PREFACE

In the curricular structure introduced by this University for students of Post-Graduate degree programme, the opportunity to pursue Post-Graduate course in any subject introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation.

Keeping this in view, the study materials of the Post-Graduate level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Co-operation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing, and devising of a proper lay-out of the materials. Practically speaking, their role amounts to an involvement in 'invisible teaching'. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials, the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that they may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great deal of these efforts is still experimental—in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

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First Reprint : August, 2010

Printed in accordance with the regulations and financial assistance of the Distance Education Council, Government of India.

POST GRADUATE GEOGRAPHY

[M. Sc.]

PAPER : GROUP
PGGR – 08 : B

Special Paper – I

Course Writing

Dr. Ashis Kr. Pal

NETAJI SUBHAS OPEN UNIVERSITY

PGGR : 08
Advanced Geomorphology

Group – B

Special Paper – I

Advanced Geomorphology

Unit-1 ❐ Applied geomorphology

Structure

1.1. ❐ Methods and uses of rain water harvesting and check dams.

Introduction

It was all a case of learning to live with their environment. They very first humans, who came to inhabit the Indian subcontinent must have soon realised that water was a very ephemeral resource for them. When the monsoon clouds come pouring dowing on them, there was water and there was life. Therefore, unlike the Europeans, they began to love the monsoon reason. In Indian literature, it is literally depicted as the season of love-a time when Mother Nature renews herself and gives everybody a precious new lease of life and young girls hang swings on tree boughs and sing love songs. Once the rains disappear, the land becomes as dry as a desert life difficult and water scarce to find. The gushing streams which overflow their banks in the monsoon months soon become tame or dead.

As social intelligence grew, people realised that human society cannot grow without extending the bounties of monsoon water from the wet months to the dry months. And, thus, slowly grew the extraordinary traditions of water harvesting in myriad forms in different oarts of India-going all the way back to the Indus valley civilisation, one of the earliest human civilisations to build urban centres and undertake international trade. It would not be inappropriate to say that Indians have historically been the world's greatest water harvesters.

Depending on the resources available to them, Indians over centuries, developed a range of techniques to harvest every possible form of water-from rainwater to ground water, stream to river water, and flood water.

India can be broadly divided into 15 ecological regions (see map on page). Hence, this chapter is divided into 15 sections, each describing the traditional water harvesting systems that the Indians have developed over time. / The Chapter also reflects the extraordinary ecological diversity of this country-from the dry, cold desert of Ladakh to the dry, hot desert of Rajasthan, from the sub-temperate high mountains of the Himalaya to the tropical high mountains of the Nilgiri, from the alluvial monotonous plains of the Gangetic Valley to the plateaus of Deccan and Chotanagpur, and from the dry solpes of the Aravallis to the humid stopes of Meghalaya, Nagaland and Mizoram.

Roots in tradition :

Let us first look at what the Indian people traditionally did with stream and river water. Wherever there were streams, especially in the hill and mountain regions of India, people developed techniques to divert its water, with the help of simple engineering structures, into artificial channels that would take the water directly to the agricultural fields. When streams become bigger and larger and turned into rivers, engineering also became more sophisticated and diversion systems became bigger and larger. The Grand Anicut on the river cauvery is an excellent example of such a sophisticated engineering structure.

Sometimes, especially in the arid and semi-arid regions where water in the streams was more seasonal and scarcer round the year, the diversion channels were first directed into a storage structure-Variously called a zing in Ladakh, an ahar in south Bihar, or a kere in Karnataka-So that water could be used in the ensuing day period for human and animal consumption, and for agriculture. However, not all storage structures were riverfed or streamfed. Many of them simply collected water running off a catchment area to be stored for later use. It is abvious that a streamfed storage system was more reliable because it collected water over a much larger catchment.

In the flood plains, people developed ingenious techniques to use the menacing floodwater, not just to irrigate their fields but also to fertilise their fields, and control diseases like malaria by making use of the fish in the floodwaters to eat away the mosquito larve, India's richest agricultural area in pre-British India, The flood plains of Bengal, which sits astride the most flood prone plains in the world, shows the development of an extraordinary mechanism for harvesting the rich floodwaters in a measured and constructive way-literally making a joke of every effort made in post-Independence India to stop the floods instead of learning how to use them.

In the coastal areas too, where coastal tides would periodically turn riverwater saline and make it unsuitable for agriculture, people developed fascinating innovations. The Khazana lands of Goa have systems that regulate the flow of high salinity riverwater, and thus control their impact on the productivity of rice agroeco-systems and long term soil fertility.

In areas with a good groundwater aquifer. Indians harvested rain water with the help of dugwells and develop various technologies using local materials to lift that water to irrigate the fields. Wells were an important source of irrigation in the groundwater-rich region of the Indo-Gangetic Plains, for instance. But people learnt to harvest groundwater in other ingenious ways too, especially where water in general, and groundwater in particular was scarce. In the dry areas of Rajasthan, for instance, people built structures like stepwells and wells below tanks and other types of water storage structures. In this way, when the dry season hit the people and the tank / A water was dried up-due to high evaporation or simply because the tank water was inadeguate to meet the overall demand of the region-people could at least harvest clear groundwater to meet their drinking water needs. In fact, in many places, the surface runoff collected in the tank would not be used for drinking if clear ground water was available from wells and stepwells. In the hills and mountains of the Eastern Ghats, people learnt the Middle Eastern technology of qanats to build subterranean structures, or rather horizontal wells called surangams to top the water seeping down the hill sides for use as drinking water.

When no options were available, people learnt to rely on rainwater for survival. For irrigation water for a down stream command area or for cultivating the tank-bed itself. In the haveli system of Madhya Pradesh, the soils and traditional crops were such that the formers found it usefull to store rainwater in the agricultural fields itself. In several places, people would construct embankments to catch the monsoon runoff from a catchment area so as to collect water in the bed of the storage structure itself. This would allow the collected water to seepdown into the soil and give it enough moisture to take a good crop in the following dry period. Thus, people did whatever they could-and they did a bewildering variety of things-within the constraints that the local ecology imposed upon them.

But in very dry areas, the primary need of the people was drinking water, and various ingenious techniques were developed to collect rainwater to use as drinking water. In Rajasthan, for instance, there is an old tradition of using the roof top as a catchment area to collect rainwater. And, in areas where land is not a limiting factor, people even developed customised rainwater harvesting structures called Kundis to obtain drinking water. Kundis are artificial wells which store runoff from an artificially prepared catchmet surrounding the well so that any rainwater that falls on the catchment rapidly.

Table - Typology of Indian Traditional Water Harvesting Systems.

Ecological regions	Systems for agriculture	Systems for drinking water
1. Hill and mountain regions	(a) Diversion channels leading directly to agricul tural fields (e.g. guhls and Kuhls of Western Himalaya). (b) Occasionally, the channels first lead into a storage structure so that water can be used in the subsequent dry period, too (eg. Zings of Ladakh).	(a) Natural springs were often harvestid. (b) Rainwater harvesting from rooftops. (c) In the Northest, spring water is often carried over long distances with the help of bamboo pipes.
2. Arid and Semiarid regions	(a) Rainfed storage structures which provided water for a command area downstream (eg. tanks) (b) Stream or riverfed storage structures. Sometimes built in a series, with overflow from one becoming runoff for the subsequent one (eg. system tanks of Tamil Nadu, Bandnaras of Maharashtra. Keres of Marnataka. (c) Rainfed storage structures, which allow runoff to stand over and moister the fertile sail-bed of the storage structure itself, which is later used for growing crops	(a) Groundwater harvesting structures like wells and stepwells were build to tap ground water aquifers (eg. bavdis of Rajasthan). (b) Ground water harvesting structures like wells and stepwells were invariably built wherever they were possible, especially below storage structures like tanks to collect clean seepage for use as drinking water (eg. several such structures can be found in the forts of chittor and Ranthambhore). (c) Rainwater harvesting from rooftops (eg. tanks of Pali).

Ecological regions	Systems for agriculture	Systems for drinking water
	(eg. Khadins of the Jaislmer district and johads of the Alwardistrict in Rajasthan). used to create such a water	(d) Rainwater harvesting using artificially created catchments which drain water into or artificial well-just about any land can be harvesting structure (eg. Kunds of Rajasthan). (e) Special rainwater harvesting structures which help to keep sweet rainwater from mixing with saline groundwater and, thus, providing a layer of potable water (eg. Virda; of Kutch). (f) Horzontal wells similar to the qunats of the niddle east to harvest seepage down till slopes (eg surangans of Kerala).
3) Plains and flood plains.	(a) In the flood plains of major rivers, people built inundation channels which allowed flood-waters to be diverted to agricultural lands (eg. flood irrigation systems of West Bengal). (b) In specific types of soil and cropping regions, people also store rainwater in the agricultural fields by bunding them (eg. haveli system of Madhya Pradesh).	(a) Dugwells.
4) Coastal areas.	(a) Regulatory systems to control ingress of saline riverwaters, especially during coastal tides, and thus maintain crop productivity in the coastal plains (eg. Khazana lands of Goa).	(a) Dugwells.

runs into the well and gets stored Kundis are common in the Thar Desert of Rajasthan, and they teach us the amazing lesson that any land, wherever it may be can be used to make a kundi and harvest rainwater.

The nomadic Maldharis of the inhaspitable kutch region of Gujarat have developed another interesting system of procuring potable sweetwater, even in an area where rainwater is scarce and grandwater is saline. They know that the density of sweetwater is less than that of saline water and hence it is theoretically possible to keep the harvesting sweet rainwater stored in a way that the sweetwater will continue to float on the denser saline water and, thus provide the people with an opportunity to live and survive in such a hostile region. They have, in fact, through their own experience and knowledge, developed precisely such a system, locally called virda.

In terms of carrying water over a difficult terrain, the people of the Northest, traditionally expert in the use of bamboo, have developed some of the most interesting and artistic systems. All over the eastern Himalaya and the northeastern hill ranges, people continue to build simple bamboo pipelines to carry water from natural springs to a convenient point, where it can be used for drinking. But this art has been raised to a sublime level by the people of Southern Meghalaya. Who live near the border of Bangladesh and have used intricate networks of bamboo pipelines to deliver water to betel leaf plantations in rocky areas, where no channels can be built. And the entire system literally works like a modern drip irrigation system which delivers measured quantities of water straight to the roots of the plants. Thus, wheather it was rain water streamwater, flood water or groundwater, people developed ingenious ways to harvest and deliver that water for irrigation and for human and animal consumption.

Let us look at the potential of rainwater harvestion on a national scale. India has a population of about 950 million people. Let us assume that the average daily water requirement of each individual on a nationwide scale is 100 litres. The average annual rainfall across the country is about 1.100 m. Therefore, the annual demand of household water-use is 34,675 billion litres and each heactare can yield 11 million litres of rainwater. Thus, if India harvested rainwater over 3.15 million hectare (mha) of land or about 1 percent of India's total land area-every household can meet its water needs. Even if the collection efficiency achieved is only 50 percent, India would need only about 6.3 mha of land. But with urbanisation and greater areas coming under roofs and concrete structurees the collection efficiency should theoretically increase.

Table - Potential of water Harvesting to meet India's Drinking Water Needs.

Assumptions			
Population :		950	million (1991)
Average annual rainfall :		1,100	mm
Land area for which land-use records are available :		304	million hectors
Average household water requirement nationwide :		100	litres/day/person

Annual water requirements	Water collection efficiency (% of rainfall collected)	Land requirement	% of India's Land
34,675 billion litres	100%	3.15 million hectares	1%
34,675 billion literes	50%	6.3 million hectares	2%

New Policies :

There is thus an urgent need to review India's irrigation policy as it has been practiced over the last 40 years, A vast majority of the Indian population continues to be nutrationally deficient. Millions of marginal formers till rainfed lands which makes their existence incredibly precarious. In such areas it is essential to store the rainwater where it falls or to facilitate its seepage into the underground aquifer.

A vaidyarathan insists that it is essential to rehabilitate the already existing traditional systems first. This activity, he says, should become part of employment guarantee programmes and other schemes of land and water improvement. But he also warns that these systems will prove to be ineffective if an integrated approach to land and water management is not adopted. He suggests that any programme intended to improve the traditional local systems should focus.

Table - Minor Irrigation Planning according to Agroclimatic Zones.

Name	Region	Rate of water harvesting
	Areas covered	systems
Western Himalaya	8hill districts of Uttar Pradesh (Up) Jammuand Kashmir, and Himachal Pradesh.	Renovation of old kuhls and construction of new kuhls, construction of small tanks development of springs.
Eastern Himalaya	Sikkhn, Assam, Arunachal Pradesh, Maghalaya, Mizoram, Nagaland, Manipur, Tripura and the Districts of Cooch Bihar, Jalpaiguri and Darjeeling in West Bengal.	Water diversion schemes rainwater retention
Lower Gangetic Plan	West Bengal	Desiltation of old tanks, construction of new tanks to alleviate inundation of surrounding flood prone areas.
Middle Gangetic Plain	26 north districts of Bihar in the alluvial plains, 12 districts of eastern UP pains.	Irrigation through tanks small weirs and barrages
Upper Gangetic Plan	12 Districts of the central UP plains, 10 Districts of the northwest UP plains 10 Districts of the Southwest UP plains.	Renovation of old tanks.
Eastern Plateau and hill regions	Chotanagpur plateau division in Bihar Purulia district West Bengal inland districts of Orissa, the eastern hills and Chattisgarh district of Madhya Pradesh (MP), wainganga plains and Chandrapur, Bhandara and Gadchiroli Districts of Maharashtra.	Disiltation of tanks
Central Plateau and hills	Banda, Hamirpur, Jalaun, Jhansi and Lilitpur districts of UP, 25 districts of MP including the plains districts of Bhind and Morena, 12 hill districts of Rajasthan, eastern Rajasthaa Plateau and hill divisions of Bansalara, Durgapur, Udaipur and Sirahi and three districts of Southern Rajasthan.	Modernisation of old tanks in MP and UP construction of new tanks
Western Plateau and hills	22 districts of Maharashtra, 11 districts of Malwa region in Madhya Pradesh and Jhalawar in Rajasthan	Renovation of existing tanks, construction of new tanks, Check dams and percolation tanks.

on some essential elements like afforestation of catchment areas of tanks, strenthening of bunds, and the restoration of field channels. He advises that the knowledge base of the user communities must be utilised as they have first hand knowledge and experience which no 'expect' can match.

Vaidyanathan argues that the development of new control works as part of the integrated watershed development programme holds vast promis. "But this may demand a radical restructuring or the government's watershed programme, it is imperative that the local people understand the rationale behind the proposed works and the changes in land use suggested for their areas. This process cannot work by government fiat. It needs extensive local involvement and informed participation. According to a UNEP study.

"...(the) relative effectiveness (of traditional water harvesting system) most probably depended on the fact that these techniques were essentially complementary rather than competing strategies within integrated water management system."

Revival or traditional systems will also have to take into account the country's ecological diversity. Imposing the same irrigation technology in the varied regions of India will be unsuccesful. The relevance of each technology in its local context must be addressed. The Eighth Five year plan approach paper syggests that agroclimatic zoning is essential for land and water resource planning. This approach takes a more integrated view of the soil types, climate, topography and water resources of each area and is location-specific. Solutions thus very from zone to zone. The planning Commission has divided the country into some 15 agroclimatic zones. Tanks can play an important role in irrigation in several of these zones.

Traditional Structures :

Traditional structures have varied from state to state and even from region to region because of diverse patterns of the monsoon in the country. The various systems used in different regions of India are shown in table.

In the hills and areas with high rainfall, rooftop collection and storage by constructing dug-cum-embankment type of structures are used. In the foothills, the flow from springs and streams is arrested.

In the Rajasthan desert, given the unfavourable hydrometerological conditions and inadequate groundwater resources, surface rain water colection is the only solution. The Southern peninsula has highly undulating and dissected land form with an elaborate drainage system. It has un uneven rainfall distribution. The traditional runoff harvesting systems here are / bandharas (weirs).

Table - Rainwater Harvesting Structures in Different Agroclimatic Zones, Especially for Drinking Water.

Agroclimatic zone	State of the art	Recommendations
1. Humid North-western Himalaya	Roof water harvesting, Diversion of perennial springs and streams in storage structures, village pond, collection from hili slope.	Improvement in roof structures and use of Proper material such as corrugated sheets for generating higher runoff and with arrangement of foul slush diversion system and proper Improvement in rooftap harvesting system as above.
2. Himalayan foothills	Collection from hill slope, Village ponds	Improvement in rooftop harvesting system as above.
3. Humid high rainfall Northestern zone	Roof water harvesting, diversion of perennial springs and streams in a storage structure (tank)	Improvement in rooftop harvesting system as above.
4. Humid Assam-Bengal Plains	Tank, anicut/check dam, gully plugging, contour bunding	Improve design of tank for minimising evaporation and seepage losses, control of sediment load and water pollution.
5. Semi-arid Sutlej-Ganga alluvial zone	Pond, Check dam, gully plugging, contour bunding	Improve design of tank for minisising evaporation and seepage losses, control of sediment load and water pollution.
6. Northhestern semi-orid and orid zone	Nadi, Tank, Khadin percolation, anicut, gully plugging, contour bunding	Adoption of improved design of nadi and tanka, sand-filled reservoir sub-surface barrier, flat batter tank.
7. Central Semi-arid Vindhyan zone	Pone, check bunding, contour bunding, gully plugging, sub-surface dykes.	Adoption of improved design of nadi and tanka, sand-filled reservoir sub-surface barrier, flat batter tank.

Agroclimatic zone	State of the art	Recommendations
8. High rainfall, high runoff chotanagupi plateau	Tank anicut/check dam, gully plugging, contour bunding.	Improve design of tank for minimising evaporation and seepage losses, control of sediment load and water pollution.
9. Assured rainfall, deep black soil Malwa Plateau and Narmada basin.	Ponds, check dams, sub-surface dams	Improvement of existing systems.
10. Variable rainfall South central Deccan plateau zone	Pond, check dam, percolation tank, bandhara, gully plugging sub-surface dam, contour bunding	Flat batter tank, selection of suitable site and improvement of existing system, better water management.
11. Chattisagarh Plateau zone	Pond, check dam, percolation tank, bandhara, gully plugging, sub-surface dam, contour bunding	Flat batter tank, selection of suitable site and improvement of existing system, better water management.
12. South-eastern brown/red soil zone	Ponds /tanks, percalation tanks, sub-surface dams	Flat batter tank, selection of suitable site and improvement of existing system, better sub-water management
13. Southern variable rainfall mixed soil zone	Ponds/tanks, check dam, percolation tank, sub-surface dam gully plugging	
14. Southern bi-modal rain-fall zone	Ponds/tanks, percolation tanks, gully, plugging, contour bunding, check dams	Improvement in existing system
15. Eastern Coromandel	Pond/tank, check dam, percolation tank, sub-surface dam	Adoption of improved design of tank, selection of suitable site and improvement of existing system-better water management.
16. Western Malabar	Pond/tank, check dam, percolation tank, contour bunding, bandhara, Kolhapur weirs, sub-surface dam.	Improvement in existing systems, better water management, construction of structures at suitable sites.

drainage system. It has an uneven rainfall distribution. The traditional runoff harvesting systems here are bandharas (weirs) Kolhapur-type weirs (open weirs), village ponds and stone-lined tanks. Construction of village ponds for domestic use, including drinking water for cattle, was once so popular that a rough estimate shows that almost 2 percent of the country's area was covered by ponds.

The temporary check dams (locally known as bandharas) across streams, have made a huge impact on the agricultural system in Hivare a drought-prone village 35 km. from pure on the Pune-Saswad road. Even a year ago, the villages of Hivare wouldn't have dared to dream of watering their fields all day, particularly in the dry season. The small bandharas have now raised the groundwater level, boosting the water-table in the wells.

It all began when some Hivare formers noticed the positive impact of building check dams in the nearby Ketkawale Village in 1990.

Premature harvest :

It is the villagers who decide how many check dams to construct and where. They found that 25 people working for 6 hours can construct a bandhara that is 5m. long and lm. each in width and height.

Community involvement has been a key factor to the success. Irrigation management in India. Where farmers have virtually no say, has very often led to corruption. It was not always thus indian formers have been traditionally managing water resources, accumulating a wealth of knowledge on the way. According to Mohan Dharia, president of VANARAI, "the rural development approach must cover the entire requirement of the community," But he adds that unless villagers agree to a community effort, no work should be initiated.

In Hivare, where the construction of bandharas started immediately after the monsoon in 1993, gunny bags filled with locally available stones and sand were arranged in rows across the rainfed village streams to arrest the water flow. So far, the villagers have constructed 23 small check dams across streams. The details of the construction are discussed in the village council and announced to all the villagers. Everybody joins in the construction work but not as a matter of order, everything depends on individual convenience.

The check dams are already paying dividends. "We now have sufficient water in the wells to cultivate a second crop," says 24 year old Hamid Shaikh, who is actively involved in organising villagers to work for the dams. "The increase in the water-table has also taught us not to harvest sugarcane before it is fully grown. Earlier, water scarcity reduced our yields by more than 50 percent." Panadharinath Ramachandra Gaikwad, another Hivare farmer, maintains that the water level in his well has risen by about 5m. Gaikwad also feels that check dams have reduced soil erosion.

References

UNEP report, Rainwater and streamwatero Harvesting in Rural Areas, in Water Ressources seris, Vol. V, Dublin

N Pant 1989, Farmer-managed Irrigation systems in India, FMIS Network, International workshop on Design Issues in Farmer-managed Irrigation systems, chiang mai, Thailand.

Singh et al 1985. Land and water Resources Management in Nort-east Hill Region. in Indian farming, Vol. XXXIV, No. 10

H Bareh (ed) 1970, Gazetteer of India, Nagaland-kohima District, Government of Nagaland, May, P 100.

Sonowal et al 1989, zabo-An Indigenous Farming system of Nagaland, India Journal of Hill Farming, Vol. II No. I.

Arabinda Biswas 1987, The Decay of Irrigation and cropping in West Begal (1850-1925) in Boudhayan Chattopadhyay and Pierre spits (ed), Food system and society in Eastern India, UNIRSED Report No. 873 Geneva.

Nirmal sengupta 1980, the Indigenous Irrigation Organisation on South Bihar, the Indian Economic and social History Review, NewDelhi, Vol. XVII, No. 2

William Willcocks 1930. Ancient system of Irrigation in Bengal. Br Publishing Corporation, Delhi.

A. S. Kolarkar, KNK Murthy and N. Singh 1980. Khadin-water Harvesting and Runoff Farming in Arid Rajsthan In Indiajournal of soil conservation, October, Vol. VIII, No. 2

Vangani, N S Sharma and P C chatterji 198, Tanka- A Reliable system of Rain water Harvesting in the Indian Desert, CAZRI, Publication No. 33 January

Sugested Readings

H. Bower 1986 Groundwater Hydrogeology, Mcgrawhill Ltd., New Delhi.

Anil Agarwal and sumita Narain 1997. Dying Wisdom, Rise, fall and potential of India's traditional water harvesting systems. State of India's ENVIRONMENT 4 A CITIZEN'S REPORT P. 404.

Questions :

- Describe the methods and uses of rainwater harvesting in the floodplain and coastal areas of India
- Explain the utility of traditional rainwater harvesting methods in arid and semi arid regions of India at present
- Explain the methods of traditional water Harvesting systems in the Hill and mountain regions of India
- Describe the role of check dams as a method of water Harvesting in Deccan Platean of India.

1.2 ❑ Geomorphic Consequences of Sealevel Change in Coasts and Estuaries

Introduction

The level of the sea is not constant, it is always rising and falling ,either through the passing of waves (including tides), meteorological influences or gravitational effects in the form of the earth's **geoid** . Long-term and significant sea level changes, however, reflect changing levels of both land and sea; **eustasy** refers to absolute changes in global sea level, and **isostasy** refers to the vertical movement of land due to local geological factors. It is the balance between these two processes at a given coastline that produces observed changes in sea level, referred to as **relative sea level change,** because an absolute (eustatic) rise in sea level may not be required to allow the sea to rise relative to the land. Figure 5.1 explores this balance in a simplified way, and a number of cases can be put forward to illustrate the relationship:

- Relative sea level rise will occur if (a) eustatic sea level rises whilst the land is isostatically subsiding, static or uplifting at a slower rate than eustatic rise; (b) eustatic sea level is static whilst the land is isostatically subsiding; and (c) eustatic sea level falls whilst the land is isostatically subsiding at a faster rate than eustatic fall.
- Relative sea level fall will occur if (a) eustatic sea level falls whilst the land is uplifting, static or subsiding at a slower rate than eustatic fall; (b) eustatic sea level is static whilst the land is isostatically uplifting; and (c) eustatic sea level rises whilst the land is isostaticlly uplifting at a faster rate than eustatic rise.
- A sea level **stillstand** will occur if (a) eustatic sea level fall and isostatic subsidence of the land occur at the same rate; (b) eustatic sea level and the isostatic land level are both static; and (c) eustatic sea level rise and isostatic uplift of the land occur at the same rate.

