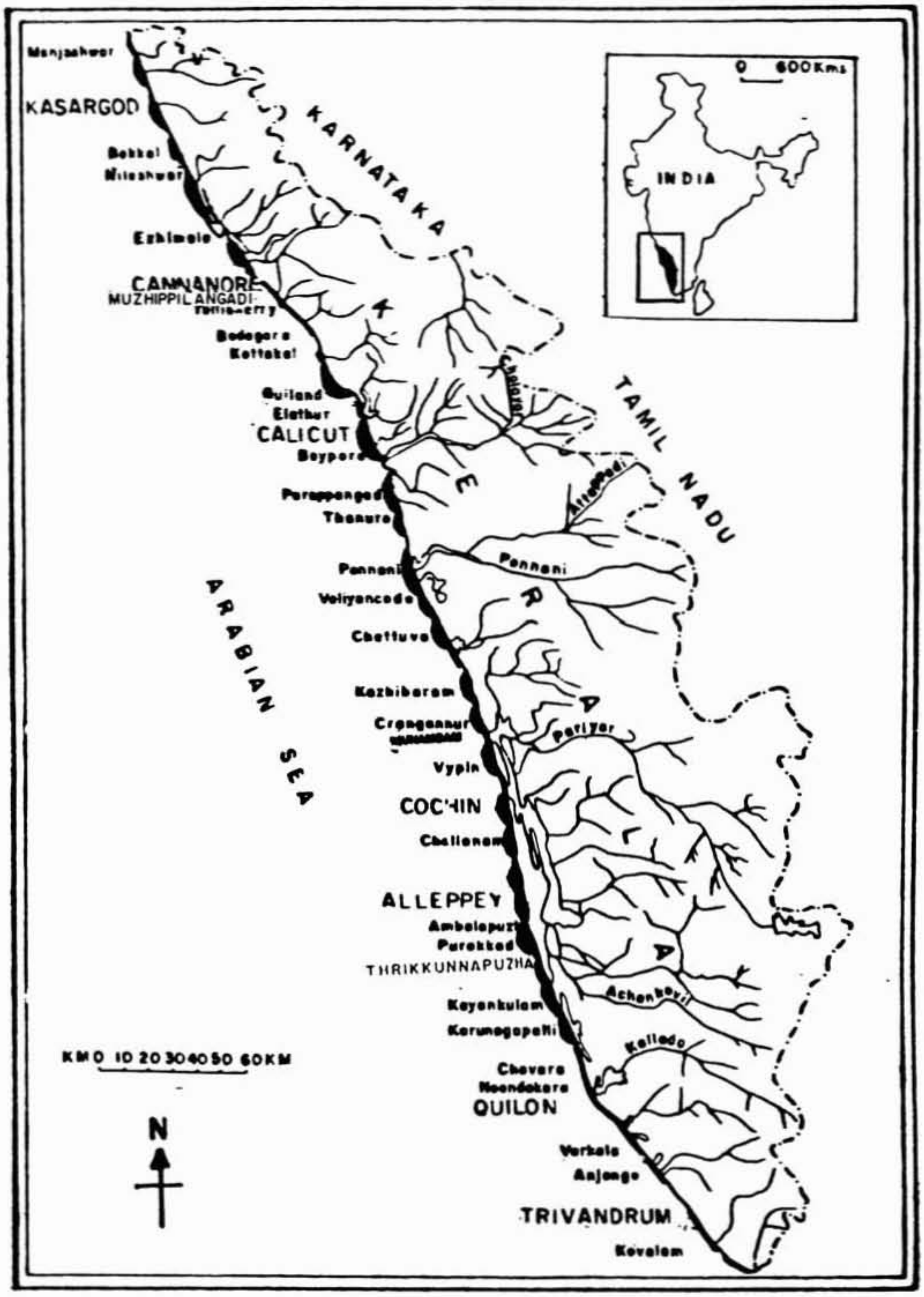

Figure 1. Southwest coast of India(Kerala coast) showing location of mudbanks

erosion during southwest monsoon. A number of known factors like seasonally reversing oceanic circulation currents, wave climate and presence/absence of mudbanks, influence the shoreline features. The generally straight coastline, trending NNW-SSE has a number of fault lineaments - some of them neotectonically active. A number of fluvial terraces along the banks of west flowing rivers, submerged shore flatforms at headland portions, formations of lagoons across the bounding bars and truncation of beach ridges are suggestive of neotectonic movements (Nair, 1987). Secondary control on shoreline development is exercised by the erosional/depositional factors. Straight line coasts are sandy permeable stretches while the crystalline shores assume irregular outline. The west coast shoreline is considered to be fluctuating which reportedly lost 600 m wide belt of coastal area during this century (KERI, 1971). The coast is described as "a submergent coast belonging to the category of terrigeneous coast of primary morphologic disequilibrium" (Garner, 1974). Hence towards attaining equilibrium, the long term tendency may be to increase the linear extent of erosional segments compensated by intervening depositional areas.

