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STATUS REPORT
ON
HYDROLOGY OF DELTAS & EAST COASTAL REGION

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PREFACE

The status report on 'Hydrology of deltas and east coastal region of India' is prepared as part of UNDP assisted project IND/90/003 'Developing capabilities for hydrological studies'.

The importance of the science of hydrology in the proper and systematic development of nations water resources is realised off late in the country. The regions hydrological problems are not yet properly understood and hence no scientific remedial measures are studied and implemented in a proper way. The recurring catastrophic effects of the excess or deficiency of water on the development of the society has brought to light the importance of understanding the hydrology of the region.

In the status report an effort is made to highlight different hydrological problems of the coastal and deltaic regions. The methodologies developed in other parts of the world to understand and mitigate the problems of similar regions are presented. The geology, physiography, drainage, climate, vegetation and different weather phenomena of the region are presented. The literature available in different sources is referred, especially 'India: A regional geography' edited by R.L. singh, is consulted for basic information. The authorities of different state governments of the region are contacted for the supply of relevant information.

The author wishes to thank all those, who directly or indirectly helped in preparing this report. Thanks are due to Dr. Satish chandra, Director for giving the opportunity to work on the report; Dr.P.V.Seethapathi, Sc'F', Co-ordinator and Head for his invaluable guidance. Thanks are also due to the author's colleagues and other staff of the Regional Centre for their help in bringing out the report.

1.0 INTRODUCTION:

Hydrology of deltas is the science of water in ancient and modern deltas emergent or in sub-surface and it deals with the processes by which river deltas are formed and the role of deposits after burial as components of groundwater reservoirs. Other topics involved in hydrological studies are geochemistry of interstitial waters in the deposits, geophysics of water-sediment relations and hydrodynamics of aquifer systems (Jones, 1969).

Delta is a deposit of sediment at the mouth of a river or tidal inlet. According to Mc Graw-Hill encyclopedia on science and technology the name, from the Greek letter ' ', was first used by Herodotus, in 5th century B.C, for the triangular delta of the Nile river. While over 150 major deltas are formed today, not all rivers, or even all major rivers, have deltas. This is the result of a rise in sea level following the last glacial period, which produced deep estuaries in many parts of the world which have not yet been filled (for example, the Amazon estuary). Deltas are the places where big cities and large concentration of population are found throughout the Globe. All the deltas face so many engineering problems: like shifting and extending of shipping channels; lack of firm footing except on levees; steady subsidence, which may reach a rate of 5 feet per century; poor drainage and extensive flood danger; scarcity of fresh drinking because of progress of salt water intrusion; tendency of the mainflow to shift away to entirely different areas creating a constant problem for water traffic. Submergence to a depth of 5m during hurricanes or cyclones is not uncommon in deltas. To mitigate these problems it is necessary to understand the formation of a delta.

National water policy, 1986 states that water is a prime national resource, a basic human need and a precious national asset. It emphasizes the necessity of non-structural measures for the minimization of flood havoc, like flood forecasting and warning and flood plain zoning as to reduce the recurring expenditure on flood relief. There should be a master plan for each flood prone basin. Also it states that the erosion of land, whether by the sea in coastal areas, by river waters inland should be minimized by suitable cost-effective measures. The policy states that for effective and economical management of water, the frontiers of knowledge need to be pushed forward in several directions by intensifying research efforts in areas like hydrometeorology; assessment of water resources; groundwater hydrology; prevention of salinity ingress; water harvesting; evaporation and seepage losses; river morphology; and improvements in operational technology.

Coastal zones often contain some of the most densely populated areas in the world. The areas close to rivers and deltas generally present the best conditions for productivity. The demand for fresh water resource easily exceed available resources in areas not directly fed by the rivers. The coastal zone, as the transition area from land and sea, and from fresh water to salt water, contains some of the world's most biologically productive units, the estuaries being the key element (Teal and Teal, 1971).

Associated with man's activities are his uses, and in many instances abuses, of coastal resources. By the year 2000, it is assumed that more than three quarters of the world's population will be at or near the coast, and will draw heavily on the already stressed coastal environment. Custodio (1987) stresses that surface- ground water relationships can not be neglected. Estuarine and groundwater outflow areas have a dilution effect of sea water salinity that affects aquatic life. River use, groundwater exploitation, urbanization impact on surface runoff and groundwater recharge modify the dilution pattern and affect aquatic life accordingly. Also marshes pose interesting problems of soils, cultivation, wildlife and disease control where groundwater outflow may have a dominant role.

Not only is water a major component of the coastal zone, but sand and gravel are also important elements. Dam construction, reforestation and deforestation, agricultural development, urbanization, land erosion control programs, water transportation, river channelization, sand and gravel extraction, etc., have a great effect on the solid transport and equilibrium of coastal areas, especially beaches. Sedimentology is as important as hydrology and hydraulics.

2.0 HYDROLOGY OF DELTAS - AN OVERVIEW

Hydrology of deltas is the science of water in ancient and modern deltas emergent or in sub-surface and it deals with the processes by which river deltas are formed and the role of deposits after burial as components of groundwater reservoirs. Other topics involved in hydrological studies are geochemistry of interstitial waters in the deposits, geophysics of water-sediment relations and hydrodynamics of aquifer systems (Jones, 1969).

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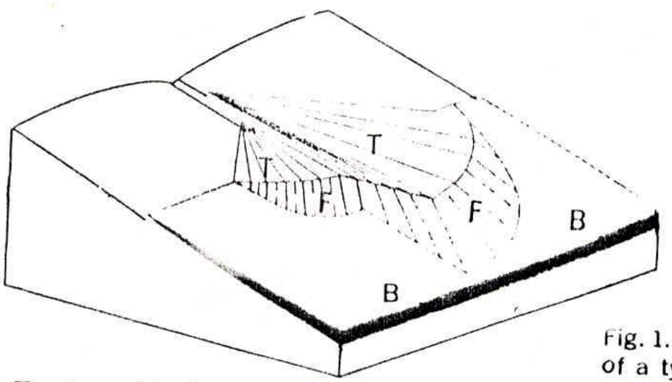
2.1 Structure and growth:

The shape and internal structure of a delta depend on the nature and interaction of two forces: the sediment carrying stream of a river, tidal inlet or submarine canyon and the current and wave action of the water body in which the delta is building. In the interaction of these forces complete dominance of the sediment carrying stream may cause formation of a still water delta or complete dominance of currents and waves may result in redistribution of sediment over a wide area and no delta is created. This interaction has a lot of role to play in the shape, structure and survival of the delta.

Most of the sediment carried into the basin is deposited when the inflowing stream decelerates. If there is little density contrast, this deceleration is sudden and most sediment is deposited near the mouth of the river. If the inflowing water is much lighter than the basin water, for example, fresh water flowing into a colder sea, the outflow spreads at the surface over a large distance away from the outlet. If the inflow is very dense, for instance, cold muddy water in a warm lake, it may farm a density flow on or near the bottom, and the principle deposition may occur at a great distance from the outlet. However, not all long-distance transport of river sediment in the sea can be attributed to deep density flow; almost half of the total load of the Amazon River is deposited more than 1600 km away near the Orinoco delta and in the southeastern Caribbean because of long shore transport by currents and waves.

Three principle components make up the bodies of most deltas in varying proportions: topset, foreset and bottomset beds. They were defined originally by G.K. Gilbert for lake and shallow marine deltas; there, sizable differences in the depositional slopes of the three units, which form part of the definition, are readily seen (Fig.1). The concept has been redefined to apply to



T = topset beds
F = foreset beds
B = bottomset beds

Fig. 1. Schematic diagram showing two stages of growth of a typical Gilbert-type delta. (*Adapted from P. H. Kuenen, Marine Geology, Wiley, 1950*)

most deltas, and as now understood, the topset beds comprise the sediments formed on subaerial deltas: channel deposits, natural levees, flood plains, marshes, and swamp and bay sediments. The foreset beds are those formed in shallow water, mostly as a broad platform fronting the delta shore, and the bottomset beds are the deep-water deposits beyond deltaic bulge. In marine deltas the fluvitile influence decreases and the marine influence increases from the topset to the bottomset beds. Concurrently, the mean grain size and lithological variability also decrease. The topset beds are variable in grain size and composition over short distances, ranging from course channel deposit, through layered levee silts and clays to the fine clays of the floodplains and marshes. The foreset beds consist of a uniform blanket of laminated silts and silty clays reflecting the seasonal influence of currents and waves on the shallow platform, while the bottom set beds are homogeneous silty clays, often characterized by abundant plant fragments. The boundary between bottomset beds and neritic shelf clays is completely arbitrary. Similarly the faunas incorporated in the sediments range from great local variability in the topset beds, with dominance of barren sediments and local pockets of rich brackish faunas, to the almost completely marine fossils uniformly distributed in the bottomset beds.

In a different way , deltas can be viewed as being composed of three structural elements: (i) a frame work of elongate coarse bodies (channels, river-mouth bars, levee deposits), which radiate from the apex to the distributary mouths (sand fingers); (ii) a matrix of fine grained flood plain, marsh, and bay sediments; and (iii) a littoral zone usually of beach and sand dunes which result from sorting and long shore transport of river mouth deposits by waves, currents, tides and wind. The relative proportions of these components vary widely. The Mississippi delta consists almost entirely of frame work and matrix; its rapid seaward growth is the result of deposition of river mouth bars and extension of levees, and the areas in between are filled later with matrix. This gives the delta its characteristic bird-foot outline (Fisk et al, 1954). A different make up is presented by the Rhone delta, where the supply of coarse material at the distributary mouth is slow, and dispersal by wave action and long shore drift fairly efficient, so that nearly all material is eventually redistributed as a series of coastal bars and dunes across a large part of the delta front. This delta advances as a broad lobate front, while the present Mississippi delta grows at several localized and sharply defined points.

2.2 Destructive phase:

Through progressive out building, the delta can become over extended with long river courses and very low gradients. Eventually, shorter and steeper paths to the sea will be developed and the existing subdelta will be abandoned in favour of a shorter course. The Mississippi delta shows good example of such subdelta migration, and the present active delta would be abandoned for a new one off the Atchafalaya river, if the artificial control did not keep the flow in check. The abandoned delta body gradually submerges and is eroded by waves and wind. The submergence results from two factors: temporary continuation of subsidence caused by loading of deltaic sediments on the substrate, and compaction of the fine sediments. These are over compensated during delta growth, but cause it to sink below sea level after abandonment. Winnowing of the sediments by waves produces a lag deposit of sand at the advancing edge of the sea, which ultimately results in a thin and discontinuous blanket of sand, often bordered by a string of sand bars and small islands near the previous shore. This sequence is called the destructive phase of delta formation.

The literature available on hydrology of deltas is very limited. Under IHD, a symposium was organised by Unesco with the collaboration of Rumanian government and with the support of IASH in 1969 at Bucharest. The views expressed at the symposium are briefly listed below:

The formation of the hydrographic network of non-tidal deltas with large sediment discharges is connected with the breaking of natural levee within the delta or with the formation of the delta fan in the sea. The complete cycle includes four stages: the lacustrine stage, the many branched stage within the delta, the single branched stage and the many branched stage at the delta fan in the sea. The duration of each stage depends on the amount of sediment transport, on the possibility of sedimentation in a flood plain or on the possibility of sedimentation at the place where the river flows into the sea. The variability of channel processes, the profile of the water surface and the water discharge distribution between the branches are studied as well as the influence of man made levees and of base level change on the processes and the duration of the cycle and its stages (Baydin,1969).

The hydrological and morphological characteristics of non-tidal delta branches are considered and the analysis of factors determining the variability of these in time and space is made by Mikhailov (1969).The hydrometric and hydromorphometric methods of calculation of these characteristics are examined. The first method is based on graphical relationships of branch characteristics in individual cross-sections with water discharge at the top of the delta (or in individual branches) and sea level near the delta front. In the second method hydro-morphometric relationships connecting all characteristics of delta branches at bankful discharge are used. The theoretical inference of these relationships is drawn. The parameters of these relationships are determined by analysis of the observational data. The hydromorph-ometric relationships may be used for determination of the tendency towards evolution of delta branches.

Hydrological processes in offings and their role in formation of a delta front are presented by Skriptinov (1969). The offing is a component of the mouth area. The factors determining the offing type and main factors determining the offing regime are considered together with the hydrological processes (water levels, currents, turbidity, salinity, ice conditions, waves etc.,). The influence of hydrological conditions in the offing on the hydrological and morphological characteristics of delta branches is discussed and changes in hydrological conditions under man-made structures are also considered. The delta front as a result of interaction between river and sea is the most dynamic type of the shore. The factors determining the formation of the type of delta front are given in particular for development of delta fronts with a prevalence of sea factors and with a prevalence of river factors. The seasonal prevalence of river and sea factors is the reason of cyclic evolution of delta fronts. The role of man's activity in changing of delta front and delta bar is considered and the possibility of the forecasting of the type of delta front with an artificial mouth is considered.

Skriptinov concludes that the delta front is formed under the influence of fundamentally different factors, river factors (water and sediment discharge) and sea factors (waves, currents, longshore sediment flow). In a river mouth with small sediment discharge at a deep offing sea factors are prevalent, and at a shallow offing river factors are prevalent. The delta front assumes a configuration relevant to the value of the river sediment discharge, coarse alluvium, wave and current regime. Different water use and hydrotechnical arrangements in the river basins and in their mouths result in irreversible processes in the offing hydrology, reformation of the bar and delta front and, sometimes of the coastal areas adjacent to them. The modern development of techniques allows, even now, changing of hydrology and morphology of river mouth regions in the good interests of mankind.

Spataru et. al., (1969) presented a model study of the effect which different construction schemes could have on the river flow at its mouth, on the salt water wedge and the bar position. The necessity of using models with both fresh and salt water is underlined.

Simonov (1969) considered the transformation of river waters to sea waters at river mouths. The experimental results of dynamic and chemical interaction between river and sea waters at the mouth (energy, suspended solids, heat discharge, slight mineralization and salt balance) are considered. The river discharge is the leading and permanent factor of water mixing. Chemical exchange accompanies the dynamic mixing. The low change of flow velocity, salinity, turbidity and water temperature during mixing at the offing is established. The general equation of mixing includes a linear component to reflect dynamic mixing conditions and a non-linear component to reflect chemical transformations. The law of transformation of salt composition typical of river water to that typical of seawater is established. This transformation of salt composition is independent of the salinity of seawater. These laws facilitate investigation and explanation of the hydrological and hydrochemical processes taking place of the dynamics of substances relevant to pollution.

The method of hydraulic calculation of channel discharge and water levels in river deltas is discussed by Ivanov (1969). The method is a further development of iteration techniques. It amounts to the determination of discharges in anabranches and water levels in the junction nodes. The method does not require the exact assumption of flow direction in the anabranches. It allows an analytical calculation of the corrections to the stage in the junction nodes and it converges the solution for delta forks of any complexity. The calculation is readily automated. A program of hydraulic calculation of complex braiding of river channels was worked out for an electronic computer of Ural 2 type. The relationship between channel discharge and water level in the zone of tidal and surge back water was investigated by hydraulic theory and electronic computer. A numerical check of the method was carried out on the deltas of the Ob river and the Kolima.

Diaconu and Stanescu (1969) presented the characteristics of water flow inside the Danube delta. The hydrologic regime of the Danube Delta presents some characteristics which have required an original method of investigation. Because of their close interrelation, the morphological aspects have to be considered as parts of the same organic whole. It follows, that the morphohydrographic elements can be divided into two distinct categories: 1) positive elements (soils of predeltaic origin, river and maritime ridges) and 2) negative elements (the hydrographical network and the depressions inside the delta). The depressions inside the delta play an important part as an accumulation basin in water circulation system between the arms and the interior of the delta. Dependent on the volume of the water brought by the Danube, the interior of the delta between the arms is divided into subdepressions during the low water period and depressions during the medium water period.

The waterflow regime in the delta is determined by the variations of the Danube discharges at Ceatal Izmail together with the influence of the Black sea levels and water accumulation inside the delta. The peculiar aspects of waterflow are presented from the quantitative point of view. Both the variations connected with the Danube discharges and the variation of the distribution coefficients of the discharge flowing through the main arms have been determined.

The problem of flooding is also dealt and is tackled by determining the complex relationship between the levels of the arms and those of delta inside. These relationships also take into account a coefficient which expresses the increasing and the decreasing gradients of the levels. Finally, using a map of flood extent, the variation curve of the delta flooded surface, conditioned by the discharges flowing through the arms, was determined. The presentation concludes with the methodology to be applied for the next stage of the delta hydrology investigation, insisting on the necessity for hydrometric activity under a special programme different from the classical one, both in laboratories and in the field so as to agree with the particular aspects of the water flow studied.

Drift dynamics in river estuaries are discussed by Schteinmann (1969). By measuring the natural radio-activity of the drift , the areas of river alluvium on the estuarine sea shore and its displacement are determined. Simultaneous use of radio acoustic recorders, measuring the thickness of the river sediments permits determination of the volume of alluvium washed to the sea shore by river flow. The relationship between the longitudinal profile of the water surface and sediment movement on the seaward side of the river are also discussed.

Quaternary delta deposits of the Mississippi river, together with interbedded marine sediments have a cumulative maximum thickness greater than 4000 m, of which the delta deposits constitute perhaps half. The late quaternary deltaic mass contains almost no fresh groundwater, although streams which cross it carry runoff from 60% of the conterminous United States. This seeming paradox is caused by expulsion of saline waters from incompetent prodelta clay beds overridden by advancing deltaic sediments having a common framework and parent trunk stream source. Distributary channel deposits terminate gulfward in marine clay and join headwards with those of the trunk stream to form an integrated system of conduits, through which water expelled from compacting sediments is discharged upvalley.

Because the delta is still growing, this discharge is continuing. It causes landward movements of saline groundwater which threatens some existing fresh water supplies, and must be considered carefully in any developments of fresh water resources in the delta (Jones,1969).

Shata and Fayoumy (1969) made some remarks on the hydrology of Nile delta. The Nile Delta (22,000 km2), occupying a portion of the gulf area dominating Egypt in Pliocene times, acts as an important reservoir for ground water. In this reservoir, the strata of hydrologic importance are composed of sands and gravels (Plesistocene and Holocene) which have a thickness exceeding 300m. The water contained in such strata (salinity of the order of 500 ppm) exists generally under unconfined conditions and depends for its source upon the surface water of the Nile (main branches as well as the irrigation canals) and upon the intermittent surface runoff of the adjacent desert areas. In this paper all aspects of hydrophysiography, hydrostratigraphy, hydrostructure, hydrochemistry and hydrology of the Nile Delta are discussed.

Deltaic deposits that formed in the Bonnevile Basin in the Great Basin of the United States during Pleistocene, and possibly late Tertiary time, are now important ground-water reservoirs. (Arnow et.al., 1969). Among the largest of the deltas in the Great Basin are those of the Waber and Sevier Rivers which cover areas of about 520 and 910 square kilometers respectively. Each delta contains two principal artesian aquifers, which are recharged by seepage from streams and from other sources. The

Weber and Sevier Deltas are small compared to many ancient and modern deltas, but their size has allowed them to be studied rather intensively. The Weber Delta in places contains fresh water to a depth of about 400 metres. Water in the delta is of three chemical types; two are probably original types, whereas the other may have been derived by ion exchange. The Sevier delta in places contains fresh water to a depth of 370 m. Recharge that has occurred since irrigation began upstream from the delta has resulted in the introduction of slightly saline water that is slowly moving downdip in the aquifers of the delta.

The presence of ground water of various chemical types, some of which are less desirable or unfit for certain uses, such as found in the Weber Delta, could be expected in many deltas. On the basis of knowledge of the hydrology of the Sevier Delta, one might expect eventual contamination of the aquifers in any delta if irrigation is extensively practised upstream from the recharge area of the aquifers.

Rofail and Tadros (1969) modelled the groundwater flow in the Nile delta using the electrical analogue method. The water bearing formations of the Nile Delta can be considered as a two layered aquifer. The hydraulic parameters of the aquifers determined from the analysis of the pumping test data conformed with those obtained by analysis of the water fluctuation in the wells. Accordingly a hydraulic diffusivity map of the Nile Delta is plotted.

The flow through the aquifer of the Nile Delta is simulated by the flow of an electric current through paper of different values of resistivity used as a conductive material. The head of water in the river Nile branches and in the main canals is represented by electric potentials. The Nile Delta basin is considered fully saturated and under hydrostatic pressure controlled mainly by the head in the River Nile branches and in the main canals. Thus the represented potential of the branches and the canals governs the flow through the represented conductive material of the Nile Delta. The points of equi-potential are determined and accordingly the water table map is plotted. The results from the model compared well with those obtained from the actual water table map.

3.0 DELTAIC AND EAST COASTAL PLAINS REGION:

The region is the area on the east coast of India from Ganga river mouth in the north; towards inland by the discontinuous line of hills forming the Eastern Ghats, more precisely by the contours of 75m in Orissa, 100 m in Andhra Pradesh (A.P) and 150m in Tamilnadu (fig.2). Politically, the region includes parts of the states West Bengal, Orissa, Andhra Pradesh and Tamilnadu and the Union Territory of Pondicherry. The West Bengal coastal plain includes the districts of 24 Parganas and Midnapur; Orissa, (Utkal) coastal plain includes small portion of Mayurbhanj, major portion of Balasore and parts of Cuttack, Puri and Ganjam districts; in A.P. the coastal areas of Srikakulam, Vizianagaram, Visakhapatnam, East and West Godavaris, Krishna, Guntur, Prakasam and Nellore districts while in Tamilnadu the whole of Chingleput and Madras, a small part of N. Arcot, most of S. Arcot (except the hilly tracts of Kallakurichich), the whole of Thanjavur, Tiruchirappalli (excluding parts of Karur, Kulittalai and Musiri taluks)and pondicherry and Karaikal areas.

In contrast to the West Coast, these are extensive coastal plains being generally formed by the alluvial fillings of the littoral zone comprising some of the largest deltas (Singh). Along with the Ganga delta, these plains have served as active sea-boards not only for the major political units within which they lie, but also for most of the country since ancient times, even though there is naturally restricted development of large harbors. The people of this region have vigorously participated in coastal as well as overseas trade, particularly with S.E.