The Quaternary Period spans from 1.81 million years ago to the present day and compromises the **Pleistocene Epoch**

(1.81 million years to 10,000 years ago) and the **Holocene Epoch** (10,000 years ago to the present). During the Quaternary sea levels fluctuated widely, with sea level highstands during the interglacials and lowstands during the glacial stages. Many interglacial sea level highstands attained or exceeded the present sea level altitude, and many fossil shorelines may be encountered above present sea level and appear to be 'raised', hence the term **'raised' beach**

The word 'raised' can be a misnomer, because many of these fossil Pleistocene

shorelines are in *situ*.

In the British Isles, mapping isostatic readjustments following the last glacial at the end of the Pleistocene shows that northern Britain is currently uplifting by up to 2 mm y-1, whilst southern Britain is subsiding by up to 2 mm y-1 .The two regions are separated by a fulcrum line that extends in a stable zone from the Tees Estuary in northeast England, through the Dees Estuary and on to the Lleyn Peninsula in northwest Wales. This post-glacial isostatic movement is reflected in the distribution of **submerged forest** sites in Great Britain. The majority of sites are located in southern Britain, whilst only a few are found north of the fulcrum line. This indicates that postglacial eustatic rise coupled with isostatic subsidence in southern Britain has led to relative sea level rise and the drowning of previously wooded landscapes, whilst in northern Britain isostatic rebound is outpacing eustatic rise, so that relative sea levels are actually falling there and resulting in coastal emergence rather than submerged.

Only in isostatically stable areas of the world can records of eustatic or absolute sea level change be possibly found, i.e. areas that have never been glaciated or suffer earthquakes, volcanic or other tectonic activity (earth movements) that may vertically displace the land. Such areas are rare, but the island of Bermuda is considered to be a stable mid-ocean carbonate platform from which a eustatic sea level record has been constructed (see Lowe and Walker 1997). Eustatic sea level curves from such areas indicate that the last glacial sea level 18,000 years ago was approximately 130 m below the present sea level. A period of very rapid rise ensued until approximately 6,000 years ago, but since then sea level has been comparatively stable with a less than 10 m rise to the present day.

COASTAL RESPONSES TO SEA LEVEL CHANGE

Relative sea level fall and the retreat of the sea from the land are known as a **regression,** whilst relative sea level rise and the associated inundation of coastal land are known as a **transgression.** Regressions and transgressions lead to the emergence and submergence of coasts respectively. The manner in which a given coastline responds to such sea level changes depends on the character of the coast, that is whether it is dominated by depositional or erosional processes.We discussed earlier the relationship between eustasy and isostasy in determining relative sea level however , along depositional coasts sediment can act as a substitute for, or in addition to ,isostasy in certain circumstances . If a beach has an abundant sediment supply,.then it may build upwards and advance into the sea regardless of eustatic regime, a process known as **progradation** ; oppositely , if sediment supply is limited and less than that lost from or redistributed within the beach system, through erosion and the action of currents for example, then a beach may retreat landward (i.e. retro gradation) under a rising relative sea level, although still maintain its relative tidal position if it is allowed to translate landward(Swift 1975). Bruun (1962) suggested a model that describes the response of a sandy coast to sea level rise, where sea level rise forces the beach to retreat landward through the erosion of the black beach area . This eroded material is then redeposited at the foot of the beach , so that the beach may maintain its equilibrium profile. This model, commonly referred to as the **Bruun rule,** has been widely applied and yet has a number of unresolved problems , such as how can we know when a shoreline is in equilibrium, what timescales are involved in morphological response , and is it fairweather or storm conditions that drive the retreat process(Healy 1991).

The response of different types of coastal systems to sea level change is often very specific to the given system. Relative sea level fall usually leads to the emergence , abandonment and fossilisation of a shoreline , and indeed many fossil Pleistocene shorelines are created in this way , such as 'raised' beaches. However sea level rise often leads to the landward migration of a mobile shoreline or the submergence and drowning of a stationary shoreline . The response of different coastal systems to sea level rise during the Holocene and into the future has received much attention, particularly for the following examples of vulnerable and dynamic soft sediment coastal types.

SALT MARSHES

The response of salt marshes to sea level rise depends to a very great extent on the sediment supply into the salt marsh system. The balance between sea level rise and salt marsh surface elevation, through vertical sediment accretion, is critical (Reed 1995). If the rate of accretion and surface elevation is less than the rate of sea level rise then the salt marsh will submerge and drown; if the rate of elevation is higher than sea level the salt marsh will emerge and perhaps terrestrialise; the rate of surface elevation may be equal to that of sea level rise, and in which case the salt marsh will neither emerge nor submerge and therefore, exist in equilibrium.

MANGROVES

Woodroffe (1995) has examined the response to sea level rise in Northern Australia. He suggests that mangroves will respond in different ways according to their overall morphology and physical setting. In the tide-dominated Darwin Harbour, mangroves occur fringing the estuary, with many tidal creeks supplying the system with sediment .Therefore, under gradual sea level rise, this fringing type of mangrove may migrate landward, supplied with sediment from erosion of the submerging lower intertidal zone. Palaeoecological studies suggest that all the studied mangroves migrated onshore this way during the post-glacial Holocene transgression. However, in other areas that are river-dominated, such as the South Alligator River, extensive deltaic plains of mangroves have been built as the shore has prograded seaward , following the stabilisation of the Holocene transgression, using sediment delivered to the coast by rivers. These near-horizontal plains are susceptible to any future sea level rise, because they are less likely to be able to migrate landward, and may simply become submerged.

COASTAL SAND DUNES

Foredunes become scarped (Carter and Stone 1989) as they are reached by the rising sea level, and this releases sediment back into the beach system, perhaps for use in dune building further inland. Sea level rise may also breach the foredunes to deposit sand behind the foredunes as wash-over fans. Through both scarping and breaching, sea level rise promotes the landward migration of coastal dunes. Along many coasts during the Holocene transgression, sand dunes were blown inland ahead of the migrating shoreline. Dune sand blown on to the top of low cliffs and now perched there, offer an opportunity to date this initial sand inundation along a coastline (e.g. Haslett *et at 2000b).*

GRAVEL BEACHES

Current research on the effect of the sea level rise has suggested that gravel shorelines may respond as follows:

- The crest may build up in height by a transfer of material to the crest from the mid-tide zone as sea level rises. A barrier may start to migrate landward through the process of **rollover**, which is the general transfer of sediment to the landward side of a barrier.
- In the absence of adequate sediment supply, the beach will steepen leading to increased reflectivity.
- Crest build-up cannot continue indefinitely , as crest construction requires spilling waves for sediment transport , which in turn requires a measure of dissipative character, so as reflectivity increases the rate of crest build-up will slow, and this shift in morphodynamic domain from dissipative to reflective will induce cusp formation.
- Cusps reaching the crest may then act as a template for overwash and breaching, and the eventual break-down of a barrier.
- In this way barriers will tend to migrate landward under a sea-level rise regime. Beaches confined by backing cliffs may develop swash ramps extending several metres above the high water mark, and with cusp development, ramps may become fragmented and separated by intra-beach erosional bays.

A characteristic feature of a landward migrating barrier is the presence of a terrace or terraces in the seaward low-to mid-tide zone. These terraces are low-angled and dissipative. Erosional slopes are often formed as a barrier migrates landward. Where a rock platform is exposed, it may supply the barrier with clasts thus slowing down migration, so the areal ratio of barrier to terrace can increase as well as decrease. There is also a type of depositional terrace resulting from sea-level rise and landward barrier migration, which is known as a boulder frame. This frame results from particle sorting, providing a residue or lag of larger and relatively immobile clasts at the foot of beach. If this residue of clasts remain immobile, then as the barrier migrates landward, the frame will expand in width. With the expansion of low-angled terraces, within the barrier morphodynamic system, reflectivity will change from being the dominant domain, to co-dominant to non-dominant through time, giving rise to an overall dissipative domain, which may lead to barrier abandonment. Furthermore, where a barrier progressively loses material to its frame as it migrates, the barrier's migration rate may increase, which may ultimately overstretch the barrier, leading to breaching. In order to maintain stability, therefore, the rate of volumetric loss needs to be balanced by the increasingly dissipative role of the frame(Carter and Orford1993).

References :

Bruun. P, 1962 : Sea level rise as a cauf of shore crosion'. Journal of water ways and Harbour Division. 88, 117-130.

Healy. T 1991 : coastal erosion and sea level rise : zeitschrift fur Geomorphologie N.F., Supplementband, 81, 15-29.

Haslet. S. K., Davies P., and curr. R.H.F., 2000 b : Geomorphologic and palaeoenvioromental development of Holocene erhed coastal dune system in Britany, France. Geografiska Annaler, series A. 82, 79-88.

Carter, R. W.G and stone, G.W. 1989 : Mechanisms associated with the erosion of the sand dune cliffs, Magilligan, Northern Ireland'. Earthscience Processes and Landforms.

Carter, R.W.G and Orford, I.D. 1993 : The morphodynamics of coarse clastic beaches and barriers : a short and long-term perspective. Journal of coastal research ; Special Issu, 15, 158-179.

Lowe, J.I. and walker, M.J.C. 1997 : Reconstructing quaternary Environment (2nd Edition). Longman, Harlow.

Read, D.J. 1995 : The response of coastal marshes to sea level eise : survival or submergence ? Earthsurface Processes and Landforms. 20, 39-48.

Swift, D.I.P. 1975 : Barrier Island genesis : evidence from the central Atlantic shelf, eastern USA : Sedimentary Geology, 14, 1-43.

Woodroffe, C.D. 1995 : Response of tide dominated mangrove shorelines in Northern Australia to anticipated sea-level rise. Earth surface Processes and Landforms, 20, 65-85.

Suggested Readings

- Submerging coasts : THe Effects of a Rising sea level on Coastal Environments. E.C.F Bird. 1993. Wiley, chichester, 184 ppp. A useful review of the response of coastlines to rising sea levels.

- Climate and sea level change : Observations, Projections, and Implications. R. A. Warrick, E.M. Barron and T.M.L. Wigley (eds). 1993. Cambridge University Press, cambridge, 424 PP. A collection of papers examining the issue of global climate change and associated sea level rise.
- Tsunami. 2005 : Ashis kro-Paul. ACB Pubicbtions. kolkata. 125 PP.
- Impacts of sea level Rise on European coastal Lowlands. S. Jelgersma and M.J. Toooley eds.) 1992) : Blackwell, Oxford, 265 PP. An example of how sea level rise impacts on a regional scale.
- Coastal Geomophy and Environment. 2002 : Ashis kr. Paul ACB, Kolkata 582 PP.
- Coastal system. Simon K. Haslett (2000) : Routledge Introductions to Environment. Londan an Newyork, 218 PP.

Questions :

- Discuss the geomorphic consequences of sea level change in coasts.
- Discuss the geomorphic consequences of sea level change in estuaries.
- Why sea level is not constant in eitheo space or time ?
- 'Relative sea level represents the balance betweem eustasy and isostasy'. Explain it with examples.

1.3 ❐ Application of Geomorphology in Terrain Evaluation.

EIA & EMP.

Applied geomorphology is now the main area of growth in the subject. It is therefore, possible to classify modern applied geomorphology into various branches and although the brahcnes have links and overlap, they provide a convenient basis for describing the subject.

The first branch is concerned with natural hazrads. These influde soil erosion, various types of slope tailure, sea and river flood, volcanoes, earthquakes and faulting. Sometimes the hazard occurs, at least parthy, because man himself has acted unwisely in some way. This is often the case, for example, with soil erosion. Sometimes the hazard is, or appears to be completely natural-earthquakes for example. Whatever man's own role in the initiation of the hazards however, their combined effect are enormous: apart form the loss of like, incalculable sums of money are involved in the damage caused and in the insurance and legal claims that follow (Coates 1980). The professional geomorphologist has a role to play here. He has some measure of understanding of the combinations of events that produce the hazards and he is therefore in a unique position to advise on such matters as predicting the occurrence of a hazard, protecting against it so as to reduce its effects and perhaps in reducing the dimensions of the hazards itself.

The Second branch is environmental management. This is the geomorphologist's role in man's deliberate and controlled impact on the landscape: The geomorphologist joins others in planning managing and developing the environment. There are close links with hazard control and in a sense environmental management includes all the work on hazards but environmental management does not necessaryily imply the presence of a major hazard. For example, geomorphologists are called upon to advise on the siting and buikding of roads and settlements and this may or may not involve a potential hazard. In this area man is trying to manage the environment in ways that are beneficial to himself whilst munimising further problems that might result from his intervention.

The third branch is the evaluation of resources. There is a general concern that we should be award of the existence of the resources that are available to us and that those resources should be the subject of suitable conservation measures. The geomorphologist has a variety of roles here. First, sometimes a resource has a particular geomorphologcal setting as with the occurence of sand and gravel deposits as river terraces. So that the evaluation of such deposits has an obvious geomorphological element. Secondly, at a more general level most land resources are closely linked to the geomorphology of the Earth's crust, so the trained geomorphologist can assess rapidly the reasource potential including mineral resources of an area from the interpretation of its landforms. This is particularly valuable in previously uncharted terrain. Thirdly, the geomorphologist is also a conservationist conservation is important for all resources but especially perhaps the soil and the geomorphologist with his knowledge of what creates and destroys soil has a crucial role to play hear. Conservation is also important for some things that we do not immediately think of as resources-scenery, for example. Therefore the techniques of scenic evalution are part of enviroumental management. Fourthly terrain analysis is also important for some things that we do not immediately think of as geomorphological. For example, it has military applications. Not only is an appreciation of terrain instilled into every solder during his basic training, but at a higher level classifications of landscape now play an important part in the planning of military operations. The demand for geomorphological information comes from a variety of organisations concerned with developing or managing the environment. These may be government bodies including authorities or consulting engineers land development land managers and those involved in the legal aspects of planning.

The type of information that the geomorphologist can and is asked to supply depends partly on the subject of the investigation but also on the scale of the planning or development problem. At a national level the exphasis tends to be on resource inventory and appraisal leading to the selection of suitable regions and locations for development. At the regional and local levels more importance is attached to detailed field mapping of geomorphological features and to process studies as bases for determining the risks associated with development. More detailed investigations are required at the scale of the individual site when the proposals of the plan are implemented. Studies at this stage are ocencerned with the nature of the surface materials slope stability and earthmoving or land-forming operations. As a planner, therefore the geomorphologist is making a varriety of contributions at different times and a different scales to numerous organisation and authorities.

Weather the geomorphologist is acting as a private consultant or a full-time employee, he brings a unique combination of skills to the job. They arise form his basic training as a geographer as is usually the case in Britain. They have been listed by Brunsden etal. (1978) as:

(a) An ability to think in spatial terms : to appreciate location and with several phenomena at a time.

(b) An ability to detect spatial correlations.

(c) An ability to change one's scale of thinking in accordance with the nature of the problem.

(d) An ability to comprehend the significance of the time dimension.

(e) An ability to use plan documents: the map, plans or aerial photograph.

Table - The protessional roles of the applied geomorphologist.

Nature of employmen	:	Consultant to an organisation, of full time employee of an organisation. Importance of communicating his knowledge to the public pressure group various agencies government departments.
Reconnassance Stage	:	Exploratory and reconnassance surveys possible at a national level, typical mapping scale would be 1: 250,000 Might involved land systems mapping Resource inventories nd apparisals. Teachniques of scenic evaluation: Landscope as a resource assesssment of conservation issues. Project Location
	:	Selection of suitable regions and locations for development.
Feasibility Stag	:	Project Feasibility and planning land Clasification and evaluation. Geomorphological mapping. A typical scale would be 1:25,000 to 1:50,000. Location of trial pits and bore holes Feasibility studies completed before the decision to invest is taken.
Site investigation Stage	:	Detailed Development surveys and site evaluation. Land suitable. Process Studies : application at knowledge from pure research

		erosion plots expermental stations etc. Hazards, mapping of existing hazards assessing dimensions of potential hazards. Land grading and land-torming requirements.
Construction Stage	:	Implementing the plain: advice given on nature of surface materials. Problems of slope instability earth-moveing and Land forming operations.
Predictions	:	Prediction of the effects of plan implementations, man's impact of environmental impact e.g. increased erosion rates. Preparation of environmental impact statements. The geomorphologist can think in terms of side effects and wider consequences.
Monitoring	:	Monitoring the effects on the environmental of plan implement of plan implementation, the dynamic changes in the environment. Advising on any new measures needed.
Protessional advice on related issues	:	Formulation of legislative or other controls over planning. Drowing up site ordinaces and building codes. Legal questions: The geomorphologist could appear as an expert witness in the courtroom; case might involve problems of erosion or sedimentation, damage to properly and water sypply caused by construction, putting a prince on superficial deposits.

It is beyond dispute that, to be successful, planners, environmental managers and developers need to be well informed about the nature of geomorphological problem and therefore need the services of the protessional applied geomorphologist. However, since in studying applied geomorphology we are analysing the relevance of geomorphology to the general needs of society it is pertinent to establish exactly what the role of the geomorphologist is in the decision making process. Where does the control lie?

The answer is that effective control lies with an enormous number of individuals, not all of whom are trained environmental scientists. Therefore, the crucial aspect of environmental management is to bring the scientist and the environmental decision maker together. There is also an element of public consulation including the farmer, forester and tourist.

Many private firms and Government agencies exist which deal with some aspect of the Earth's geomorphological systems. From this it follows that geomorphological infomation is required by all kinds of organisations concerned with developing or managing the environment. At an international level, UNESCO in its concern for the welfare of mankind has acknowledged the important role of applied geomorphology. At the national level there are a number of Government bodies such as national planning units and departments of hydrology ad agriculture which require such information. Regional and local planners also make use of geomorphological contributions. Private from include consulting engineers, land developers land managers and those dealing with the legal aspects of planning. Upper table indicates the range of contribution that geomorphology can make in various types of planning. The applied geomorphology can make in various types of planning. The applied geomorphologist usually is not working alone and the final decision will probably be made by someone else. He generally works as a member of surveying or planning term, and the information he provides goes into a deta bank derived from a range of disciplines. He frequently works alongside other specialists including civil engineers agriculturalists economists geologist geotechnical experts soil scientist and agricultural botanists.

Geomorphology is no longer a purely academic subject where ideas and theories can be tossed around by intellectuals. The subject its theories and conclusion have to 'work'-they have to help to solve real problems. It demands an accuracy precision and scientific rigour which has not been required before. In short it is a challenge. Other sciences such as medicine are expected and though to be entirely credible. Geomorphology now finds itself in the same position.

References :

Cook and Doorncamp 1988 : Geomorphology in Enivirnment Managment, oxford Univ. Press, London

Mitchell, C. W. 1991 : Terrain Evaluation, 2nd edition, Longman Scientific and Technical, Harlow : 441 PP.

Tinkler, 1985 : A short History of Geomorphology crom Helm Ltd. Beckenham : 315 P.

Chorley, R.J. and B.A. Kennedy. 1971 : Physical keography : a systems approac Londan : Prontice Hall.

Hallam, A. 1973 : A revolution in the earth sciences. Oxford : Clerendon Press.

Kuhn, T.S. 1962 : The structure of scientific revolutions. Chicago : University of chicago Press.

Demek (ed.). 1972 : Manual of detailed geomorphological mapping Academia.

Paul, Ashis kr. 2002 : Coastal Geomorphology and Environment. ACB Publications. Kolkata, 582 P.

Derbyshire, E. and C.H.B. sperling, 1981 : The right materials for the job. Geogr. Mag. 53. PP 455-457.

Suggested Readings

Environmental studies (2001). Anil kr. De and Arnab Kr. De. New Age International publishers. Calcutta 209 P.

World Resources, A guide to the Global Environment : (1994-95) : OXFORD UNIVERSITY PRESS, Delhi. 402 P.

Questions :

- Describe the role of geomorphology in Terrain Evalution.
- Explain the process of Terrain Evalution with the application of Geomorphology.
- What is geomorphological mapping ? Explain it's role in the socio-economic importance of decision-making.
- Explain the importance of Environmental Impact Assessment (EIA)
- What is Environmental Managemnt lan ? Explain the importance of Environmental Plan (EMP).

1.4 ❑ Principles of Integrated Drainage Basin Management and Integrated Coast Zone Management with Reference to Coastal Regulation Zones

1. River Basin Development

River basins have long been attractive spatial units for regional resource development. Following World War II, integrated river basin planning was seen as the keystone of development schemes in many developing regions (United National Economic and Social Council, 1970). Much of this optimits stemmed from results of the Tennessee Valley Authority eexperiment in the Univer states, which sought to combine water management and economic developmet in a depressed region (United Nations, 1950). In the 1950s, a number of complex projects were promoted in basisn such as the Mokeng and la Plata. The Mekong project, in particular, was seen as an integrated plan for unlocking the vast development protential of southeat Asia (White, 1964). The Indus Basin Teraty of 1960 was followed by massive water resource investment in India and Pakistan aimed at developing South Asia along the same lines (Michel, 1967)

In this seminal work, white (1957,1964) indentified the major elements of integrated basin development as follows :

1. multiple-purpose storage reservoirs;
2. basin-wide planning and
3. comprehensive regional development.

Another goal was te integration of land and water resource planning under a unitied river basin administration (Wescoat, 1992). Some or all of these elements were found and analyzed in the case study basins.

The integrated river basin development approach has received considerable attention in Africa and Asia, some of it critical. Perritt's (1989) review of African basin projects argues that negative effects, including urban development at the expense of rural areas, lack of local participation, and environmental degradation, have frustrated integrated development. Anticipated benefits had not materialized to affect positively the lives of large number of people in Africal conuntries (Perritt, 1989, P. 205). A through assessment of the strengths and weaknesses of river basin development theory and practice is beyond the scope of this study, but the gap between the ideals and accomplishment is important for assessing regional vulnerability to climate change and for evaluationg the prospects for 'sustainable development' in a changing climate. After discussing the main impacts of climate change projected in the basin case studies, we return to the broader issue of vulnerability can adjustment.

Table-Modeling approaches in case study river basins.

	Modeling	
Basin	**Hydrological**	**Management**
Uruguay	Type: Physical Time scale : ave year Time step: daily Spatial scale : partcal w/analog for full basin	Type : Water resource planning tools Time step: monthly Spatial scale : partial project and regional.
Mekong	Type: satistical Time scale: ave year mitsm Time step: monthly Spatial scale : full basin	Type : river basin simulation Time step: monthly Spatial scale : full basin
Indus	Type: Physical Time scale: ave year Time step : daily Spatial scale : partial w/analog for full basin	Type : river basin optimization World Bank IBMR Time step : monthly Spatial scale : full basin
Zambezi	Type : Physical/conceptual Time scale : time series Time step : monthly Spatial scale : full basin	Type : river basin simulation MITSIM Time step: monthly Spatial scale : full basin
Nile	Type: water balance Time scale : ave year Time step: monthly Spatial scale : full basin	Type : river basin simulation DSSEWM Time step: monthly Spatial scale : full basin

Integrated Coastal Management:

Due to the complexity of human activities, natural systems and ownership in the coastal zone, an integrated management scheme is needed to allocate coastal resources efficiently and minimize environmental degradation. Choices have to be made between competing uses, and limits to resource exploitation must be set, if escalating conflicts and resource degradation are to be avoided.

Planning for sustainable resource management is based on weighing priorites, transtating these priorities into polices and finally defining goals. A management plan defines the steps required to achieve these goals, identifies the entities responsible for each step and established a time frame for action and review.

There is no one 'right' way to manage coastal areas. However, there are certain common threads to all integrated coastal management plans.

Key Steps

The Key steps is coastal management and in decision making in general, are to :

- ❑ agree on the problems or goals;
- ❑ acquire the necessary information;
- ❑ analyze the information to better understand the problems and opportunities;
- ❑ generate and action plan to respond to these problems and opportunities;
- ❑ accept that it will be necessary to modify management;
- ❑ organize Interagency cooperation, coordination, integration and leadership.

❑ Improved Understanding

In order to pratise effective coastal management, planners need to understand the way the natural environment and human activities are interconnected to form a system. Key aspects of the system include the environmental processes that create coastal ecosystems and maintain their health and productivity, functioning of coastal ecosystems flows of resources that coastal systems generate, potential use of these resources to fulfil social and economic development objectives and the type and extent of existing and future conflicts in resource use within the context of changing social, economic and political circumstances.

Each of these factors is greatly influenced by activities within and beyond the coastal zone. It is for this reason that the resolution of conflicts in the use of coastal resource requires a broad perspective on environmental processes and interactions among human activities. The definition o a narrow and rigid coastal zone boundary is therefore inappropriate.