Coast of Kerala

The Kerala State has an area of 38, 860 km^2 ($8^{o}15'$ - $12^{o}45'$N; $75^{o}52'$ - $77^{o}08'$E) with a coast line of length 560 km. More than 20 rivers, cut the land surface of this coastal land. This coast falls under the category of "trailing edge" (Inman & Nordstorm, 1971) indicating relatively high sediment yields during the monsoonal climate. The features identified include beaches, beach cliffs, stacks, islands, shore platforms, spits, bars, beach ridges, estuaries, lagoons, mudflats, tidal flats and deltaic plains (Nair, 1987). A peculiar feature of the Kerala coast is the formation of mudbanks during monsoon; disturbing the equilibrium conditions of the coast adjacent to them (Srinivasan _et al_., 1980). Thrivikramji (1979) classified the shorelines of Kerala state as: strand plain shoreline, cliffed shoreline without a beach and cliffed shoreline with a beach. The wave and beach characteristics show that the direction of littoral drift is towards south in June and July months and towards north during other months (KERI, 1978).

General characteristics of mudbanks (Zones of Bio-Rhythm)

The formation of mudbanks triggers an active fishery season in the coastal environments of Kerala. The mudbanks generally occur on the alluvial belt of the coast extending from Thrikkunnapuzha to Cannanore over a distance of 270 km which is more significantly characterised by backwaters of Kerala: the coastal land between these regions is low and sandy with promontories and stacks (Nair, 1983). The mudbanks appear most often a week or so after the onset of the southwest monsoon. The phenomena brings about suspension of sediments in a semicircular region, affording calm and turbid waters. A seaward extent of 5 to 6 km and alongshore extent of 4 to 6 km have been recorded. The banks are laden with heavy suspension of fine clay (90% of $<6\ \mu$) at surface and highly viscous bottom sediments of unconsolidated ooze-like liquid mud (80% of $<10\ \mu$). The suspended load content varies from 1000 to 1800 mgl^{-1}. The fine clay is characterised by soft, plastic touch, dark greyish green in colour with an oily appearance.

As many as 27 locations (Figure 1) were identified where the mudbanks had appeared sometime or other along the Kerala coast; this has been classified into three regions, viz. the southern strip (Thrikkunnapuzha - Alleppey), the Central strip (Chellanam - Munambam) and the northern strip (Calicut north pier - Muzhappilangadi) (Nair, 1983). The lagoon barrier complex is backed on the shoreside of the first two strips whereas the third is backed by lateritic terrain surrounded within Korapuzha and Kallai river systems (Nair, 1983).

Historical account of mudbank studies

The occurrence of mudbanks, centuries old, is evidenced from the reports of mariners, as these regions provide safe and smooth anchorage even in the gales of the southwest monsoon. Alternatively, various terms have been used in regional languages to denote this phenomena viz. Chakara or Santhakara (quite shores) or Ketta Vellam (stinking water). Navigators often consider the area as calm water anchorage.

Mudbanks along the southwest Indian coast was first mentioned as far back as 1678 in Pinkerton's "Collections of Voyages and Travels" appearing in the "Administrative Report of 1860 of Travancore" (India). The term "Mud Bay" has been applied by Captain Cope (1755) to denote Alleppey mudbanks in his book, "A new history of the East India". Crawford (1860) first gave an explanation that the bank of mud is created by the hydraulic pressure caused by the level of water in the vast backwaters, during monsoon, some 4 feet higher than the sea level. Crawford & Logan (1882) noticed the "mud volcanoes" or "mud cones" bursting up in the sea during the rainy season. Later, Philip Lake (1889) and Davey (1903) too observed mud cones at Alleppey. King (1884) in his report "considerations on the smooth - water anchorages of mudbanks of Narakkal and Alleppey on the Travancore Coast (1881)", discussed the migration and formation of the mudbanks between Alleppey and Purakad and between Cochin and Narakkal. John Rhode (1886) confirms the earlier observation of Crawford (1860) on mud volcanoes bursting up in the sea during the rainy season, which appeared "as if a barrel of oil had suddenly been started below the surface".