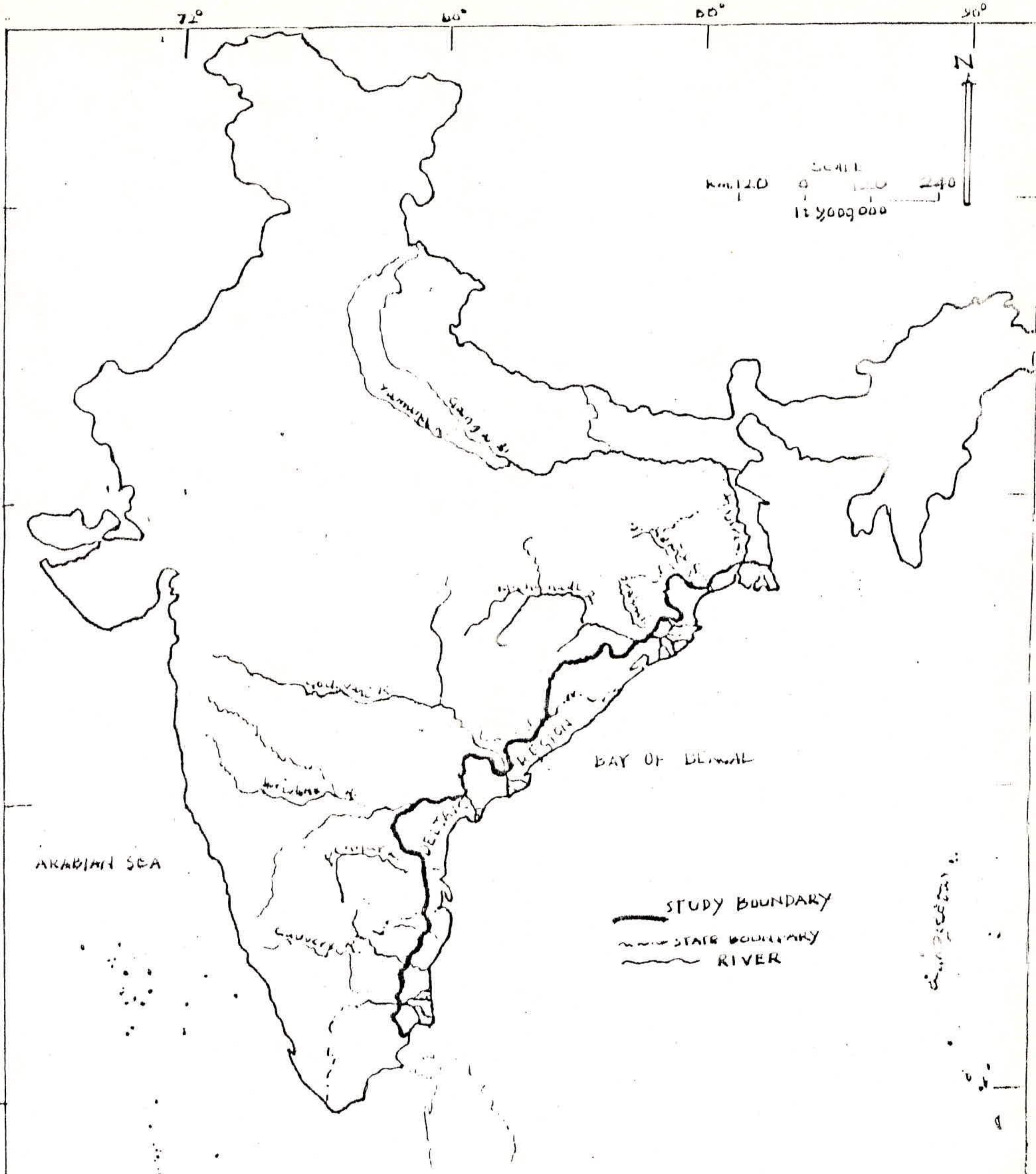


FIG. 2 DELTAIC AND EAST COASTAL PLAINS REGION

Asian Realm and have succeeded in putting the stamp of Indian culture on far-off lands.

3.1 GEOLOGY:

The East Coastal Plains predominantly consist of Recent and Tertiary alluvium. Patches of Archaean gneisses and sandstones etc. are also found along the coast.

In the Orissa Plains, a group of limestones, sandstones and clays occur in the beds of Burabalong river south of Baripada town. Similar beds were also encountered several km southward along the river in well borings. Waterworn specimens of a Lamelli branch referable to the genus Paphia have been found on the foreshore at Puri. Pleistocene alluvium occurs at several places along the coastal tract. Large deposits of laterite occur as capping over Khondalite hills. Such laterite is of in situ origin, while the laterite occurring at lower levels is of detrital origin. The coastal tracts of Balasore, Cuttack and Puri are covered with deltaic sediments of the Mahanadi, Brahmani and other rivers, formed in recent time. The narrow strip of coastal alluvium in Ganjam also belongs to this age.

In Andhra Pradesh, Tertiary formations are found in East and West Godavari districts and in small areas in Nuzvid taluk of Krishna district. Parts of Rajahmundry and Peddapuram taluks in E. Godavari and Eluru, Tadepalligudem and Kovvur in West Godavari contain Tertiary formations of clays useful for the ceramics developed near Rajahmundry. Laterites occur in Kavali, Kovur, Gudur and Sulurpet taluks in Nellore district. Some patches of Laterites are also found in Visakhapatnam district. The Recent deposits occupy the entire coastal plains of A.P. expect in portions between Srikakulam in the north and Visakhapatnam in the south, more in the mainland in Guntur, Krishna, East and West Godavaris.

In the Tamilnadu coastal plains strong earth movements followed by intrusions of basic dykes gave rise to Charnockites in Pallavaram. These rocks contain a high percentage of silica. Several exposures are found in N. and S. Arcot and Chingleput. In Tiruttani the Archaean intrusions were granitic fluids. The close of this era was punctuated by quiescence when schists and gneisses were denuded. The Archaean era was followed by the Palaeozoic era when limestones and dolomites and thin beds of shales were deposited on the edge of the Dharwarian rocks-Cudddapah systems. During the Palaeozoic period numerous dyke intrusions were formed in the Cuddapah system in Tiruchchirappalli, S.Aroct, Tirunelveli and Chingleput. Sandstones of the Gondwana system (Upper) occur at Satyavedu near chingleput and shales in Sriperumbadur.

The Mesozoic period is marked by marine transgression, submerging Pondicherry and the Cauvery valley during early Cretaceous. In Tiruchchirappalli also excellent examples of cretaceous formations have been found. Marine regressions started since mid-Tertiary. Eocene formations have been found in Pondicherry and Miocene and Pliocene formations away from coast in Thanjavur and Karaikal. Upper Pliocene and lower Pleistocene formations are located north of Kanchipuram, consisting of gravels, shingles and grit known as Conjeevaram gravels. The beginning of the Quaternary Era witnessed the emergence of the present coastline. Several parts of SE Coast of Tamilnadu are covered with aeolian formations, sands and sand dunes, particularly in Ramanathapuram and Tiruneveli. Riverain alluvia cover the deltas (Saravanam, 1968).

3.2 PHYSIOGRAPHY:

Topographic expressions in the West Bengal region hardly speak of any well-defined stage of their evolution. The monotonous surface is dissected frequently by the channels of the tributaries or distributaries of the main streams, i.e., the Ganga and the Brahmaputra. This tract of recent alluvium, on detailed investigation, presents at least two areas where the relative relief is somewhat significant (about 12 m to 30m). These are (i) the Malda West Dinajpur tract where the inliers of the lateritic alluvium are sufficient to break the general monotony of this plain; (ii) Midnapur Coast where the sand dunes on the terraces appear to be more significant elements of landforms, though of a micro order. Elsewhere the bils, of the swamps and marshes and the levees are the only remarkable components of the physical landscape.

The tract SW of the Hooghly-Bhagirathi basin has a comparatively shallow basement characterised by a series of sub-surface ridges. This the only belt of pre-cambrain metasediments in the region. The surface is criss-crossed by numerous rivers with meander scars, valley fils, etc. illustrating its complex origin. The coastal landform (Midnapur coast) reveals the effects of the changing sea level and the north-easterly winds sweeping the coast. The old coast-line lies about 1 km inland and the

Digha beach at present is flat and has a straight shore line which, under the influence of the littoral drift, is being eroded away rapidly (cliff erosion). There is hardly any backshore left. The same littoral drift, being parallel, is responsible for the accretion on Orissa coast. As many as four parallel lines of dunes can be observed here, some of which rise to about 13 m above the ground and are 45-75 m wide. These dunes are partly stabilized.

To the east of this shore line lies the deltaic bulge of the Ganga (Sundarbans) where the depositional activity of the streams is prominent and new surface is being Continuously added. The easterly shift of the Ganga (1787) has rendered the area, comprising the district of Nadia and Murshidabad east of the Bhagirathi-Hoogly, a land of dead and decaying rivers. Only in 24-Parganas is delta building still active. Even a 7m high tide is sufficient to submerge the region up to Calcutta (inclusive). The saline water expanses in the vicinity of Calcutta testify the recent withdrawal of the sea and occasional march of the tides in this region. Wihtin this low-lying area the gradient is rather imperceptible.

The general slope of the Lower Ganga Plain, as revealed by the drainage system, is to the southeast which is natural in a hinge zone trending NE-SW. But the sharp southerly turn of some of the rivers in the region can be explained by the postulation of gradual change in basin axis from east-south-east to south-east rather than by the hypothesis of gradual southerly tilt of the delta which would hardly have allowed the easterly migration of the main channel of the Ganga (padma), The Delta proper has a gradient of less than 2cm per km while the areas in the immediate vicinity show gradients up to 40 cm.

The eastern littoral is a wide coastal plain comprising the deltas of the Mahanadi, the Godavari, the Krishna, and the Cauvery (fig.2) and intervening tracts of Tertiary marine sediments, and forms an emergent unindented coast. Between the Subarnarekha in the north and the Kanyakumari in the south, the plains rise gradually from the Bay of Bengal to merge with the irregular alignment of the Eastern Ghats where, roughly, the 150m contour in the south (Tamilnadu) and 75m contour in the northern parts separate the region from the Peninsular Uplands. The coastal plains are wider in the deltaic regions and narrow down in between the deltas and thus the region can be grouped into three sub-regions, the Tamilnadu Coastal Plain, the Andhra Coastal Plain and the Utkal Coastal Plain, being coterminous with state boundaries corresponding with the deltas of the Cauvery, the Krishna-Godavari and the Mahanadi respectively. The plains also have well-defined morphological units parallel to the shore-line.

The region has a remarkably straight shoreline with well-defined beaches of sand and shingles. The most famous beach is the Marine Beach in Madras which is expanding southwards since the construction of Madras harbor. The beach ridges on the Utkal Coast indicate the emergence of the coast. In the continuous stretch of this emergent coast there are archaeological evidences of submergence of Royapuram, Mahabalipuram and parts of the Thanjavur coast where the coast of Kaveripumpattinam was buried.

All along the coast there are several sandbars generally athwart the river mouths as shown by the Adyar, the Godavari and the Mahanadi. Along the strand, the plain of marine and aeolian deposits found up to 10km inland is a zone of sand dunes. These are found at several places throughout the coastal plain and are caused mainly by the action of wind at low-water tide. In the Orissa Plain, Parallel sand dune ridges composed of decomposed granites, zircon etc., brought by ocean currents and winds from southwest, rise 16 to 27m high and are 1-4km long. These are supposed to have originated due to coastal uplift. In puri, the maximum height reached is 9m in some isolated patches near about Puri, but generally they are 4.5 to 6 m high and extend inland. Each of these hills marks an old sea coast indicating the recession of sea. Further south, sand dunes rise 10 to 16 m in the Krishna-Godavari delta region. In Tamilnadu sand dunes form a conspicuous feature along the coast of Tiruneveli and are scattered elsewhere as in Mahabalipuram. They rise 30 to 65 m high and are locally called 'Theris'. They are composed of quartz, ilmenite and magnetite sands with a typical red colour induced due to diffusion of iron grains. The dunes carry a thin vegetation of Palmyra palms and thorny scrub which bind the soil. Some of these move slowly towards east and south-east. The veneer of sandstone indicates an uplift since Pleistocene.

Adjoining the line of sand dunes all along the coast are found lagoons formed recently in association with coastal uplift. The Chilka lake and Pulicat lake areas are the largest and most important. The samang and Sur located north and north-east of Puri are sweet water lakes which have come into existence between the 7th and 8th stage of the delta development. The Chilka lake is located in the southwest edge of the Mahanadi delta. It is 65 km long from northeast to southwest and is wider in the northwest and narrowed only to 8km in the SW. It is the biggest lake in the country and its area varies between 780 sq.km and 1,144 sq.km from the winter to monsoon months. The salinity declines to a minimum during the monsoon but in winter, due to the overflow of the tidal water through the narrow opening from the Bay of Bengal, it is maximum. The lake is shallow in the NE due to heavy silting by detrital matter brought by the Deya and the Bhargavi. It is deep in the SW where the spurs of the Eastern Ghats enter the lake. Further south, on the border of Andhra and Tamilnadu coastal plains, is the Pulicat, a backwater lake. It is cut off from the Bay by a long spit of sand and mud. The tides have free entrance and the water though constantly changing is brackish. Salinity is less in November and greater in summer. This lake, 80km long NS and 3-18 km across, comprises several small islands within it. Further south along the coast are other small backwater lakes like Ennore and Mahabalipuram which are mostly silted up. The backwaters of the sea have also given rise to Marakaran, Veakaranyam, the Mangreni Swamp in Orissa and Lake Kolleru in the Krishna-Godavari delta. Thus, in general, three types of shorelines have developed along the East Coastal Plains- the rocky shorelines appear between the deltas, the prominent stretches being in Ganjam and Vishakhapatnam transverse to the grain of the Ghat ranges; upon the Tertiary gravels have developed the sandy shorelines, while the alluvial and silty deltaic shorelines are found at the mouths of the Mahanadi, the Godavari, the Krishna and the Cauvery.

The coast forms a monotonous plain rising gently westwards to the foot of the Eastern Ghats with wide variations in width. The plains are marked by the deltas and lower courses of mature rivers forming broad shallow valleys. The monotony of the topography is broken by the presence of numerous hills, being more conspicuous in Tamilnadu, especially between the Adyar and Palar rivers. These hills show not only accordant levels but also appear to be strikingly similar in shape with almost pointed summits and rise steeply from an otherwise flat plain. The hills have a distinct NNE to SSW trend forming 3 ridges tending to converge towards the SW where the highest peak is found in Ketchimalai (240 m). Though similar rocks occur to the south and west of the Palar, these hillocks do not show linear arrangement. They are considered to be inselbergs left standing on a flat plain as a result of differential erosion over a low peneplain (Sita,1954). The hillocks in the Mahanadi deltaic region are considered to be outer flanks of the Eastern Ghats. The spurs have extended from Kharao and Delang as isolated dome-shaped hillocks which suggest volcanic origin. The low hills of Baradihi (280 m), Udayagir (188 m) and Kalasiri (261 m) have deflected the drainage of the Birupa and the Kimiria Mai eastwards.

3.3 DRAINAGE:

Drainage system of the West Bengal region is constituted by the tributaries and distributaries of the Ganga and the Brahmpurtra, along with some insignificant systems (the Kasai, the Subarnarekha, etc.) discharging into the Bay of Bengal and draining the south-west part of the region. Conspicuously enough, the Padma and the Bhagirathi, both distributaries of Ganga, delimit the areas prone to the action of the distributaries within the fork and that of the tributaries outside it.

To some extent, more adjusted to structure in their upper, and with aggradational characteristics in the lower reaches, are the streams draining the Rarh Plain notable among them being the Mayurakshi, the Damodar, the Dwarkeswar, the Kasai and the Subarnarekha, the first three belong to the Bhagirathi-Hooghly system. The Damodar and the Dwarkeswar are more active in swinging their courses, and a significant impact of the southerly sweep of the Damodar to join the Hooghly south of Calcutta, about 150 km downstream from its previous confluence, has resulted in the accelerated silting of the Hooghly channel which had already suffered a set-back owing to the eastward migration of the main channel of the Ganga.

The Padma-Hooghly fork is the belt of the distributaries where the to-and-fro swing of the streams associated with other conditions have given rise to bils, baids, ox-bows and marshes. The shifting courses have their significant impact on the human occupance of the region. The ancient centres of trade and commerce like Sonargaon, Satgaon, Tamralipti etc., have lost their significance, and there is constant threat to the Calcutta port and the city as the siltation of the Hooghly is increasing.

The region is endowed with ample ground water resources but their occurrence varies seasonally as well spatially. In the coastal tract, the lower Hooghly-Rupnarain basins and the Barind tract, groundwater remains within 7m from the surface. The depth also increases from east to west (>4m-<13m) south of the Padma. During rainy season, water table rises up to the surface in most of the areas, notably the Sunderban region, the lower Hooghly - Rupnarain basin and the Barind tract. The condition of water table has led to the prevalence of surface and gravity irrigation-cum-surface types of water management.

There is possibility or richer sources of confined aquifers which may be tapped through deep boreholes. With precise assessment and utilization of such waters, in future, seasonal water deficiencies may be made up.

In the West Bengal region irrigation facilities are inadequate. Though the average rainfall is fairly high, yet irrigation is essential for agricultural prosperity due to irregular monsoons and dry winters. Moreover, water balance is adverse in the Lower Ganga Plain region at various intensities. The completion of DVC and Mayurakshi Projects have now provided large scale irrigation. Irrigation from ponds, bils and other sources is more popular in Murshidabad, Midnapur, Howrah. Well irrigation is not so popular.

The main rivers of the region rise from the Western Ghats and owing to long denudation through geological times have almost reached the base level with broad and shallow valleys. Being rain-fed, they remain mostly unsuitable for navigation (Fig. 2).

The Mahanadi in combination with the Brahmani and Baitarani forms extensive alluvial tract stretching from Lake Chilka in the south to Bhadrak in the north, 172 km long and over 80 km wide. The Mahanadi is one of the most vigorous rivers of India though erratic in its discharge.

Most probably the Mahanadi delta (fig.3) developed in 8 successive stages. There was an isostatic change in the coast line which resulted in the emergence of 3 sets of parallel dunes along the coastal which disturbed the old pattern of drainage considerably. A distinctive feature in the growth of the delta is that it has its maximum growth not in the centre but in the northern part. Prior to the formation of the delta, the original shoreline was concave owing to the hard bed rocks in the Eastern Ghats. But this character was very aptly maintained up to the sixth stage of the deltaic growth. It was modified in the subsequent two stages of the delta building due to : (a) the Brahmani joining the Baragenguti and the Birupa (the extreme NE boundary) and (b) the Kharasuan joining the Brahmani further down in the lower reaches. The combined action of the rivers has pushed the delta head to its northernmost limit.

The Mahanadi is subject to heavy flooding, causing immense damage. The combined waters of the Mahanadi, the Brahmani and the Baitarani discharged through a common mouth cause floods to linger on and extensive damage to life and property. The floods of 1896 and 1960 proved very disastrous. 94% of the annual total

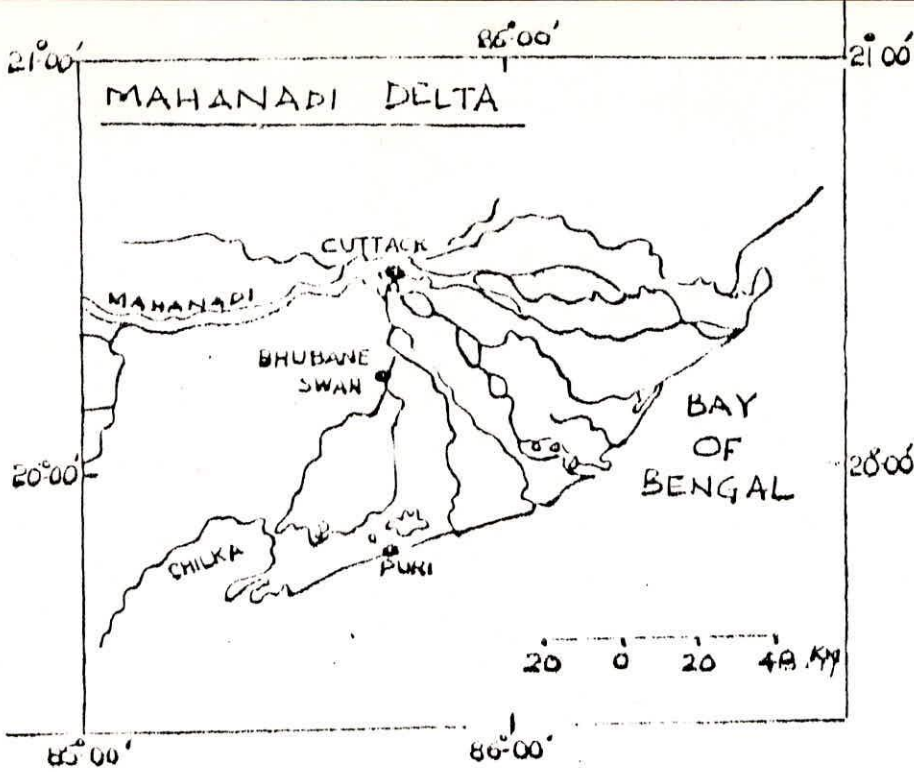

MAHANADI DELTA
CUTTACK
MAHANADI
BHUBANE
SWAR
BAY
OF
BENGAL
CHILKA
PURI
20 0 20 40 KM
21°00'
20°00'
86°00'

FIG. 3

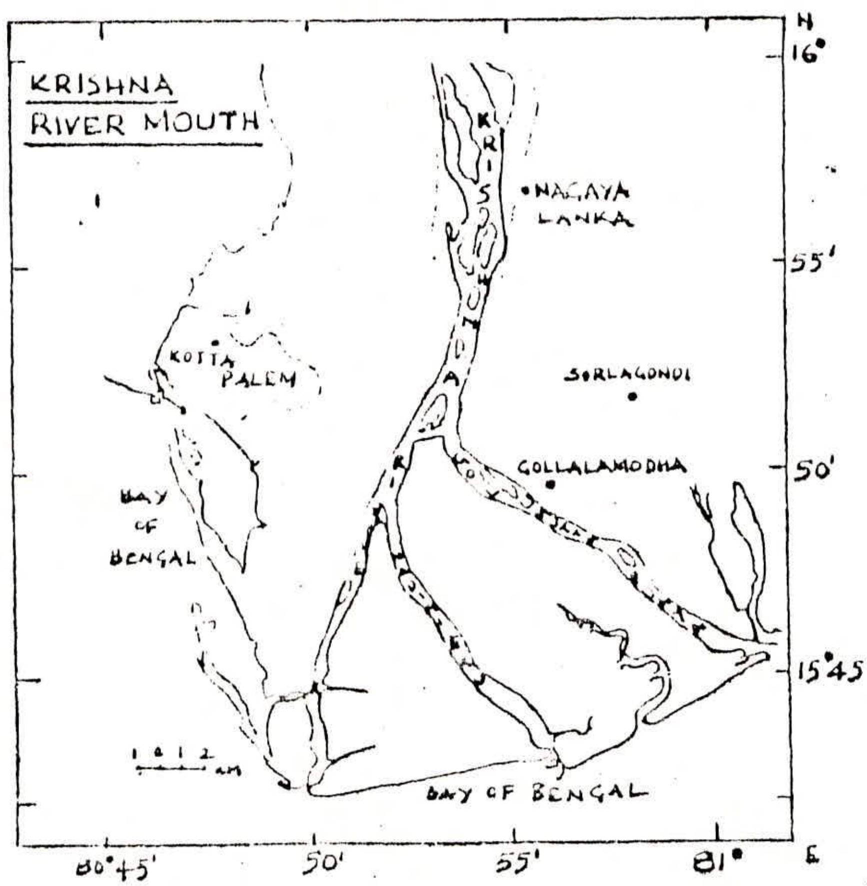

KRISHNA
RIVER MOUTH
NAGAYA
LANKA
KOTTA
PALEM
SORLAGONDI
GOLLALAMODHA
BAY
OF
BENGAL
BAY OF BENGAL
16°
55'
50'
15°45'
80°45'
50'
55'
81°

FIG. 4

and 95% per cent of the monsoon rain of the entire catchment basin are to be discharged through the Mahanadi delta. The construction of the Hirakud Dam has reduced the incidence of floods in the Mahanadi. The Rushikulya is a notable stream in Ganjam with no delta formation though the coastal plain is extensive enough.