INFORMATION NEEDED FOR COASTAL MANAGEMENT

- **Biological**
  type and extent of ecosystems, primary productivity, species diversity and abundance, nursery grounds, life cycles.
- **Physical**
  Geology, temparature, salinity, nutrients tides, sea level and currents, sediment types and distribution, flooding and erosion/accretion.
- **Socio-economic**
  Human population distribution and growth, economic activities land use.
- **Legal and Institution**
  Land tenure system, resource-use rights, relevant laws and regulations, responsible agencies, availability of financial and human resources.

• **Tools and Techniques-**

The systematic collection and analysis of data yields vital information to the resource manager, Including quantification of existing conditions, *j* identification of information gaps and projection of future trends (e.g. population growth sea-level rise). Routine monitoring also provides feadback to the manager, making possible the evaluation and adjustment of management actions. Ultimately, data collection and analysis should result in an understanding of the "carrying capacity" of limits for sustainable use of the system and an ability to predict the effects of changes to the system.

Systematic ocean observation, including observations of coastal zone, provide the knowledge and predictive capabilities. The Global Ocean observing system (GOOS) initated by the intergovernment oceanographic commission (IOC) of UNESCO in cooperation with the World Meteorological Organization, the Uniter Nations Environment Programme and the International Council of Scientific Unions, provides a framewoirk for international cooperation in this field.

• **Data Collection** : Allthough it is preferable to have detailed information upon which to base management decisions, in most coastal areas planners cannot afford to postpone action for lack of a sophisticated data base. Instead, planners should seek to develop effective management plans based largely on available data. Information derived from remote sensing or aerial photography is often extremely valuable in the initial stages of planning, particularly where existing data are sparse and human and financial resources are limited. Over a longer period of time, planners can implement more sophisticated data collection efforts to broaden understanding of coastal systems.

- **Data Management** : Because of the tremedous diversity of information relevant of coastal resource management, and the numerous potential users of these data, data management should be considered early on in the planning process. Establishment of a centralized data bank is one common approach data bank is one common approach to ensure data consistency and accessibility.

- **Data Analysis** : Overlay mapping is a valuable technique for the organization and analysis of diverse spacial information. By mapping ecological areas that provide critical "public" goods and services (e.g. nursery grounds) and areas of major coastal used and environmental pressures, actual and potential resource-use conflicts can be identified. Geographic information systems (GIS) provide a particularly flexible approach to the manipulation of spatial data, although the initial training and date entry phases can be extensive and should not be underestimated.

Economic valuation and environmental assessment are complementary techiqus for coastal planning. Environmental valuation is used to identity and compare the value of the goods and services provided by coastal ecosystems. Environmental assessment can be used to determine whether development activities are likely to adversely affect coastal ecosystems and these goods and services.

AQUACULTURE AND MANGROVE LOSS.

Between 1918 and 1988, an estimated 210,500 hectares of mangroves approximately 44% of the mangrove area of the Philippines-were converted to fishponds for the agriculture of milk fish. In response to increasing awareness of the value of mangroves and concerns at the rate of loss, the government has attempted to minimize conversion of mangroves by:

- Conducting mangrove inventory programmes.
- Halting conversion to fishponds pending revision of the fishpond lease agreement so that feel more closely reflect the value of ecological goods

and services provided by mangroves.

- Forming land classification Terms to identify which mangrove areas could be used for fishponds, lumbering or conservation.
- Focusing on increasing yields of existing fishponds rather that increasing fishpond areas.
- Implementing regulations requiring fishpond where to maintain or plant mangrove borrowers buffer zone along rivers, shorelines and fishponds.
- Forming a national mangrove committee which has been effective in slowing the rate of conversing and promoting data collections efforts.
- Initiating mangrove restoration projects with the involvement of nongovernmental organizations.

Constrains to management have included an incomplete data base, lack of trained manpower at the regional and provincial levels, lack of coordination between agencies with regulatory interests in coastal management, inconsistent regulations on land use and low public awareness.

• Broadscale and Targeted Approaches

A combination of broadscale and targeted management approaches is required to ease pressures on the coastal zone.

A broad scale approach entails developing legislation, regulations and economic incentives and disinectives applicable within the entire coastal zone. These management practices should be well integrated with both marine and terrestrial management practices (e.g. upland watershed management). The enforcement of existing regional and international agreements is important in this regard as is the transnational harmonization of any new policies that may affect resources shared by saveral coastal states. Many insights can be agined from traditional approaches to the management of coastal systems.

Coastal areas also require targeted management schemes at the local level that are tailored to site-specific natural socio-economic and political conditions. These approaches include the establishment of protected areas and the rehabilitation of heavily degraded ecosystems.

The protection of particularly productive, vulnerable or seenic areas is a key element in most management oprogammes. the conservation of these areas in an investment in preserving the ecological integrity and thus the overall economic potential of the coastal zone.

A part from their intrinsic value in maintaining critical habitats and species diversity, protected areas play an invaluable role in sustaining fisheries maintaining water quality and protecting against flooding and erosion and protecting against flooding and erosion and are often and important draw for tourism and recreation. Coastal and marine protected areas often provide good opportunities for testing the value of different coastal management regimes providing insights that can be applied to larger and more complex coastal marine settings.

The high population density in most coastal areas makes coastal protected areas among the most difficult to establish. In general marine protected areas should incorporate both terrestial and marine ecosystems to ensure the integrity of species, habitats and processes in coastal areas.

Land acquisition by nongovernment organizations provides a non-legislative vehicle for establishing protected areas. In Great Britain, For example the National Trust owns and manages over 650 kilometres of the nation's most scenic and valuable coastline. Where funding for conservation purposes is in short supply a variety of creative means have been devised to raise it, such as debt for nature exchanges and taxes on tourism revenues or real estate transactions.

INCENTIVES AND ALTERNATIVES

The following incentives can be effective management tools, particularly if surveillance and enforcement are lacking :

- Control of coastal resources by communities (as found under many traditional systems of tenure) or individuals through long-term leases grants, etc.
- Technical and financial assistance (e.g. extension services) to improve the efficiency and profitability of existing activities without increasing adverse impacts.
- Tax and other financial incentives in shift development activities to less sensitive areas,
- Development of alternatives in parallel wish restrictions on resource use (i.e. marine based, such as agriculture, salt-making fish-processing or land based, such as agriculture industry reforestation.

THE WADDEN SEA: COASTAL MANAGEMENT ACROSS NATIONAL BORDERS

Shared by Denmark, Germany and the Netherlands, the Wadden sea is a wetland system in the southeastern part of the North sea. It is the largest inter-tidal area in the world, the main sursery ground for many fish species that are harvested in the North sea and the location of vast oil and gas reserves. Situated on the rim of one at Europe's most develop and populated areas, the sea is subject to a variety of threats from both within and outside the region. The three wadden sea states have been working together since the 1970s to develop an integrated management strategy and detailed management plans. The major steps have been to:

- Recognize that the wadden sea should be jointly managed as a single ecological entity.
- coordinate implementation of international legal instruments (e.g. Ramsar Convention).
- Adopt, in 1982, a "Joint Declaration on the protection of the wadden sea" in which the countries declare their intention to hold regular political consulations to evaluate progress towards sustainable development, assess the present state of the environment, and decided on additional cooperative measures.
- Establish a common secretarial to improve coordination.
- Adopt a common management goal-'to achieve, as for as possible, a natural and sustainable ecosysten in which natural processes proceed in an undisturbed way"-and common management principles that cut across legal and administrative differences (e.g. the "Precautionary Principle".)
- Adopt a common objectives governing (among other) sea defence salt marsh management, dune protection, harbour and industrial facilities, shipping, dredging energy resources, extraction of sand and clay, fisheries, re creation, hunting, air traffic, military activities, input of pollutants, climatic changes and sea-level rise, entorcement environmental impact assessment and cooperation in scientific research.
- Agree to develop by 1994 common ecological targets for a natural and / sustainable ecosystem and comprehensive measures to achieve these targets.

A tri-national UNESCO biosphere reserve is being developed for the wadden sea, building on four existing biosphere reserves in Germany and the Netherlands. In 1994, a 10 year moratorium on oil and gas development ends, and policy makers will tace tough decisions about how best to use the region's resources.

LEGISLATION FOR COASTAL MANAGEMENT

Since enacted by the Federal government in 1972, the US Coastal Zone Management Act (CZMA) has been instrumental in initiaing and supporting coastal planning at the state Level. This voluntary programme is based on broad guidelines and a flexible approach, and supports management through the provision of matching funds for state planning and implementation, federal review and approval of state programmes, and technical support and coordination. All 35 coastal states have participated in the programme; 29 states had federally approved plans as of early 1993.

Two new programmes were established under 1990 amendments to the CZMA. The coastal zone Enhancement Programme encourages states to develop new approaches to eight national priority areas: wetlands protection, coastal hazards mitigation public actress the coast-control of cumulative and secondary impacts of development reduction of margin debris ocean resources, management, special area management, and facilitation of coastal energy and government facility siting. The coastal Nonpoint Pollution Control Programme requires coastal states with federally approved coastal management programmes to address non Point source pollution, which steams from sources such as agriculture-marinas and urban run-off.

The National Estuary Programme, established in 1987 under the clean water Act. Complements the CZMA. The programme created a strong initiative and support for the created a strong initiative and support for the management of designated major estuaries that are threatened by deteriorationg water quality and living resources. To data, 17 estuaries have been included with in this programme, many of which span two or more states. The goals of this programme are the development of management, implementation and monitoring plans for each estuary, which are based on a clear understanding of the system and its issues.

Legislation

Establishing a coherent legal basin for coastal management can be extremely difficult. In most countries, a complex assortment of local, regional and national agencies have administrative responsibilities within this area. More often than not, their mandates overlap or conflict.

Coast-specific legislation varies widely among nation-some countries, such as the united states, have enacted laws specifically addressing coastal management. In other coastal management is addressing coastal management. In other, coastal management is addressed through environmental management laws have no national legislation on coastal management. The level àt which jurisdiction is exercised also varies-in the Netherlands; for example where coastal management is a matter of survival there is strong control by the central government other countries (e.g. Australia) Leave coastal management responsibilities to state or regional governments.

Whatever the approach an effective coastal management programme requires legislation on a few basic points. These points include the clarification of ownership versus right-to-use, the identification of a lead agency for coastal management and a definition of its responsibilities, and the establishment of minimum standards (e.g. permissible contaminant levels).

Regulation

Regulation is used to set limits on the types and intensity of activities occurring in the coastal zone. Typically, certain activities are prohibited outright (e.g. discharge of toxic wastes, blast fishing, destruction of wetlands), •while others are controlled through the issuing of permits and licences. Regulation forms the of many successful management programmes. However, their effectiveness largely development of penalties (tines, loss of licences, confiscaion of equipment and imprisonment) and on public acceptance and support.

Zoning is a powerful regulatory technique used to delimit specific land and water areas for specific used (e.g. residential commrcial, agriculture, aquacultare, conservation uses) and to nforce relevant standards within these areas. For example, regorous construction standards may be imposed in areas *h* subject to coastal flooding and building setbacks may be required for' construction along eroding shorelines. Zoning can be a valuable technique for guiding future growth. However in areas which are already derisely developed zoning is to limited value and can have the unfortunated side effect of spurring inappropriate development, as landowners scramble to develop their properties before new restrictions come into effect.

Administration :

A key factor in effective coastal management is having a lead agency to implement the management plan. This agency may have a variety of responsibilities including planning and coordination, establishing standards, developing regulations, issuing licences and permits, surveillance and enforcement. Responsibilities may be restricted to a centralized national agency or shared between national and local administrative bodies. To operate successfully agencies must be statted by trained personnel and adequately fonded. In situations where responsibilities for coastal resource management are fragmented, a coordinatives from different agaendes may be required as has been done in the Philippines.

Emergency Preparedness :

Mitigation techniques for oil spills include preventive, preparedness (e.g.r.sk assessment and contingency planning) and technology (barriers recovery systems chemical and biological treatment) Availability of a trained and highly mobile crew is crucial for effective mitegation.

There are three major approaches to minimizing the destructive/ consequences of natural hazards such as coastal storms and tsunamis. The First /\ approach is to avoid a great deal of death and damage through appropriate **control** of development in flood-prone areas (e.g. limitations on new construction in high risk zones, building setbacks construction specifications). The second approach is essentialy that of "informed retreat" through storm forecasting and warming systems evacuation plans and storm-proof shelters. The third approach is coastal fortification through major engineering structures. This approach, exemplified by the Netherlands Delta Plan, Thames River Baries and Japanese tsunami barriers, can be very effective in conserving both human life and property but usually involves high economic and ecological costs.

INTERNATIONAL PRIORITIES

Agenda 21, the action plan of the 1992 United Nations Conference on environment and development, outlines the following priorities of coastal management:

- Integrated management and sustainable development of coastal area including exclusive economic zones.
- Sustainable use and conservation of marine living resources under national jurisdiction.
- Addressing critical uncertainties for the management of the marine environment and climate change.
- Strengthening international, including regional cooperation and coordination.
- Sustainable development of small islands.

1.5 ❐ References

Hanchey J.R., K.E. Schilling, and E.Z. Stakhir 1988 : Water Resources planning under climate Uncertainty. In Preparing for climate change, ed. climate Institute. Washington. D.C. Government Institutes. Inc.

Hosier, RIchard H. 1986 : Energy Planning in zimbabwe : An Intergrated Approach. Ambio 15 (2). 90-96.

W.E. Reibsame ; K. M. stozepek etal. 1990 : COmplex River Basins. Institute of Behavioral science. University of colorado In. Ippcce climate change vol.

United Nation Economic and social council, 1970 : intergrated River Basin Development. DOC. NO. E/3006 NewYork, United Nations.

White, G.F. 1957 : A Perspective of River Basin Developmen. journal of countemconteporasoy Problems 22:157-87.

White, G.F. 1964 : contributions of Georaphical analysis to River Basin Development. Geogrophical Journal 129. 412-436.

Unit - 2 ❑ Case Studies of Landforms and Landuse

Structure

2.1 ❑ Badland on Lateritic Duricrusts (Garhbeta and Santiniketan, W.B.)

Badlands on laterite duricrust (Garhbeta of Western Medinipur)
The laterite tract of western Medinipore is produced with the combination of various activities, like post glacial graveli ferous sediment deposits prolonged weathering process under tropical hot and humid climate, tectonics in the form of slow but steady upliftment of the depositional surface, change of drainage characteristics and rate of denudutional process. The process of laterization is also influenced by high rainfall (1500 to 2000 mm) and continuous high temperature (22-25°C) throughout the years and seasonal fluctuation of groundwater table. The basic parent materials of graveliferous sediments, having sufficient iron bearing ferro-magnesian minerals were congenial for the development of laterites in the area under investigation.
There are three to four types of lateritic materials encountered in the field areas of western Medinipur. Quartz grains or silica particles coated with iron oxides in the form of nodules or conoretionary products are found in a type of geomarphic surface resulted from weathered debris and differential rate of erosion. In many areas, the planation surface is copped by laterite hard crust. They are developed by eluviation and illuviation process and also by seasonal groundwater fluctuation in a contain depth of soil profile with concentration of sesquioxides which hardered to exposures under the removal of plynthites. A feal areas urlder floral cover have cemented with silica grains and clay particles by hydrated oxides of alluminium and iron concentration. Such cemented surfaces with hydrated oxides are eroded by surface runoff and renained in the forms of mesas and earth pillars. Loterite conglomerates are formed in the surface of upper terrace by concentration of sesquioxides as

cementing agent to agglomerate the gravel beds. It is possible to establish a sequence of soil maturity correlated with the morphology of the landscape. Different geomorphic surface give rise to a sequence of younger, mature and relic soils in the parts of western medinipore district.

There are four major types of laterites on the geomorphic surfaces of the landscape. They include as packed pisolithic laterite of delrital composition, spaced pisolithic laterite of in-situ farmation, vermiform laterite of indurated sesquioxides and secondary laterite of clay minerals and hydrated iron and aluminium oxides.

Processes involved in the formation of laterites :

Laterites at mottoled horizon are develop due to the accumulation of sesquibxidic materialsleached down to water table. Both pedogenetic process and ground water movement are responsible for the concentration of iron and illuminium in nodulees or slag-like concretions in the mottled horizon. Seasonal migration of water table causing upward movemet of iron and alluminium in to zone atternately affected by wet and dry. Erosion removes the top soil (plinthite) of solter variety upto the depth of concretionary zone which irreversibly hardens with sub a erial exposure to form crust of indurated laterites.

A thick horizon of laterite profile (about 21m. thick) is exposed on the erosive bank of shilaboti river at Garbeta. The laterite profile is developed over a Tertiary graveliferous deposit with deep weathering activities under wet and dry conditions and active ground water movement. A zone of concretions is overlain by hard crust at Garbeta and which extends upto mottaled zone of concretionary laterites. The Pallied zone lies below this horizon and it is characterised by the accumulation of silica and clay in cemented form. This zone is by definition pabe coloured due to leaching iron, and thus the coexistence of iron depleted and or iron enriched horizon is developed in the thick profile of Garbeta.

Nodular horizons are the product of wealthering of the hard crust laferite (Banerjee, 1972). Disintegration of quartz grains and re-granulation into nodules in the upper horizons seem to take place by concentric growth of nodules with iron oxide coating.

Geomorphic Characteristics of the sites to which each type of laterites are associated :

A massiver vesicular or concretionary ironstone formation neearly always associated with upliftment peneplains originally associated with areas of low relief and high ground water (Bridges, 1978). Laterites conglomerates are visible ^ on the valley margins and terraced banks of Subarriarekha river and Dulong river basin. The erosine plains of highland tract under Kasai-Subarnarekha-Shilabati interfluves are associated with concretionay ironstone formation. Uplift of such kind surface has resulted in increased fluvial erosion by streams which have cut deeper valleys and lowered the acater table. Valleys are widened by shifting drainage courses and incised by undermining the bankwalls after the uplift of land surface in the region. Erosion has also stripped off the overlying leached horizonsso that the laterite usually occurs as a platform remnant in the interfluve position. The ironstone horizon has become exposed and holdered to contact with the air after removal of softer soil cover from the uplifted surface.

Weathering of the exposed crust has led to the variable growth of modified surface with strong runoff deposits and nodular composition of materials. Variation of laterites is also visible associated with or without the cover of vegetations in the uplifted surface. Planation surface laterites are also visible in unindurated condition under forest covered interfluves. The laterite remains permeable as long as the original soil cover and forest vegetation remain in the areas of interfluves. The laterite is incised and eroded on the bank margins by shifting drainage courses and the planation surface laterit is indurated after deforestation of the laterite which loses its permeability, Finaly, the deforested areas of indurated laterites are affected by weathering fragmentation and regramulation of weathered materials with iron oxide coating. Such development of land surface leads to the formation of wasteland on the margins of degraded forest belts in western Medinipore. Moderate to gently sloping margins of highlands with weathered laterites are also affected by rilling and gullying actions by strong surface runoff at the wet season. Valley floars of gulley channels are filled up with concretionary nodules by runoff deposits from the bank margins of eroded highlands. These nodules of concretionary products are also cemented with the concentration of iron and alluminium oxides in feal places where the water table is very close to the surface. In western Medinipur, those highlevel laterites which were formerly forested and permeable are markedly deformed by weathering and erosion.

The location of interbedded silicified wood fossils from the detrital laterite deposits of Garbeta and Lalgarh surface perhaps provide more significant information about the nature of vegetation at the time of laterite formation than does the vegetation currently seen on the laterite surface of western Medinipore. In many areas of sal dominated forest floor, iron is readily removed by humus-rich solutions and hydrated alluminium oxides, however, concentrated in the surface to produce cemented crust with marginal erosion. The railing interfluves of subarnarekha-Kasai-Shilabati Basins are characterised by pisolithic laterites with non-static water table and massive laterites with seasonal static water table. The large vertical spread of pisoliths within such interfluves can also again be associated with a lowering water table. The pisolithic laterites are immature form of laterite which appears to be developed in the immature planation surfaces. The mature planation surfaces can be associated with the exposure of underlying massive laterites after removal of pisolith bearing surface from the top. The older alluviuns and underlying gravel beds of the upper terrace of Subarnarekha river banks are lateritized in successive stages. The higher parts of interfluves with hillocks are locally known as 'dungri'. They are mostly forested and characterized by discrete concretion variety of surface form. The areas of degraded forests with exposed planation surface laterites of massive structure are locally known as 'dohi'. The surface is roughened in this part because of weathering and fragmentation of the laterite hardcrust. The surface is also extended upto the margins of present day river valley alluvium deposits. The youger alluvians of river valleys are cultivated and soils of bank margins are more or less . affected by hydrated oxides of iron and alluminium in feal places. Finally, the course of the river bed restricts the growth and extension of valley plants between interiluves.

Lateritic Duricrust :

Duricrusts are results of rock weathering and soil formation. The lateritic duricrust of Garhbeta badlands is assumed to be genetically linked with the surrounding upland (remnants of Pleistocene lateritic belt of West Bengal) and associated topography. The duricrust overlying typical deep wealthering profile comprising indurated, mottled and pallied horizons signifies the process of deep chemical weathering which operates exclusively in the humid tropical regions and has farmed in situ during the process of pedogenesis and so are genetically related to them. (Fariran and Jeje, 1983) various'types of landforms those are associated with duricrust in humid sub humid tropical environments are cop rock escorpments, assopciated hill side slope, mesas, buttes, relief inversions, pipe, sliumps. debris stream basements etc.

Escarpment :

A steep escarpment is found along the concave bank of the river silai Southward shifting of river Silai towards the lateritic upland produced such escarpment. The height of the escarpment varies between 15 and 25 metres. Rockfall, slab failure and overhang detachment are the main processes of escarpment retreat, wide surfaces are exposes due to retreat of escarpments and lowering of the divides (Plate 7)

Gullies :

As seen before, the badlands of Garhbeta can be classified as western (or less matured) and eastern (or mateured) ports. In the western part, gullies are short and discontinuous, stope of the gully wall is between 60-90°, their height varies between 18-25m. whereas in the eastern part, gallies have greater length, slope is gently and convex (5-45), height of the gully wall is below 15m. our observation shows the orientations of the gullies are very much integrated with nature and properties of laterite profile. The profile shows, there are 4-5 distinct horizons and due to differential sedimentary composition each profile has differential resistance to erosion. As a result gullies in Gangonir Danga occur in different levels. One set of gully drain the surface of the lateritic duricrust and the other cut into the lower horizons originating from the retreating cliff line.

'V & 'U' shaped gully Channels :

Distinct characteristic difference can be seen between eastern and western gylly channels. V-shaped gullies form in material that is equally or increasingly resistant to erosion with depth. U-shaped gullies form in material that is equally or decreasingly resistant to erasion with depth. (Fig). As the substratun is washed away, the overlying material loses its support and fulls into the gully to be washed away, most V-shaped gullies become modified toward a 'U' shape once the channel stabilizes and the banks start to spell and slump (plate 8).

Pipe Structure :

In Garhbeta badland sector, a zone of medium grained sand with a large, well preserved erosional channel exhibits a feature which has been called the pipe structure (Mallick and Niyogi 1972). The feature resembles nearly cylindrical pipes of which the central partion is either hollow or is filled with a white Kaalinitic material. Th diameter of the pipes varies from 0.5 cm. to 20 cm. the walls of the pipes are generally uniformly thick and hard and contain many sand grains cemented by iron oxide. Pipes branch at all possible angles and are mostly vertical but inclined or even horizontal pipes are not uncommon. The zone containing pipes is about 1.0m to 2.5m. thick. The origin of pipe structure is not clear. These appear to be the less lateritised version of the hard pipes and may represent paths of percolation of vadose water created by roots or in some other manner (Plate 9). It is possible that hard pipes of the Garhbeta profile have formed in the some way where decayed roots of plants created such path like paths for percolating water. Subsequent cementation may have taken place through normal lateritic processes. Evidence in support of this view is the branching pattern of these pipes resembling that of roots (Mallick and Niyogi, 1972).

Mesa and Buttle like expressions :

In the central part between eastern and western gully sector meses have been developed (about 15-20 m. high) by fluvial action which is caped by top level duricrust. The buttes have also formed

By flow dissection (3-4 m. high) which are capped by thin indurated horizons present in the pallid zone (Das & Bandyopadhyay, 1988) (plate 10).

Caves :-

The most important sub-surface feature in the badland of Garbeta is formation of cave. Sub-surface water movement, lateral erosion by the gully channels and slab failure/root collapse are the causes and effects of such formation. In the study area six such small caves have been formed mainly in the western sector of the badland terrain. The average length and width of those caves is about 5m. and 2m. respectively (plate 11).

Earth Piller or Hoodoo like expressions :-

Earth Pillars or Hoodoo are well known morphological expressions of

Dakota Badlands of USA. Similar features with a varying height of about 3 - 6m. are also found in our study area when tall column of pallid zone materials are capped by comparatively harder materials (Plate 12).