R.C. Bristow, founder of the Cochin Harbour, made an organized attempt to study the mudbanks in his book "History of Malabar Mudbanks" (1938), published in two volumes (Volumes I and II). He also details his exhaustive observation on the origin, formation and other features of the mudbanks in this book.

Theories on Mudbank formation

Various theories stated by different workers from time to time are briefly summarised hereunder. More details on the theories are available elsewhere (Kurup, 1977; Murthy et al., 1984)

1. Subterranean channel flow

Crawford (1860) explained the formation of mudbanks as due to the flow of accumulating water with vast quantities of soft mud from the inland rivers and backwaters through the subterranean channels into the sea. King (1881), in his report, made a suggestion that the position of banks within certain ranges of the coast, is entirely due to the discharge of mud from under the lands of Alleppey-Purakad and Narrakkal, this being effected by the percolation or underground passage of lagoon water into the sea. John Rhode (1886) explained the flow of mud and water as due to the hydraulic pressure developing in the backwaters during heavy rains in the southwest monsoon period. Captain Drury (1903) supports the above views on subterranean channel flow.

Ducane et al. (1938) is of the view that since the narrow strip of land separating the backwaters from the sea is a low-lying area, the increase in pressure is restricted to a maximum value of 21 lbs/sq inch for a maximum possible rise of water-level of 5 feet in the lake; above this level water will overflow. This pressure may not be sufficient to overcome the frictional resistance set-up by solids in suspension.

2. Water bearing stratum

Bristow (1938) opined that the theory as to the existance of an "underground river" which is made operative by a rise in the backwater level and is of sufficient stability to convey and discharge backwater mud or silt, roots of trees etc. into the ocean, appears to be highly doubtful. He proposed that a water bearing stratum exists at a good depth below the surface which brings down water from the hills and crops out under the sea at varying distance from the shore, thereby lifting the mud above it.

3. River deposition

Ducane et al. (1938) proposed that the mudbanks were formed by the churning up of clay and silt near the coast which were deposited gradually by the discharges of rivers during the monsoon period.

But this theory could not hold good for the formation of mudbank near Alleppey where there is no river or backwater emptying into the nearby coastal area.

4. The upwelling phenomena

Banse (1959) suggested that the southwest coast of India is a region of upwelling during monsoon season. Ramasastry & Myrland (1959) suggested that the formation of mudbank can be accounted as due to the upwelling during the southwest monsoon, which produces vertical acceleration with resultant lifting of bottom water/mud. According to them, the presence of upwelling is restricted to 20-30 m bathymetric lines of the coastal lines.

However, the presence of upwelling at such depths, does not help to explain the formation of mudbank from shore to 10 m depth, unless there is some other mechanism in the region of the bathymetric difference of the locations of the two processes (Murthy et al., 1984). Further the upwelling should commence from the bottom, so that the mechanism can operate and lift the bottom mud. Ramamirtham & Rao (1973), pointed out that the upwelling is all along the southwest coast, while mudbanks are limited to only certain regions.

5. Phase phenomena

Recently Murthy et al. (1984) proposed a hypothesis based on the relative fraction of the mud entering into three stages, namely, the thixotropic phase, the solphase and the gravity-influenced suspended stage. The theory also explains other characteristics of the mudbank region, such as longevity, intensity of calmness and stability of mudbank. Accordingly, the higher grade of calmness observed at the Alleppey mudbank is due to the richness in the first two fractions of the mud. They also suggested that towards the end of monsoon, in the absence of fresh supply of mud into the water column, the already available mud fraction which increases viscosity, gradually diminishes and thus, the mudbank dissipates.

Mud(Re-) suspension and the calmness in mudbanks

Different hypotheses were put forward in order to explain the two peculiar characteristics, viz. the mud(re-) suspension and calmness, observed in the mudbank areas. They may be summarised briefly as follows (Kurup, 1977; Murthy et al., 1984 have reviewed these aspects in detail).

1. Oil as a calming agent

King (1881) pointed out the presence of oily matter in the Alleppey mud, derived, perhaps, in part from the decomposition of organisms, but principally from the distillation of oil in subjacent lignitiferous deposit belonging to the Varkala strata. He attributed the damping of waves in the mudbank region as due to the presence of oil in the mud. But Keen & Russel (1938) later ruled out the possibility of any such oily matter in the muds at Alleppey.