Godavari is the largest perennial river in Peninsular India. After crossing the Eastern Ghats through picturesque gorge (Papi Hills gorge) it emerges at Polavaram into the coastal plain. The width of the river is over 3 km at Rajahmundry and about 6 km at Dowleshwaram. Below Rajahmundry it splits into the Gautami, Vasishta and Vainataya branches which form the delta (fig.5). The 3 branches join the sea near Yanam, Narasapur and Razole respectively.

The krishna is the second important river. It is superimposed across northern end of the Cuddapah ranges where the gradient is 0.7 m per km. Near the sea the gradient is 0.15 m per km. The river carries silt enough to cover daily an area of 5 sq. miles to a depth of one foot during high floods. It flows into two branches near Paugadda in Krishna district enclosing the island of Diwi, and 16 km downstream splits into 3 branches (fig.4). The Vamsadhara and Nagawali are other notable streams of the Srikakulam district.

Cauvery is the largest and most important river of Tamilnadu. It splits into two branches (fig. 6) west of Tirruchchirapalli. The northern branch is called the Coleroon and the southern the Cauvery; 27km below the bifurcation point, the

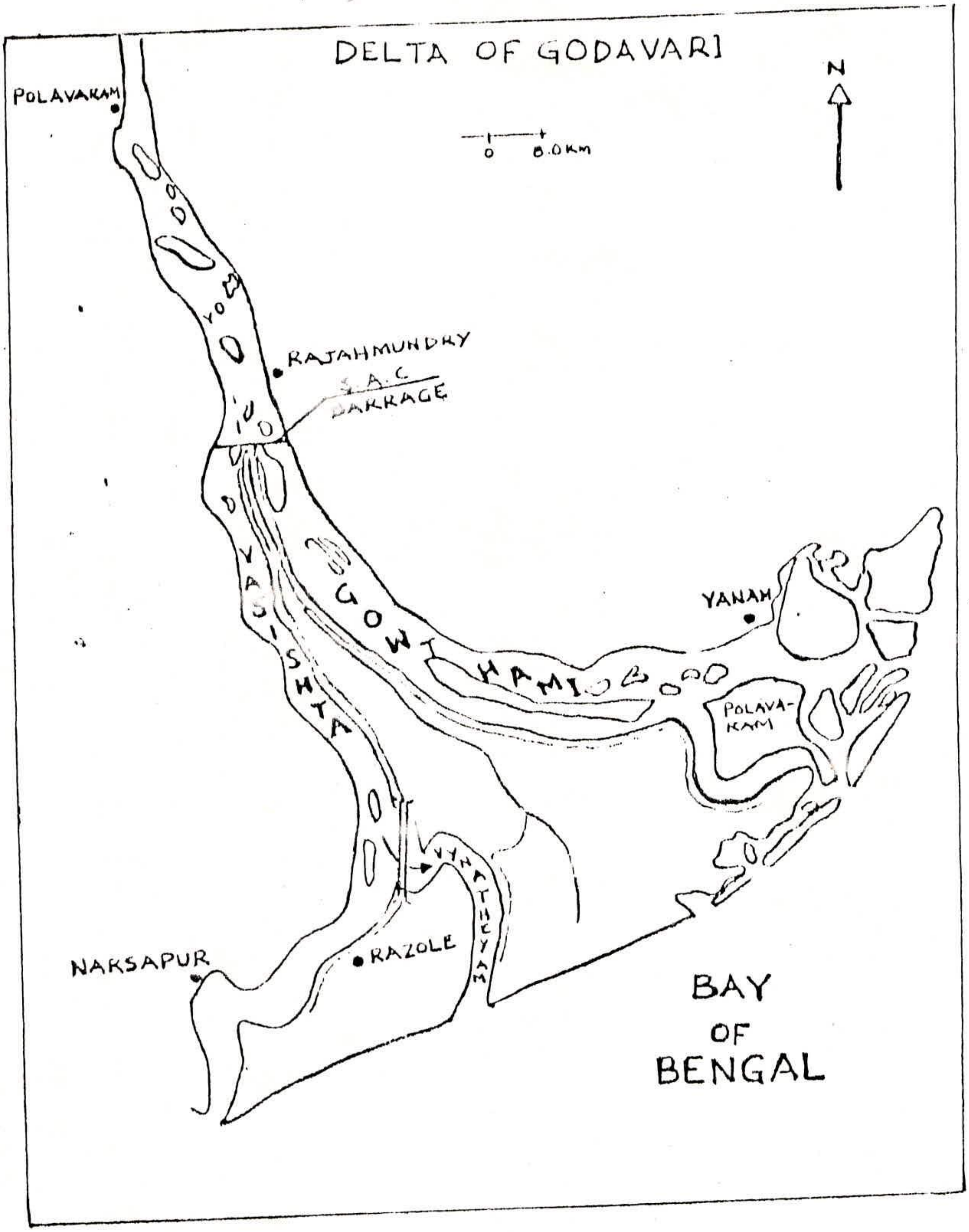

DELTA OF GODAVARI
N
POLAVARAM
0
8.0KM
RAJAHMUNDRY
S.A.C
BARRAGE
GOWTHAMI
VASISHTA
YANAM
POLAVA-
RAM
RAZOLE
NARSAPUR
BAY
OF
BENGAL

FIG. 5

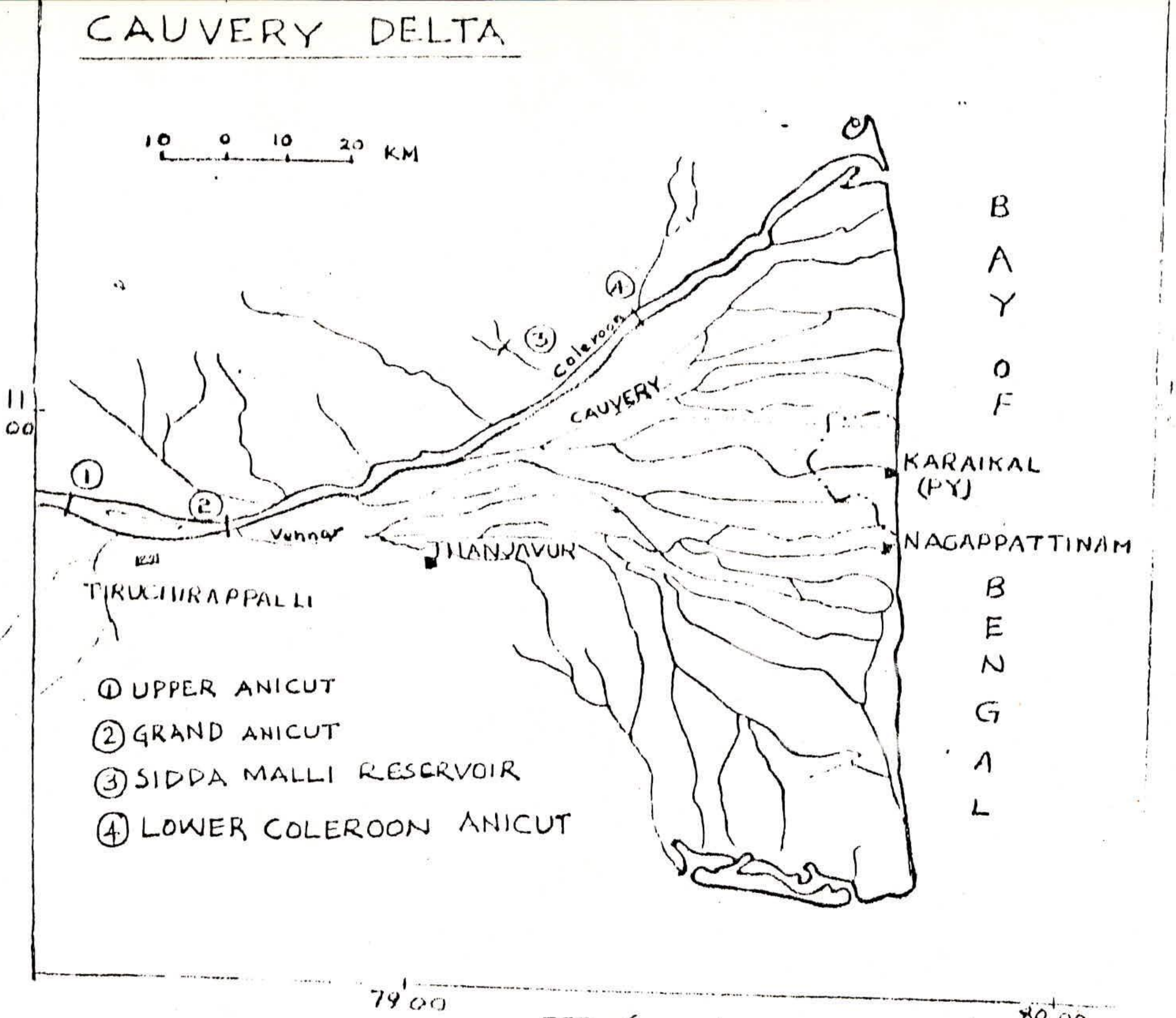


FIG. 6

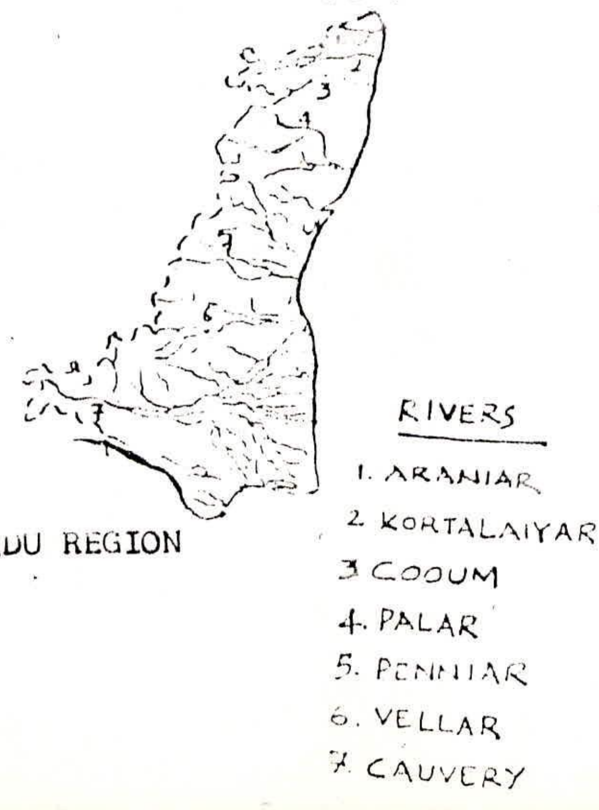


FIG. 7 TAMILNADU REGION

streams unite to form between them the island of Srirangam, but thereafter the Coleroon takes a north-easterly direction skirting Thanjavur district along its entire length on the north and enters the sea at Devikottai with its water practically undiminished; while the Cauvery takes a southerly direction splitting into numerous branches and covers the whole delta with a vast net-work of irrigation channels. Some of the branches of the Cauvery find their way into the sea carrying surplus water. Others get lost into the expanse of rice fields. The Cauvery, now reduced to an insignificant channel, debauches into the sea at Kaveripatnam; the main branches of the Cauvery are the Vena, Kedanurtiyar and Asasalai. The Addapar, Uppanan and Korriyar are navigable in the lower reaches.

The Ponnaiyar flowing through Tamilnadu for over 300 km carries a highly variable discharge being dependent on local rains. The only significant tributary is the Pamban which joins it on the left bank in Salem. The palar along with its tributaries, the Ponnai and the Cheyyar, drains the North Arcot and Chingleput districts. The Vaigai is an important river of Madurai district, and joins the Bay at Attangari east of Ramanathapuram. During most part of the year the river bed is dry in Madurai and Ramanathapuram. The Tambraparani rises in the Western Ghats in the southern slopes of the Agastiyamalai in Tirunelveli district and descends the plains in 5 beautiful falls near Papanasan. The river flows in a south-easterly direction through Ambasamudram, Tirunelveli, Srivaikuntam and Tiruchendur covering a distance of 120 km and empties itself in the Gulf of Mannar near Pannaikayal.

The Vellar is formed by the junction of 2 streams, the Vasistanadi and Sweta Nadi. The Kortalaiyar flows from an overflow of the surplus waters of the Kavaipatnam tank in N. Arcot district; eastwards it flows into the backwater of the Ennore, north of Madras. The Arni enters Chingaleput district in Tiruvallur taluk and joins the sea at Pulicat. The Coovam is formed by the surplus waters from the Kuvam tank in Kanchipuram taluk. It flows eastwards through Madras and joins the sea at Fort st. George. The Gingee known as Vasistanadi rises in Tindivanam taluk and enters the sea at Pondicherry. The Gadilam rises in Kalakurichi taluk in S. Arcot, 96 km west of Mulattai; a natural channel connects it with the Ponnaiyar and the river flows into the sea near Fort St. David, 2 km to the north of Cuddalore. The Vaippar rises on the eastern slopes of the Western Ghats in Srivilliputtur taluk and flows through Tirunelveli district and empties itself into the Gulf of Manaar near Vaipar village.

3.3.1 Note on Godavari and Krishna deltas:

The coastal belt of Andhra Pradesh stretches over a distance of about 1,000 km from just north of Madras to near Rushikulya basin in Orissa. Half the area of coastal Andhra consists of the deltas of the States three major rivers, the Godavari, the Krishna and the Pennar, which together drain about 150,000 sq. km. of the Deccan Plateu. The deltas which reach 64 km inland to Dowlaiaswaram on the Godavari (fig.5) and 72 km to Vijayawada on the Krishna (fig.20) form together over 1 M ha. of potentially highly productive lands. The natural slope of these lands varies from 1.0 m per 4.2 km. in the head reaches to 1.0 m per 7.5 km. in the lower reaches of the deltas and are traversed by numerous depressions, former lagoons, and tidal inlets. Poor natural drainage conditions form a major impediment to sustained high crop yeilds, which are aggravated by occurrence of major storms.

Some salient features of Godavari and Krishna rivers and the Kolleru lake sandwiched between the two deltas are given below:

Godavari drains an area of 312,812 sq.km. which is 10% of the geographical area of India. Maximum discharge of the river at Sir Arthur Cotton (S.A.C) barrage, Dowlaiswaram, was 3,500,000 cusecs on 16th August 1986 during the period 1969-1989. Krishna has a catchment of 258,948 sq.km. which is about 8% of the geographical area of India. Maximum discharge observed at Prakasam barrage, Vijayawada, was 714,000 cusecs on October 13 1975 during the period 1970-1989. Average flows of the two rivers and storage capacities created upto 1978 are as follows:

River Basin	Annual Flow	Cumulative Gross Storage
Godavari	118,982 M.Cu.m	16,600 M.cu.m (14%)
Krishna	68,283 ,,	38,866 ,, (57%)

The discharges observed on Godavari and Krishna during 1969,1977 and 1990 severe cyclones seem to indicate that maximum floods at Dowlaiswaram and and vijayawada do not usually coincide with the arrival of coastal cyclonic storms, but are due to high monsoonal rainfall in the upper catchments.

There have been problems arising from the changes in the regimes of the major rivers and their tributaries, which drain the surrounding upland, often leading to new and unforseen drainage problems. Natural drainage courses, for instance, have been encroached upon and are being used for agriculture. The problem of drainage congestion worsens in the deltas' downstream. The problems arise at +10.00 m msl and become frequently acute in the zone between +5.00 m msl and the sea.

3.3.2 Kolleru Lake:

Kolleru is the largest inland fresh water lake in the country with a water spread of 168 sq.km (fig. 8). It is designated as an International Wet Land and Bird Sanctuary. The lake is sandwiched between both the Krishna and Godavari deltas. During floods there will be heavy swell in the lake. Fig. 9 shows the flood swell in Kolleru lake on 29-7-1987 as obtained from Indian Remote-sensing Satellite (IRS 1-A). The total area of the lake is about 90,000 ha. at an elevation of +10.00 ft. It drains an area of 4,760 sq.km. of which 1360 sq.km. is deltaic. While 12 major streams drain to it, there is only one outlet in the form of a stream called Upputeru connecting the lake to Bay of Bengal.

Agriculture is practiced on the foreshore of Kolleru lake. Paddy is grown in an area of about 34,000 ha. in the Kharif season (June-Nov.) and on about 28,500 ha. in the Rabi season. A study of maximum lake levels from 1916 onwards revealed that the lake has risen above +8.00 ft. almost every year since 1956, whereas in the period 1916-1955 it has risen to this level only once in six years. The 'Mitra committee' cited that excessive inflow, inadequate outflow and reduction in the capacity of the lake due to silting are the reasons for this remarkable increase in the lake levels.

The problem is aggravated by the Yanamadurru drain (Max. flood discharge of 576 cumecs) which joins the Upputeru about 13

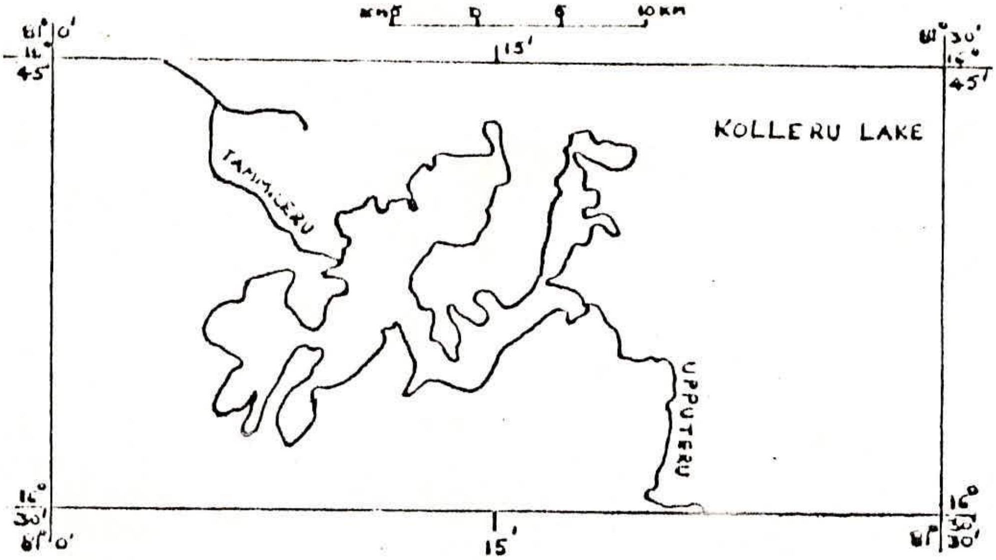


FIG. 8

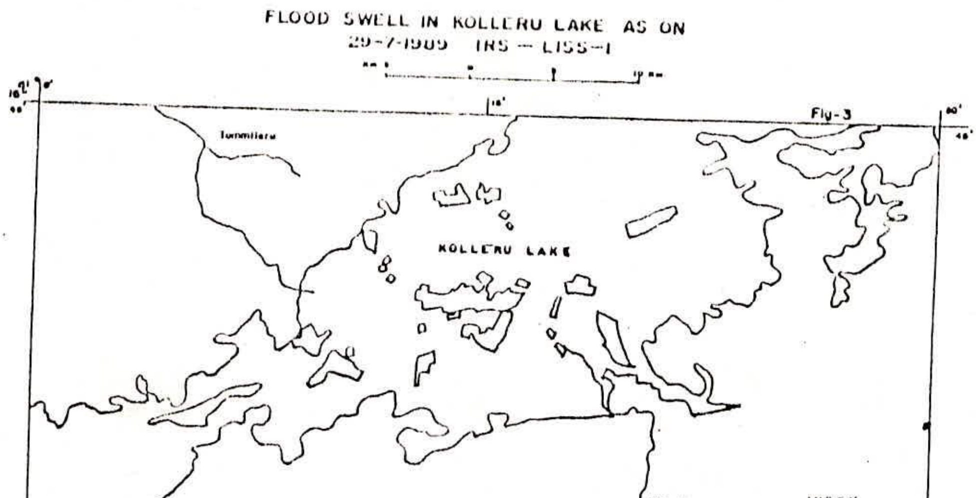


FIG. 9
(Rao, 1992)

km. upstream of its outfall in to the Bay of Bengal. The capacity of the Upputeru downstream of this junction is inadequate to discharge the flows, which causes the Upputeru to back up into Kolleru lake. A straight cut from Upputeru to the Bay of Bengal was dug in 1983 at Km 47/0 of Upputeru, but has proven to be still insufficient.

3.3.3 East flowing Rivers North of Godavari:

This area is in several ways distinctly different from the deltas. Its main features are

(i) the steep hills of the Eastern Ghats rising to an elevation of 1,200 metres;

(ii) the interior plain which descends from the foothills towards the sea;

(iii) the coastal plain along the Bay of Bengal.

the region has a humid tropical climate with an average rainfall of over 1000 mm. Most of the rains, however, occur during the months from July to November in heavy downpours often of cyclonic disturbances, and are followed by prolonged spells of drought.

A number of rivers of medium catchments drain this region and fall into Bay of Bengal. The Tandava, the Varaha, the Sarada, the Gosthan, the Champavathi, the Nagavali and the Vamsadhara drain the Eastern flank and do not form deltas. Tidal river stretches are found at their confluence with the sea, in which a fresh/salt water interface moves up and down the rivers depending on their fresh water discharge. Storage reservoirs are built on five of the seven rivers in the foothills of the Eastern Ghats, serving some 30,000 ha of irrigated land of coastal plain between the hills and Bay of Bengal. Some 82,000 ha are irrigated during the Kharif season from canals, tanks, wells, tube wells, lift irrigation and other sources. Both the interior and coastal plain are covered with substantial deposits of coastal alluvium, which form aquifers of potential interest for borehole irrigation. This is particularly so where the paleo river channels are found, which have been cut into the bedrock formation of the 'Basement Complex', which occurs at depths varying from 30 to 70 metres. Groundwater quality is good, except in a narrow belt near the sea where saline groundwater underlies the upper fresh water aquifer.

The frequent cyclonic storms and heavy monsoonal rains cause extensive damage to the public. River diversion works are overtopped due to inadequate designs based on poor hydrological assessments of flow regime. River embankments are eroded and often breached. Very large number of tanks are silted up or breached. Numerous open dug wells are filled with sand in the flood plains. Wells along the coast line are subjected to saline tidal surges and become useless for drinking.