Water fall :

A number of water fall (about 2 - 6m. high) have been developed originating from the gully head and edge of the escarpment at Garhbeta. Compare to the eastern sector the western gully head are steeper as they produce the waterfalls in a forceful manner. The amount of rainfall surface slope, amount of vegetate cover and sub-surface water movement are the controlling and contributing factors of waterfall development. Such waterfalls have a great impact on gully head wall an escarpment retreat, formation of plunge pool at the base of the waterfall.

Fossil horizon with void and silicified tubes :

Trace fossils are recognised as one of the most important environmental indicators of the geological succession of Tertiary-Quaternary strata in western part of Bengal basin (Bera 1996). Outcrop sediments exposed at Garhbeta along river silai section are also crowded with trace fossils. It has been identified as the youngest trace fossil zone of Bengal basin. Trace of autochthonous burrow fossils and petrified woods indicating a tropical to sub tropical humid near-share environmental deposition of sediments during the Lower Pleistocene (?) (Bera and Banerjee 1986).

Gully Fan :

This is a unique depositional feature, occurrence of which takes place when gullies meet river Silai, Distinct Far like structures are also found in the mouth of the major gullies.

Laterite Upland (Santiniketan) :

The western part of the study area is occupied by the Laterite upland. This includes both the hard crust of laterite and the underlying mottled clay. With an increase in the sand-silt content and decrease in iron concentration the hard crust grades down to the mottled clay. Mottled clay is generally exposed as a result of erosion of the overlying hard crust and is characterised by an undulating surface having a relief lower than laterite hard crust and higher than older Deltaic Plain (ODP). The upland occurs as a continuous belt running approximately NNE-SSW and separates the Quarternary formation from the older ones. The boundary follows a sinuous pattern from north of Dhulian to Bolpur at south and passes through Suri, Rampurhat and Pakaur. The Western limit of the laterite developed on Quaternary sediments could not be determined. This belt is cut through by a set of parallel rivers and small streams which have built relatively broad individual terraces on the upland.

Laterite is easily distinguished in aerial photograph by its dark photo tone, coarse texture and pitted appearance while the mottled day surface is characterised by a greyish white tone with medium texture. Characteristic features of upland are :

1. Occurrence at higher level, ranging between 36m. to 120m. above mst; general slope 1.2m. per km. towards east.
2. a greater degree of dissection.
3. thick soil profile, hard crust 3 - 5m. thick and mottled clay nearly 6m. thick containing ferruginous nodules, size of which varying between 3mm to 5mm.
4. absence of any fluvial geomorphic features in the surface due to masking effect of thick soil profile.
5. valley fills of ODP
6. mottled clay showing sedimentary structure in the sections.

The hard crust is a nodular hardpon where ferruginous concretions are cemented together by colloidal iron oxides. This may easily be disintegrated into iron oxide dust and loose concretions commonly known as 'moran'.

Mottled clay is made up of sand, silt and clay (parent sediments) in which terruginous concretions have developed. Mottled zones show definite compositional control in the development of ferruginous soil profile. The sandy portions generally escape lateritisation whereas silts and clays are prone to the development of mottline. Mottling usually develops in a concentric manner around a grain with different shades of brown coloured rims which are layers of colloidal iron oxides and hydroxides.

Polyprofiles of laterite are encountered at many places (Fig). A typical polyprofile of laterite section found in the area is presented below :

Units	Description	Approximate thickness
III	Hard brown clay	40 cm
	Mottled clay	150 cm
	.... erosional contact	
II	Hard crust	115 cm
	Earthy mottled clay, cherry red to brown with vernacular structure	260 cm
	course grit with a few pebbles (Parent Sediments)	40 cm
	Pebble rounded to surrounded and angular with an average diameter 2.54 cm. Pebbles generally elongaed	150 cm
	.... erosional contact	
I	Mottled clay	38 cm

Polyprofile may develop with a fresh phase of alleviation over a truncated older laterite surface followed by another phase of lateritisation of the later alluvium and so on. On the other hard, with a quick lowering of the regional water table, the site of maximum accumulation of iron might be lowered resulting in the formation of a polylaterile profile.

A number of valley-cuts are present on the laterite upland. These are minor valleys, generally dendritic in nature which were scooped out by tributary streamlets meeting rivers and the then sea during degradiational stage. These are filled up by the sediments of the next younger unit. i.e. ODP forming valley fills (Fig).

References :

Bandyopadhyay, S. 1987 : Ma-initiated gullying and slope formation in a Lateritic terrain at santiniketan, W.B. Geographical Review of India ; Vol. 49 (4), PP 21-26

Bandyopadhyay, S. 1988 : Drainage Evolution in a badland terrain at Gangani in Medinipur District, W.B. Geographical reviw of India ; Vol. 50(3) OO. 10-20.

Baner jee, A. K. 1972 : Weathering of Laterite crust in Medinipur district, W.B. Proc. Seminar. I.I.T. Kharagpur PP. A7–A11

Bera, S. 1996 : Remarks of Paleoenviroment from the trace fossils from subsurface and outcrop Tertiary–Quaternary sediments of the Western part of Bengal Basin. Journal of Geography and Environment, Vol.I, PP.1-15.

Goswami, A.B. 1980 : Hydrology of Lateritic terrain of Bankura and Medinipur districts. Proc Int. Sem. on Laterization Process, Trivandrum, India, PP 407-410.

Niyogi, D. Mallick, S. 1973 : Quaternary Laterite of West Bengal, It's geomorphology, stratigraphy and gensis. Q.J. Geol. Mital. Soc. Ind., Vol. 45 (4), PP. 155-174

Chaterjee, Soumendu., and Paul, Ashis kr. 2007 : Some observations of the diverse Pateritic landscape of subarnarekha-kasai-shilabati interoflumes of Paschim Medinipur, W.B. Indian Journal of Geography and Environment. Vol. 8 and 9 PP. 82-95.

Sen, J., De, S. and bandyopadhyay, S. 2004 : Geomorpholagicm Investigation of Badlands : a case study at karbeta, West Medinipur District, W.B. India. In Geomorphology and Env. S. Singh., S. Sharma., De. Sunil (ed.). ACN publications. PP. 204-234.

Suggested Reading

Laterite and Landscape. 1976 : M.J. Mcfarlin. Academic press PP. 151.

Tropical and Subtropical soil science 1986 : S. N. Zonn. Mir publishers. Moscow PP. 422

Questions :

1. Explain the stages of development of Badlands on Lateritic Duricrusts with special reference to Garhbefa.
2. Identity and describes the various geomorphological features of shantiniketan Badland.
3. Describe the drainage networks of Gully channels of garhbefa Badland on Laterite Duricrusbs.

2.2 ❑ Tors and Insclbergs : Chhotanagpur, Jharkhand

Inselbergs

Although not confined to granite, inselbergs have been considered the most characteristic granite landform. However, ideas concerning the origin of inselbergs and the relationships between inselbergs and rock structures have been hampered by confusing definitions and terminology. The term 'inselberg' was used by Bornhardt in 1900 to describe the abrupt hills he encountered in Tanganyika. King (1953, 3957, 1962) extended the term to describe any steep-sided residual hills that had arisen from the operation of scarp retreat and pediplanation, and Twidale (1968) has defined inselbergs as residual uplands in tropical regions which stand above the general level of the surrounding plains. But both latter definitions are unsatisfactory. King has argued for a particular form of slope evolution, which might be inappropriate, and unless inselbergs are always jregarded as palaeociimatic indicators, the definition of Twidale would not include inselbergs that have been described from a number of extra-tropical regions. In this respect, Kesel (1973) found that, in the published studies he examined on inselbergs, 40% came from savanna climates, 32% from semi-arid or arid areas, 12% from humid continental and sub-arctic climates and 6% each from the humid tropical, subtropical arid Mediterranean zones. Also, not all inselbergs rise above generally level plains.

Young (1972) has produced a more general definition, arguing that inselbergs are steep-sided isolated hills., rising relatively abruptly above gently sloping ground. He distinguished the following types, not all of which o cur on granite :

(a) Buttes, found in horizontal strata or where duricrust forms a resistant cap rock.

(b) Conical hills, having rectilinear sides, common in arid regions.

(c) Convex-concave hills, entirely regolith covered. These are transitional with hills not defined as inseibergs.

(d) Rock crests over regoiith-covered slopes.

(e) Rock domes, often with near vertical sides, but merging with low domes and rock pavements.

(f) Tors (koppies) formed in part of large boulders but usually with a bedrock core.

Most of the key issues concerning the relationships between rock structure and landforms are associated with the last two types which can be called domed inselbergs (bornhardts) and boulder inselbergs (tors) respectively. In addition, Thomas (1976) has argued for a third feature, stacks or rock towers.

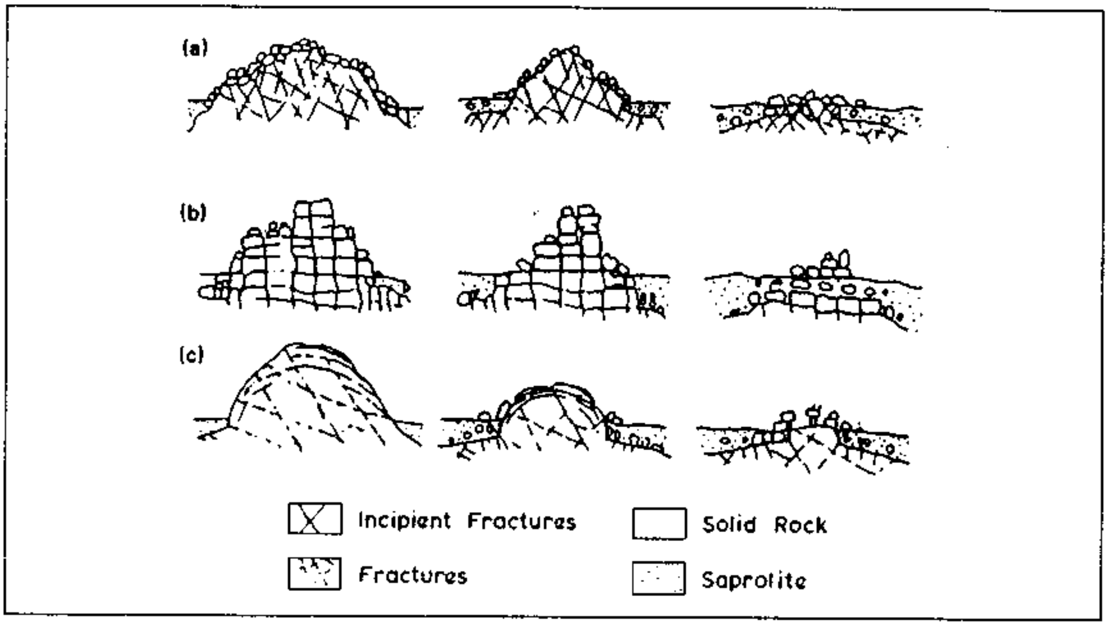
Domed inselbergs (bornhardts) are dome-like summits with precipitous sides, often becoming steeper towards the base with an absence of talus, was Willis (1936) who proposed that Bornhardt's name should be used &o describe such structures. Domes may exceed 300 m in height, with only &he summits of the larger domes exhibiting pronounced convexity. They are found in foliated rocks such as gneisses and migmatites as well as granites. Most domical forms are associated with sheeting and may ibssess tabular tors on their summits.

Boulder inselbergs (tors) are residual masses of bare rock, rising from a ;&asal rock platform which may be covered with regolith. They are usually isolated by steep faces on all sides and are rarely less than 3 m or more fihan 50 m in height. They occur on summits, valley sides, spurs, valley foors and extensive plains. Thomas (1976) has subdivided tors into tower-like forms defined by blocky, rectilinear jointing, tabular forms induced by strong lateral features such as sheet jointing, and hemispherical forms where a domical form is present among the boulders.

Stacks (rock towers or castle koppies) are angular, castellatea forms which exhibit few signs of spheroidal modification. They are often confused with or referred to as tors. Isolated forms have been called stacks (Linton I955) and those on hillslopes, buttresses. The term rock tower has also been used (Jahn 1962).

There are clearly overlaps between all three types which has led to considerable confusion. The confusion is compounded by the possibility What one form may develop into another in a developmental sequence.

Brook (1978) has tried to make a distinction between conical hills and



[Figure 8.1 Evolution of (a) conical hills, (b) boulder hills and (c) bornhardts.
Source: Brook 1978.

bornhardts on the basis of more irregular steeply dipping joints in the former (Fig. 8.1). Conical hills are mantled by loose joint blocks, 7-10 m thick, but have fresh rock interiors crossed by networks of tightly closed, steeply dipping joints which inhibit the movement of water. They are very similar to features which Twidale (1982) has called nubbins. Sheeting structures are poorly developed and do not influence morphology. In the Transvaal of South Africa most conical hills have almost linear 30° slopes, and may be true 'boulder inselbergs' as opposed to tors, which stand as moncliths.

The nature of the jointing has also been invoked by Cunningham (1971) to distinguish tors from domes. He suggests that tors are characterized by horizontal jointing while domes cxhibil curvilinear sheeting. But where curved sheeting has occurred on domes, the sheets may £plit into blocks which become weathered into tor-like forms. This appears to be the situation on the granitic uplands of southwest England, where tor groups are located on the summits and around the edges of domes (Gerrard 1974). Tors generally possess more closely spaced vertical joints.

Much of the confusion occurs because the terminology has been used differently in different parts of the world. This is especially true of the word 'tor', which is extensively used in England to describe angular residuals, usually in granite but also on gritstone (Palmer 1956, Linton 1964) and dolomite (Ford 1962). The term has also been used in Central Europe (Demek 1964a, b, Jahn 1974), Africa (Falconer 1911, Handley 1952, Thomas 1965, Gibbons 1981), Australia (Mabbutt 1965, Caine 1967, Leigh 1970) and North America (Cunningham 1969). But, as Twidale (1982) has pointed out, the term has been used to describe isolated blocks and boulders as well (e.g. Williams 1936, Hills 1940, Browne 1964). Features in other parts of the world similar to the tors of southwest England are commonly called castle koppies. In this account tors and stacks (castle koppies) will be treated as one type of feature subsumed under the more general term boulder inselbergs.

Domes and tors often occur together and there is much evidence to support a relationship between them, but it may be unwise to seek a single hypothesis to explain either all domes or all tors. White (1945), comparing the domes of Yosemite, California, with prominent exfoliation patterns, with those of Georgia, USA, with little or no sheeting, has suggested that a principle of 'convergence' might be operative, whereby similar forms have been produced from separate origins by the operation of different processes. This concept has been recognized as the principle of equifinality (Bertallanffy 1950) and has often been invoked when considering the origins of domes and tors and their features (Selby 1977a, 1982b). But great care needs to be taken to ensure that in fact similar forms are being described (Gerrard 1984).

Isolated Residual Hills (Burus and Dungris) (Chhotonagpur, Jharkhand)

The residuartiills or monacmocks have brought about divefsity in the wide undulating plains at different altitudes to form the typical landscape of the Subarnarekha basin. These isolated hills of various origins are locally known as 'buru' or 'dungri' which generally rise abruptly from the current cyclic surfaces. Like the other elements of the landscape they account for a variety of cyclic processes have been involved. The different types of rocks have offered an unequal resistance to erosion and so have given rise to contrasting types of landform. The softer rocks such, as mica-schist and phyllites have weathered into small basins and productive plains; the harder types among which granophyres quartzites and chlorite schists etc. predominate and form higher and relatively drier hillocks, called *buru* or *dungri* such as Kenra Dungri, Bhurkuli Pahar, Hensa Dungri, Krishna Chandra Dungri, Tama Dungri, Ajodhya Hills, Gorga Buru, Bansa Hills, Raisindri Pahar, Kuti Buru, Jamda-

Jamerda Buru, Chandru Buru, Sawai Buru, Phool Dungri etc. located at the eastern plains (below 200 m.; a.s.l.) of Singhbhum and Panch Pargana lying below the Ranchi Plateau. The important isolated hills or inselbergs of the Ranchi Plateau (600 m., a.s.l.) are Bharom Hills, Morabadi Hill, Ranchi Hill and Semo etc. Most of the *monadnocks* are of conical shaped hills but dome shaped hills or flat topped hills are also common.

Generally the granite country of the upper and middle parts is mainly flat or gently undulating with a cultivated thick soil mantle. The typical rugged *tors* or *knolls* are present in some parts where relatively harder variety as outcrops of these rocks have produced some monadnocks as above. White quartz veins are associated with quartzite ridges scattered mainly throughout the lower part of the basin to the east of Ranchi Plateau. Frequently the debris from such veins covers the hill slopes in the basin. Near Turliga Parbat (22°26' N; 86°17' E, 759 m., a.s.1.) ascending the ridge from the granophyre plains the upward variation in the quartzite has been observed. In the southern edges of the Panch Pargana Plain in and around Chandil (22°57' N; 86°04' E) the distinct parallel ranges of hills consist entirely of black phyllites (carbon-phyllites). In the northern part of Ledasal (22°44' N; 86°25' E, 524 m., a.s.l.) along the border between the Subarnarekha and the Kangsabati basin some interbedded limestones and phyllites give rise to prominent topographic forms. The dome-shaped and other small hills at Chirugora (22°52' N: *86"28'* E), the saddle-shaped hill north of Gangamanna (22°51' N; 86°28' E), the low ridge east of Aspara (22°52' N; 86°29' E) and west of Bhelagora (22°52' N; 86°24'E) and a few small isolated outcrops near Patamda (22°35' N; 86°24' E) are examples of cherty carbonaceous rocks after phyllites. In the eastern part of Singhbhum Plain Tama Dungri (22°44' N; 86°02' E, 250 m., a.s.l.) consists largely of chloritic-phyliite with chlorite-schist and quartzite. Towards the Kharkai river in the north of this ridge (Tama Dungri), especially in the vicinity of the old copper pits, the phyllite varies to chloritic mica-schist. Mention would be made of a line of low hills between Kacha (22°45' N; 86°10' E) and Rugridih (22°43' N; 86°15' E) consist of finely cleaved muscovite schist with biotite and tourmaline. It is important to note that the Newer Dolerite dykes mainly in Singh-bhum granite usually offer a greater resistance to erosion and they form long serrated ridges or linearly arranged series of low hills or *dungris* in the plain country.

These residual hills may be regarded as one of the important features which illustrate the striking way in which the geological structure and the character of the rocks are expressed in the landforms. However, the present study lies primarily in the interpretation of the major 'buru or dungris' (residual hills) mainly in and around scarp zones with the Subarnarekha drainage to the wide old-age plains it etches (Mukhopadhyay 1970c).

References :

Anhaeusser, C. R. 1973 : The geology and geochemistry of the Archaen grantes, and gneisses of the Johannesburg Protoria Dome. Geol. Soc. S. Afr. Spec. Publn-3, PP. 361-85.

Bakker, J. P. 1967 : Weathering of granites in diferent climates. In L'evolution des versants' P. Macar (ed) congre's it colloques di' L'Universite' de Leige, No 40 PP. 51-68

Derobyshire, E. 1972 : Tors, rock weatheriing and climate in southern Victoria Land, Antractica. Inst. Bro Geog. Spec.Publn. 4, PP 93-105

Doornkamp, J.C. 1974 : Tropical weathering and the uttra-micres-copic characteriestics of regolith quartz on Dartmoor. Geografiska Annalaro ser. A 53, PP. 92-99.

Gerrarod, A.J. and 1974 : The geomorphological importance of Jointing in the Dartmoor granite. Inst. Br. Geogs. space. Publn 7, PP 39-51

Gerrard, A.J. 1978 :Tors and granite landforms of dartmoor and Eastern Bodmin. Moor Proc. Usshero Soc. 4 PP 204-210.

Handley, J.R.F. 1952 : The geomorphology of the-Nzega area of Tanganyika with special reference to the formation of granite tors. cong geologique international. C.R. 21e PP.201-210 Algiers.

King, L.C. 1958 : Correspondence : The problems of tors. Geogr. J. 124, PP. 289-291.

Linton, D.L. 1955 : The problem of tors. Gegro. I. 121, 470-86.

Ollier, D. L. 1960 : The inselbergs of Uganda. Z. Geomorph. 4, PP. 43-52.

Palmer, J. and R.A. Neilson, 1962 : The origin of gramite tors on Dartmoor. Proc yorks geol. Soc., 33, PP. 315-340.

Thomas, M. F. 1978 : The study of inselbergs. Z. Geomorph. Supp. Bd. 31 PP. 1-41.

Suggested Reading

A. J. gerrard 1988 : Rocks and Landforms. Unwin hyman. London, PP. 319.

M. J. Selby 1982 : Earth Surface Processes and Landforms J. Wiley and sons.

R. P. Mishra 1972 : Geomorphology of Chptonagpur Platean.

Questions :

1. Explain the development of Tors and Inselbergs in chhotonagpur plateau (Jharkhan).
2. Give an account of the origin of granite tors of sigbhum belt of chhotonagpur belt.

2.3 ❑ Alluvial Fans : Sub-Himalayan West Bengal

Alluvial fans that develop in humid climates have many similarities with their counterparts in arid environments. All fans are in similar geologic and geomorphic settings; that is, they require an area of high relief and an adjacent low-lying area for sediment accumulation. Alluvial fans in general are related, as least indirectly, to tectonic activity because of the need for high relief. Humid fans require high rainfall in addition, which tends to place them on the oceanic side of mountain ranges, generally not far from the moisture source, the ocean. The western margin of North and South America provides such a setting. Many humid fans also develop as outwash fans in front of glaciers, such as in Alaska. In these fans the glacier itself may provide most of the relief for the depositional setting.

A variety of humid fans has been recognized from the rock record (e.g., McGowen and Groat, 1971; Vos, 1975; Koster and Steel, 1984). Unfortunately, the spectrum of modern counterparts is not great; probably the best examples are the proglaciai outwash fans in Alaska and Iceland (Boothroyd and Nummedal, 1978) and along the southern flank of the Himalayas (Gohian and Parkash, 1990), although Kuenzi et al. (1979) argue'that fluvial deposits on the western coast of Guatemala also qualify. These authors have proposed a humid alluvial fan model that appears to be applicable to all humid fans, not just those of glacial orgin.

General Morphology :

In most respects the shape of humid fans is comparable to that of arid fans. Humid fans may become large, with areas of a few hundred kilometers in Iceland (Boothroyd and Nummedal, 1978) and up to 10,000 km2 in India (Gohain and Parkash, 1990). The geologic setting of humid fans is typically much more varied that that of arid fans. Relief is certainly important to the development of broad, coalescing fans. Some humid fans are longer than they are wide.

One of the striking contrasts between humid and arid fans is in their longitudinal profile and slope (Ryler, 1972). Both types may conveniently be subdivided into proximal, middle and distal fan segments. Humid fans display long, gently sloping profiles in comparison to steep arid fans. Humid fan gradients rarely exceed 50 m/km, whereas those of arid fans are generally at least twice that value.

Channel patterns in Alaskan humid fans are characterized by from one to three deeply incised channels in the proximal zone. The midfan zone contains numerous braided channels with numerous longitudinal bars separating the channels (Boothroyd and Nummedal, 1978). The Samala River of Guatemala is incised nearly 50 m into its fan near the apex, 36 km from the Pacific Ocean; 22 km downstream but still in the upper fan area, this incision decreases to less than 10 km (Kuenzi et al. 1979). Distal fan areas contain braided channel patterns similar to those of the middle fan but with smaller channels and less dense braiding. During flooding conditions the channel bars in this region are inundated, and the active channel complex contains a continuous sheet of water (Boothroyd and Nummedal, 1978). Probably the largest humid fan is along the border between Nepal and India : the Kosi Fan. It is associated with a braided stream system and feeds the Ganges River. It is nearly 200 km long and over 100 km wide. Discharge is continuous but quite seasonal because of the monsoon climate (Gohain and Parkash, 1990). Most of the fan is comprised of sand and mud with gravel restricted to near the present river course.

Processes:

Continuous discharge is typical of humid fans, although there may be strong seasonal variations. Those related to glaciers experience extreme discharge during spring and summer. Low-latitude areas may have strong seasonality because of precipitation patterns. Boothroyd and Ashley (1975) measured velocities and other flow parameters in the Scott and Yana fans in Alaska. Upper-fan velocities over 2 m/sec were common, with midfan values about one-half that. Froude numbers at or in excess of critical flow were common. All data point to a very high-energy situation, at least on the upper fan.

Sediments and sediment Body Morphology :

The general characteristics of sediments on humid fans are much like sediments on arid fans : The upper fan is characterized by the coarsest particles, with a marked decrease toward distal portions of the fan. Humid fans seem to display relatively low stratigraphic variability in sediment texture. A hypothetical section near the apex would be expected to consist almost entirely of particles of pebble size or greater. This is in contrast to the situation in arid fans, which tend to show more interbedding *of* fine and coarse strata. Such textural sequences merely reflect the relatively constant flow conditions of humid fans in contrast to the extreme ranges of flood and static conditions on arid fans.