2. Elastic nature of mud as calming agent

The elastic or springy nature of the mud absorbs the wave energy, as waves pass over it by alternative contractions and expansions, so as to bring them to rest (re-emphasized by Murthy et al., 1984). Keen & Russel (1938) had discarded this theory as the primary characteristic of any mud is plastic and not elastic.

3. The deflocculation processes

Keen & Russel (1938) found that the mud of the mudbank remains suspended (deflocculated) at lower salinity. This hypothesis was adopted by Kurup (1969) and Padmanabhan & Eswara Pillai (1971) in order to explain the high load of suspended solids.

4. Thixotropic effect

Keen & Russel (1938) have suggested that the wave damping effect (calming effect) of waves on the banks was due to the thixotropic properties of the mudbank mud. One of the condition, i.e. the loss of an electrolyte mentioned in the definition of thixotropy by Kerr et al. (1970) is well accounted by the decrease in the salinity during mudbank period and the other condition, i.e. a sudden shock, may be the decrease in temperature and change in features of monsoonal waves and coastal currents.

5. Rip current formation

Varma & Kurup (1969) said the rip flow, carrying fine offshore sediments, prevents the onshore transport of sediments by waves. Hence localisation of suspended sediments take place at the rip head. They also suggested that the rip currents carry low salinity nearshore water towards offshore, thereby dilutes the water of the mudbank and this will help the deflocculation of sediments in suspension. Reddy & Varadachari (1972) have also reported the presence of converging littoral currents at several points along the Kerala coast during the southwest monsoon season which result in rip currents.

However, Gopinathan & Qasim (1974) observed no strong rip currents either before or after the mudbank becomes active, because the converging waves at the mudbank get some what dampened and the coastal currents in this region are always stronger than any rip current that might be produced as a result of wave breaking at an adjacent area.

Migration of mudbanks

A number of workers have noted the migratory behaviour of mudbanks (Ducane et al., 1938; Ramasastry & Myrland, 1959; Varma & Kurup, 1969; Gopinathan & Qasim, 1974; Nair, 1983 etc). Murthy et al. (1984) suggest that in the case of mudbanks of Alleppey, it moved from the place of incidence by about 0.5 to 2 km, year by year southward and this was due to the gradual discharge of mud by the southerly flow of the water. This movement continued till the beginning of the northeast monsoon winds, and the subsequent reversal of the southerly drift, when conditions had already set in for the dissipation of the mudbanks. Kurup (1977) suggests that the movement of any mudbank is the result of changes in the location of rip flows which is determined by changes in the refraction pattern caused by changes in the bathymetry and in the spectrum of waves approaching the shoreline.

Implications of mudbanks

The formation of mudbanks have wide and varied environmental impacts. The socioeconomic life of fishermen and fisheries resources of the State of Kerala are largely dependent on the rich aquatic life in these mudbanks. Gopinathan & Qasim (1974) called the mudbanks as "God's gift given to Kerala fishermen". The mudbanks are considered to be a "boom" for fisherman, as the calm area, abound in prawns, sardines, mackerel, soles etc. provide a temporary fishing harbour in which it is possible to do fishing by indigenous crafts during the southwest monsoon period, when the sea is highly turbulent elsewhere. Gopinathan & Qasim (1974) suggested that the viscous stirring up of mud by the wave action probably forces the fish and prawns to move upwards. Further, the upwelling effects prevailing along the Kerala coast, force fish and prawn to move towards the shore to avoid the oxygen deficient waters (Sankaranarayanan & Qasim, 1969). This condition, in conjugation with the southerly surface drift, may bring shoals of fish and prawn more towards the shore, close to the mudbank (Gopinathan & Qasim, 1974). Biologically, the migration of fish and prawns towards the mudbank could also be for feeding purposes as the mudbanks provide a richer source of food than the adjoining sea.

The presence of mudbanks have varied effects on the shore stability and induces coastal accretion/erosion processes in adjacent areas. The effect of mudbanks on the coastal processes is summarised by Moni (1971): (1) traps the littoral material from the updrift side and thereby prevents its down coast movement (2) causes refraction and diffraction of waves on its sides and (3) causes accretion of the beach within the mudbank areas.

However, Padmanabhan & Easwara Pillai (1971) explained the influence of mudbanks in relation to erosion processes. The material trapped within the mudbank cannot reach the downdrift side owing to the absence of waves in this area, so that the shore immediately on the downdrift side gets eroded to make up the deficiency.