3.4 SOILS:

By far the most important, in the Ganga mouth region areally as well as agriculturally, are the alluvial soils. The minor differences in the parent materials distinguish the alluvial soils which, though at places inter-digitated, have distinct spatial locations. The narrow alluvial strip along the lateritic and red soils in parts of the districts of Murshidabad,Bankura, Burdwan, Hooghly and Midnapur are different from the Ganga alluvium which covers parts of the North Bengal Plain and the whole of the remaining West Bengal Delta excluding the coastal strips in 24-Parganas and Midnapur. In the former alluvial group the riverine tracts of the Damodar and the Kasai have alternating sand beds and immature and irregular stratification and hence ill-developed profiles. The soils are neutral (pH 6.5-7.2) and relatively poor in plant nutrients and organic matter. Relatively greater leaching of clay, mottling, etc., characterise the flat land soils of the tract. These are mildly acidic in reaction (pH 5.8-6.8). Relatively mature profile and high leaching have affected the uplands of the tract, leading thereby by acidity (pH 5.8-6.9) and deficiency of organic matter.

The Ganga alluvium is, however, rich in the plant nutrients and organic matter and is alkaline in reaction (pH 7.0-8.2), though the uplands, i.e., the older alluvium is somewhat neutral in reaction. The riverine tracts are prone to frequent siltation which mars the proper development of profiles. The grayish colour owes to the existence of fine sands. The interfluvial zones are covered by soils, clayey to sandy in texture, depending on the location. With the altitude or the distance from the flood plain,the process of concretion accelerates, and profile developments are also fair.

The coastal soils are the outcome of the interaction of rivers and tides and have developed in the districts of 24-Parganas and Midnapur. THe soils are saline and alkaline and contain deposits rich in Ca, Mg, and half-decomposed organic matter.

The region abounds in alluvium. Red soils, black soils and laterities are also found as transported soils. Alluvial soils are mostly found in river valleys, deltaic tracts and along the coastal area; their composition and textures vary with the geological nature of the catchment area. These soils are of 2 types-coastal alluvium and riverine alluvium. Coastal alluvium occurs all along the coast from Balasore to Kanyakumari, occupying the littoral tracts varying in width from 10 to 20 km. Riverine alluvium is found in the lower courses of the valleys of most rivers and in the deltaic regions. These soils are exceptionally fertile and highly valuable for agriculture, especially paddy. The degree of fertility decreases gradually according to the distance from the river. The soils are generally rich in lime, poor in nitrogen and phosphoric acids. The alluvial soils of the Tambraparani are black loams, well-suited to irrigation.

Laterites are tropical and sub-tropical soils formed by the decomposition of gneiss. The most important components for lateritic formation are iron, alumina and silicic and acid as primary materials for the parent rock. In the Utkal plains laterite is found in the northern portion of Balasore district with a width varying from 50 to 100 km. In the Andhra Plains it occupies parts of the Godavari and Nellore districts. In Tamilnadu, laterites are significant in the red hills region of Ponneri and Tiruvallur taluks (Chingleput) and in the vallam tableland of Pattukotai taluk (Thanjavur). Laterites are also found in small patches in other parts.

Red soils occupy a large part of Tamilnadu and considerable parts of Srikakulam. Vishakhapatnam, and E. Godavari districts and small areas of Krishna, Guntur and Nellore of A.P. They are derived mainly from Archaean gneisses. The red brown colour is attributed to the diffusion of iron content. The soils are poor in lime and magnesium but rich in iron. According to texture they may be subdivided into clayey, loamy, ferruginous soils (Lower Palar Valley), sandy loamy soils (Chingleput) and sandy loamy ferruginous soils (adjoining coastal alluvial tracts).

Black soils are tropical black clays or 'regur' rich in lime, magnesium and aluminium, but poor in phosphorous, nitrogen and organic matter. They are found in depressions or in plains without notable relief and contain a high porportion of fine elements and shrink considerably in the dry season. They originate either from decomposition of basic basalt or certain sedimentary clays or decomposition of calcium and magnesium. Scanty rainfall plays a part in their formation. The black soils in this region are not as thick as the deccan Trap. It is less moisure retentive, but more friable and suited to irrigation. Regur has a layer of dark nodules formed by the segregation of calcium carbonate. Its fertility is due to self-ploughing character. Black soils occur in a patch near Chilka lake, parts of West Godavari, Guntur and Krishna districts adjoining coastal alluvium, limited area in Nellore and in parts of Tirumangalam (Madurai), Sattur and Srivilliputtur (Ramanathapuram) and greater part of Kovilpatti (Tirunelveli) taluks. Cotton is generally grown on these soils.

3.5 VEGETATION:

The mangrove and tidal forests in the Sunderbans are the only preserves of natural vegetation in the Ganges delta. Deciduous and scrub vegetation covers region of Midnapur. Scattered and isolated patches are also visible in Howrah and

Hooghly districts of the Delta Proper. The tropical evergreen forests include casuarina and mangrove in this region.

The coastal plains have a very small percentage of the area under forest cover. Most of the flat lowlying area is devoted to agriculture. Natural vegetation is in the form of littoral forests, marshes and swamps, scrub wood lands or discontinuous thorny thickets. Often these scrubs are removed and plantations of casuarina or coconut are introduced.

Tropical Moist Deciduous Forests are found in a haphazard manner throughout Ganjam, Puri and Cuttack. In Andhra Pradesh they are found mainly in Srikakulam, Vishakhapatnam, East and West Godavari districts; these forests dominate in the districts where the rainfall is high. However, these are almost absent in the Tamilnadu Plains.

Scrub-woodlands have a thorny growth (7 to 10 m) with a clear canopy and open undergrowth and ground cover. Sometimes Acacia is associated with the undergrowth of thorny shrubs which are negligible in the Utkal Plains. In the Andhra Plains it is found most in Nellore and Prakasam district except in Darsi and Podili taluks, while in Tamilnadu, in Tiruneveli and Ramanathapuram districts. Acacia colonizes the coastal dunes near Pamban and Rameswaram.

Littoral forests occur in a narrow strip along the sea coasts of Cuttack and Balasore districts. In Andhra Pradesh these are found in parts of Krishna, Guntur, Prakasam and Nellore districts. A small coastal area in Kandukur and Kavali taluks is also covered with Rhizophosa species.

Thorny thickets are found scattered throughout the Tamilnadu coastal plains. These are nonspiny species which grow in the middle of protective bushes. Some scattered trees emerge from places of places. Some climbers and grasses are also found.

3.6 REGIONS:

The East Coastal Plains are delimited from the adjoining Eastern Ghats, primarily on the basis of physiography and structure. The region is described in detail in the following sections.

3.6.1 West Bengal and Orissa coastal plains:

The West Bengal coastal region comprises of 24 Parganas, Howrah and Hooghly and Midnapur districts. The mature delta is an area of choked rivers. The Hooghly-Howrah plain has Aman-Jute culture with fairly high urbanisation and high degree of development. The Midnapur plain is the least developed region in the mature delta with moderate degree of develpoment, Aman rice culture and least urbanisation (Singh). In this region Midnapur - Kharagpur area is emerging as the industrial pocket in the region and thus becomes distinct from the dune infested coastal tract where the dominance of fishing becomes natural; the central tract in between stands as a distinct unit.

The active delta is the land of marshes, levees, saline water lakes and the coastal forests. It is characterised by high urbanisation and over all high degree of development. The upper delta (northern) has the highest degree of development, agricultural(Aman-Jute region) in the east and industrial in the west. The lower delta (southern) has the zone of tidal forests of

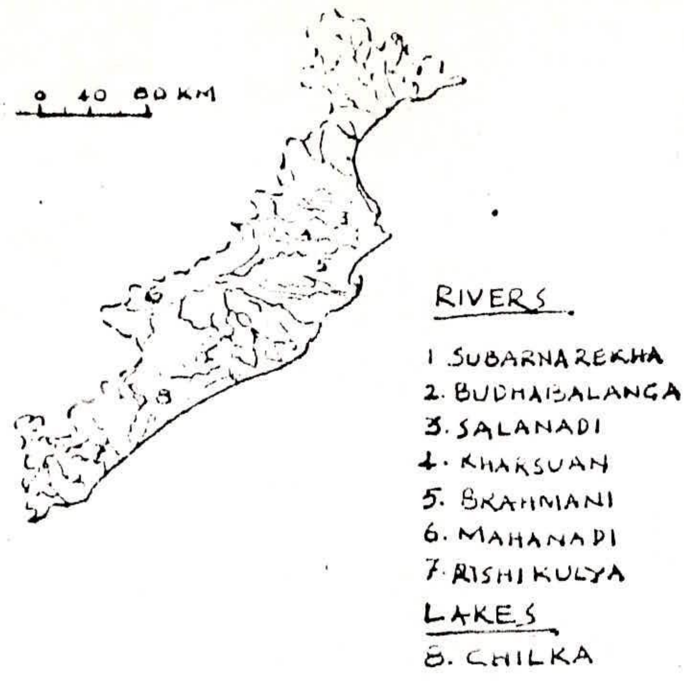


FIG.10 ORISSA PLAINS

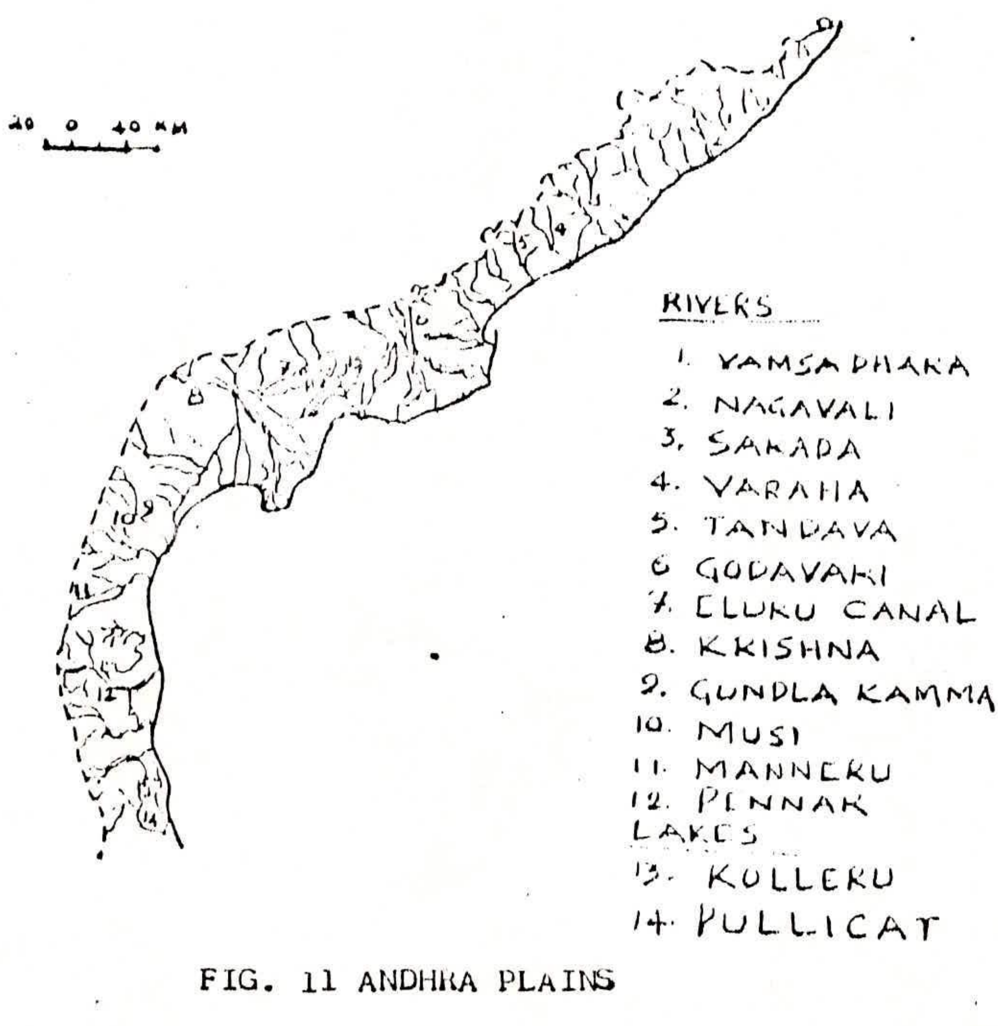


FIG. 11 ANDHRA PLAINS

Sundarbans in the south as also a zone of patchy cultivation by reclamation in its northern section.

The Orissa (Utkal) Coastal Plains (fig. 10) are further divided into three second order regions on the basis of morphological peculiarities and climatic and edaphic conditions. The boundaries are adjusted to the differential patterns in economic activities, like agricultural development or land use pattern, pressure of population, occupation of the people and transport and communication facilities; these sub-regions are: (i) The Northern Coastal Plain or Balasore Plain; (ii) the Middle Coastal Plain or Mahanadi Delta, and (iii) the Southern Coastal Plain or Chilka Region.

The Balasore Plain comprises of the flood plains and deltas of the Subarnarekha and Budhabalanga rivers and roughly covers the whole of Balasore district. This is narrow in extent and bears evidence of marine transgression as shown by marine deposits. Lack of active development and absence of fan-shaped deltas on the river mouths differentiate it from the rest of the Coastal Plain of Orissa. Economically the area is under-developed as compared to the other coastal areas; it not only lacks irrigation facilities, but it has also been a region of depopulation during the last half century (1901-51). It is one of the worst flood-and drought-affected areas of Orissa. The floods inundate the lower plains and the region also lies in the direct path of the cyclones from the Bay of Bengal. Low per hectare agricultural out-turn, lack of double cropping and crop failure are some of its distinguishing characteristics. The economic activity of the area is controlled by Balasore which has a very slow rate of population growth. This region is, however, a surplus paddy area and has now majority of rice mills of Orissa. The region can be further subdivided into: (a) Subarnarekha Lower Valley, and (b) Budhabalanga Lower Valley.

Mahanadi Delta is composed of the combined deltas of the salanadi, Baitarani, and Brahmani in the north and Mahanadi in the south. Here the plain is widest. The actual delta growth, the presence of back bay at Aul and Kendrapara and the lakes like Sai and Sonang in the Puri coast are some of the peculiarities which differentiate it from the other portions of the coast. The presence of an extensive irrigated area and insurance against annual inundation by a well co-ordinated embankment system lead to a maximum pressure of population and high yield per unit of land in Orissa. Extensive areas are not only double-cropped, but instances of triple cropping are also not lacking. Cultivation of jute is extensive. The presence of tidal forests, known as "Little Sundarbans" in the river estuaries, recent fluvitile deposits in the lower reaches and the older alluvium are notable. Some of the oldest towns of Orissa like Cuttack, Puri, Kendrapara and Jaipur are also located here. The agricultural prosperity of the area will be further accentuated after the Salandi and delta irrigation projects are completed. The port of Paradeep will boost the economy of the region. The newly constructed express highway from Daitrani mines to the port and the proposed rail link from Cuttack will open up new hinterland area for the port.

Bhubaneshwar , the state Capital, is a modern planned town.

Cuttack (327,412) and Paradeep will continue to be the commercial hubs of the region. Cuttack is the largest city of the State, while Puri is one of the most important religious centres of India. Chowduar is an industrial suburb of Cuttack. The region can be further subdivided into :(i) The Salandi-Baitarani-Brahmani delta and (ii) The Mahanadi delta.

The Southern Coastal Plain or Chilka Region is completely cut of from the Middle coastal plain by the Chilka lake and the spurs of the Eastern Ghats. It is built up by the fluviatic deposits of the Rushikulya. Unlike the Mahanadi delta there is absence of well-developed fan-shaped delta, dead level flat plains and back-bays or well-developed lagoons. The undulating topography has limited the irrigation to favoured tracts. The higher frequency of failure of rainfall and rainy days often leads to crop failures here. Relatively it is better served by roads. Berhampur controls the economic activity of the region and is the third largest town of the Utkal Coast. The region may be subdivided into two third order units: the Chilka Plain and the Berhampur Plain.

3.6.2 Andhra Coastal Plains:

Based on physical factors and economic activities, the Andhra coastal plains (fig. 11), like the Utkal plains, can be divided into 3 second order regions : the Srikakulam-Vishakhapatnam Lowlands or Northern Coastal Plain, the Krishna-Godavari Delta or Middle Coastal Plain and Nellore or Southern Coastal Plain.

Srikakulam-Vishakhapatnam Lowlands cover Srikakulam (excluding Sallur and Parvatipuram) and Vishakhapatnaam (excluding Chintapalli and Paderu taluks) districts. The lowland narrows down to 19 km under Mahendragiri, but on either side of this gate are embayments of the Rushikulya and the Vamsadhara. The balck soil of the valley floors grades upwards to red soils. There are numerous gneissic outcrops. Vishakhapatnam lies between the Kalina ridge (490 m) and Yaroda (335 m), the latter running into the Dolphin's Nose which shelters the harbor. Rice covers a third of the cultivated area, followed by sugarcane, ragi, oilseeds, millets and pulses. Industrial development is confined mainly to jute and rice mills, and ship-building. Vishakhapatnam (603,630) is the only city and port of importance. The Srikakulam region is more agricultral and less developed than the Vishakhapatnam region which is fairly urbanized and industrialized.

The Krishna-Godavari Delta includes the lowlands below Vijayawada and Polavaram forming the twin-delta. These lowlands are vulnerable to floods and cyclones but form a vast expanse of rice-fields and are reputed as the "Granary of the South". Between the two deltas lies the Eluru Region where the Kolleru Lake occupies a depression cut of from the sea by siltation and serves as a good fishing ground; this region is transitional in character with Eluru and Rajahmundry (268,370) as the regional hubs. The twin delta region is essentially agricultural with 80% of the area under paddy. In places jowar, sesamum and groundnuts are cultivated. Guntur (367,699) , Vijayawada (543,008) and Machilipatnam (Bandar) are regional centres in the Krishna delta.

Nellore Coastal Plain is a transitional belt between the

Andhra and Tamilnadu plains. It is physically dominated by tank irrigation except for canal irrigation in the Pennar valley. Most of the plain is cultivated mainly for jowar, followed by rice, cotton and groundnuts. The most important coastal feature is the great salt water lagoon of Pulicat. Nellore is mainly administrative and commercial centre. Its Northern region is thus distinct from the Southern which is greatly influenced by Nellore city.

3.6.3 Tamilnadu coastal plains:

Tamilnadu East Coastal Plains (fig. 7) can also be divided into two second order region on the basis of coastal morphology and economic attributes: the Cauvery Valley and Delta and the Palar-Ponnaiyar Basin.

The Palar-Ponnaiyar Basin includes the districts of Chingleput, S. Arcot and part of N. Arcot and Tiruchchirappalli. This Northern plain is traversed by the lower courses of several rivers such as the Arni, Kortalaiyar, Adyar, Cooum, Palar, Ponnaiyar and Vellar are important because of their agricultural significance for rice, sugarcane, betel-vine and flowers. Tank and river channels are the main sources of irrigation. Groundnut is grown in the irrigated tracts and North Arcot is most important district for its production. The region is also important industrially. The industrial complex around the city of Madras (4,289,347) falls in this zone with oil, chemical, automobile, railway coaches, leather goods, fertilizers, textiles, etc. There is a sugar factory set up in Padadam. Kancheepuram and Arni specialize in handloom, silk weaving, etc. Other notable centres are Pondicherry (251,420), Cuddalore and

Chidambaram. Smaller towns include Tiruttani, Tindivanam, Villupuram, etc., which are fast growing.

On the basis of resources development this region can be futher subdivided into : (i) Madras Metropolitan region which is distinguishable by its industrial and market garden landscape and (ii) Lower Palar Valley including the valleys of the Palar and Cheyyar, which has intensive agricultural development based on canal and well irrigation. Industries like silk and handloom are also important. (iii) Lower Ponnaiyar Valley comprising the narrow coastal tract from Pondicherry to the Coleroon with rich alluvial soils has emerged as paddy and sugarcane region, mostly based on tank irrigation. Groundnut is grown in the irrigated tracts. A number of urban centres like Pondicherry, Cuddalore and Chidambaram are located here. (iv) Interfluvial Tracts are located between the Palar and Vellar. These tracts are at higher elevations than the valley floors and are subject to widespread soil erosion. A number of medium-sized towns like Chingleput, Ponneri, Arni, Tiruttani, Vriddhachalam, villupuram etc., are notable.

The Central Region includes the lower Cauvery valley from the confluence of the Amravati with the Cauvery up to Tiruchchirapplli; the valley is narrow and well defined by gradually rising interfluvial tracts to the north and south. The Cauvery splits up into distributaries east of Tiruchchirappalli forming an extensive delta which is largely agricultural due to canal irrigation. Most of the cultivated area is double cropped being dominated by paddy. Density of population is high and there are several urban centres. The region has rice, sugar and other agro-processing industries. The region can be sub-divided into

the Cauvery valley between Karar and Tiruchchirappalli and Cauvery delta with Thanjavur as the regional focus.

3.7 CLIMATE:

The east coastal region exhibits a hot tropical climate characterized by oppressive summer, low daily range of temperature, high humidity and moderate annual rainfall. The coastal tract from Orissa to the Krishna delta experiences a tropical savanna climate; from the Krishna delta to the south it is a tropical wet and dry climate with distinct dry summer. Parts of the southern districts experience a tropical monsoon climate with a short dry winter season; and the interior districts have a tropical arid steppe climate with winter drought. Thus this narrow strip of coast experience a tropical climate with some local variation.

In general high humidities prevail throughout the year in coastal areas. In Tamilnadu it varies from 60% (June) to 80% (November - December). In Orissa it remains 60% from December to April and over 80% in July-August. In both the regions September records slightly lower humidity further inland, 40-60% in the rainy season and 40% or less in summer.

Winds are of moderate strength throughout the year becoming stronger in the monsoon season (15 km per hour) and weaker in October (5-10 km). From October to January winds blow from north-east and from south-west during the summer monsoon. In the Tamilnadu coast gusty east-south-easterly to south-south-eastly winds of an average speed of 16 km per hour in April set in at mid-day and at a later hour in October at 2 P.M. From November to March the prevailing wind is from northeast and east without showing any change during the day.

3.7.1 Temperature:

In Ganga delta region January invariably appears as the coldest month, the temperature ranging between 17 and 21 C and increasing southward (Sagar Islands 20.4 C). The temperature starts raising gradually throughout from February but the raise is well marked (4 to 6 C) in March and it continues till the end of May; the raise like other monsoon is checked by the outburst of monsoon which in this region becomes active by the first week of June. May records the maximum average temperature of 30 C. Conspicuosly enough, the average monthly temperature shows a range seldom exceeding 5 C over a span of seven months: April to October. The gradual decline in average monthly temperature commencing from June becomes well marked when it falls by 3 to 5 C between October and November. This marks the start of the winter season..

The average relative humidity is generally high (over 50%) throughout the region except in the western fringes where for about two months, March and April, it is less than 40%. This is also the period of lowest RH all over the region except the Sundarbans. December and January, however, show the minimum in the coastal tract (Sagar Island 68.5 and 69.5% respectively). It can well be observed that during July, August and September the average RH remains over 80% which spatially decreases westward

(Krishnanagar 84.2% and Asansol 82.7%). From the monthly RH pattern the oceanic influence is also distinct. The diurnal range is maximum in the month of February (> 30%) and minimum in August (>7%) when the monsoon is at its climax.