The maximum clast size shows a distinct relationship to the humid fan gradient. There is also a pronounced increase in roundness in a down-fan direction. This is not necessarily the case for arid fans, which are typically steeper (Boothroyd and Nummedal, 1978). It seems logical to conclude that the continuous sorting and winnowing of humid fans produces at least near equilibrium conditions among texture, morphology, and processes; that is not the case for arid fans, which are more like a "dumped" deposit.

Imbrication of large clasts is widespread, with the planes of the long and intermediate axes dipping upstream (Rust, 1972a; Boothroyd and Ashley, 1975). It should be observed, however, that the long axis is typically transverse to flow, although long axes parallel to flow have also been observed. Laboratory studies indicate that such orientation results from contact or rolling transport.

Sediment bodies with a fan are typically longitudinal bars, but they display rather systematic changes across the fan profile (Boothroyd and Ashley, 1975). Upper fan bars are diamond-shaped, are composed of coarse gravel, and occur in interstream areas between incised channels. They are rarely subjected to flooding. Midfan bars are typically composed of both gravel and sand, with prograding slip faces developing on the finer-grained bars (Boothroyd, and Ashley, 1975).

Some bedforms may develop on the bars. Longitudinal bars in the midfan area are more elongate than upper-fan bars and are activated during most flood conditions. Sandy bars on the lower fan display both longitudinal and linguoid bar forms (Boothroyd and Ashley, 1975) in the braided portions of the fan. Some of the distal areas contain meandering channels which produce point bars.

The general fades model for humid fans consists of three core fades associated with various lateral fades (Boothroyd and Nummedal, 1978). The core fades are coarse gravel, fine gravel, and sand, which correspond to upper, middle and lower fan, respectively. The laterally adjacent facies depend on many variables but include such environments as swamp, marsh, eolian dune, and if near the coast, wind tidal flats. Into the basic framework one must incorporate various textures and sedimentary structures in order to produce a humid fan model.

Alluvial fan system of sub-Himalayan West Bengal :

The Quaternary evolution of an alluvial fan system in the Himalayan foothills reveals two distinct phases. The Early Quaternary Siwalik system (I) and the Late Quaternary intramontane piggyback system (II) have been studied in detail in the Subathu sub-basin of IMW Himalaya (with system I followed by system II). Sedimentary architecture and fades analysis from chronologically constrained sections (using magnetostratigraphy and TL/OSL) indicate that systems I and II, although developed in similar hinterland-basin settings, indicate contrasting aggradation and entrenchment.

System I is characterised by predominant fan aggradation, in contrast to the variable aggradation—entrenchment response in time and space for system II. System I is time transgressive laterally from east to west with the central part remaining as the uplifted inter-fan domain. Further confinement of system I along the basin margin indicates its syn-orogenic evolution linked to the intra-foreland thrusting. This continued with the formation of the piggy-back basin of system II.

Glacial-nterglacial cycles influenced the evolution of both alluvial fan systems. However, greater sediment yield and larger accommodation space favored aggradation during system I. In contrast in System II, insufficient accommodation space relative to sediment yield and ongoing upliftment (and reduced subsidence) resulted in aggradation at the fan head during incessant precipitation, followed by entrenchment during low precipitation. The latest phase, Late Quaternary to Recent, is characterised by two level terraces (at ca.16 and 5 ka) within the entrenched streams, due to variation in water budget and sediment load governed by glaciaMnterglacial cycles. This study thus demonstrate the variable importance of accommodation space, base-level change and magnitude of tectonic and climatic forcing as controlling factors on aggradation and entrenchment in Quaternary alluvial fan systems of the Himalayan foreland basin.

References :

Rohtash Kumar, N. Suresh, Satish J. Sangode and V. Kumaravel 2006 : Evolution of the Quaternary alluvialfan system in the Himalayan foreland basin : implications for tictonic and climatic decoupling. Wadia Institute of Himalayan Geology. Dehradun.

Dipayan Guha, Sandeep Bardhan et.al. 2006. Imprints of Himalayan thrust tectonics on the quaternasoy piedmont sediments of the Neora-Ialdhaka valley, Darjeeling-sikkim sub-Himalayas, India. GSI, Bidhan Nagar Kolkata-91.

N. Suresh, T.N. Bagti, V.C.Thakur, Rohtash Kumar and S. J. Sangode. 2002 : Optically stimulated luminescence dating alluvial fan deposits of Pinjaur Dun, NW Sub-Himalaya. Wadia Institute of Himalayan Geology-Dehradun.

Suggested Reading :

Basu, S.R. 1992 : Geomorphology of the Allwial Fans of Darjeeling Himalaya foothills : The cocept of economay. In : Himalayan Environment, Man and the Economic Activities : Essays in honour of Prof. A.B.. Mukherjee. (ed. by J. L. Raina) Vol. 2, 513 P. Vedms Books (P) Ltd. New Delhi.

Questions :

1. Describe the geomorphic evolutions of alluvial fans with special reference to sub-Himalayan West Bengal.
2. Explain the economic significance of alluvial fans located in the Sub-Himalayan West Bengal.

2.4 ❑ Deltas and estuaries : Lower Ganga delta, West Bengal and Bangladesh

To the geomorphologists delta is a triangular shaped depositional landform in the river mouths developed by fluvio-marine sudiments of Quarternary period. According to Coleman and Wright (1977), terrestrial sediments derrived by the rivers have filled in the mouth of river valleys drowned by Holocene marine submergence to form the aepositional feature projecting towards the sea from the general outline of the coast. Delta will be advanced towards the sea if sediment accumenlation is very high in the river months to the sediments carried out by waves and currents. Geologically, delta is a major sedimen sink in which sediment is accumulated under a structural basin. Small deltas may develop inh the sheltered lakes devoid of waves and tides, but large deltas are developed by the big rivers on the shallow marine basins of wave action and tidal scur with abundant supply of sediments.

Deltas are probably the most comples of all depositional systems. There are many distinct environments of deposition within the large deltaic system. Deltas are economically significant because modern deltaic deposits represent fertile alluviums for cultivation and space for setlements, and ancient deltaic represent major sources of fossil fuels, like coal, gas and petroleum.

Thogh Deltas are located in different parts of the world, but developments of deltas are restricted-du to climatic, geomorphic and tectonic constraints. Thus, large active draiange system with sufficient discharge of water and sediments must be needed to develop delta. Deltas are generally absent in the landmass covered by ice sheets (Particularly in Antarctica and Greenland). The location of major deltas indicates the global tectonics is also a significant factor for sediments supply and sediment accommodation in the depositional feature. Thus, the ideal physical settings are decidee by the global tectonics. Very few large deltas are located on *collision coasts* due to small drainage divides of the rivers close to the ocean or sea, and absent of wide shallow shelp in the tectonic setup, However, the numerowo deltas are-located in the *Trailing-edge coasts* and *Marginal Seacosts* supported by well developed drainage basins, sufficient supply of sediments and presence of wide shallow shelf.

The delta system of Lower Ganga :

World's largest delta is located on the Lower Gangetic Plain of the

Bangal Basin. Much of the coast of West Bengal and Bangladesh is occupied by the Ganges-Brahmaputra delta complex. The river delta is largely influenced by tides in the coastal parts. The Ganges-Brahmaputra delta complex has 159.2×10^3 km^2 drainage area, mean annual discharge of 30769 m^3 s^{-1} water, and also a large amount of sediment load like 1670×10^6 tons yr^{-1} (H.G. Readings et.al.1977). The striking morphology and sediment accumulations are also influenced by low wave energy, high tidal range (over 4 m), and high frequency of cyclones on the seaface and wide rivers mouths.

Numbers of distributaries is bifurcated from the mainstream Ganga and extended over wide delta plain before reaching the Bay of Bengal. The delta system is also characterised by identical river mouths located on the seaface. In many respects this delta is similar to a large braided stream complex that suddenly meets the sea. The discharge of-sediment and water is very high particulary in the season of monsoon. The large sand accumulations of the braided stream type of situation are moblised by the dramatic events of monsoon floods. Inter distributary flood basins are very shallow and usually inundated at high discharge monsoon periods. Elongated sand ridges are very common in the river mouths which are largely influenced by bi-directional tidal currents.

This delta can be subdivided very ideally into three broad environments : the delta plain or the low-lying landward part of subaerial environment with subaqueous prtions ; the delta front or the seaward portion under intertidal environment ; and the delta head or prodelta, the distal parts of the delta under shallow marine environment.

The Ganga delta is though a product of large accumulations of sediment, erosio dominates in some areas and particulary during cyclones, tidal waves and, monsoon floods. Strong tidal actions, and wave dash activities of premosoon summer phase are the primary agents of erosion on river mouths and delta front shorelines. Presently, the-erosion is also accompained by relative rise of sea level in the delta (Paul, 2002). A large part of the delta is now abandoned commonly because of beheaded character of some distributary channels and also because of channel avulsion. Howeever, the tongue of subaquous fams is visibl-from the satellite images on the distal portions of the delta. A large amount of sediment of the delta system bypasses through the 'swatch of no ground' (Ganga canyaon) into the submarine fan (Ganga Fan) of the Bay of Bengal. The subaquous fams are possible extended at seaward directions due to mobilization sedimets of the of braided stream deposits from the deltaplain streams.

The active part of this delta is dominated by progroadation of deltaplain with accrwation of bars or formation of islands at the major distributaries. Beaches, beach ridges, and sand dunes are developed along the shores of abandoned delta. The coastal parts of the delta plain are covered by world's largest mangrove forest, locally known as 'the sundarban' which is now mostly reduced due to historical land reclamations for rice paddy cultivation and settlements on the rich deltaic allaviums.

Delta classification :

Modern deltas are classified on the basis of depositional patterns, process variations, gradient of the delta profile, morphology of the delta, and shape of the delta. Two principal types of the deltas have been distinguished under depositional patterns. They are (i) shoal water or inner shelf deltas, and (ii) shalf margin or shelf edge deltas. The first category of deltas include protruding delta fans onto continental shelves include protruding delta fams onto continental shelves and rlatively smaller sized deltas build out into lakes, bays, lagoons and estuaries. The protruding delta fams onto continental shelevs can be distinguished from the current satellite images of the Ganga-Brahmaputra delta complex. However, the smaller size daltas are developed in the estuaries in the form of depositional islands, shoals or bards.

The second category of delta was formed at the edge of the continental shelf when the sea level was lower than the present. This type of depositional pattern also can be explained from the Ganga delta in the form of advancing delta lobes formed by coastal progradation and transgression when sea level lower. The sediment foci of the delta lobes have been shifted from east ward directions due to the basement faulting, sea level fluctuations and coastal progradation. THe location of line of marshes rowards the morth of sundarban also can be explained as palaeo shoreline from which the delta is advanced at the edge of the continental shelf.

River deltas are well classified by using the process-based scheme into (i) river-dominated deltas, (ii) tide-wave interaction deltas, (iii) wave-dominated deltas, and (iv) tide-dominated deltas. Our Ganga delta is a tide-dominated delta where the deltaplain is significantly penetrated by large funnel shaped river month estuaries. Subarnarekha delta, Brahmani-Naitarani delta complex, and canvery delta are included as were dominated deltas char acterised by beach-ridge strandplains of longhore drift. Tide-wave-inter-action deltas include Godavari, Krishna and Mahanadi of the Bay of Bengal coast where the shoreline reworking is significant but tidal currents penetrate far inland along the estuaries. This type of classification scheme is criticisvd on the ground that all the deltas are not properly categorised under this scheme. The process based scheme can be extended by using grain size (Orton and Reading, 1993) or by evolutionary process (Dalrymple, zait-lin and Boyd, 1992).

The oldest classification of delta is based on the gradient of the delta profile. The gradient of delta profile is represented by river mouth sedimentation process. Gilbert's classic delfaic model includes topset, foreset, and bottomset components across the delta profile (Gilbert, 1885). THe topset of delta has very Lowgradient profile with partly subaerial and partly subaqueous environments for deposition. However, the frontal parts of delta have relatively steep gradient slop, and series of foreset beds of inclined draping ; and finally the bottomset beds are horizontally bedded deposits in the form of seaward delta slope. The bottom set beds were later referred to as the low gradient prodelta.

Reading and collinson (1996) clasiified delta on the basis of process variation as (i) delta plain, or mostly the subaerial parts of the delta dominated by riverine and tidal processes ; (ii) delta front, or the zone of interaction between fluvial (riverine) and basinal processes of shelf areas ; and (iii) the prodelta, or delta head of suspension load deposition disturbed only by gravity sliding and mass flow deposition.

Bagchi (1945) classified delta on the basis of Land building activity as (i) matured delta, in which land buiding process is ceased; (ii) moribund delta, in which tidal channels are choaked by sediment filling process ; and (iii) active delta, in which land building process is still active. According to him the present sunderban is located on the part of Ganga delta.

In tide dominated deltas sediment delivered to the coast bya river is redistributed by tidal currents. They possess tidal channels as well as river channels which creates a typical finger-like shoreline separated by interdistributary flood basins. This can be further enhanced by tidal sand ridges parallel to the tidal currents, tidal shoals, bars and inlets, situated within the larger mouths of tidal channels. The Ganges-Brahmaputra delta of India and Bangladesh falls within this category (Galloway's model of delta classification scheme, 1975).

The influence of sea level change on delta development has been reviewed by Boyed et al. (1992), and based on earlier research guided model showing that the regression or transgression of a delta shoreline is due to a combination of the rate of relative sealevel change and the rate sediment supply.

Delta plain characteristics of Lower Ganga :

Usually the delta plain comprises an extensive low-lying areas behind the delta front. The delta plain of Lower Ganga is influenced by tidal and flavial processes. There are two significant-features of fluvial dominated component, as (i) fluvíal distributary channels and (ii) interdistributary areas.

The active and abandoned parts of the Ganga delta is interresected by network of rivers and watercoursis. The great trunk channels enter the sundarcourses. The great trunk channels enter the sundarban from the north, and are connected by innumerable distributaries, which, after candless bifurcations and interlacings, unite into large estuaries falling into the Bay of Bangal. The principal of these distributary channels proceeding from west to east are : 1) The Bhagirathi-Hugli, 2) Bidyadhari-Matla, 3) Jamuna-Ichhamati, 4) Roymanagal, 5) Kalindi, 6) bhairab, 7) Gorai 8) Mathabhanga, 9) Attrâi, 10) Roopsa-Pussur, 11) Madhumati 12) kobodak, 13) Padma. All the distributary rivers are characterised by depositional features like bars, shoals and islands with high braiding index. Every river in the lower delta receives its supply of silt in greater or lesser quantities. All the rivers spill their water over the banks in the monsoon season and deposit a large amount of silt on the monsiin season and deposit a large amount of silt on the land. These channels are very tortuous and amount of silt on the land. These channels are very tortuous and are liable to suden changes in the positions of the oftakes. Such type of multiple-channel distributary system divide the discharge equally and channels of different magnitube co-exist in the delta plain and also wax and wane in response to avulsion and abandonment.

Inter distributary areas of fluvial delta plains are segmented into many components. Flood generated processes are the principal means of sediment supply to the interdistributary areas and features which result from these processes include levees, various types of crevase lobes and crevase channels. The spatial distribution of process operation in a fluvial dominated interdistributary area is determined by the distance from active distributary channels.

However, in tide dominated delta plains high tidal range, tidal currents enter the distributary channels during tidal flood stage, spillover the channels banks and inundate the adjacent inter distributary area. Tidal currents therefore predominate in the lower distributry couses and the inter distributary ares assume the character of intertidal flats.

Shore parallel sandy ridgs are characterristic of deltas that are subject to strong wave action. Where waves approach obliquely they move sand alongshore and form spit : for example the south western part of the Lower Ganga delta in the bay of Bengal has some prominent spite at present.

Tide Influence on the delta :

The most prominent chaacteristic of a delta that is influenced by tide processes is the pronounced tapering of channels. A regular decrease in width is shown with distance on channals that occur in macrotidal sittings. It also becoms increasingly prominent on former distributaries and other shorline indentations after abandonment or where river input has been decreased for other reasons. The macrotidal delta of the Ganga-Brahmputra-Megha Rivers is examined as an example.

The Ganga-Brahmaputra-Meghana delta is one of the largest in the world, and exhibits many features that are typical of deltas in Southeast Asia. The rivers are very flood prone as they flow through the Bengal Basin, and most of low-lying areas of Bengladesh and West Bengal are under water in the wet season, with exception of the pleistocene terraces on the north and western margins. The shorelines of easten India or West Bengal and western margins Bangladesh comprises the Ganges tidal plain, which is the abandoned plain of the Ganges. This area is composed of sediments derived from sea-ward, and is now dominated by tidal influence and covered by extensive mangrove forests, termed the Sundarbans. The active deltaic plain in the east, called the Meghna Deltaic Plain, experiences a large fluvial discharge (96% of the discharge of the rivers; 4% is carried by the former distributaries of the Ganges such as the Gorai). The Bay of Bengal has a substantial tidal range reaching around 4.8 m at calcutta, and adjacent to sandwip Island, but around 3.5 m for much of the rest of the delta. In addition, the mean water level varies over an amplitude of 85-90 cm as a result of wind set-up, barometric changes, freshwater input and density differences. Cyclones occur in the May to October period and can rais-water levels by 2-4 m, Locally in creasing them by up to 6 metres.

The tide affects currents in the various channels of the Hugli and Meghna

: the flood tide is of shorter duration than ebb flows, and landward ransport of fine sediment is indicated in some areas around sandwip Island. Active coastline change is especially prominent in the river-dominated eastern sections, with deposition of sandbanks, termed chars, that are stabilished after floods by mangroves. Sandwip Island has bun eroding on the northeern side at rats up to 250 m a^{-1}, but has undergone atleast 50 km of progradation southwards in the last 200 years, though still subject to erosion during individual storm surge events.

Tides dominate water movement in the Gangetic Tidal Plain, and the coas of the sundarbans is dissected by numerous, tapering, tidal creeks and is gradually retreating. The Hugli River, which used to be an active distributtary of the Ganges, is chaacterised by crosion on the southern side, and sagar Island, as well as many of the mud flats of the sundarbans are being eroded.

Sea level has been a major constraint on the late Quaternary evolution of the Ganges-Brahmaputra-Meghna delta. Drilling has idenfied and oxidised gravel layer at deptho of 50 m or more in the central plain, which eadiocarbon dating indicates to be related to subaerial exposure during the last glncial maximum. THe postglacial transgrssion, 11000-7500 years BP, is recorded by the presence of Marine shelly silts and sands. Radiocarbon dating of 7000-6500 years BP on shall and wood at depths of 11-18 m indicates transgression in the Khulna area. THe Ganges--Brahmaputra-Megna dilta appears to have been prograding during sea-level-rise becans of the estremely high sediment dischassge of the rivers amplified by a strengthened monsoon, in contrast to most deltas worldwide. That were undergoing landward retriat at the time. Mid-Late Holocene progradation of the delta is recorded in the upper most muds and pents radiocarbon dated around 6000-2600 years BP at calcutta, and 4000-3000 year BP near Khulna. Although the delta front is undergoing progradation, sediment is also deposited over the active floodplain, and some is lost down the swatch of No Ground, a submarine canyon, to contribute to the Bengal Fan.

Tide Dorminated Delta Fronts :

In the tide-dominated delta fronts of the Lower Ganga the shortline and distributary mouth areas are often an illdefoned maze of tidel current rides, channels and islands which may extend a considerable distance offshore before giving way to the delta front slop.

The main features of the type of delta front are the tidal current ridges with limited distal islands over the current ridges which radiate from the distributary mouths.

In the Lower Ganga delta the ridges are an average 5 to 8 km long, 500 m to 1200 m wide and range in height from18 to 35 m. Channels between the ridges contain shoals and bars covered by flood-and ebb-oriented bedforms.

In an idealized vertical succession from this delta, the tidal current ridge sands at the top of the delta front coaesening-upwards sequence are composed of bi-directional trought cross-beds with occasional clay draps and numerous minor channels.

Fluvial-wave-Tide interaction Delta front :

Tidal currents frequently operate in conjunction with wave processes at the delta fronts. Tidal effects are confined to distributary mouth areas whilts waves operate over the remainder of the delta fronts, and the shoreline is composed of wave produced beaches or cheniers separted by tide dominated distributary channels and mouth areas.

Offshore bathymetric contours and facies belts parallel to the shoreline, although there may be slight protrusions in the vicinity of distributary mouths.

Delta Abandonment :

Deltas often have a two-fold history comprising a construtional phase during which the delta the delta progrades and a destructional or abandonment phase initiated by a reduction in the amount of sediment supplied to the delta.

One cause of delta abandonment is alluvial-or distributary channel switching which results from over-extension of the channel system as the progrades into marine shelf basin. However, the initiation and abandonment of delta tobes or complexes is related to the frequency of channel avulsion. The delta abandonment may also result from a rise in sea level, from fluctuatios in sediment input due to climatic changes in the source area, or from tectonically induced river capture. For example in the Ganga-Brahmaputra delta, river capture has resulted from basement faulting in combination with erratic major floods. Cpature of the Hugli river resulted in the abandonment of a large deltaic tract noe occupied by a dense swamp area (the Sundarbans jungle).

The Ganges-Brahmaputra-Meghna delta is one of the largest in the world, and exhibits many deatures that are typical of deltas in southeast Asia. The Ganges River flows from the Himalayas to meet with the Brahmaputra River, and the broad channel south of their confluence is called Meghna. The rivers are very floodprone as they flow through the Bengal Basin, and most of the Low-Lying areas of Bangaldesh are under water in the wet season, with the exception of the Barind Tract and Madhupur Terrace which are Pleistocene terraces (Morgan and McIntire, 1959). The large tidal range in the Bay of Bengal means that much of the delta is tide-dominated. The shoreline of eastern India and western Bangladesh comprises the Ganges Tidal Plain which is the abandoned deltaic plain of the Ganges. This area is composed of sediments derived from seaward (Allison and Kepple, 2001), and is now dominated by tidal influence and covered by extensive mangrove forests, termed the sundarbans. The active delta plain in the east, called the Meghna deltic plain, experiences a large fluvial discharg 96% of the discharge of the rivers, 4% is carried by the former distributaries of the Ganges, such as the Gorai). The Bay of Bengal has a substantial tidal range reaching around 6 m at calcutta (Khidirpur), and adjacent to Sandwip island, but around 3 m for much of the rest of the delta (Barua 1991). In addition, the mean water level varies over an amplitude of 85 cm as a result of wind set-up, barometric changes, freshwater input and density differences. Cyclones occur in the May to October period and acn raise water levels by 2-3 locally increasing them by up to 6 m (Umitsu 1996).

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Tides dominate water movement in the Gangetic Tidal Plain, and the coastline of the sundarbans is dissected by neumerous, tapering, tidel creeks and is gradually retreating (Allison, 1998 ; Stanley and Hait 2000). The Hooghly (Hugli) river, which used to be an active distributary of the Ganges, is characterised by erosion on the southern side, and Sagar Island, as well as many of the musdflats of the sundarbans are being eroded (Paul et al 1987 ; Saenger and Siddiqi, 1993).

Selevel has been a major constraint on the Late Quaternary evolution of the Ganga-Brahmaputra-Meghna delta. Drilling has indentified an oxidised gravel layer at depths of 50 m or more in the central plain, which radiocarbon dating indicates to be related to subaerial exposure during the Last glacial maximum (Good bred and kuhl, 2000). The postglacial transgression, 1000-7500 years BP, is recorded by the presence of marine shelly silts and sands. Radiocarbon dating of 7000-6500 years BP on shell and wood at depths of 11-18 m indicates transgression in the khulna area (Umitsu, 1993). The Ganges-Brahmaputra-Mghna delta appears to have been prograding during sea-level rise because of the extremely high sediment discharge of the rivers amplified by a strengthened monsoon, in contrast to most deltas worlswide that were undergoing landward retreat at the time (Goodbred and kuehl, 2006). Mid-late Holocene progradation of the delta is recorded in the uppermost muds and peats radiocarbon dated 6000-2600 years BP at calcutta, and 4000-3000 years BP near Khulna (Vishnu-Mittre and Gupta 1972 ; Barui and chaanda 1992 ; Umitsu, 1993). Although the deltafront is undergoing progradation, sediment is also depositied over the active floodplain, and some is lost down the Swatch of No 'Ground', a submarine canyon, to contribut to the Bengal Fan (Kuchel et al 1997).

References :

Elliot, T. 1977 'Deltas'. In H.G. Reading (ed) sedimentary Environmental Facies Analysis (2nd Edition) Blackweel science Oxford, PP.

Reding, H. G. and collinson, J. D. 1996. 'clastic coasts' In. H.G. Reading (ed.). Sedimentary Environments : Processes, Facies and stratigraphy (3rd Edition). Blackwell sciences. Oxford. PP. 154-231.