Temperature continuously increases from the end of February to May, the hottest month with 30 C at Puri, 35 C at Machilipatnam and Madras and over 37 to 40 C in the interior (Gannavaram, Palaymkottai and Cuttack). The coldest month (January) records a temperature of 22 C in the coastal regions and 19 to 20 C in the interior. It is obvious, therefore, that there is little variation in annual normal temperature mainly because of low relief and moderating influence of the sea.

The diurnal range of temperature is lower, than in the interior. It is of the order of 2 to 3 C during June to December and 4 to 6 C from January to May.

3.7.2 Rainfall:

The rainfall (120 to more than 400 cm) is fairly widespread in West Bengal region though with uneven seasonal and spatial distribution characteristic of the monsoonal condition (Fig.6.4 and 6.5). Out of the four sources of rainfall, i.e., westerly disturbances of winter, convectional overturning of air resulting in local depression (Kal Baisakhi) during March-May causing pre-monsoon showers, cyclonic disturbances of the monsoon and post-monsoon periods and the monsoon currents occurring along the convergence lines of the sea-level monsoonal troughs, the last two account for the major precipitation received in the region (Sagar Islands about 85%, Krishnanagar about 80%). In the southern belt, i.e., the active delta, August is the wettest month (41.0 cm). December undoubtedly is driest though with relatively damper atmosphere (RH more than 55%).

Spatially the southern parts, owing to the proximity of the Bay, experience relatively more annual rains (Sagar Islands 190 cm) than the central part.

The erratic nature of precipitation is evident by the fact that even the wettest months receive sometimes rain below 20 cm, eg, Krishnanagar 8.59 cm in August, 1892 and Sagar Islands 11.45 cm in July, 1919; while their averages for the respective months are 27.11 and 40.94 cm. Similarly the heavy downpours of 71.43 and 96.42 cm have also been recorded for stations in the respective months in the years 1909 and 1913. Even the drier months sometimes record exceptionally heavy downpours. Heaviest down pours within 24 hours ever recorded are at Calcutta 369.1 cm on September 20, 1900; Sagar Islands 359.2 cm on June 5, 1927.

The overall impact of the climate elements can be interpreted in terms of water surplus and deficit in the region, which have direct correlations with the agricultural economy. The seasonal surplus period, often between mid-July and end of October, is a common feature all over the area. Depending on the amount of rainfall the uplands show maximum surplus equivalent to about 60 cm of rain in July/August which aggravates the work of running water resulting in floods, shifting of river channels, etc. It is also evident that there is a general water deficiency period from January to mid-June. The soil moisture in the Active Delta is sufficient for about three months to get evaporated while in the remaining parts it can stand only for two months.

The Bay depressions bring in the monsoon by the first week of June. Series of such depressions sweep over the region during June-October and cause heavy to moderate rainfall with July-August emerging as the rainiest months. The withdrawal of the monsoon by mid-October is followed by a short transition between the rainy and the cold season (post-monsoon season). The commencement (June) and the end of the rainy season (September/October) are associated with more thunderstorms than the rainy months of July and August. High relative humidity (70% and above) alongwith high and almost uniform temperature (26-31 C) and heavy downpours are the characteristics of the season. The climate is often sultry during rainy seasons.

The region can be distinguished by the humid maritime which includes the coastal parts of the Midnapur and 24-Parganas, Calcutta, Howrah and parts of Hooghly, experiences a rainfall of 200 cm and temperature range 10 C (Sagar Island).

Rainfall decreases from the shore (140 - 170 cm) to the interior (70 - 80 cm) on the east coast. Balasore on the coast gets 168.6 cm, Puri 148.2 cm, Kakinada 117.9 cm, Madras 121.6 cm, Nagapattinam 136.7 cm and Tuticorin 60.2 cm, while in the interior Cuttack gets 144.2 cm, Gannavaram 103.1 cm and Palayamkottai 92.8 cm, showing wide variations in distribution from north to south as well. Rainfall in Balasore is highest decreasing in amount till it reaches the Krishna - Godavari delta as shown by Kakinada and Gannavaram. Further south it increases up to Nagapattinam (136.7 cm). South of it the rainfall again decreases to 60.2 cm (Tuticorin) and 92.8 cm (Palayamkottai).

This variation in rainfall distribution is largely due to the fact that Orissa and northern Andhra Pradesh get rainfall from the SW monsoon (78%). Southward up to the Krishna delta the decrease in rainfall is mainly because the region lies off the main track of the monsoon and the associated depressions. But further south most of the rainfall is caused by the retreating monsoon (44-60%) which is mainly associated with the storms and rainfall while striking the coast. The decrease in rainfall further south at Tuticorin (60.2 cm) is due to the barrier-like effect that Ceylon exerts by preventing the rain-bearing winds from reaching this region. One contrast observed in this region is that Palayamkottai in the interior gets more rainfall from the S.W. monsoon which comes through gaps and river valleys, depicting two maxima for the region. The winter rainfall for the northern region and summer rainfall for the northern region show a similar distribution, giving a district transitional rainfall zone between the two regions. Rainfall histograms of 1992 for the six stations from north to south along the east coast are shown in fig.12 for Calcutta, Bhubaneshwar, Calingapatnam and in fig.13 for Gannavaram, Madras, Cuddalore.

Rainfall Reliability: Moderate rainfall reliability (25-30% coefficient of variability) is found in most parts. The regions of low reliability correspond with areas of high inconsistency of rainfall. The moderately high variability is due to the fact that rainfall is associated with depressions from the Bay of Bengal which themselves are erratic. Areas of somewhat moderately low reliability lie in the coastal plains of Ganjam and Puri. High variability is noticed in the Chidambaram-Karur area of

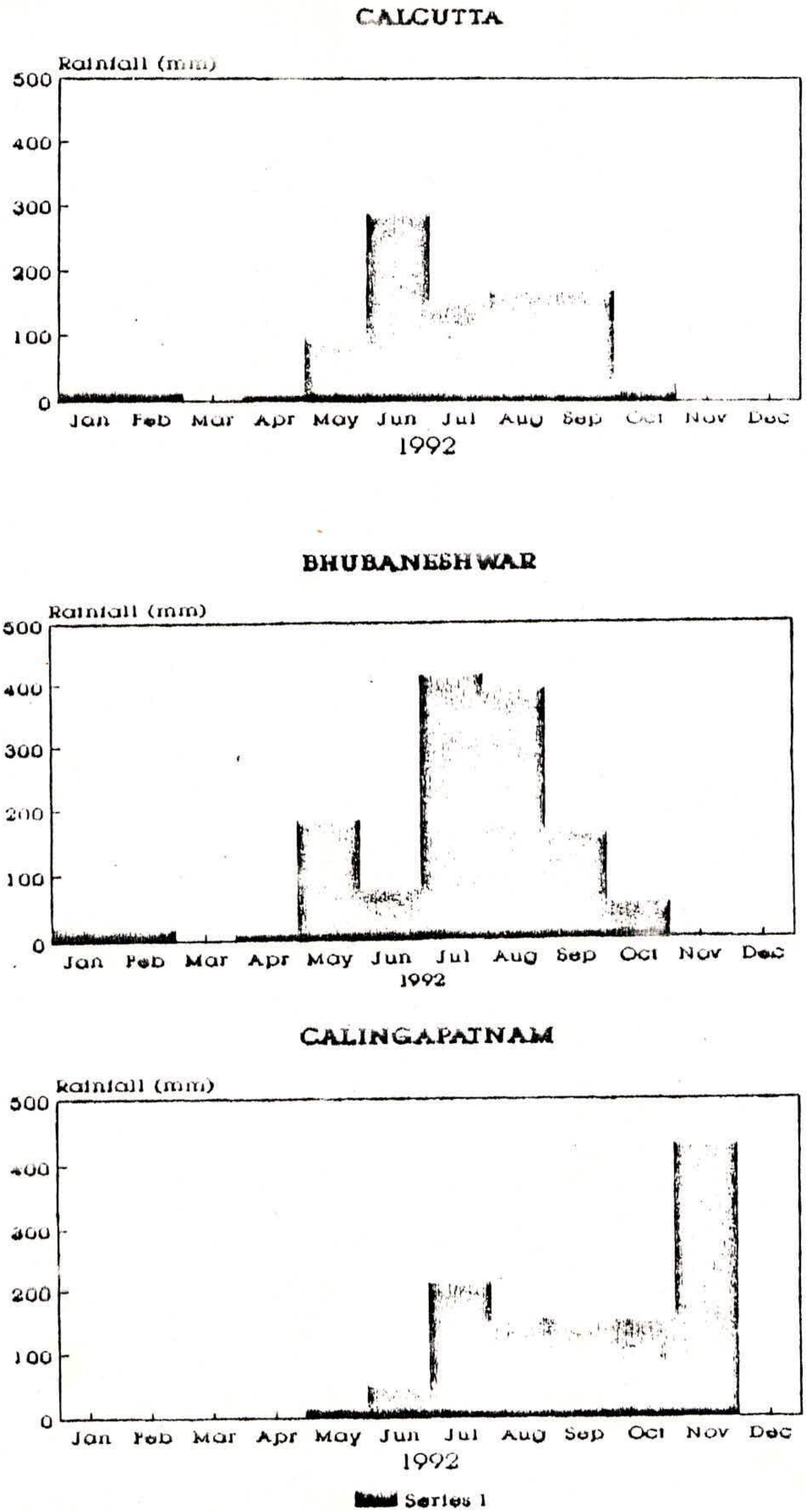


FIG. 12 RAINFALL HISTOGRAM

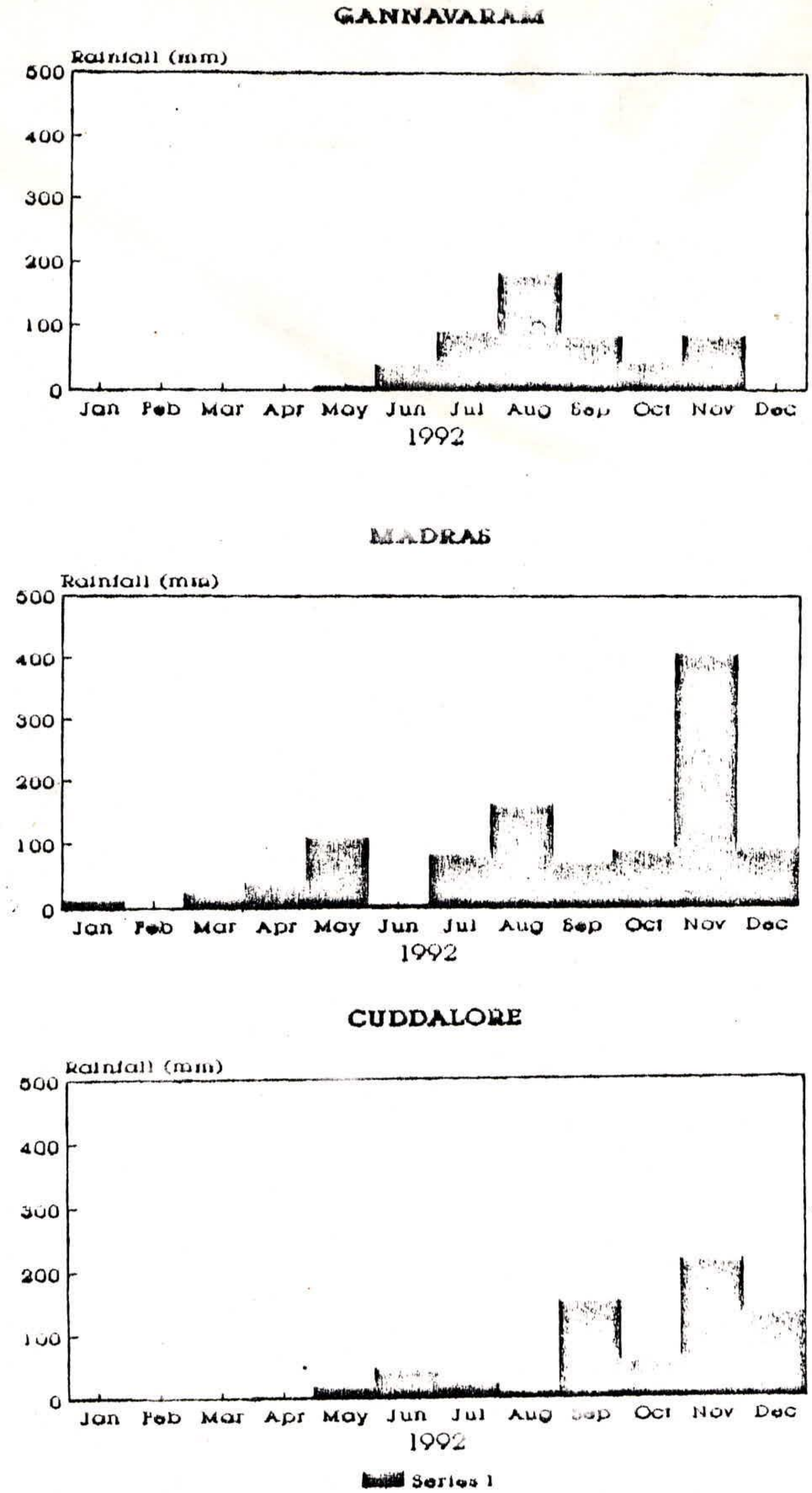


FIG. 13 RAINFALL HISTOGRAM

Tamilnadu.

Special weather Phenomena : During the post-monsoon and early part of the N.E. monsoon storms and depressions originating in the Bay affect the weather of the region. Some of these depressions intensity into severe storms with strong winds (80-140 km per hour) and squalls giving heavy rainfall to the coastal regions and causing considerable dislocation to communication and loss to property. Some of these storms sometimes cross over to the west coast.

4.0 WEATHER PHENOMENA

The main concern of the meteorologist is an understanding of the general circulation of atmosphere with the aim of forecasting the movements of pressure patterns and their associated winds and weather. It is sufficient for the hydrologist to be able to identify the situations that provide the precipitation, and for the practicing civil engineer to keep a 'weather eye' open for the adverse conditions that may affect his site work.

4.1 MONSOONS:

Monsoons are weather patterns of a seasonal nature caused by widespread changes in atmospheric pressure. The most familiar example is the monsoon of southeast Asia where the dry, cool or cold winter winds blowing outwards from the Eurasian anticyclone are replaced in summer by warm or hot winds carrying moist air from the surrounding oceans being drawn into a low pressure area over north India. The seasonal movements of the intertropical convergence zone (ITCZ) play an important role in the development and characteristics of the weather conditions in the monsoonal areas (Shaw, 1983). In general the regularity of the onset of the rainy seasons is a marked feature of the monsoon.

4.1.1 Southwest monsoon:

Towards the end of May, when the summer is at its peak in India, the southwest trades in the Indian ocean extend rapidly northwards across the equator into the Arabian sea and the south of Bay of Bengal and in course of about two weeks become established over both the seas as two branches; the Bay of Bengal current and the Arabian sea current. The Bay of Bengal current which is mainly from the southeast affects the northern Andhra,

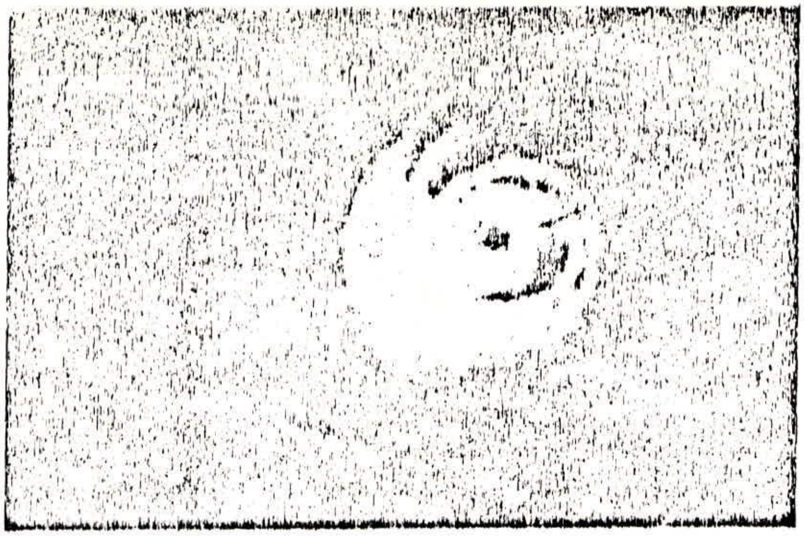


Fig. 14 : Mature cyclonic storm with eye in centre

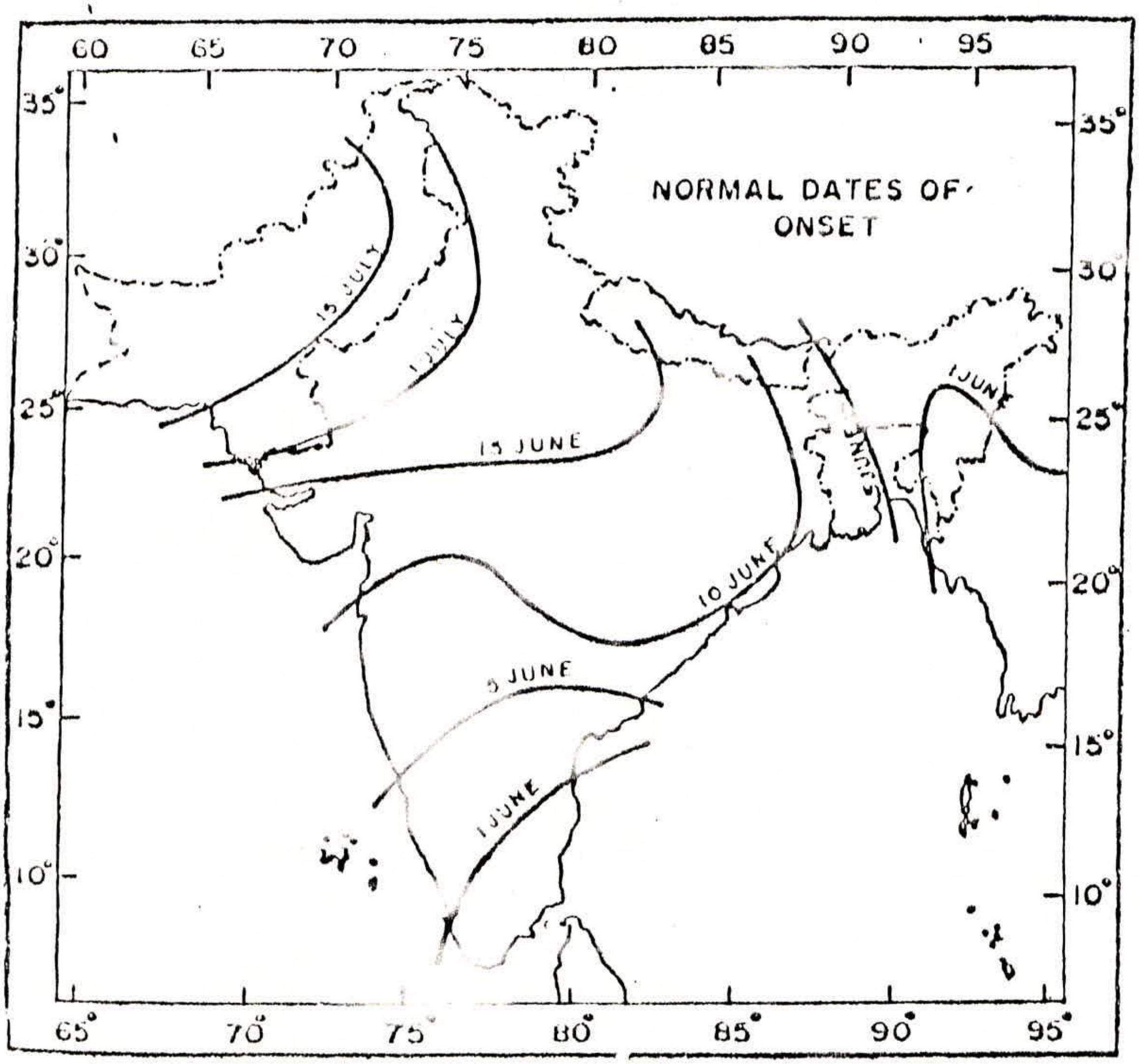


Fig. 15

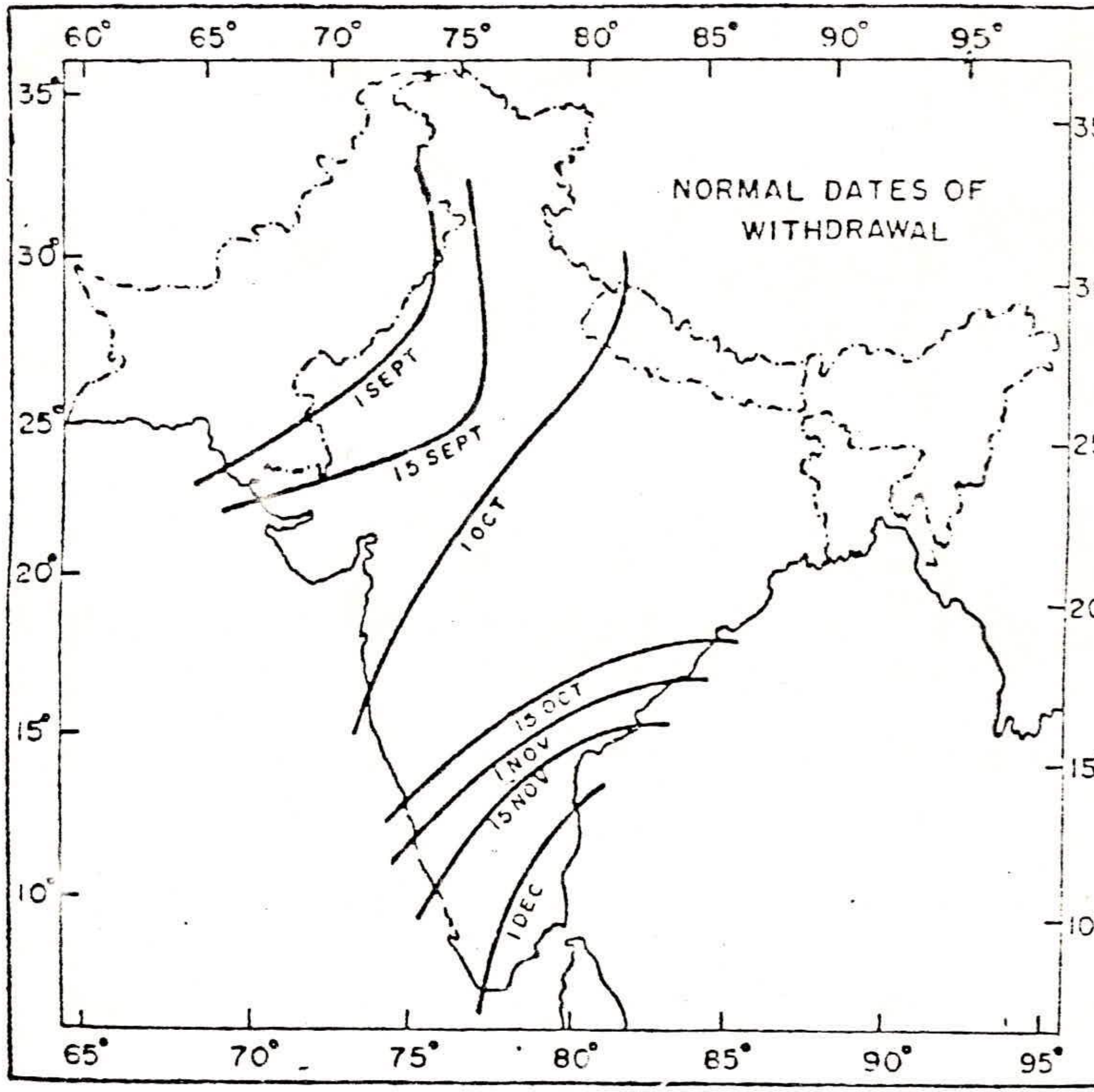

NORMAL DATES OF WITHDRAWAL
1 SEPT
15 SEPT
1 OCT
15 OCT
1 NOV
15 NOV
1 DEC
60°
65°
70°
75°
80°
85°
90°
95°
35°
30°
25°
20°
15°
10°

Fig. 16

4.2 CYCLONES:

Tropical revolving storms that form over Bay of Bengal and the Arabian sea in Indian ocean are called cyclones. A tropical cyclone when fully developed is a vast violent whirl 150 to 800 km across, 6 to 10 km. high, spiraling around a centre and progressing along the surface of the sea at a rate of 300 to 500 km per day. The speed of the wind in a mature storm can be occasionally 160 km per hour or more. The winds associated with such storms are most violent and the rainfall is very heavy. Generally high tides of 4 to 5 m and swell of sea are experienced with cyclones.

As in mid-latitudes, the wave may simply pass by and gradually die away, but the low pressure may deepen with the formation of a closed circulation with encircling winds. The cyclonic circulation may simply continue as a shallow depression giving increased precipitation. However, rapidly deepening pressure below 1000 mb usually generates hurricane-force winds blowing round a small centre of 30-50 km radius known as eye. At its mature stage, a hurricane centre may have a pressure of less than 950 mb. Copious rainfall can occur with the passage of a hurricane; record amounts have been measured in the region of southeast Asia (Shaw, 1983), where the effects of the storms have been accentuated by orography. However, the rainfall is difficult to be measured in such high winds. In fact, slower moving storms usually give the higher records.

Hurricanes tend to be seasonal events occurring in late summer when the sea temperatures in the areas where they form are at a maximum. They are called 'typhoons' in the China Seas and 'cyclones' in the Indian Ocean and off the coasts of Australia. These tropical disturbances develop in well defined areas and usually follow regular tracks; an important fact when assessing extreme rainfalls in tropical regions (Riehl, 1979).

The cyclone has four phases which are described below:

4.2.1 Formative Phase:

In this phase the atmospheric pressure falls gradually over the area and one or two closed isobars with a low pressure area in the centre could be seen on the weather map.

4.2.2 Developing Phase:

The pressure fall continues and squalls increase and the skies become overcast in this phase. The wind speeds would be in the range of 25 to 40 km per hour. The stage of cyclone is referred to as depression by meteorologist. From this stage onwards the system acquires a lateral movement. While some systems do not develop further others develop beyond this stage. When the wind speed exceeds 60 kmph (38 Knots) the term 'cyclonic storm' is used and when the speed exceeds 85kmph (48 Knots) the storm is called 'severe cyclone'.

4.2.3 Mature Phase:

In the mature phase the cyclone (fig 14) will consist of

(i) a calm central area, called the eye, varying between 10 to 30 km in dia where absolute calm air or very light winds with clear to partly clouded sky prevail.

(ii) an inner ring of hurricane winds (90 kmph or more) 50 to 150 km in width, within which the pressure fall is excessively steep and fierce squalls and torrential rains occur.

(iii) an outer storm area within which the winds reach strong to gale force and which is generally asymmetrically situated with respect pressure centre.

(iv) the outer most area of weak cyclonic circulation.

4.2.4 Dissipating Phase:

Soon after the ring of hurricane winds enter a land area the dissipating phase sets in. The increased frictional effects of the land and the lack of moisture supply from a warm oceanic surface rapidly decrease the energy supply into the system. This is the phase in which the hydrologist is more interested because the rainfall will be heavy to very heavy and all the streams will be in spate causing severe damages to the public life.

4.2.5 Cyclonic Monitoring in India:

Cyclonic storm is common in tropical seas except the south Atlantic and southeast Pacific. The incidence of cyclonic storm is maximum in summer months i.e. July to September in the northern hemisphere and December to February in the southern hemisphere. The only exception is the Bay of Bengal and the Arabian sea area where June to September is the southwest monsoon and systems do not develop due to the shift of the convergence zone northward to the land. Over the Bay of Bengal tropical cyclones develop mainly during the premonsoon months of April and May and postmonsoon months of October, November and December.

Cyclones are associated with high pressure gradient and consequent strong winds. These in turn generate storm surge. Storm surge is an abnormal rise of sea level near the coast with devastating effect. The size of the tidal waves increases when peak surge occurs at the time of high tide. According to India

Meteorological Department Vulnerability to storm surges is not uniform along Indian coasts. In Andhra Pradesh, the coastline between Ongole and Machilipatnam is highly susceptible to tidal waves. Heavy rainfall is a common feature of tropical cyclones. Often rain persists long after the other aspects of the storm have dissipated. Damage potential of wind is increased by the accompanying rainfall.

On an average four cyclones develop over the Bay of Bengal in a year and one will hit the Andhra coast. In a study at India Meteorological Department the vulnerability of coastal district of east coast of India is assessed based on the cyclonic data for the last 100 years (Table 1). Nellore is the most vulnerable district in Andhra Pradesh accounting for 29% of the storms. Krishna district stands next followed by Srikakulam. Similarly coastal districts of 24 Paraganas in West Bengal, Balasore in Orissa, Chengulput in Tamil Nadu are the most cyclone prone. The details of the cyclonic storms that were incident along the east coast of India from 1877-1989 are available in WMO report on tropical cyclone program (Mandal, 1991) and are presented in Table 2 . The table indicates the number of cyclones and severe cyclones that have crossed different section of east coast of India in any month during the above period.

4.2.6 Storm surges:

Among the adverse weather associated with a tropical cyclone, the storm surge is the most destructive and is responsible for 90% of the loss of life and property associated with the tropical cyclone. It is more important over the north

Table 1 : Incidence of Cyclonic (Severe) Storms on India's East Coast (1877-1989) (Mandal,1991)

Coast	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Orissa-West Bengal	0 (0)	0 (0)	0 (0)	0 (0)	10 (9)	24 (3)	36 (7)	30 (4)	31 (9)	22 (11)	10 (6)	1 (1)
Andhra Pradesh	1 (1)	0 (0)	0 (0)	1 (0)	6 (3)	4 (0)	2 (0)	1 (0)	5 (3)	33 (10)	23 (15)	3 (0)
Tamilnadu	3 (0)	0 (0)	2 (2)	1 (0)	7 (4)	0 (0)	0 (0)	0 (0)	0 (0)	6 (1)	28 (18)	12 (7)

Table 2: Cyclones Crossing India's East Coast-District wise (1891-1989) (Mandal, 1991)

State	District	No. of Cyclones	State	District	No.of Cyclones
West Bengal	24 Parganas	23	Andhra Pradesh	Krishna	14
	Midnapur	12		Guntur	3
Orissa	Balasore	19		Nellore and Prakasam	21
	Cuttack	17			
	Puri	10	Tamil Nadu	Chingleput	15
	Ganjam	7		South Arcot and Pondicherry	5
Andhra Pradesh	Srikakulam	14		Tanjavur and Pudokottai	13
	Visakha Patnam	8			
	East Godavari	8			
	West Godavari	0			

Bay of Bengal coast where due to the combination of several favorable factors, storm surge generated even in association with a moderate cyclone is extremely high. There are some objective techniques available for the estimation of the surge envelope along the coast line and probable maximum storm surge (PMSS). Some of the techniques are in operational use in the Regional Meteorological Centre (RMC) of WMO In New Delhi. Figures 17 to 19 present the PMSS along the east coast of India as given in WMO report TCP No: 28.

For cyclone forecast and advance warning, Cyclone Detection Radars (CDR) are established at Calcutta, Paradeep, Visakhapatnam, Machilipatnam, Madras and Karaikal on the east coast by India Meteorological Department (IMD) each having a detection range of 400 km. Weather satellite picture receiving (APT) equipment are available in the Centres. The operations related to cyclone are being carried out by IMD through their Area Cyclone Warning Centres (ACWC) and Cyclone Warning centres (CWC). From 1987, INSAT (INdian SATtelite) based Disaster Warning System (DWS) is in operation from Madras. Through about 100 DWS receivers messages are sent directly to public in the state of Tamilnadu. Other states along the east coast may also be provided with such DWS.

Cyclones in association with torrential rains, hurricane winds, tidal waves cause considerable damage like most other natural disasters. The worst damage occurs while the storm crosses the coast, especially on low relief areas. Deltas being the zones of large concentration of population are affected much. This situation is further aggravated if the storm surge

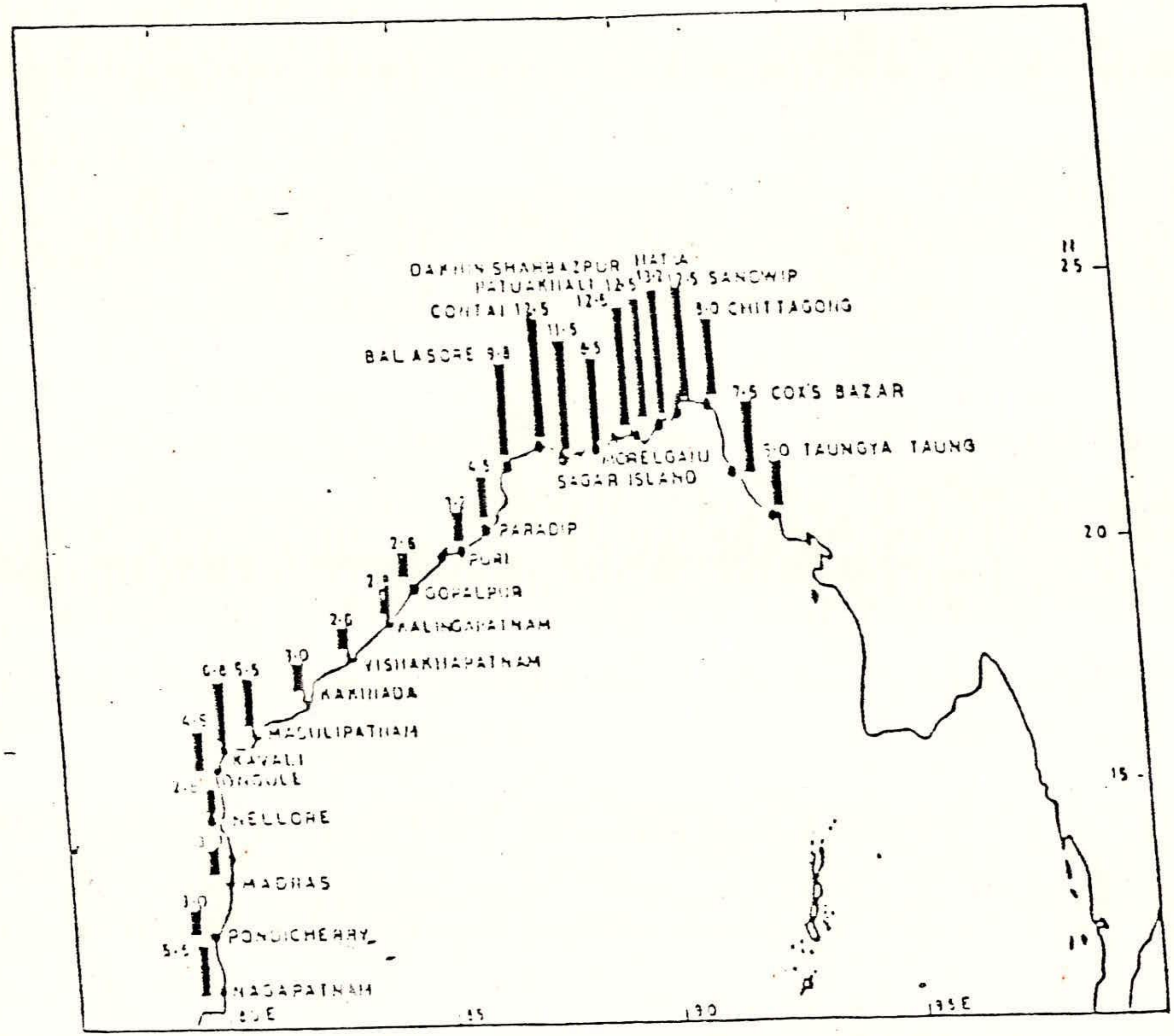
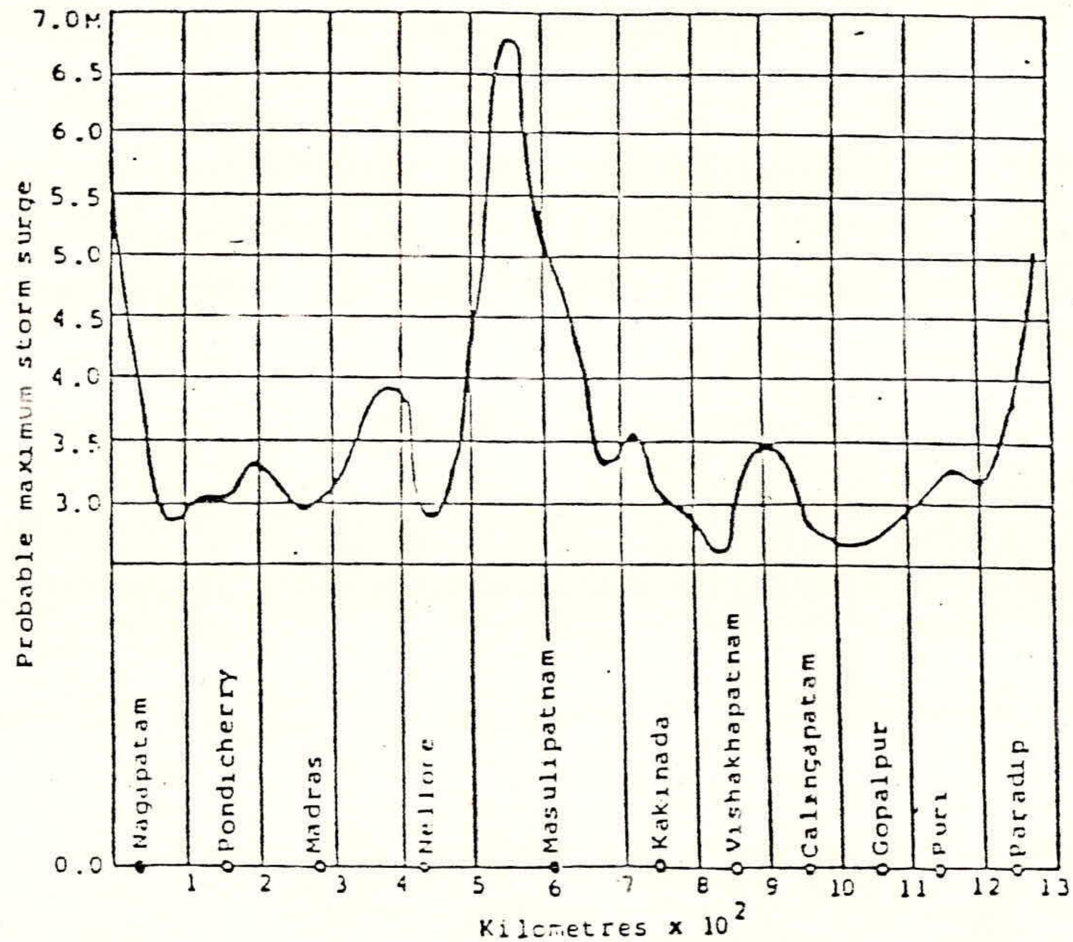
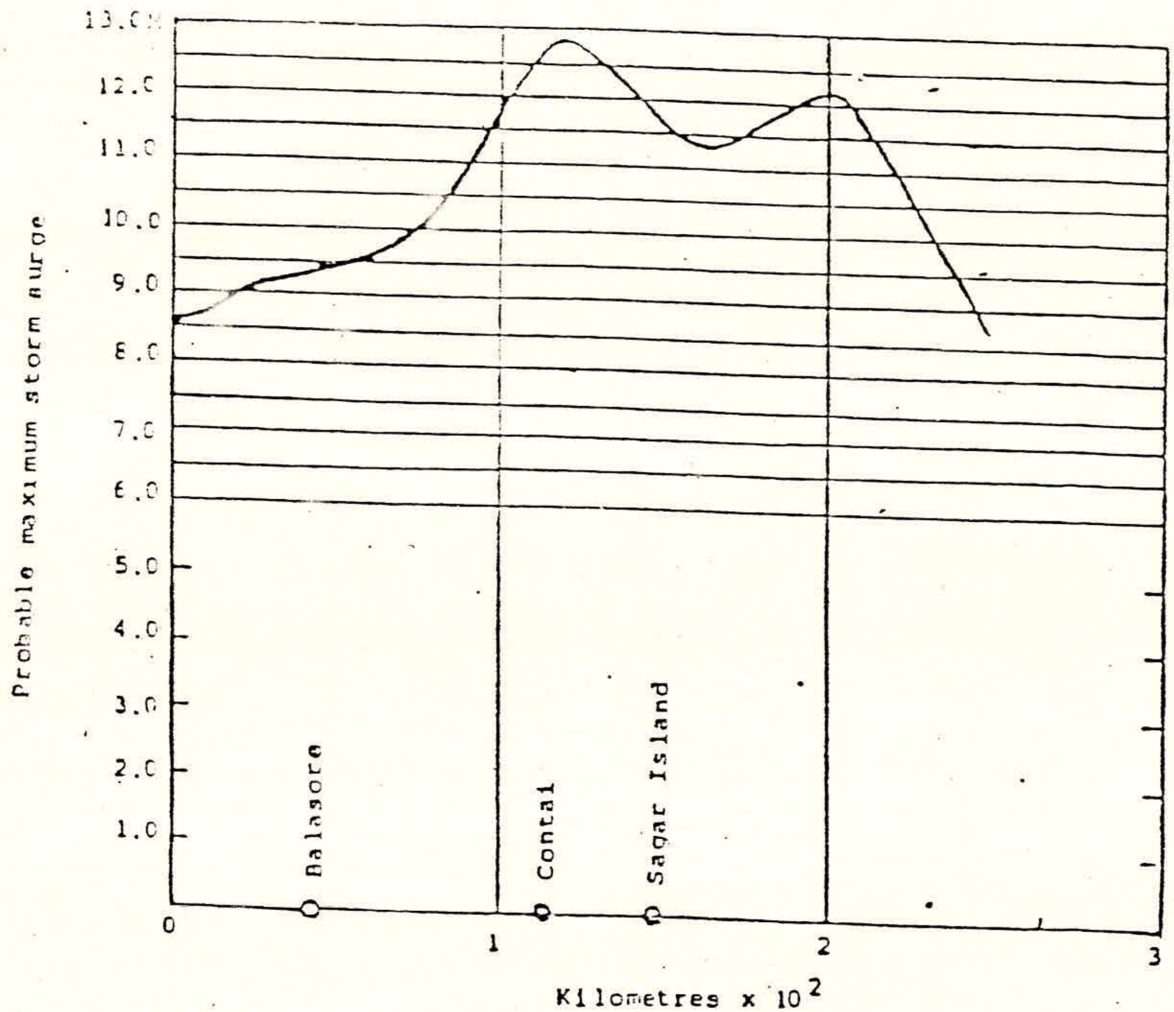


FIGURE - 17 PROBABLE MAXIMUM STORM SURGE IN METRES



Probable maximum storm surge (PMSS) on the southeast coast of India (north of 10 °N)

FIG. 18



PMSS on the northeast coast of India.

FIG. 19

coincides with spring tide. In Andhra Pradesh amongst all the cyclones that have crossed its coast the cyclone of 19th November 1977 called 'Diviseema Cyclone' is the most devastating one with tidal waves as high as 6 m inundated coastal area 15 km inland in the Delta of river Krishna (Naidu, 1989). Description of a few cyclones of recent past that formed in the Bay of Bengal and crossed the East coast are listed (Mausam) in Annex I.

5.0 HYDROLOGICAL PROBLEMS IN COASTAL AREAS

All the coastal areas and deltas face so many hydrological problems of engineering importance: like shifting and extending of shipping channels; lack of firm footing except on levees; steady subsidence, which may reach a rate of 5 feet per century; poor drainage and extensive flood danger; scarcity of fresh drinking because of progress of salt water intrusion; tendency of the mainflow to shift away to entirely different areas creating a constant problem for water traffic. Submergence to a depth of 5m during hurricanes or cyclones is not uncommon in deltas. To mitigate these problems it is necessary to understand the formation of a delta. Some of the problems being faced frequently and the available remedial measures are discussed.

5.1 Waterlogging & Drainage:

An agricultural land is said to be waterlogged when the soil pores in the crop root zone get saturated with water. This is usually caused by a rise of the sub-soil water table. Waterlogging can also be caused by excess soil moisture due to periodic flooding, overflow by runoff, over-irrigation, seepage, artesian water and impeded sub-surface drainage. This results in low agricultural yield, turns the lands alkaline or saline and makes the fields unfit for cultivation.

The average annual natural runoff available in India is estimated to be 1880 cubic km. for the main land excluding the Islands. Out of this the utilisable water from surface structures is about 690 cubic km. Similarly the Central Ground Water Board has estimated the possible utilisation from groundwater as 418 cubic km. Thus the assessed surface water resources of India are about 3% of the World's surface water resources, whereas the country's population is about 16% of the World population. Hence, the water resources in India are limited and for the ever growing population and increasing number of industries, unless a systematic attempt is made for the proper planning and management of water resources, the country will have serious problems regarding the water availability to various sectors in future.

Under irrigated conditions, the farmers do uncontrol irrigation there by the excess water than the capacity is added to the ground water table. Some times waterlogging occurs in lowlying lands due to seepage from the irrigated uplands and from the canal system. Also the obstruction of natural drainage by roads, railways and other structures with poor or choked cross drainage facilities causes the ponding of monsoon runoff thereby creating waterlogging in the fields. This is due to the negligence shown towards the surface hydrology aspect. Although irrigation and drainage should go hand in hand for proper utilisation of water, the drainage aspect has not been given the due attention in most of the water resources projects.