Thom, B. G. 1967. Mangrove ecology and deltaic geomorphology : Tabasco, Mexico, Journal of Ecology, 55 : 301-343.

Stanley, D. J. and Warne, A.G. 1998. Nile Delta in its destructional phase. Journal of coastal Resarch, 14 : 794-825

Stanley, D. J. and Hait, A. K. 2000. Hotlocene depositional patterns, neotectonics and sundarban mangroves in the western Ganges-Brahmputra Delta. Journal of coastal Research, 16 : 26–39.

Book List :

Woodroffe, C.D. 2002. Coasts : Form, process and evolution. Cambridge University Press. 327-355.

Haslett, S. K. 2000. Coastal systems. Routledge. London. 120-135

Paul, Ashis Kr. 2002. Coastal Geomorphology and Environment. ACB Publications. Kolkata 582 P.

Question Bank :

1. Assess the validity of using the contribution of wave, tide and river activity to classify deltas.
2. Examine the links between the hydrodynamics, sedimentology and geomorphology of delta systems.]
3 Citing examples, evaluate the physical changes brought about through human interference in the river cntchments of delta systems.
4. Describe the geomorphological characteristics of delta plain areas of the Lower Ganga.
5. Explain how delta abandonment takes place with special reference to Lower Ganga delta.

References :

- Gilbert, G. K. 1885 : The topographic features of lake shores. Annual Reports of the US Geological survey, 5, 75-123.
- Elliot, T. 1978 : Deltas. In : Sedimentary Environmental Facies Analysis. H. G. Readings, edt. Blackwell Scientific publishers. PP. 113-154.
- Morgan J. P. and shaver R. H. (eds), 1970 : Deltaic sedimentation Modern and Ancient 312 PP. spc. Publ. soc. econ. Palent. Miner. 15, Tulsa.
- H. G. Reading and J. D. collinsson. 2000 : Clastic Coasts (2nd Eds.) PP. 154-253. Sedimentary Environment. Blackwell scientific Publishers.
- Coleman. J. M. and Wright, L. D. 1975 : Modern River Deltas : variability of processes and sand bodies. In : Deltas. Models for Exploration)\(Ed. by M. L. Broussard) PP. 99-149. Houston Geol. Soc.

Extended References :

Morgan, J.P. and McIntire, W. G> 1959 : Quaternaty Geology of the Bengal basin, East Pakistan and India. Geological Society of America Bullefine, 70. 319-242.

Umitsu, M. 1993 : Late quaternary sedimentary environments and Landforms in the Ganges Delta. Sedimentary Geology, 83 : PP 177-186.

Umitsu, M. 1997 : Land forms and floods in the Ganges Delta and coastal Lowlands of Bangladesh. Marine Geology, 20 : PP. 77-87.

Barua, D. K. 1991 : The coastline of Bangladesh : an overview of processes of civil Enggineers. New York PP. 2284-2301.

Allison, M. A. 1998 : Historical Changs in the Ganges-Brahmaputra delta frnt. Journal of coastal Reseach. 14 : P. 1269-1275.

Stanley, D.J. and Hait, A.K. 2000 : Golocene depositional patterns, neotecfonics and sundarban Mangroves in the Western Ganges-Brahmaputra Delta. Journal of coastal Research : 16. PP. 26-39.

Paul, A.K., Bondyopadhyay, M. K. and Chowdhury, A. 1987 : Morphoecological in the sundarban mudflats. Geographical review of India. Kolkata. 49 : PP. 1-14.

Saenger, P. and Siddiqi, N. A. 1993 : Land from the sea : the Mangrove afforestation program of Bangladesh. Oceam and coastal Managment, 20 : PP. 23-39.

Goodbred, S. L. and Kuehl, S.A. 2000 a : Enormous Ganges-Bramaputra sediment discharge during strengthened early Holocene monsoon. Geology, 28 : PP. 1083-1086.

Goodbred. S.L. and Kuehl, S.A. 2000 b : The significance of Large sediment supply, active tectonism, and eustasy on margin sequence development : late Quaternary stratigraphy and evolution of the Ganges-Brahmaputra delta. Sedimentary Geology : 133, PP. 227-248.

Kuehl, S.A. Levy, B. M. Moore, W.S. and Alliso, M.A. 1997 : Subaqueous delta of the ganges-Brahmaputra river system. Marine Geology, 144 : PP. 81-96.

Barua, D. K. 1990: Suspended sediment movement in the estuary of the

Ganges-Brahmaputra-Meghna river system. Marine Geology. 91 PP. 243-253.

Questions :

- Asses the validity of using the contribution of wave, tide and river activity to classify deltas.
- Examine the links between the hydrodynamics, sedimentology and geomorphology of delta systems.
- Citing examples, waluate the physica changes brought about throuh human interference in the river catchments of delta systems.
- Discuss the geomorphology of subaeral delta plain, delta front and the submerged prodelta of Lower Ganga delta.

Suggested Readings :

- Coastal Geomorphology and Environment, 2002 : Ashis kumar Paul. ACB publications, PP. 582.
- Coasts, Form, Process and Evolutions, 2002 : Colin D. Woodroffe. Cambridge University Process, UK. PP. 622
- River Deltas, In Davis, R.A. coastal sedimentary environments Wright, L.D. 1978 : Springer-Verlag. NewYork.
- Sediment transport and depositions in a macrotidal river chanel : Ord River, Wn. Australin. Wright, L.D., coleman, J.M. and Thom, B.G. 1975 : In cronin, L.G. (ed.) Eastuarine Research II, Academic Process, NewYork.
- Estuaries : a physical introduction. 1973 : K. R. Deyr : Wiley NewYork.

Unit-3 ☐ Management of Geomoraphic Problems

Structure

3.1 ☐ Management of Mining Subsidence With Special Reference To Raniganj Coal Belt :

The collapse is called subsidence. Although few people actually get killed, land subsidence causes a great deal of damage to houses, roads, railways and pipelines.

There are many causes of subsidence Collapse into underground mines is common in Britain as the removal of large quantities of salt and coal create space into which the rocks above can collapse. If buildings fail to have solid foundations they may lean like the famous leaning tower of Pisa. Underground liquid exerts pressure on overlying rocks so that if the liquid is extracted the rocks are liable to subside. This has happened in California where 9000 square Kilometres of land have been affected by subsidence following water extraction. The same applies to oil. Natural weathering of limestone forms underground caverns whose roots could collapse.

In Britain the main cause of subsidence is coal mining. The effect on the surface of the mining of part of a coal seam. Subsidence damages property, disrupts pipelines and causes cracks in roads, as withnessed by the Ml motorway in Noting hamshire.

The National coal Board has had to pay compensation to people whose houses have been damaged. In some cases the houses have had to be re-built. Underground mining techniques have been changed so that wide pillars at coal are left unmined to support the rocks above. Another strategy is packing waste into old galleries to prevent root collapse.

Almost every colliery has subsided areas and some of them have fire occurrence. The traditional 'bond and pillar' method has been adopted in the underground coal mines of this area. Most of the upper coal seams were exploited either fully or leaving small pillars in the underground. This system of mining has caused irregular subsidence on the surface at a number of places. At the time of private ownership of coal mines morning operations were mostly done by numerous small mines.

In satgram the subsided area covered 23.54 percent that is, almost a quarter of the leasehold areas of Satgram and the volume of subsidence void is estimated at 7,474000 cubic metres. Most of these collieries have underground workings from the earlier part of this century . All the upper seams of Raniganj Strata Mnamely Ghusick 'A' (R-IXA), Nega/Ningah (R-VIII); Narainkuri (R-VII), Bogra (R-VI) Satgram (R.V) and Mithapur, a local seam, are being worked indiscriminately.

Table - Land damage caused by subsidence in satgram area of Raniganj Coal field

Sl. No.	Coal Mine	1 Unit Hectare	Total area (hectare) (metre)	Seam coved (caving thick ness in matre (Cubic metre)	subsidence Area	Depth	Volume
1.	Satgram	(i) New Satgram	246.87	Bogra (2.1) Satgram (3.6)	115.50	2.05	924,000
		(ii) Central Satgram	135.35	-do-	32.50	2.05	260,000
2.	Ratibati	Ratibati	752.68	Ningah (4.6)	258.52	3.00	2585,000
3.	Benale	Benale	554.77	Bogra (2.1) Satgram (3.6)	35.10	2.05	280,000
4.	Mithapour	(i) Mithapur	343.78	Mithapur (2.0)	24.00	1.05	120,000
		(ii) Nageswar Satgram	175.95	Satgram(3.6)	42.00	1.05	200,000
5.	Nemeri	Jemeri	441.64	Bogra (2.1)	103.50	2.01	724,000
6.	Pure Searsole	Pure searsole (old)	270.16	Narayankari (2.4)	32.49	1.05	162.000

Sl. No.	Coal Mine	1	Unit Hectare	Total area (hectare) (metre)	Seam coved (caving thick ness in matre (Cubic metre)	subsidence Area	Depth	Volume
7.	Jaykaynagar	(i) (ii) (iii) (iv) (v) (vi) (vii)	Pure Searsole Sitaldasji Selected East Jamehari Kannani Nimcha Jemehari Selected N. J. Khas Khas Chalbalpur	980.06	Ningah (50)	488.00	3.00	880,000
8.	Nimcha		Nimcha	883.41	Ningah (4.8)	3.79	1.05	19,000
9.	Kuardi		Kaurdi	342.57	Ghusicka 'A' (3.0)	132.00	3.00	1320,000
10.	Tirat		Tirat	327.54	-	-	-	-

At present there are two localities within this belt which are included in the list of unsafe areas likely to be affected due to subsidences as declared by the Director General of Mines Safety. The localities are (i) Santal bustee of Jamehari Khas and East demehari units of Joykay Nagar colliery and (ii) Khoyrandanga and Jogibagan bustee of Searsol Colliery. The largest area under subsidence which is under the greater risk of ground movement and fire is located around Nimcha village in the southern part of the Grand Trunk Road having and extent of 8 square kilometres. Numerous abandoned pits, inclines, shafts, shallow quarries, spoil dumps and caves are found on the surface of this area. The total area has been left as derelict hands without any proper land use. Nimcha village is under danger because through the surface cracks heat wave comes out which is the outcome of underground fire. Illegal mining by the local inhabitants is going on in the abandoned quarries, inclines, shafts.

Another area called Chapui-Chalbalpur has an area of 0.25 square

Kilometre under subsidence. Pot holes of this area have a diameter of 2 to 2.5 metres and cracks are seen occasionally. The whole area is covered with bushes. On the either side of the Noonia Nala, a tributary of the Damodar almost one square Kilometre of land has been subsided. Dense bushes have grown all over the places which have several big pot-holes and abandoned pit heads. A post from the above notable areas, there are a larger number of subsided areas scattered all over the Satgram coal mine.

Jaykay nagar fire, as the fire of this area is called, occurs due to oxidation of sulphur, which produces intense heat and releases large volume of toxic gases, fumes and smoke. Development of subsidence, cracks, and fissures half oxygen come in contact with the coal left over in the underground. Smoke and different obnoxious gases from fire create atmospheric pollution in the surrounding areas.

These subsided lands have no water retention capacity and therefore cultivation is not possible on these lands. The visual impact of subsided areas cannot be neglected. A complete change of surface configuration has been noted in places where subsidences occur. The entire subsided zone becomes devalued because they can no longer be put to any productive use.

Sand stowing was made a statutory requirement for coal extraction after the report of coalfields committee in 1922. But it had not been followed properly, even after nationalization (1973). For economic reasons after depillaring of coal, the area has deliberately been allowed to subsided by the mining authority. Controlled extraction of coal along with hydraulic stowing can lessen the possibility of subsidence or land deformation. The coal company must keep in view the tar-reaching consequences of subsidence damage. Because with the further development of Asansol-Durgapur industrial complex, every inch of land area of coalfield would be required for development.

References :

Chowdhury A.B. (1991), Minc Environment and Management. Asish Publishing House.

Chatterjee, Chandana (1005) : Mining Hazards : Its impacts on Environment in Indian scenario. In : Combating Disaster (ed.) Antara Banerjee et.al. acb publications.

Baksi, G.K. (2001) : Minc Disaster in Bagdihi in PEOPLE'S DEMOCRACY, vol. 25 Feb. 18.

Lahiri, S.c. (1997) : Mineral Development and Environment. In YOJANA, vol. 41, No. 8, pp 88-92.

Book List :

Combating Disaster, Perspectives in the new millennium (2005) : (Ed.) Antara Banerjee, B. Mallick, Debasish Sarkar It al. acb publications. kolkata. pp. 150-154 and 214-219.

Simon Ross (1987) : Hazard Geography. Longman Group UK Limited. 94p.

Question Bank :

1. Why mining subsidence tqakes place in the coal belt? Explain the disaster reculted from mining bubsidence.
2. Explain the management options for mining subsidence with special reference to raniganj coal belt.

3.2 ❐ Management of river discharge with special reference to Damodar valley corporation and Farakka Barage Project.

The river Damoder is originated from chhotanagpur plateau and flows towords east and southeast direction across the parts of West Bengal (Bardhaman, Bankura and Haora Districts) and debouches into the Bhagirathi-Hugli River of Gangetic West Bengal. The River was sorrow to West Bengal for its high rate of monsoonal discharge and flod activities.

The Basic fiature of the Damodar valley Project is that it constitutes a compact, unified multipurpose river basin development, viz., (i) flood contro ; (ii) promotion and operation of irrigation schemes, water supply and drainage ; (iii) generation, transmission and distribution of electric power ; (iv) promotion and control of navigation ; (v) promotion of afforestation and control of the soil erosin in the Damodar valley; and (vi) promotion of agriculture, industrial, economic and general development of the valley and its area of operation.

Various schemes, which the project sought to implement, were to be taken up in two phases : The first phase programme comprised : (a) four dams at Tilaiya, Konar, Maithan and Panchet Hill with hydel power stations atached to each of them (except in the case of Konar) with a total capacity of 104 mw. (b) Three thermal power stations at Bokaro, Durgapur and Chandrapura with a total capacity of 957,000 K.W. (c) A grid covering over 1280 Km. of transmission lines, and number of substations and receiving stations. (d) An irrigation barrage at Durgapur with about 2500 Km. of irrigation-cum navigation channels.

In the second phase were envisaged four dams at Balphari, Bokaro, Aiyar and Bermo together with hydroeectric stations and corresponding extensions to transmission system.

Some subsidiary activities like afforestation, soil conservation, malaria control and fisheries development were also to be taken up.

The Dams

The Tilaiya dam is an all-concrete dam on the river Barakaro, about 208 km. above its confluence with the Damodar. It is 30 m high and 3666 m Long has a gross storage capacity of 394.7 m.cu.m There are two power houses of

2000 kw. each with a provision for third unit.

The Konar dam has been built across the Konar river valley in Hazaribagh district. It is an earthen dam with concrete spillway 49 m high and 3,546 m long with a gross storage capacity of 337 m.cu.m.

The Maithan dam is an earthen dam on he river Barakar. It is 94 m high above the river bed and 144 m long and has a gross storage capacity of 1,357 m.cu.m. It is mainly designed for flood control. It has 3 units of 200,000 kw. each.

The Panchet Hill dam, has been completed in 1959, across the river Damodar in Dhanbad district. It is 45 m high above river bed, 2545 m long earthen dam with a gross storage capacity of 1497 m.cu.m. Its main purpose is to control floods. It has one unit of 40,000 kw. power station.

Perennial irrigation over a wide area in the lower valley is cnsured by twin dams of Maitham and Panchet Hill. The above mentioned four dams give an effective control of floods upto a peak of 1295 m.cu.m. discharge.

Durgapur Barrage was completed in 1955. It is a concrte dam, 16 m high and 692 m long which has been built across the Damodar about 16 km from the Durgapur railway station. It receives water from the storage dams and diributes it for irrigation through a network of cnals and drainage channels of about 2500 km in length. They are to irrigate 4.17 million hectares in Bardhama, Hooghly and Hoara districts. Two canals have been taken out from the barrage. The right bank main canal is 89 km Long and left bank main canal is 137 km. The latters is constructed mainly for navigation to the Hugli River, while the former is for irrigation.

Power stations

The DVP has an insfalled capacity of 1181mw. The transmission and distribution lines spread over Damodar valley coverin the industrial belt of Jharkhand and West Bengal and also over the adjoining districts of Bihar and West Bengal.

Other Benefits

The other benefits of Damodar valley Project include (a) A number of erosion-resisting structures Like The Adivasi dam, Deochand dam, Bachi dam and Gauria Karma dam hold rain water, prevent gully erosion and supply water for irrigation. (b) Denuded forests are well managed. Large scale plantation of timber, mulberry and othe fast growing trees in the denuded forests. Lac culture has also been started. (c) The storage reservious of DVC have a total annual fish culturable area of about 20,235 hectares wetland with a production potential of about 1000 tonners of fish every year. (d) THe DVC accounts for nearly 10% of the country's total power output. THe major industries are located in Jharkhand and West Bengal with operation of DVC Power. (e) Electric tractio of trains on DVC power was first introduced in 1958. (f) Receational facilities for swimming and boating in the lakes, drinking water supply and control of malaria and reclamation of marshy lands in he river valleys.

Farakka barage Project :

At 10 km upstream of the border of Bangladesh, Farakka barrage is constracted across the River Ganga in West Bengal to divert water of the Ganga to supply headwater for the Bhagiathi-Hooghly to increase and maintain better depths for the navigable reach. The barrage was constrted in 1975 to share the Ganga water both by West Bengal (Hugli R.) and Bangladesh (Padma R.) equally. However, the adma or the Ganga of Bangladesh was serousely affected at Hardinge Bridge due to lack sufficient water flow. The river bed was dried out and also was filled up with sediment deposition at Ganga downstream sections probably due to the construction of Farakka Barrage in India. Disputes arise between the countries for equal sharing of Ganga water in different seasons. Ganga River is an International river and for this reason various aggrement book place in the decades of 80° and 90° of previous century for sharing amount of Ganga water between the two countries. About 35000 cusees of water of Ganga River were released from Farakka Barage for the demand of Bangladesh Farmers at the winters season (dry spell) for irrigation and navigation purpose. For this reason our calcutta Port of Hugli River is also affected particularly at the winter season for low flashing rate and larger influence of tidal waters at the Hugli.

However, various study shows that the commissioning of Farakka Barrage across the main river system of Gamga in the year 1975 has influenced the ecology of the esuarine and coastal ecosystem to a great extent leading to the changs i planktonic and benthic communities of organisms besides, causing frequent abundance of freshwater fish species ore towards the lower cstuarine and coastal zones.

There is a proposal for linking the Brahmaputra-Ganga rivers which envisages construction of a diversion barrage at Dhubri or other suitable place on the Brahmaputra in Assam and a connecting feeder canal about 320 km upstream of the Farakka Barrage on the Ganga. A potion of this feeder canal will lie in Bangladesh and it will be necessary to have an agreement with its government for this project.

This scheme will also be beneficial to Bangladesh for a portion of the waters divirted from the Brahmaputra, could meet its irrigation requirements. Due to the topographical feafures, the diversion of the Brahmaputra waters into the Farakka pond may require pumping at suitable intermediate points, the total lift being 10 m to 15 m.

References :

William Willcocks. 1930, Ancient system of Irrigation in Bengal, B R Publishing corporation, Delhi.

Arabinda Biswas. 1987, The Decay of Irrigation and cropping in West Bengal, 1850-1925, in Bondhayan chattopadhyay and Pierrw spits (ed). Food systems and society in Eastern India, UNRISD, Report No. 87.3, Geneva.

Book List :

C. B. Memory 1974, Multipurpose River valley Projects. In : Economic and commercial Geography of India. Kalyani Publishers, New Delhi. Kapil Bhattacharya 1977, Banglar Nadnadi.

Question Bank :

1. Explain the basic features of Damodar Valley Project.
2. Describe the various benefits of Damodar Valley Project
3. Explain the features of Farakka Barage project.

3.3 ❑ Management of urban water supply and disposal with special reference to Kolkata :

The occurrence of ground water in Kolkata is controlled by the geological set-up of the area. The subsurface geology of the area is completely blanketed by Quaternary sediments (Coulson, 1940). Both Recent and Pleistocene sediments have been deposited successively by the Ganga River as flood plain deposits (Biswas, 1959). In Kolkata. clay and silty clay : with an average thickness of 40 m. occurs at the upper part of the sedimentary sequence. This is underlain by coarse clastics of 300m. thickness consisting of sands mixed with gravel. These coarse elastics form the aquifer material. Below this, there is again a clay bed where thickness is over 300 m. Because of the presence of clay beds at the top and bottom, the groundwater in kolkata area occurs under a confined condition. But in Ballygung, Dhakuria and Kasba area shallow aquifer occurs with 12 mbgl as thin lenses and ground water occurs here under unconfined condition. Potential fresh water aquifer occurs in the depth range of 40-100m. in the northern part, within 60-160m. in the central part and within 180-300m in the southwestern parts of KMC area (Biswas and saha, 1990).

Ultimate source of ground water is the rainwater. The predominance of impervious clay in the near surface strata of Kolkata area and its immediate neighbourhood signifies that not much local recharge to deeper aquifers in Kolkata region is possible. Therefore the major recharge area of Kolkata region must be lying in the north and western side of greater Kolkata region. In north, at Bhatjangla near Krishnanagar in Nadia district and the zone of Tarakeswar-Nalikul-Mogra to Pandua serve as the zone of prolific recharge to groundwater annually (Coulson, 1940).

At present, there is a total requirement of 330 MGD of water to serve 4.5 million population @ 50 gallon person per day average and 2.5 million floating population @ 10 gallon per person per day for Kolkata city (World Bank Report, 2000). But the surface water contributes only 60 percent of total water supply (total surface water 220 MGD). The present unaccounted for water has been estimated at about 34 percent. There is a large demand-supply gaps i.e. nearly 110 MGD. The filtered water supply for drinking purpose is so insufficient for 4 million population; hence, ground water is being tapped by hand pumps, heavy-duty power driven tubewells and private tubewells. Groundwater supplies 24 percent of total present water supply

(2001) system in Kolkata metropolis.

Groundwater was first accessed as an important source of drinking /c water in Kolkata city after partition in 1947, when a huge influx of refuges settled in the southern fringes of the city mainly in Tallygunj-Bansdroni areas and also eastern part of the city mainly in Tiljala and Park Circus areas. Thus, many heavy-duty tubewells were installed either by Government or by Private agencies to supplement the Tala-Palta surface water supply in Tollygunj areas, which had no other source of water till the Garden Reach water works was set up. The analysis shows that in Borough-VII (Park Circus area), Borough-X (Jadavpur area), Borough-XII (Kasba-Tiljala-Picnic and Garden Reach area). Borough XIII and Borough XIV (Behala and Thakurpukur) have the highest numbers of larger diameter small diameter and private tubewells in Kolkata City (World Bank Report, 2001). Because the southern part and the southeastern part and south-western parts of the city have grown as a major residential areas after partition. The partition of Bengal (1947) and the consequent rise in population led to an over whelming demand for drinking water in these areas. Moreover, inadequate surface water supply in these areas has made possible to make their own arrangement for water by sinking tubewells.

Ground water withdrawal in Kolkata city has increased 6 times in the last 50 years from 12 MGD in 1956 to 70 MGD in 2000. But the total quantity of groundwater entering into KMC is 45 MGD (C.G.W.B. 1998). Groundwater is being over exploited to the tune of 25 MGD in KMC area. As a result of this development, there has been noticeable change in the hydrological regime in the farm of recession of the piezometric surface. The over exploitation of groundwater in excess of natural recuperation has resulted in the develppment of a more or less north-south elongated basinal pattern of the piezometric surface in the south-central part of the study area (Sikdar, 1999). It has distorted not only, the aquifer recharge withdrawal equilibrium, but also results in formation of an acute 'groundwater trough' in this part of Kolkata city.

Ground Water Zonation :

On the basis of the present utilisation, water demand, ground-water condition, long-term change in the piezometric surface in the last 50 years and gradient (pre, post and fluctuation) analysis of groundwater the entire study area (KMC) may be divided into the following zones.

Zone 1 High Risk Zone :

It covers the central portion of the study area mainly Beleghata, Kyd street, Park Circus, Picnic Garden, Tiljala, Topsia areas of east, Bansdroni and Naktala areas of south, Babughat commiserate Road on the western bank of Hooghly and Chitpur area in the north. These are the "high risk zone' in the Kolkata because uncontrolled withdrawal of groundwater than that of its recuperation has resulted in lowering of undergound piezometric level as below as 10m. in 1958, the piezometiric level was around 4 to 5 mbgl in Beleghata. Park Street, Tiljala, Topsia and Picnic Garden areas, but due to over expooitation of groundwater the piezometric level has lowered to 15 to 16 mbgl in 2003. The entire areas largely depend on groundwater resources and groundwater contributes nearly 50 percent of the total deman of water. This zone is not only characterised by negative trend in both pre-monsoon and post monsoon period, but also greater rate of declinig of piezometric level of post monsoon period than that of pre-monsoon period implies on alarming or worst situation. Mosreover, the gap between pre and post monsoon period i.e. the fluctuation is alarmingly deteriorating which may generate stresses on ground water regime in near future in these areas. If te increasing fluctuation trend would continue, the deficiency will cross the optimum level, causing disequilibrium. This implies a worsensing situation developing in this region. The situation goes beyond the normal limit where yearly normal monsoon is incapable of recuperation the preceding cycle of water deficiency progressively and hence a-Ve post monsoon water table is evolved, only with exception in Park Circus area (Dargah Road) within this high-risk zone.

As Park Circus is situated in the central portion of 'Ground water trough', the ground water flow from all directions has resulted in increase of water level. But Park Circus is still within the highest risk zone because in the last 50 years, the piezometric level has been declined below 10 m. and the present groundwater status is 16 mbgl. The highest risk zone is represented by the pre, post and fluctuation gradient graph of Beleghata, Park Circus Bansdroni and Kys street area (Figure).

Within this zone, Beleghata, Picnic Garden and Kyd Street are highly vulnerable to land subsidence problem and Bansdroni-Naktala areas are more arsenic prone areas due to the over pumpinc of aquifer. The maximm subsidence of 12 mm per year is recorded in Tiljala-Tangra area, Park Circus and Beleghata areas. This zone needs an immediate attention for scientific management and planning of ground water to preserve this valuable natural resource, arrest the possibility of land subsidence and prevent aresenic contamination in future.

Zone 2 Medium Risk Zone :

This zone as shown in the Figure is the 'medium risk zone7, where large withdrawal of groundwater has disturbed the natural equilibrium of input-output ground water balance and also there is 8 to 10m, drops in the piezometric surface in the last 45 years from 1958-2003. This zone includes south-western part southern part and western parts of the city, mainly Kalighat, Hazra, Harish Mukherjee Road, Jodhpur Park, Kasba, Bhabani Bhaban, Jadavpur, Tollygunj in the south to Chingrighata, Panchasayer, Mukundapur, and Kalikapur in the east and Behala and Khidirpur area in the western part of the study area. Ground water accounts 30 to 45 percent of the total demand of water in this zone # 2

An illustration of hydrographs and fluctuations with trend equations of regression lines of Kalighat, Jadavpur, Hazra and Keyatala area representing this zone is shown in figure . This region is having negative gradient in both pre and post monsoon period but the post-monsoon trend values lie more or less nearer to pre monsoon value and the pre and post monsoon gap (fluctuction gradient) is much better or improving in comparison to zone # 1.

Zone 3 Low Risk Zone :

It includes Bagbazar, Sinthee, Hedua Beniatola Street in the north to Sarsuna, Thakurpukur, Garia and Sanarpur in the South-western and south-eastern parts of the city. This zone is characterised by both pre and post monsoon-Ve gradient, with exception in Garia and Harinavi areas where + Ve post monsoon gradient has been observed (Figure). Pre-monsoon water table shows a decling trend but the post-monsoon trend is either rising or maintaining the equilibrium with that pre-monsoon period. This is indicative of no major harm that has occured in the region up to the present time. However, if the exploitation of groundwater increases considerably in near future (as is indirectly evidenced by the +Ve fluctuation trend or of increasing the pre-post monsoon water table gap) the situation may alter with distortion of the existing equilibrium. Moreover, in this zone, there is no significant change in the piezometric surface in the last 45 years from 1958-2003. This zone is represented by the Hydrographs of Harinavi, Hedua and Beniatala areas (Figure). Thus, this zone is much safe and further development of a limited number of additional tubewells is possible for municipal use.

Discussion and Conclusion :

It is evident from the gradient map (Figure) that in all stations within the KMC area are having 'negative7 and 'declining' trend in both the pre monsoon and the post monsoon period only with exception in Garia, Harinavi and Park Circus, Dargah Road where positive trend in post monsoon period has been observed. This indicates, not only the increase of ground water withdrawal because of high water demand in the entire study period in KMC area, but also, persistence of the same in post-monsoon indicates inadequate recuperation of the aquifer. The most interesting result obtained in analysing the trend value that in Beleghata, Kyd Street, Park Circus, Picnin Garden, Tiljala, Topsia areas of east, Bansdroni and Naktala areas of south, Babughat, commiserate Road on the western bank of Hugli and Chitpur area in the north are experiencing not only greater rate of declining of piezometric level (higher negative trend value) of post monsoon period than that of pre-monsoon period but also fluctuation trend or pre-monsoon and post monsoon gap is rapidly diminishing which implies an alarming or worst situation. These are the 'high risk zone' with respect to ground water utilisation in the Kolkata.

Besides, Tollygung-Jadavpur-Kalighat and Hazra areas are also affected by the lowering of piezometric level due to continuous over pumping of the aquiter. The gradient map shows that the eastern part, southern part of the city and western bank of River Hugli are highly affected by maximum withdrawl of ground water and or inadequate recuperation of the aquitor than that of the northern part of the city. Thus it results a negative and declining trend of pre and post monsoon water table. Due to unplanned utilizations, heavy-duty tubewells and hand pumps have been installed haphazardly as per local requirement without giving any considerations to the potentiality of the aquifers.

Thus, it is imperative to formulate a management plan with recommendations to maintain groundwater quality and quantity for zone # 1 and zone # 2 in the Kolkata Metropalis. Only proper management and scientific utilisation of groundwater can handle this alarming situation by :

1 Use of Artificial Recharge Techniques where ever essential and applicable.

1 Giving full stop to over exploitation either by enforcement of law or imparting knowledge in this regard.

Ground water quality and quantity can be improved in these high-risk areas (zone # 1 and zone # 2) considerably through artificial recharge by means of injection wells. This technique may help regain the piezometric level and maintain recharge withdrawal equilibrium. In sum, multiple preventive-and demage control measures are to be taken or a priority basis to conserve the precious natural resource of groundwater to avoid impending disaster. Moreover, the presence of Lakes in Subhas Saravar and Rabindra Sarovar are the great advantage for artificial recharge in Kolkata City because the water of those takes can be utilised for recharging ofter treatment. The takes should be desilted to in increase the storage capasity so that, more*fo* water can be stored during the monsoon period. In recently Basnavghata-Patuli areas this type of artificial recharging has been done successfully to rejuvenate the piezometric level (Ananda Bazar Patrika, 5th August 2003).

Groundwater exploitation should be restricted in these high risk areas (zone # 1 and zone # 2) by phasing out tubewell operations, introducing well construction permit programme, increasing public awarences and ensuring abundant supply of surface water that can help reduce the overwhelming dependence of groundwater resource for domestic proposes. People must be made aware of this problem through mass media that in the localities where both surface and groundwater are available, total dependence on surface water should be invoked. Conservation of groundwater for future is the best solution. People need to be made conscious that they are all groundwater users and all have a vested interest in preserving the maintaining its quality and quantity for everyone's use for years to come.

References :

Bhattacharya, S. K. (1991) : Calcutta's Water supply, in : Dasgupta, B. et. al (ed) calcutta's urban Future, Govt. of W.B. CMDA (1979) : Report on Water Distribution system for calcutta Service District, Vol. I

Basu, S. R. (2001), Drinking Water supply of the deltaic West Bengal and calcutta. In : Singh, L. R. (ed), Impact of Man on Ennvironment : Some cases of concern.

Calcutta Water Supply, Sewerage and Drainage Project, Final Report, Execlutive, summary. World Bank Project 2000 : No. P.O. 50648 (Page 3-1 to 3-6).

Biswas, A. B. (1990) Water supply in calcutta. In : S. Chaudhuri, Calcutta : The Living city, present and Futre. Vol. II Oxford Univ. Press (Page 162-166).

Biswas, A. B. and Saha, A. K. 1986 : "Ground water conditions of Calcutta Metropolition area" Unpublished Project Report CSME.

Chatterjee, G. C., Biswas, A. B., Basu,s and Niyogi, B. N. (1964) : Geology and Groundwater Resources of the Greater calcutta survey of India series 'B' 21 (page 1-150)

Ray, Alpana (2004) : The gradient of Piezometric level and Ground water zonations in Kolkata city a statistical analysis. In Geomorphology and Environment (ed). S. Singh, H. S. Sharma and Sumi Kr. De. AcB Publications, Kolkata P. 309-324.

Book List :

Munsi, S. K. (1975), Calcutta Metropolitan Explosion-Its Nature and Roots.

CMC (1990-91) : Year Books

CMC (1986) : Calcutta "City of Joy" : Comprechensive Development Programme, Planning and Development Department, Cacutta corporation, Kolkata.

Question Bank

1. Describe the Mangagement of urban water supply of Kokata.
2. Explain the spatial variation of ground water potential zones of Kolkata Urban areas.

3.4 ❐ Management of reclaimed coastal arcas with special reference to Indian sundarban :

Much of the areas of the deltaic coasts were occupied by distinctive wetland swamp and forest areas in the eighteenth century. Such broad flat low-lying areas with wide intertidal zone and large tidal range were the ideal ground for tropicai wetland swamps. Silt carried by the rivers was deposited along the river channels, at the mouths of the deltas, and on the channel banks or into the floodplain areas by sheet flows during the freshets. Tidal sediments carried into the river mouths, channel creeks and tidal inlets were deposited along the channel beds, channel banks and also in the iarge intertidal areas under protective sheltered flat. A researcher conservatively estimated that about 10 km2 or more new land was created each year by deposition in the deltaic coasts under natural environment (Figure 2-8).

Hunter's (1875, vol. 1. pp. 285-350) account of the Sundarban during 1870s indicates that, the Sundarban was dominated by the tropical evergeen species *Heritiera fames* known in Bengali as *Sundari-* The coastal half of the

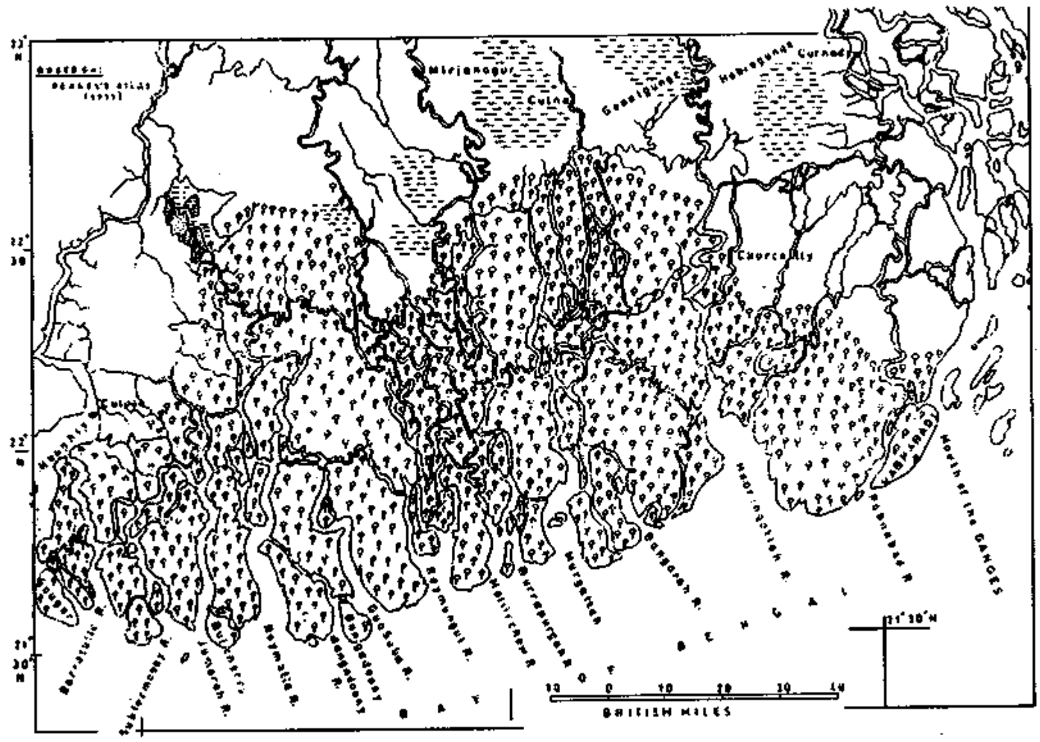

Figure 2-8 : Deltaic mangrove swamps and chain of marshes at the northern fringe of the Sundarban coastal zone through the historical records of rennel's Atlas.

region displayed salt tolerant mangrove forests. Throughout the Sundarban several hundred other plants and animal species were linked with a dense productive wetlands ecosystem. An intricate series of water channels stretching outward from the main river courses braided throughout the Sundarban. As much as a quarter of the land area would be under water in the rainy seasons.

The water-logged foresfs and swamps of the lower delta (Ganga) were demarcated by Dampier and Hodges in 1830 after the imposition of a new rule of landed property for Bengal under the terms of the 'Permanent Settlement' in 1793 by Cornwallis, the British Governor-General of Bengal for the East India Company. Since then land reclamation and settlement in the Sundarban progressed systematically year after year by putting up marginal embankments along the tidal creeks for stoppage of saltwater intrusion and bringing the reclaimed lands under cultivation as the wetlands proved to be generally fertile in the deltaic coasts. Finally, the rapid land use changes in the Lower Bengal over the past centuries resulted in steady depletion of wetlands . The land use changes in the Sundarban (1880-1980) were estimated by John F. Richards (1990) in his recent work on 'Agricultural Impacts in Tropical Wetlands'. He estimated that within the districts of 24 Parganas (India), and Bakarganj and Khulna (Bangladesh), total wetlands (both tidal mangrove swamps and surface water space) declined by 2750 km2 in the 60 years between 1880 and 1940, and between 1940 and 1980 the pace of reclamation quickened, which resulted in further loss of 5230 km2 of wetlands within the period. The remaining 10,000 km2 of the Sundarban lands came under grovernment forest status by 1947, and among them 60 percent went to Bangladesh and 40 percent to India after independence (Figure 2-9).

One estimate shows that an area of 9630 km^2 of the Sundarban in the West Bengal portion is bounded by Dampier and Hodges line on the north. Bay of Bengal shoreline on the south, Hugh river on the West and Ichhamati-Kalindi-Raimangal rivers on the east. Among this only 4264 km^2 are under mangrove forests (of which only 50 percent, are occupied by forests and another 50 percent by water space) and the remaining area (5366 km^2) is inhabited by about 35 lakh people with a density of 652 persons per square kilometre at present (Figure 2-10).

Protective embankments stretched for 3500 km in the 24 Parganas districts (both North and South) in the Indian Sundarban. About 58 polders (out of 104) are protected by a line of such earthen embankments which gave rise to the artificial lows devoid of further siltation.

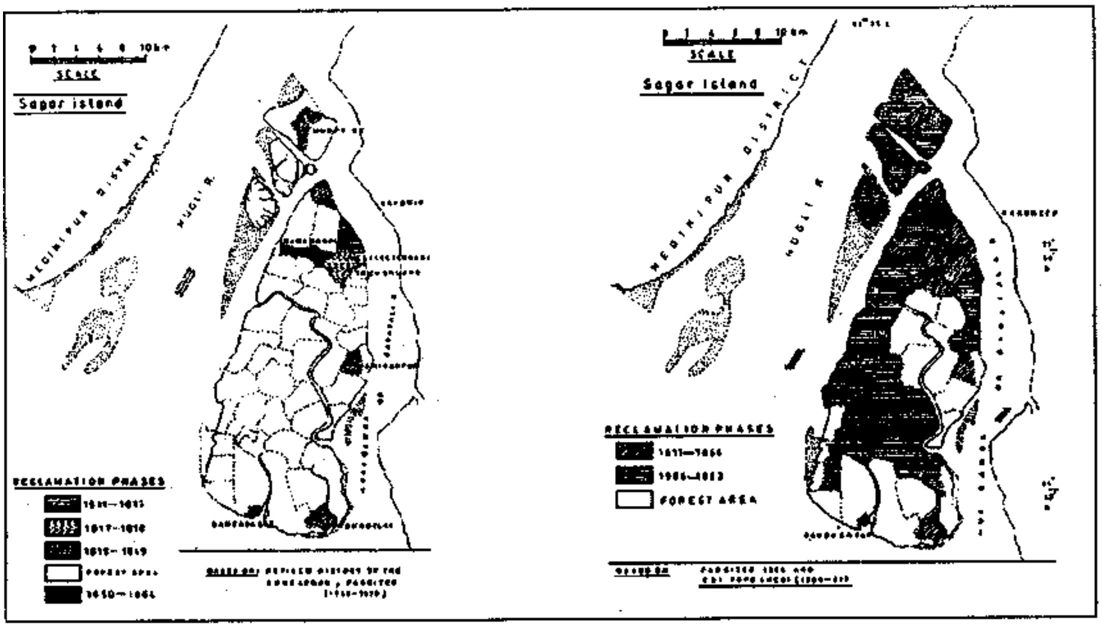

Figure 2-9 : Historical land reclamation phases at the largest deltaic island of the Sundarban (West Bengal portion)

Broad low-lying flats of lower Kasai delta, lower Rupnarayan Plain, lower Damodaraelta and lower Subarnarekha delta along with some portions of Kanthi coastal strandplain have been reclaimed. The area is thickly inhabited and cultivated to meet the subsistence demands of the population in the last few centuries. There are four groups of embankments in Medinipur littoral tract. These include Silai and Rupnarayan group, Kasai and Haldi group, and Kaliaghai group of embankments along with the great sea dyke from Subarnarekha river mouth to Rupnarayan river mouth at the margins of Hugli estuary and Bay of Bengal shoreline. There are also embankments on both sides of Rasulpur river, circuit embankments around Khejuri and Kaukhali lighthouse, and the Jokai embankment to the West of Kanthi to protect the flood waters of Subarnarekha river in the vast littoral tract (Figure 2-11). The area around the lower reaches of Kasai river lies only at 1 to 1.6 m above mean sea level, and these extreme low-lying lands are liable to inundation by Kasai flood waters, tidal intrusion and ponding rain waters. Land reclamation temporarily started in 1765 A.D. in some places of Hijili, Tamluk, Mahisadal and Kanthi divisions but the process has quickened after 1822 A.D. in the low-lying littoral tracts. At present, the entire areas of the coastal alluvial plain are protected by embankments stretching for 1200 km.

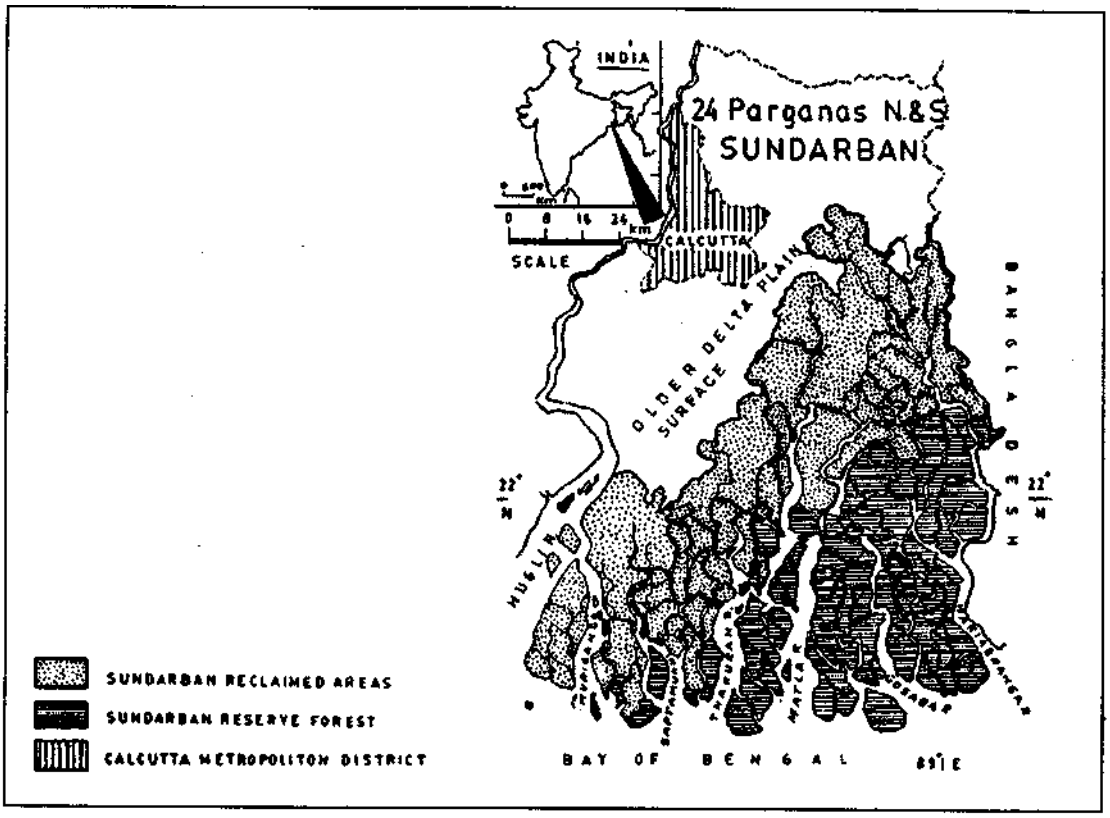

Figure 2-10 : Reclaimed areas and existing forest areas of the Sundarban in West Bengal

Large tidal basins around Rasulpur, Pichabani, Pataspur, Bhagabanpur, Digha-Ramnagar and Mayna have been embanked and reclaimed during 1873 A.D. These basins were connected with Rasulpur, Pichabani, Digha estuary, Kaliaghai and Haldi rivers by many tidal creeks. These creeks were maintained by nature efficiently to discharge the drainage water of the monsoon season in the region. Drainage of the more inland tracts is now blocked due to excessive land reclamations and the silting of the tidal creeks. Hijili tidal canal (constructed in 1873) and Orissa coast canal (constructed in 1886) link the silt-bearing rivers or tidal estuaries (Rupnarayan, Haldi, Rasulpur, Pichabani, Digha estuary and Subarnarekha estuary) of the coastal plain. These canals lie just 10 to 20 km inland parallel to the present day coastline. They were opened for transportion of local goods or agricultural products to Calcutta market. Island configurations have been changed historically in the Hugli estuarine complex. Changing configurations of the buffer islands are

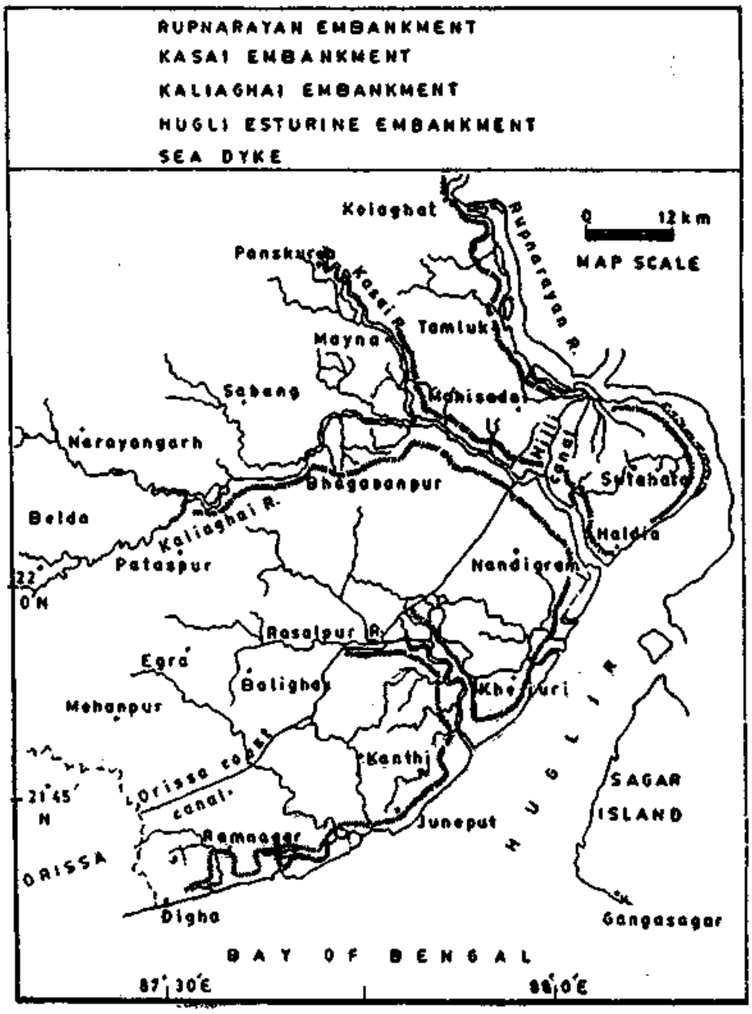

Figure 2-11 : Major groups of embankments of Medinipur littoral tract

mappable through the historical and instrumental records of the last century (Figures 2-12, 2-13, 2-14).