5.1.1 Quantification:

The norms of monitoring of groundwater table for determining the extent of area waterlogged varied from State to State. However, the Experts' Group, set up by the Ministry of Water resources in 1986 , adopted the criteria for deciding the waterlogging conditions as the water table rising upto 2 m. depth from the ground surface observed in the month of November and April. Therefore, there is at present no uniformity in the definition of waterlogged areas and thereby the measurement of water table level to provide reliable data of the total area affected by waterlogging in the country is lacking the standardization. Subject to this the below given table gives the extent of the waterlogged area as estimated by various Agencies/ Organizations.

Table 3 : Extent of Waterlogged Areas (in M ha.)

State	I (1972)	II (1976)	III (1990)
Andhra Pradesh	NR	0.339	0.339
Orissa	NR	0.060	0.060
Tamil Nadu	NR	0.018	0.018
West Bengal	1.850	1.850	2.180

I: As per National Commission for Irrigation
II: ______do______ on Agriculture
III: As estimated by Ministry of Agriculture

5.1.2 Prevention/Remedy:

However, a fair judgment can be that canal induced area under waterlogging/salinity in the country may not be more than 1/3 rd of the total area under waterlogging/salinity. The problem of waterlogging is required to be tackled through two pronged strategy. One is of preventive type and the other is of remedial nature. The approach of conjunctive use may have to be adhered to.

This require emphasis on groundwater investigation. Once the possibilities of safe withdrawal of groundwater are known, the requirements of each crop set for the balanced surface water can be estimated.

As envisaged in the National Water Policy, 1987, the irrigation planning should reflect a close integration of water use and land use policies. Also there is need for establishing water table observation stations in adequate density for monitoring the rise of groundwater table and the quality of water.

5.2 Aqua culture along coasts:

In the tail end reaches of the deltas and along the coastal areas decreasing returns from paddy in comparison to aqua culture has led to the growth of pisciculture and prawn ponds which are yielding high profits. Enormous growth of uncontrolled increase in aqua culture along the coast is disturbing the natural equilibrium of the sensitive environment.

In Andhra Pradesh the experiment of prawn culture has started in the brackish water ponds from 1985 onwards. Now, this culture is being undertaken in a big way in tanks or surface reservoirs. It started in the waste lands along the coast as part of government decision and later led to illegal encroachments of the coastal area where high concentration of populations inhabit. The fish ponds were depending on the irrigation drains but with the growth of this culture along the coast, now they depend mostly on the ground water. The lands are being dug upto 3-4 metres deep leading to landward development of salt water intrusion.

The scarcity of drinking water is another growing problem. Fresh water that is being collected in surface tanks for drinking is turning into brackish water, being surrounded by a number of fish ponds. Drinking water scarcity is severe during the summer months of February to July for the last two years. Paddy grown in small land holdings is worst affected due to non availability of fresh irrigation water. During intense rains there is the problem of water logging due to the obstruction of natural drainage by fish ponds.

Hygiene of the people in villages around the fish ponds is getting affected because of the pollution created by aqua culture. The improper way of releasing the waste water from fish ponds pollutes the water bodies around. Spread of deceases like diahrea is fatal to human beings especially during lean flow periods of summer, when the natural self cleaning capacity of flowing waters is low.

5.3 Influence on the river down stream of the Dam:

There will be strong effects on the lower reaches of river because of diversion works on it such as dams, wiers and barrages (Evrard, 1985). This is because substantial part of the sediment usually carried by streams is trapped. Hence the grain size distribution of the released sediments is modified as most of the course particles are retained in the reservoir.

5.3.1 Influence on river morphology:

The modified discharges down stream of the dam with reduced sediment content will scour the river bed. The bed load transport will increase in the down stream direction until an equilibrium between the transport capacity and sediment load is reached. The river bed will degrade down stream from the dam, unless limited by rock sills in the bed. The deeper river channel will be favourable for the passage of flood; but on the other hand, degradation of the riverbed will also have negative effects:

__The deepening of the river channel may affect the water table in the valley either by lowering it if the groundwater flows towards the river , or by reducing the supply if the groundwater is fed from it.

__It may lead to the pollution of groundwater or increase the salinity of the soil in the vicinity of an estuary.

__It can contribute to the undermining of the structures and river banks.

The length of the reach subjected to erosion varies between river to river and for a particular stream , over time. Williams and Wolman (1984) showed that the length of the degraded reach increases with time. On the colorado below Hoover dam, the length of the degraded reach 6 months after dam closure was 21 km. 1 year after: 28km, 2 years after: 50 km., 3 years after: 85 km., and 5 years after: over 120 km. Determination of the. rate of migration of erosion is of considerable theoretical and practical interest. Unfortunately data are very limited. The maximum recorded down stream rate of movement is 42 km per year according to Raynov et. al.(1986). Mean rates of migration can also be large as high as 40 km per year downstream from Iron Gate I dam on the river Danube and more than 30 km per year downstream of Aswan dam in Egypt.

Considerable attention has not yet been given to changes of channel width in streams downstream of dams. However, where much of the stream flow is being diverted from the river, width can be reduced by deposition and vegetation growth. Nenov's (1985) studies showed that in most cases a reduction in channel width is observed and may be as high as 70% downstream of reservoirs in which a large part of the stream flow is diverted for irrigation or water supply. Any reduction in channel width reduces the flood capacity of the channel, which can negate the effect of the reservoir in reducing the flood damage.

If a part of the discharge is diverted by the dam the eroding effects will be reduced since the released discharges will be lower. The released discharges may be saturated with sediments if an important part of the sediment is also flushed into the river down stream of the dam. The eroding capacity of such waters is then reduced and deposits of sediments may appear below the dam. The resulting increase of bed level may hamper the passage of floods and may cause the channel to meander.

The effects of the project on the river morphology should be studied by means of mathematical models, by which the down stream water course can also be represented. By using such models the necessary protection works and operational rules may be determined.

The reduction of low and medium floods by the reservoir and the trapping of most of the sediments prevents the possibility of warping, i.e., of conducting fertile silt onto the land in river valley. It must be remembered that apart from fertility, the deposition of silt in the valley is useful because it may counteract the effects of eolin erosion, enhanced by cultivation of the land and thus favours the conservation of the soil.

5.3.2 Influence of sand quarrying:

Due to interception of gravels and sands upstream of dams, the renewal of gravel/sand layers is prevented or reduced. It is therefore important to develop a policy in managing the quarries so as to prevent premature exhaustion of resources. It would be advisable to encourage quarrying upstream of the dam. Excessive excavation could cause a lowering of the water table and uncontrolled quarrying might cause serious damage to the stability of the channel during high floods.

5.3.3 Influence on the Estuary:

The reduction of sediment transport disrupts the balance of sediments at the river mouth, particularly in a delta region. Coastal erosion by currents and wave action is no longer compensated by the deposition of sediments brought by the river, and fertile agricultural land may recede or completely disappear.

High floods may abruptly complete the action of the currents in underscouring the coast, particularly if the reservoir is near the estuary; so that the unsaturated flow during the floods has a significant potential for erosion. The inflow of flood discharges may also lead to the development of recirculating currents along the shore which may strengthen the littoral transport of sediments.

If these effects are found intolerable, it is possible to remedy them by appropriate protective structures, such as dykes, breakwaters, groins, etc. However, these structures are very costly and should be designed by experts, on the basis of mathematical or physical models, after having their objectives clearly defined.

5.3.4 Effects of sediment ejection:

Accumulated mud is ejected into the river downstream from the dam in conjunction with operations carried out for the following reasons:

- Maintenance: regular emptying of reservoir, (when underwater inspection is not adequate), repairs, periodic testing of gates...
- Reservoir operation: release of floods...
- Economy: preservation of the storage capacity by flushing of sediments, application of particular operational rules for the evacuation of mud, dredging, siphoning...

The downstream ejection of mud is inevitable, in any case, even if it is not wanted. At the end of the operational cycle, when the storage becomes empty, the river cuts its bed in the muddy deposits, until it has reached the level of the original river bed. The mud terraces are thus drained and large sections collapse. Hence the emptying of a reservoir will increase the slides. In the case of deliberate release of mud, the consequences can be attenuated by judicious mixing of surface and bottom layers of water.

The concentration of sediment in the released water can cause irreparable damage. The released sediments will be deposited selectively, the coarsest particles near the dam, and the finer particles farther downstream to form sand banks, silt banks and finally silt shoals. The deposition of these will modify the slope of the river beds and obstruct the flow. This may disturb the passage of floods and cause submersion of riverside land. Siltation of the river bed may clog the river bed and hamper infiltration into the ground, which can cause serious damage to agriculture. Finally the release of mud could be detrimental to the environment (Evrard, 1985).

5.4 Effect of Embankments on River and Sea Floods:

Embankments are the most ancient, the most simple and in general the most economic way of protecting land areas against river floods. Where as protection against river floods can also be achieved by upstream flood detention reservoirs, flood diversion and channel rectification, embankments form the only means of protecting land areas in the coastal zone against flooding by storm surges at sea.

Volker(1987) described the effects of embankments or flood protection bunds on the non-tidal reach of a river as well as on the tidal front. These effects often called as 'side-effects' are of various kinds: Hydraulic effects, morphological effects and effects on the water management of the land areas.

5.4.1 Effects on non-tidal reach:

Hydraulic effects may occur in the form of a rise in flood levels and an increase in discharges. When the bank-full discharge which enters a flood plain is exceeded the water overtops the natural levees and flooding of the land areas occur. This flooding means that a substantial volume of water goes into temporary storage and the discharge downstream is smaller than the discharge at the station where the river reaches the flood plain. Embanking causes the overland flow confined to the cross-sectional area between the two embankments resulting in an increase in the discharges compared with the original situation. Also overbank storage is eliminated, causing a further increase in the channel discharge. The effect of elimination of overbank storage is most pronounced in the case of flash floods. Accurate predictions of the hydraulic effects of embankments in the non-tidal reaches can be made using physical analog models and mathematical models of special type.

Embankments may affect the river morphology, resulting in a rise in the river bed and an increased tendency towards meandering and bank erosion. These effects must be duly taken into account when designing embankments. Embankments hamper natural drainage of excess water from local rainfall. After embanking, a drainage system has to be installed consisting of outfall structures, conveyance systems and field drainage. Embankments also eliminate the beneficial effects of flooding such as supplemental irrigation of wet rice during the local dry spells and the flushing of the land areas and channels after a long dry season.

5.4.2 Effects on Tidal reach:

Embankments to protect low lying lands along the coast modifies the horizontal and vertical tides in the creeks. The vertical tides are of significance for the gravity drainage of the land areas and the horizontal tides determine the morphology of the creeks. Enclosure of tidal embayments and estuaries in order to create fresh water reservoirs and to reduce the length of the lines of defense against storm surges may also modify the tides outside the enclosing dams. This is important for navigation and the maintenance of harbors in the remaining tidal area.

Storm surges flood the non-embanked areas to a considerable height. Embanking of such areas eliminates the overbank storage and may cause higher maximum levels at the site, especially in the case of surges of short duration. Accurate prediction of the effects of embanking on the astronomical tides and storm surges is possible using physical or mathematical models provided that adequate information on the tides and surges under the original conditions.

5.5 Hazards Analysis:

The purpose of hazards analysis is to quantify the still-water surge heights, waves and windspeeds for various categories, tracks, directions and forward speeds of hurricanes considered to have a reasonable probability of striking a particular coastal basin. Potential freshwater flooding from a rainfall accompanying hurricanes or cyclones is also considered; however, due to the wide variation in amounts and times of occurrence from one storm event to another, rainfall can only be addressed in general terms.

Graham (1985) in an overview of major analyses of hurricane evacuation studies mentions about the Sea, Lake and Overland Surge Heights from Hurricanes (SLOSH) numerical model, developed by the National Weather Services, is commonly used to determine the still-water surge heights and windspeeds associated with various simulated hurricanes modelled for a coastal basin. Although other models and methods have been used, the SLOSH model is considered to be the most sophisticated and appropriate for evacuation studies. Other models have reliably calculated surge heights for the open coastline; however, the SLOSH model has the added capability to simulate the routing of storm surge into bays, estuaries, coastal rivers and overland. Developed for selected Gulf and Atlantic coastal basins, the SLOSH model incorporates a curvilinear polar coordinate grid scheme (a fan shaped grid) in which a basin's bathymetry, topography and natural and man-made barriers are mathematically represented.

The grid configuration of the model has a resolution of approximately one-half square mile for inland areas near the focus to approximately one and half square miles at the coastline. Simple time-dependent input parameters for the desired storms to be modelled are supplied by the user and from which calculations are made of surge heights in feet above datum, wind speeds in mph and wind direction as an azimuth from which the wind is blowing. The input parameters, entered at six-hour intervals for a simulated 72-hour storm track, are storm position by latitude and longitude, central barometric pressure in millibars and the radius of maximum winds.

Prior to modelling the desired storms, a maximum of sixty model grid points are selected for which time histories of surge heights, wind speeds and wind directions are tabulated for at least a 30-hour segment of a simulated storm track. The selected grid points normally represent locations of critical roads and bridges of low elevation, potentially vulnerable population centres or areas adjacent significant natural or man made barriers. The model output for each storm run consists of a surface envelope of water which represents the maximum surge values calculated for each grid point irrespective of the time the maximum height occurred. These values are displayed on printouts on which the grid points are referenced by a system of coordinates.

After all individual storm runs are made for a basin, these can be combined into Maximum Envelopes of Water (MEOW) by category of storm, direction, forward speed or any combination of parameters. Normally the MEOWs are prepared by the category of storm and combine all other storm parameters in order to determine the maximum surge heights possible for a location regardless of landfall location, forward speed or direction of movement. Individual storm runs are combined into MEOWs because the ability to accurately forecast landfall locations and forward positions of approaching hurricanes is not great. The MEOWs also allow the data to be simplified and and more easily utilized by emergency management agencies during a hurricane threat.

Amounts and arrival times of rainfall associated with hurricanes are highly unpredictable. For most hurricanes, the heaviest rainfall occurs near the time of arrival of gale-force winds; however, heavy rains in amounts ranging to 50 cm can precede an approaching hurricane by as much as 24 hours. Unrelated weather systems can also contribute significant rainfall to the basin in advance of a storm. Due to the unpredictability of rainfall from hurricanes, no attempt is made to employ sophisticated analysis in quantifying the effects of rainfall for an area. Areas and facilities which have historically flooded during periods of heavy rainfall are identified and assumed to be vulnerable under hurricane threats.

Murthy et. al.(1992) studied the utility of satellite remote sensing as an effective tool for monitoring individual drains / canals the proper functioning of which is crucial during floods. By analysing the temporal satellite data during the disaster period, various levels of flooding can be mapped, which is, by no other means so accurately possible. Stagnation of flood waters coupled with plume dispersion near the outfalls of the drains, gives an inset to suggest different flood alleviation measures to mitigate disaster in Krishna delta (fig. 20). But the hydro-dynamic impact on the coast line because of the proposed measures is most important because of the sensitive equilibrium of the coastal and deltaic environment. Here comes the importance of undertaking modelling studies.

5.6 Coastal Environment:

Coastal zones often contain some of the most densely populated areas in the world. The areas close to rivers and deltas generally present the best conditions for productivity. The demand for fresh water resource easily exceed available resources in areas not directly fed by the rivers. The coastal zone, as the transition area from land and sea, and from fresh water to salt water, contains some of the world's most biologically productive units, the estuaries being the key element, as shown by the following data (Teal and Teal, 1971):

Source	Production rate t/sq.km./year
Arid agriculture	0.5 - 3.5
Moist agriculture	3.5 - 12.0
Estuarine zone	12.0 - 24.0
Coastal water	2.5 - 3.5
Open ocean	~1.0

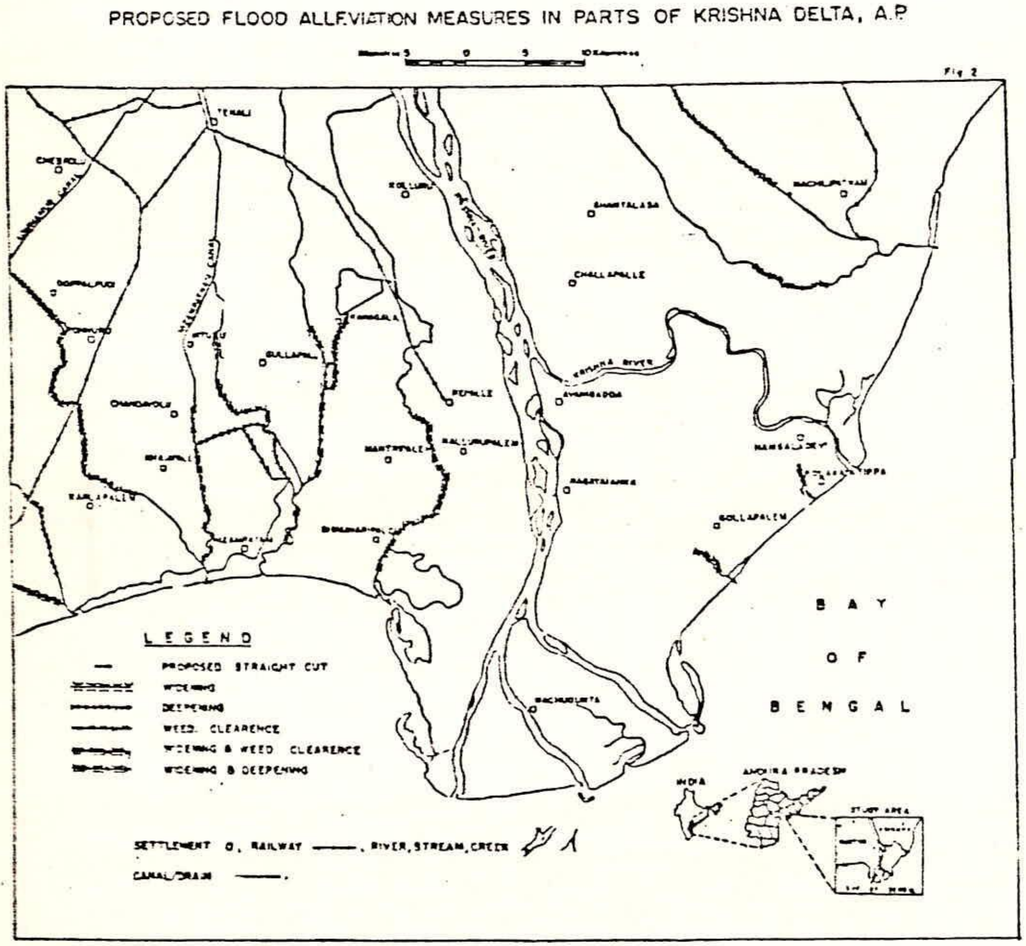


FIG. 20 (Murthy, 1992)

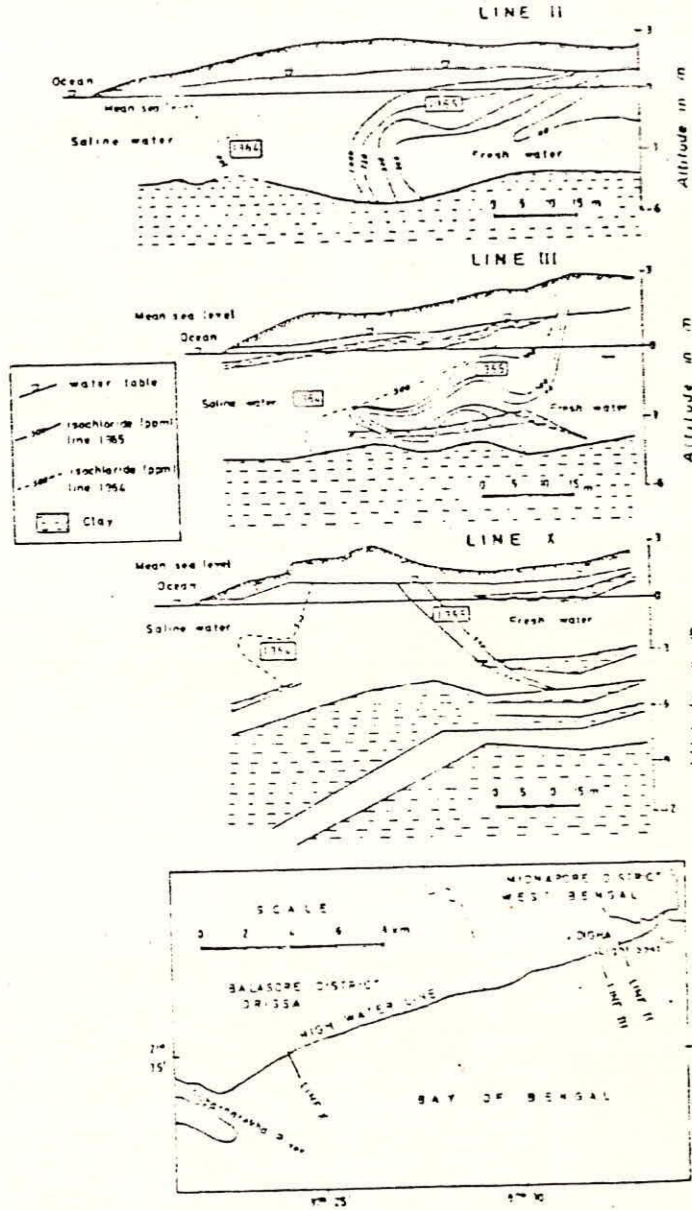


FIG. 21
(Goswami, 1968)

Associated with man's activities are his uses, and in many instances abuses, of coastal resources. By the year 2000, it is assumed that more than three quarters of the world's population will be at or near the coast, and will draw heavily on the already stressed coastal environment. Custodio (1987) stresses that surface- ground water relationships can not be neglected. Estuarine and groundwater outflow areas have a dilution effect of sea water salinity that affects aquatic life. River use, groundwater exploitation, urbanization impact on surface runoff and groundwater recharge modify the dilution pattern and affect aquatic life accordingly. Also marshes pose interesting problems of soils, cultivation, wildlife and disease control where groundwater outflow may have a dominant role.

Not only is water a major component of the coastal zone, but sand and gravel are also important elements. Dam construction, reforestation and deforestation, agricultural development, urbanization, land erosion control programs, water transportation, river channelization, sand and gravel extraction, etc., have a great effect on the solid transport and equilibrium of coastal areas, especially beaches. Sedimentology is as important as hydrology and hydraulics.

5.7 Sea water intrusion :

Sea water encroachment in coastal aquifers have been recognized since the first quantitative studies at the turn of the century, and have not been considered an important separate aspect of groundwater hydrology until recently. A good historical discussion on what is known as salt water intrusion can be found in Kashef (1972). Probably the first classical book to include salt water intrusion problems in coastal aquifers is Todd (1958). Also a technical paper by Cooper et. al. (1964) is an important benchmark. Perhaps one of the first international meetings to include sea water intrusion problems expressly was the Haifia Symposium organized by the International Association of Scientific Hydrology (IASH Pub No. 92).

The great length of coasts requires that a small but significant part of the continental water discharged to the oceans outflows directly from the ground. A much greater part discharges to the lower tracts of rivers, in areas where coastal conditions prevail. Since the hydrogeological hydrodynamical data along the coast are generally inaccurate, Zekster and Dzhamalov (1981b) made an estimate by applying to the discharge along the coast the same specific figures obtained for the lower tracts of the rivers. Direct groundwater outflow is thus about 5% of the total continental fresh water outflow, although due to its greater salinity, it contributes about 1/3 of total continental salts transported by water from the continent to oceans, and thus it has a significant effect on the sea salt balances and on many geochemical processes leading to rock and mineral formation. Susceptibility to easy degradation by sea water intrusion poses delicate problems for the use of the sometimes great groundwater reserves in highly porous coastal formations. A 3% sea water percentage can render the water too salty for many uses, and 5% practically renders it useless, except if very expensive desalting processes are used.

5.7.1 Types of coast:

The measurement and classification of coasts and shores can help in the understanding of their importance. The total length of the perimeter of the entire World ocean has been calculated to be about 777,000 km (Luk'Yanova and Kholodilin, 1975). The above figure refers to the shoreline, which has a macroscopic aspect given the initial type of dissection, and a microscopic aspect that depends on the sinuosity, produced mainly by wave action.

The shore can be considered as the zone bounded by the seaward and the landward water limiting lines. The length is measured by the smoothed median curve. An allowance is made for the microelements in plan, mainly due to wave action.

The coast is defined similarly, but the definition must consider the macroelements, such as heads of fiords and rias, open lagoons and continental islands.

When considering the shore and the coast lengths, the perimeter of the World Ocean is reduced to 469,000 and 413,000 km respectively (Custodio,1987). The coast classification is more adapted to the description of the different relationships between fresh and salt groundwaters in coastal areas. However, it is necessary also to consider hydrodynamic conditions (water table, confined systems, semiconfining layers, low lands, etc.,), that can greatly influence relationships. Sea bottom sediments also can play an important role. From the hydrogeological point of view not all coast types have the same importance, since those of hard, low fractured rocks (granites, gneisses) are almost unproductive, while terrace deposits and great recent sedimentary basins have a clearly overwhelming interest.

Classification:

(a) unconsolidated materials (Glaciated, alluvial, marine and eolian), mainly accretional, about 25% of total coast.

(a1) water table

(a2) small islands

(a3) confined

(a4) semiconfined

(a5) multilayered

(a6) young deltas

(b) Consolidated materials (some mountains, tablelands and plateau), mainly abrasional or denudational, about 20% of total coast.

(b1) fissured hard rocks

(b2) karstified rocks

Other factors to be considered in subclassification are:

- sea behaviour (tidal regime, storm surges, wave action, sea bottom sediments)
- climate (wet tropical, semi-arid, temperate, mediterranean; predominant winds; rain intensity)
- recharge regime
- man interventions (desiccation, poldering, river basin modification, agriculture, urbanization)
- long-term evolution (sea water transgressions or regressions, subsidence)

5.7.2 Sources of sea water:

The main source of salt in coastal areas is sea water. Sea water has a rather constant chemical composition except for small changes due to the variable evaporation rates or great continental fresh water contribution. Greater differences can be found in closed or half-closed seas. Typical sea water analyses (from Custodio and Llamas, 1976) are:

Table 4: Typical sea water Analysis

Salt	in g/l (ppm)
HCO3	0.07 - 0.14
SO4	2.40 - 2.70
Cl	17.50 - 19.00
Na	9.70 - 10.50
K	- 0.36
Ca	0.38 - 0.40
Mg	1.00 - 1.30
TDS	33.00 - 35.00

According to Custodio (1987) other sources of salt can be found in coastal areas and must be taken into account when considering the different processes that lead to fresh water salinization. The complexity of sedimentation in deltas and coastal basins, and the movement of pore-water due to load and compaction gradients, complicate the entrapped salt water distribution. In some areas fresh brackish or salt water may be under geo-pressurized conditions.

Evaporation from surface water bodies or directly from the ground when the phreatic table is at a shallow depth produce saline water, even from fresh continental water without any previous mixing with sea water. It appears in very flat and low lying coastal areas in dry climates.

Since the sea is the lowest drainage area of many great continental basins, regional flow systems with very low flow and long residence time can discharge brackish water and even salt water near the coast. This situation is not related to the sea water salinity and must not be confused with an oceanic influence. Other sources of salt such as the dissolution of evaporite deposits are less important and only of very local importance. They are only significant in special situations, generally localized ones.

The most frequent situations that can lead to an unstable condition are those in which saline water lies on fresh water. Cross-sections perpendicular to the sea coast near Digha showing the saline-fresh water contact in 1964 and a year later after dry period are given in figure 21. The contact migrates landward until some ten metres. Nonhomogeneity of aquifer permeability and introduction of salty water through the ground surface after heavy storms, produce an unusual form of mixing zone, with an upper layer of salt water. The storms produce a retrogradation of the shore line (Goswami,1968). The standards that are being practiced for hydrological in the region are listed in Annex-II.

6.0 SCOPE OF STUDY AND ITS USE IN THE REGION:

The delta and coastal region is one of densely populated and commercially important part of the country. The region is frequently facing the fury of the nature in the form of flash floods in medium sized river catchments during intense rains resulting from monsoons or cyclonic disturbances. The problem of inundation and waterlogging is also there because of drainage congestion in channels and rather flat slopes of coastal plains (Annex III). Every year a number of urban areas along the coast and in deltas are subjected to these problems. Also the problem of fresh water availability in the region especially in lean flow periods or summer months makes the situation worse. The intrusion of sea water along the surface streams and along the coastal coastal aquifers into interior is developing with time. The limited finances (Annex III) with which the responsible organisations have to tackle these problems is another reason for not showing proper attention towards the importance of the hydrology of the region.

6.1 Scope of study:

The major hydrological problems being faced in the region are flash floods due to intense cyclonic storms in medium sized catchment rivers; drainage congestion of streams in the flat coastal plains and the associated problem of inundation and waterlogging.

In the training to be obtained it is proposed to undertake research and attempt to develop necessary software for solving the problems related to flash floods in medium sized catchment rivers along the east coast of the country. The techniques developed elsewhere in the world for avoiding the drainage congestion of streams and waterlogging and drainage of the deltaic plains will be studied and suitable modifications will be made to suite to the native conditions.

6.2 Utility of the Study and output:

Every year the highly populated coastal and deltaic region of the east coast of the country is subjected to the fury of nature in the form of floods and related drainage problems. Though attempts are made from time to time to mitigate the impact of the ill effects caused due to this natural phenomenon, their positive contribution for remedial solution is rather not noteworthy. This is due to the lacuna of applying the latest available methodologies in the field of hydrology appropriately.

The training obtained under the UNDP fellowship will facilitate in undertaking the research work in a systematic and efficient way to solve and mitigate the hydological problems of this nature. Specific case studies will be undertaken using the knowledge acquired through the training. It will also be attempted to induce the need for systematic studies and for the use of latest developments and methodologies in the direction of mitigating the above said hydrological problems of the region through the preparation of reports and organization of workshops.

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Description of Cyclones crossing East Coast of India

1. Deep depressions of 10-14 August 1986:

Under the influence of a cyclonic circulation in the lower and mid tropospheric levels over west central and adjoining northwest bay, a deep depression formed over west central bay on 10th evening. It crossed north Andhra coast near Kalinga Patnam in the night of 12th August 1986.

The system brought an active spell of monsoon rains over coastal Andhra Pradesh. The significant amount of rainfall in cm were: Kothagudem 21, Visakhapatnam 18, Nididavole 14, Khammam 13, Chandrapur 9 on 12th, Chandrapur 20, Nidadavole 17, Ramagundam 16, Kothagudem 14, Nagpur AP & Sukma 13 each, Jagadalpur 12 on 14th, Shajapur 19, Narwar and sehore 17each, Hoshangabad 15, Indore 12, Ujjain 11, Murtzapur & Wardha 7 each on 15th August.

As per press reports heavy rains caused floods among other places in coastal areas of Andhra Pradesh and claimed 115 lives.

2. Depression of 24-26 September 1986:

Under the influence of a cyclonic circulation in the lower tropospheric levels, which lay over north-west bay and adjoining land areas on 21st, a depression developed over northwest Bay on 24th September 1988. Moving Northwestwards it crossed the north Orissa coast near Balasore in the forenoon of 25th September.

Under the influence of the system monsoon became active to vigorous over gangetic West Bengal. The heavy rain that occurred over gangetic West Bengal due to the system caused deluge in Calcutta and in several places in the district of Howrah, Hooghly, Midnapur and 24-Paraganas. It also claimed 18 human lives and rendered over 6.15 lakhs people homeless.

3. Bangladesh cyclonic storm of 7-9 November 1986:

The equatorial trough over south and adjoining central Bay was rather active from the lastweek of october. In this trough a depression developed over West Central and adjoining Southwest Bay on 7th Nov. It intensified in to a cyclonic storm before crossing the Bangladesh Coast on 9th Nov.

In association with the system, there was heavy to very heavy rainfall on one or two days over orissa, Gangetic West Bengal. According to press reports considerable damage occurred to paddy and rabi crops in Balasore, Cuttack, Puri and Ganjam districts of Orissa. Many fisherman living near Chilka lake coast lost their houses due to inundation by lake water. Also several live stock were lost.

4. Nellore severe Cyclonic storm 31 Oct. - 3 Nov. 1987:

A low pressure area, which was observed over the south east and adjoining south west Bay on 30th October, concentrated in to a depression on 31st Morning. It further intensified in to a cyclonic storm by the morning of 2nd November. The system moved in a trochoidal path and crossed south Andhra coast just north of Nellore on 2nd November Night.

The system caused widespread rainfall with isolated heavy to very heavy fall over coastal Andhra Pradesh on 3rd and 4th Nov. Nellore recorded an unprecedented heavy rain of 52 cm on 3rd Nov. 1987.

The storm affected a population of about 6.8 lakhs in 288 villages of Andhra Pradesh. It claimed 50 human lives and 25,800 live stock. It also inundated vast stretches of paddy fields, disrupted road and train services and damaged about 68,000 houses. Though no storm surge inundated any coastal areas, the sea waters entered in to Buckingham canal in Nellore district and breached its embankment. Saline waters from the swollen canal flooded the adjoining fields.

5. Balasore severe Cyclonic storm of 23-27 May' 89:

A cyclonic circulation in the middle tropospheric levels was first observed over the central Bay on 18th May. It intensified into a severe cyclonic storm over north west bay on 25th evening. Afterwards, it took a northerly course and crossed north Orissa - West Bengal coast about 40 km northeast of Balasore around 1500 U T C of 26th.

The impact of the storm was felt in cuttack and Balasore districts of Orissa and Midnapore, 24-Paraganas and Hooghly districts of West Bengal. Tidal waves of 3 to 6 m height were observed in the coastal areas of Balasore, Midnapur and 24-Paraganas. In Balasore district, sea water entered in to the low lying areas of Rajnagar, Rajkanika, Pattamunda and Mahakalpara through the adjacent rivers Brahmani, Nuna, Birupa and the tributaries of Mahanadi. Seawater of 5 to 6 feet high also entered through Suvarnarekha river in Baliapal block affecting few villages. In Bahanaga block sea water entered about 6km inland submerging low lying areas. In most of the places sea water submerged land areas 4 to 6 km inland along the coast and the river belts. 10 feet high water entered land areas near panchupalli and Avana villages. At khorasahapur, Avana and

Ramthali villages saline water reached a height of 6 feet in the morning of 26th May. Maximum tide level of 5.72m was observed at the southern end of sagar Island. The hurricane took a toll of 61 lives and affected about 6.9 million population in Orissa and West Bengal. In association with the hurricane significant amount of rainfall occurred over the 2 states.

6. Kalingapatnam cyclonic storm of 21-25 July '89:

The genesis of cyclonic storm started on 20th July Morning as an upper air cyclonic circulation in the lower and middle tropospheric levels over north and adjoining central Bay. By the evening of 21st the disturbance concentrated in to a depression over West Central and adjoining northwest Bay of Bengal. It took initially a westerly course, intensified in to a cyclonic storm and crossed north Andhra south Orissa coast near Kalingapatnam during the night of 22nd July.

The rainfall in association with the system had the usual typical pattern associated with a monsoon depression. Rainfall amounts to the north of the track were quite low, while they were excceptionally heavy in its southern sector, in the districts of west and east Godavari, Krishna and Khammam districts of Andhra Pradesh. The very heavy rainfall occurred in the belt of about 100-200 km wide stretch at a distance of 250-350 km away from the central line of depression.

The unprecedented heavy rainfall over the West and East Godavari, Krishna districts of Andhra Pradesh and Khammam district of Telangana and at other places caused severe floods in those areas. Apart from high floods there were high gusty winds, which aided the destruction and devastation. The system also affected coastal districts of South Orissa. In the Andhra Pradesh river Godavari and its tributaries were in spate. High floods occurred in lower Krishna basin. Heavy rain caused breach of Irrigation tanks in West Godavari and Krishna districts of coastal Andhra Pradesh causing several floods on 23rd July. Eluru, headquarters of West Godavari district was submerged under water. Flood in river Budameru in Krishna district was worst since 1964. It submerged thousands of houses in low lying areas of Vijayawada Town. 23 villages in the district were submerged under flood waters. The system claimed about 1000 lives in the country.

7. Kavali hurricane of 1-9 November'89:

The hurricane developed over the Gulf of Thailand on 3rd November. Initially it moved northwestwards for a day. Then moving westwards across south Thailand - south Burma it emerged in to Andaman sea. There after it took a west northwesterly to westerly course, crossed the Andaman group of islands and struck south Andhra coast near Kavali around midnight of 8th November 1989. The hurricane was unique one in that the aerial extent of the gale force wind hardly extended at any time beyond one degree from the centre of hurricane. Moreover it was one of the few most severe storms of this century. It was second storm in 100 years that entered the Indian seas from the Gulf of Siam and neighborhood. It was the only storm in the Indian seas in the last hundred years that traveled west to west Northwestwards over 2600 km over the sea waters.

The windspeed when it crossed near Kavali could be estimated at about 100 to 120 knots per hour with a radius of 10 km. It was reported by the villages of the Thummalapenta, which is situated a few kilometres to the east of Kavali that high speed wind and rain started at 2200 hours IST on 8th November 1989 and lashed the coast up to about 0130 IST of 9th November 1989. Then there was a lull period for about 15 minutes. There after the fury of rain and wind commenced gain, with complete change in the direction of wind. The strong wind lasted for about one hour. The pattern of destructions around Kavali also substantiated this description.

In association with the system very heavy rainfall was reported from one or two places in south coastal Andhra Pradesh. Though the hurricane hit the coast at the time of lowtide, 3 to 4 metre high tidal waves lashed a stretch of 40km of the coast. At Thummalapentapalem sea-shore up to 1/2 km inland was inundated. Standing crops in thousands of acres of land water damaged in Nellore and Prakasam districts.

8. Severe Cyclonic Storm of May 1990:

The system developed as a depression over southwest Bay on the night of 4th May 1990. Moving in a northwesterly and then westerly direction it developed in to a cyclonic storm on the afternoon of May 5th over southwest Bay. It further intensified into a severe cyclonic storm and then attained a core of hurricane winds by May 6th afternoon. Then moving in a north northwesterly direction it crossed the south Andhra coast at the mouth of river Krishna on May 9th evening as a hurricane.

The cyclone was tracked by INSAT-1B throughout the period. Radars at Karaikal, Madras, Machilipatnam and Visakhapatnam tracked the system as it came within their range. With the timely warnings given by the IMD and adequate preventive measures taken by the State government, the loss of life was reduced. The casualty was around 1000. This is mainly because of the flash floods that occurred on all the east flowing medium or small rivers north of the track of cyclone. The entire transportation system was thrown out of gear for about one week due to washing away of railway tracks and roads in many parts of coastal Andhra. Since May being the peak summer season, the incidence of this cyclone is untimely and most of the operating staff at different reservoirs located at remote places are caught on the wrong foot. The delay in opening of dam gates on time made the flood situation worse at many places in the plains due to the forced floods created by sudden opening of gates in panic.

ANNEX -II

Standards of hydrological use being followed in India

1. Criteria for design of small embankment dams: IS:4453 (1987)

2. Drainage system for earth and rockfill dams: IS:9429 (1980)

3. Guidelines for fixing spillway capacity: IS:11223 (1985)

4. In situ permeability tests (for over burden): IS:5529 (1969)

5. ___do___ (for bed rock): IS:5529 (1973)

6. Classification and identification of soils for general engineering purposes: IS:1498 (1970)

7. Control of sediment in reservoirs: IS:6518 (1972)

8. Watershed management relating to soil conservation and recommendations: IS:6748 (1973)

9. Guide for storm analysis: IS:5542 (1969)

10. Design of section of unlined canal in alluvial soils: IS:7112 (1973)

11. Criteria for river training works for barrages and wiers in alluvium: IS:8408 (1976)

12. Design of cross- drainage works: IS:7784

13. Guidelines for planning and design of surface drains: IS:8835 (1978)

14. Guidelines for planning and design of river embankments (levees): IS:12094 (1987)

NOTES ON TAMILNADU DEPARTMENT ACTIVITIES REGARDING HYDROLOGY

(vide communication from K. Natarajan, Chief Engineer, Ground water, Tamilnadu)

I. Measurements, Recording and publication of Hydrological data on rainfall, surface water, groundwater from quantity and quality aspects at space and time level.

a. Rainfall: Rainfall particulars are being collected by the Groundwater wing of Public Works Department, Tamilanadu from 400 rainfall stations every month.

TAMILNADU State comprises of 22 districts and the geographical area of the state is 130058 Km.

The rainfall stations are maintained by various agencies like Revenue, P.W.D., I.M.D., etc. The rainfall is measured and recorded daily. The data collected from the field officers are compiled in this office and monthly bulletins indicating the actual rainfall, the percentage deviation from normal rainfall etc. are prepared and sent to Government departments other agencies. Annual bulletins are also prepared and sent to the various organizations.

b. Surface Water: This is dealt with the Irrigation branch of P.W.D. Tamilnadu.

c. Groundwater quantity: About 2100 control wells have been selected by the Groundwater branch of P.W.D. throughout TAMILNADU for monitoring groundwater level fluctuations. Water levels are being observed in these wells during the first week of every month. The water level data is received from the field officers and a monthly bulletin, indicating actual water level, the rise or fall in water level in every taluk compared to the water level of the same month during the previous two years is prepared and sent to Government in PWD and various organizations. The Groundwater potential is assessed periodically blockwise, for the entire state.

d. Groundwater quality: Water samples are collected from the 2100 observation wells in Tamilnadu once in 6 moths (during premonsoon and postmonsoon periods) and analysed for quality in the Geochemical laboratories of this wing functioning at Madras, Thanjavur and Madurai. Maps of electric-conductivity and sodium absorption ratio are being prepared every six months. During the extension and consultancy services the villagers are being advised on water quality aspects etc.

II.ORGANISATION AND MANPOWER WORKING IN THE REGION ON THE SUBJECT

The collection of rainfall data is attended to by Public Works Department, Statistical department, I.M.D. etc. The collection of surface water data is dealt with by Irrigation branch of P.W.D and Central Water Commission.

The collection of hydrological data as well is data on quality aspects is dealt with by the Government branch of P.W.D and Central Groundwater Board.

III NATURE OF PRACTICAL HYDROLOGICAL PROBLEMS OF THE REGION AND REMEDIAL MEASURES.

Tamilnadu is having a coastal belt of about 1000 KM, stretching from Pulicot Lake in the North to Kanyakumari in the South. The entire Tamilnadu coast is influenced by both North East Monsoon and South West Monsoon. However, major contribution is from North East Monsoon during October to December. The coastal area is drained by 17 major river systems which include Cauvery Delta also covering the districts of Tanjavur and Nagai-quaid-E-Milleth. Normally, the rainfall contribution from North East Monsoon is due to the formation of depression/cyclones in the Bay of Bengal. Consequent on this, the coastal terrain gets inundated due to high intensity of rainfall during North East Monsoon. The lack of adequate drainage causes heavy damage to the crops and hardships to human beings. This is a common phenomenon in Cauvery Delta. In the coastal areas there are fertile cultivable lands which are affected due to failure of monsoons also.

To overcome the problem due to inundation, straight canals have been cut in Cauvery Delta to facilitate quick drainage and to save the standing crops from inundation. In short, the benefit enjoyed by North East Monsoon is greater than the hardships experienced due to sudden splash of rainfall during North East monsoon in the coastal region.

NOTES ON WORKS OF GODAVARI EASTERN DIVISION: DOWLESWARAM, A.P

(vide communication from P.Rama Raju, Executive engineer)

Sl.No.	Name of Canal	Length in KM	Ayacut in Acres	
1.	G.E. Main canal	6.70	2,692	Acres
2.	Bank canal	53.90	58,070	"
3.	Kakinada canal	40.55	52,303	"
4.	Samalkota canal	53.01	33,309	"

Sl.No.	Name of Canal	Length in KM	Ayacut in Acres	
5.	Kovvur-Manjaru canal	14.87	13,594	"
6.	Mandapeta canal	21.75	36,858	"
7.	Coringa canal	35.50	40,512	"
8.	Injaram canal	17.70	19,190	"
9.	Vemagiri pumping scheme	--	1,709	"
			2,58,237	OR
			2,58	Lakhs.

The total ayacut in G.E. Delta system is 2.58 Lakhs acres which includes ayacut of 1,709 acres under vemagiri pumping scheme in Vemagiri (V) Limits of Kadiyam Mandalam. In fact, the ayacut under this scheme is 3,331 acres. But the ayacut developed being 1,709 acres. The balance ayacut could not be developed as the ryots are not interested in paddy cultivation but interested in commercial garden crops and raising nurseries.

The entire ayacut of 2.58 lakhs acres is being fed through the Dowleswaram head sluics situated at KM 0.00 of Godavari Eastern Delta main canal.

This century old irrigation system is being maintained by one Executive Engineer assisted by 3. Dy. Executive Engineers and number of Assistant Engineers/Assistant Executive Engineers and irrigation conservancy assistants.

PROBLEMS:

For maintenance of canal system for supply of water to the 2.58 lakhs acres of ayacut, the grant being allotted at Rs.30/- per acre as per present yardsticks is about Rs.78.00 lakhs. Out of this amount, the expenditure on salaries of workcharged establishment etc., is nearly Rs.40.00 lakhs. Thus the grant available for maintaining the canal system is only Rs.38.00 lakhs. with this meager amount only very essential repairs such as desilting the canals and channels, repairs to sluices, locks and weirs could only be done during closure period of canals to facilitate supply of water to the entire Rs.2.58 lakhs acres without much trouble. But for want of sufficient grant, the canals system could not be improved to carryout sufficient water, to the tailend ayacut in time. Hence it is quite essential to chance the maintenance grant at least to a minimum of Rs.75/- per acres from the existing Rs.30/-. This is because of frequent increase in salaries of work charged establishment and thus defreasing the amount of maintenance grant. Further due to increase in the cost of materials and labour rates, the maintenance works have to be minimised to the extent grant available.

2. Unauthorised Irrigation:-

It has become very difficult to arrest unauthorised irrigation in the absence of any judiciary powers to irrigation officials. This aspect needs a very close examination for effective control and the irrigation water management.