Physical environment of the coastal plain has been changed even in the last few centuries due to excessive land reclamations, construction of dams or barrages across the rivers, shortages of freshwater flows and sediment discharge by channel maintenance, greater coastal development, land use changes and other human activities. A large portion of tidal wetland swamps has been reduced in the Sundarban and in the vast littoral tracts of Medinipur due to land reclamations. Thus, the vertical accretion of sediments under tidal inundations and riverine flood flows have been diminished gradually

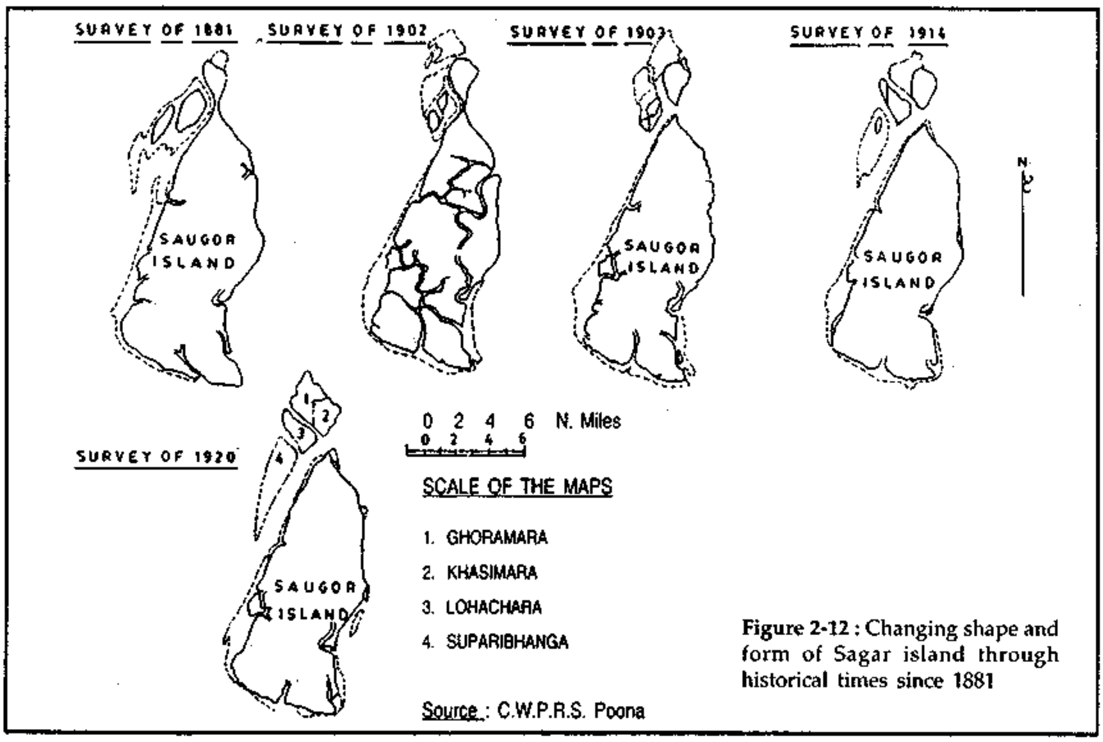

Figure 2-12 : Changing shape and form of Sagar island through historical times since 1881

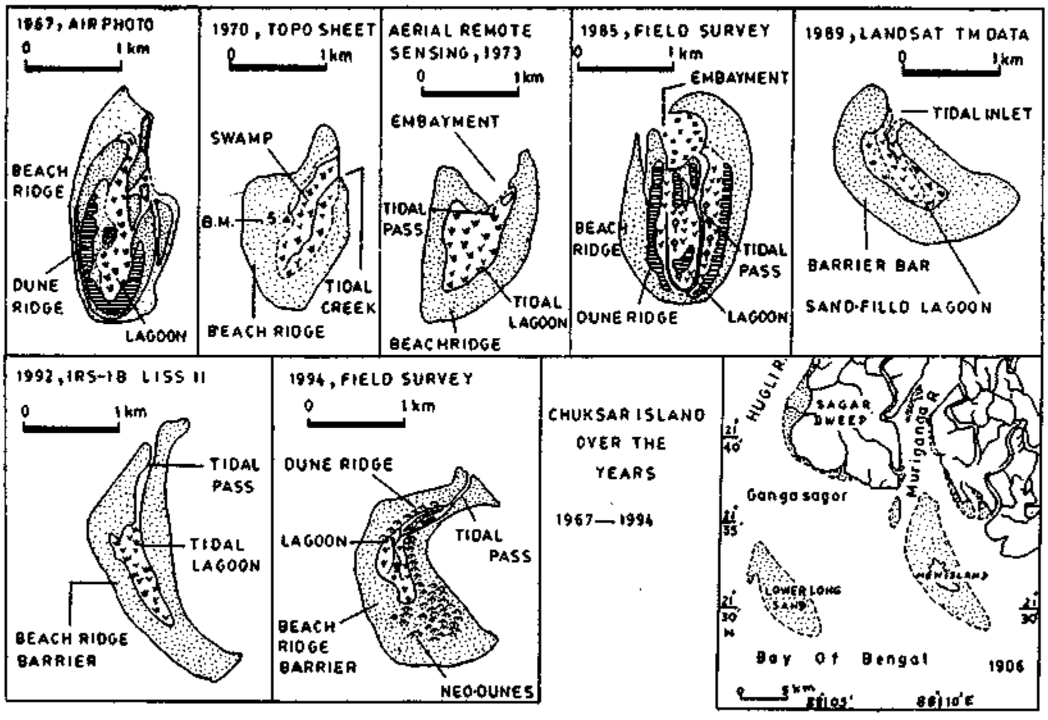

Figure 2-13 Changing surface configurations of Chuksar Island through Air photo. s.O.I. Toposheel and Remote Sensing images (1967-1994)

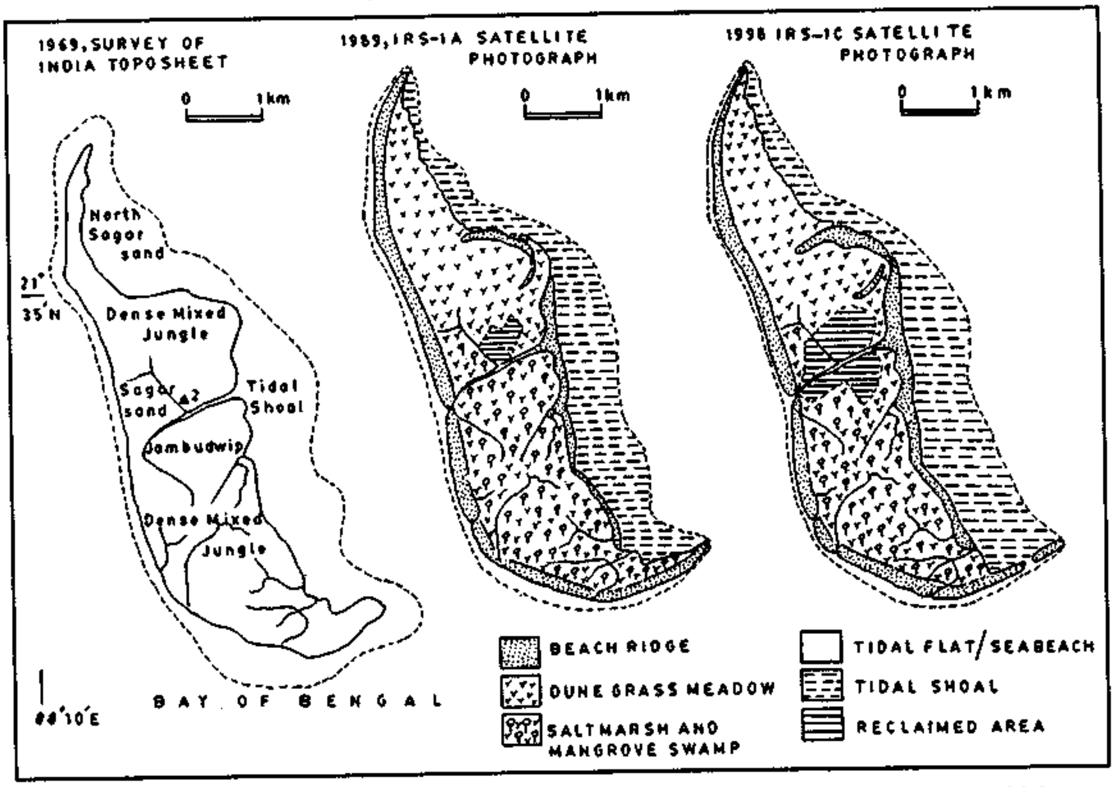

Figure 2-14 Changing surface configurations of Jambu Island which acts as buffer against high energy storm wavs at the delta front

on the delta surface due to protective flood banks. The heavily silt laden tidal influx is concentrated within the channel by protective embankments and is gradually raising the bed of the creeks of rapid siltation. These creek beds are rapidly rising above the adjoming land surface which was formerly drained. There is an absolute necessity of the embankments for the protection of the lands in the interior, which slope away from the rivers, and for avoiding the submersion of lowlands by the rivers overflowing their banks in the lower part of the deltas. Thus, a great portion of the area is rendered habitable by the sea dykes or the embankments that run along the tidal estuaries, tidal creeks and the shorelines. Finally, the flood basins between the distributaries and tidal channels are transformed into saucer-shaped hollows or polders as they are deprived of siltation by protective flood banks. The result of such land reclamations was a rapid deterioration of the drainage channels. The drainage is blocked within the basins of the Rasulpur, Haldi, Kasai and Pichabani rivers in Medinipur Plain and also within the basins of the

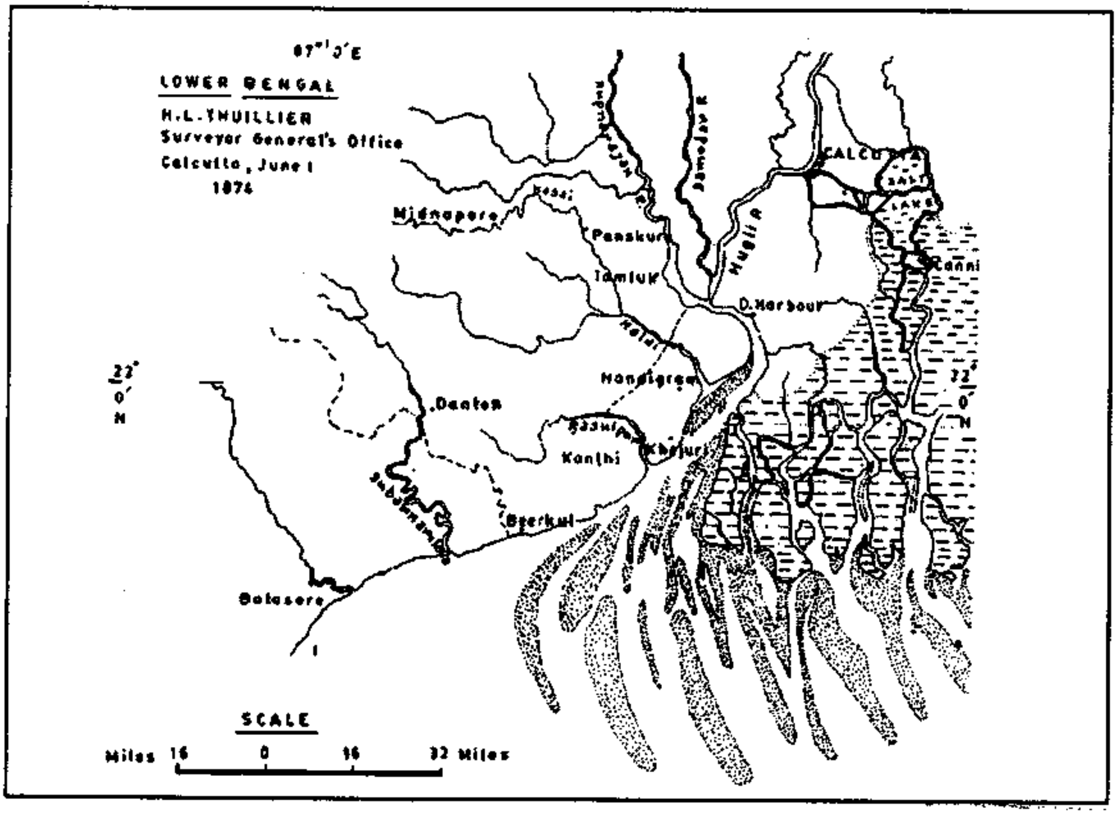

Figure 2-15 Lower Bengal by the historical map of M.L. Thuillier (1874). Tidal sand ridges, swamp margins and active spill basins are shown in the map

Bidyadhari-Piyali-Matla and Ichhamati rivers in the Sundarban littoral plain (Figure 2-15). Thus, the causes of inundation of the protective basins include : a) saltwater incursion, b) ponding rain water, c) breaching of embankments, d) overflow of high flood waters of the Subarnarekha and Kaliaghai rivers in Medinipur and Bhagirathi-Hugli and Ichhamati rivers in the Sundarban interior, and e) the tidal waves produced by the passage of cyclones in the spring high tide period. It is evident that the danger of saltwater inundations is even greater than that of freshwater floods which was realised by the cultivators in the historical Hijili division of Medinipur district and Sundarban tracts of 24 Parganas districts.

Prevention of the inrush of saltwater from tidal creeks and the protection of the coastline from the invasion of the sea however created many new problems in the physical environment. The unconsolidated alluviums of the delta surface always tend to subside due to auto compaction of sediments. This natural subsidence was compensated by vertical accretion of tidal silts and overflow of riverine silts accumulated by tidal wetland swamps or saltmarshes in the coastal plain before excessive land reclamations. As the tidal spill areas and flood basins are protected by flood banks or embankments, the natural stability of the delta surface has been affected in the region. Thus, the subsidence is taking place without compensatory siltation over the protective areas. At the same time the contraction of tidal channels and estuaries by rapid siltation is raising their beds under protective embankments. Finally, the fury of tidal currents and wave dash activities are restoring the wetlands naturally by beach erosion, dune elimination, river bank erosion, breaching of embankments, overwash activities, tidal ingression, saltwater inundations particularly in the storms, and by raising water tables. Though slow, the local sea level is rising steadily with the continued subsidence of the land level and with the addition of eustatic rise of the present sea level. Together, these two changes along with the slow rise of sea level and increased coastal populations at unprecedented rates will put excessive environmental stress on the coastal zones in West Bengal in the near future, as it happened in Bangladesh.

Historical land use changes

Entire coastal belt lowlands were covered by salt-tolerant mangrove forests and associate plant species in the recent historical past (Tamluk, Hijili and Kanthi divisions of eastern Medinipur and Sundarban of 24-Parganas district and the districts of Bakarganj and Khulna). The extensive sandy plain and associate rows of sand dunes, from Subarnarekha delta to Rasulpur river mouth, were also covered by various indigenous plant species in the past (1867), An intricate network of tidal channels stretching outward from the major river courses or distributary streams braided throughout the Sundarbans. Tidal channels also extended over the surface depressions between the successive dune rows of Kanthi coastaS plain. Much of the lowland was under water in the rainy season. One can estimate the nature of the coastal half of the Ganga delta from Hunter's (1875, vol. 1, pp. 285-350) account of the Sundarban during the 1870s. Only a few fishermen, salt-makers, smugglers and pirates were living in the islands of coastal mangroves. The entire wetlands were not used for permanent settlement in this period. From the history of Medinipur, it is also estimated that the coastal lowlands on the western bank of the Hugli river upto Subarnarekha were known as 'Salt Parganas' (History of Midnapore, vol. 3, 1956, N. N. Das). Salt agents of the region used the land to extract salts particularly from the tidal floodplains of Jellasore, Kanthi, Hijili and Tamluk divisions during 1850s.

Land reclamation and settlement, agricultural expansion along with mangrove felling and other forms of resource extraction have changed the wild landscape from the interior parts towards the shoreline in the rich alluvial soils of the delta and coastal plain in the past century (Figure 7-8). Tidal wetlands of the entire coastal belt continue to change under the pressure of human settlement and

Figure 7-8 Illegal felling of mangroves started from (Top: L - R) i) trie forest fringe, ii) inner part of the forest, (Bottom: L - R) iii) channel bank and iv) shore fringe areas by early settlers, wood cutters, pirates and poor people

other form of activities in the recent years. The broad fiat low-lying Sundarban area with one or two metre height from the sea level was extended over 18000-20000 km2 in the lower part of Ganga delta in the historical past. Active distributary channels of the Ganga flowing into the delta and several tributaries of the Bhagirathi-Hugli drained a large part of eastern India. The deltaic land was extended into the sea with the creation of new land each year by the deposition of silt load along the river channels, into the flood basins and at the mouths of distributary channels. The role

Table 7-8 Changing occupied forest areas and agricultural areas in the Sundarban coastal zones (24 Parganas - North and South)

Year	Net cropped area in(km²)	Year	Net forest area in (km²)
1924-33	4990.00	1910-14	6100.00
1951 -52	6620.00	1976-77	4262.60
1976 - 77	7022.50	1992 - 93	4307.26
1977-78	7149.00	1994-95	4307.71
1978-79	7204.00	1995 - 96	4305.21
1994-95	6692.42	1996-97	4234.83
1995-96	6541.48		

Data sources District Gazetteers;
District Statistical Handbooks;
Forest Department.W.B.

of local hot and humid climate in vegetative growth added extensive biomass to the deltaic deposits. Thus, all the physical, climatological and biological factors were linked in a dense productive swampy wetland ecosystem in the deltaic depositional surface.

The water-logged forests and swamps of the lower delta were cleared, settled and reclaimed by the private landowners for rice cultivation after the imposition of a new rule of landed property for Bengal under the terms of the 'Permanent Settlement1 in 1793 (Cornwallis, the British Governor-General of Bengal for the East India Company). Local people were encouraged to extract timber and fuel wood from the Sundarban forests for the growing need of Calcutta and other areas of Bengal. A protracted survey conducted by Dampier and Hodges was completed in 1830 to demarcate boundaries of low-lying forest areas and to offer security of tenure to improving landowners in this difficult terrain of isolated forested islands (Hunter, 1875, Pargiter, 1934. *See* Table 7-8).

Land use changes in the lower Bengal for the past two centuries indicate a clear picture of wetlands depletion (Richards, 1990). Wetlands of Kolaghat, Tamluk, Sutahata. Haldia, Nandigram, Khajuri, Kanthi, Ramnagar and Subarnarekha delta plain areas are largely depleted because of reconstruction of landuse changes with extensive built-up areas (residential, recreational, industrial lands, and areas covered by roads and other transport systems, as well as technical infrastructures) and arable lands in the latter half of the past century. Existing wetlands behind the shoreline dune barrier and along the channel banks influenced by tidal flood flows of the entire region are converted into the fish ponds, saltpans, dumping sites of city wastes, industrial wastes and other wastes, as well as pasture land and cropland. They are isolated from the lowland hydro systems by largescale flood banks and coastal dykes. The natural flood absorbance capacity of extensive shoreline wetlands is reduced alarmingly, so that large areas behind the depleted wetlands are now prone to inundation by overspill waters of Kasai and Subarnarekha flood discharges. Lack of repairing and maintenance of the embankments, siltation problems of the several drainage outlet channels for flood waters in the area and developing charlands into the estuary sections of Rupnarayan river and Kasai or Haldi river also exist as other associate problems of the vulnerable areas. Each year the people of the lowland region are apprehensively waiting for another form of devastating flood in the monsoon season. Breach in seven points on the Kangsabati's (Kasai R.) 84-km embankment and subsiding embankment of Kolaghat along the Rupnarayan river flooded

Table 7-9 Land use changes in the Sundarban 1880 - 1980

Land use type	1880	1900	1920	1940	1960	1980
Total arable and settled (km2)	14570	16140	15830	16710	20820	21860
Total wetlands (km2)	15160	13960	13940	12410	8530	7180
Total population (in million)	5.5	6.8	8.0	11.5	15.9	25.1

Data sources: J.F. Richards, 1990;
District Gazetteers;
District Statistical Handbooks;
Agricultural Statistics of Bengal

large part of the Panskura and Kolaghat regions around monsoon season of 1995 (September) and 1996 (August). Tidal waves from the Bay of Bengal repeatedly devastated the coastal dykes in the same period and wreaked havoc in several coastal villages in Kanthi subdivision, stretching from Digha estuary to Khejuri (upto Haldi-Hugli confluence). Vast croplands, orchards, both sweet water and saltwater fishing ponds of Khejuri, Nandigram and Ramnagar blocks have been flooded each year either by tidal waves or cyclones in the last two decades of the past century (1981,82, 84, 85, 88, 89, 90,93, 95, 96, 97, 99 and 2000). The famous beach resort of Digha may be washed out and the condition of boulder embankment and newly built five-stage wave breakers are getting worse every year. Gangadharpur, Gobindabasan and four other villages of Ramnagar block near Digha estuary may be engulfed by the sea at any time. Many villagers will have to be displaced in the coming years from the coastal sites in the entire coastal belt (Table 7-9).

Out of the total areas of Sundarban region with waterlogged forests and swamps in West Bengal (9630 km^2 areas) the present forests are reduced to only 4264 km^2 and the rest of the forested wetland is reclaimed and isolated from the natural systems by embankments for agriculture and settlement in the protective lowlands. The large scale depletion of tidal wetlands (about 5366 km^2 areas) is also a significant result of the historical reclamation projects in West Bengal portion (both 24-Parganas north and south) of the Sundarban region. The mature delta plain of the north has left many irregular levees, abandoned channel beds, discontinuous wet beds of old channels, bills or marshes and extensive flood basins (back swamps) of inter distributary regions. Ganga, Churni, Ichhamati, Jamuna, Kalindi, Raimangal and Hariabhanga are linked with the productive wetland systems of marshes, swamps, channels, and flood basins to the east of Bhagirathi-Hugli complex. All the rivers flow into the deltaic parts of West Bengal and Bangladesh and debouch into the sea. Most of the rivers are partially choked in their upper courses, thus only influenced by uprushing tides from the sea upto certain upstream distances. New char lands are growing within the courses of tidal streams and also within the embanked courses of active channels. Finally the major flood basins of delta catchment area around North 24-Parganas district (Khardah basin, Nowi basin, Sunti basin, Sealdah-Gung basin, Nonagung basin, Panskhali basin, Bagjola-Ghuni-Jagatgachi basin, Bager Khal basin and North Salt Lake basin) are more or less converted into built up areas and arable lands by the refugee colonies of displaced persons from earlier East Pakistan (later

Bangladesh). Remaining wetlands and arable lowlands are recently (since 1970s) converted into brackish water fish farms on the both banks of Ichhamati and Raimangal (both in Bangladesh and West Bengal). Ultimately the drainage capacity of major channels was depleted in the past century due to unprecedented growth of human settlement and extensive paddy cultivation in the reclaimed wetlands, as well as developing char lands within the channel beds. The natural gradient of the mature delta plain (southeastward slope) is artificially obstructed on both sides of Bangladesh and West Bengal by large embankment schemes. The disaster of flood during the monsoon months (September, 2000) around North 24-Parganas district is the result of above mentioned human activities at the catchment area, as well as other factors (overspill of Bhagirathi and Ganga waters along the downstream course of Ichhamati, natural gradient* heavy rain within 72 hours in the upper catchment of Ganga delta, and lower course of Ichhamati Raimangal being in spate with pushed up tidal waves from the Bay of Bengal in spring and neap tide cycle).

The catchment areas of Hugli river and the water courses stretching outward from the main river around Calcutta are the sites of severe conflicts over resource use. It is the largest built up area around the estuary section of the HugH river in the lower Bengal. East Calcutta wetland, the past tidal spill basin of Bidyadhari is reduced alarmingly with the expansion of the city of Calcutta to the east. Remaining wetland is used for pisciculture to meet the growing demand of Calcutta. Marginal areas of the wetland basin are also converted into the largest dumping ground of city wastes in lower Bengal. Bidyadhari-Piyali and Adiganga channels are almost choked up with the deposition of wastes from the sewerage system and city garbages, as well as tidal silts. The bank margins of the water courses are occupied by the extension of refugee colonies and urban growths. In September, 2000 a large tract around the channel margins of Adi Ganga, Tolly's Nullah, central lake channel, Kestapur channel, Bagjoia channel and the HugH main river banks were inundated by uprushing spring tides at the bankfull discharge of Hugli down stream section. The drainage capacity of Calcutta canals or water courses proved inadequate to carry out the tidal spill waters of Hugli downstream, thus the urban lowlands were largely affected by tidal inundation. Such type of inundation may increase in the near future with the expected sea level rise.

City expansion is also encouraged at the upper catchment area of Matia river aound Rajarhat area (Megacity scheme) at the mature delta plain. The broad flat lowlands and smaller surface depressions initially used as arable

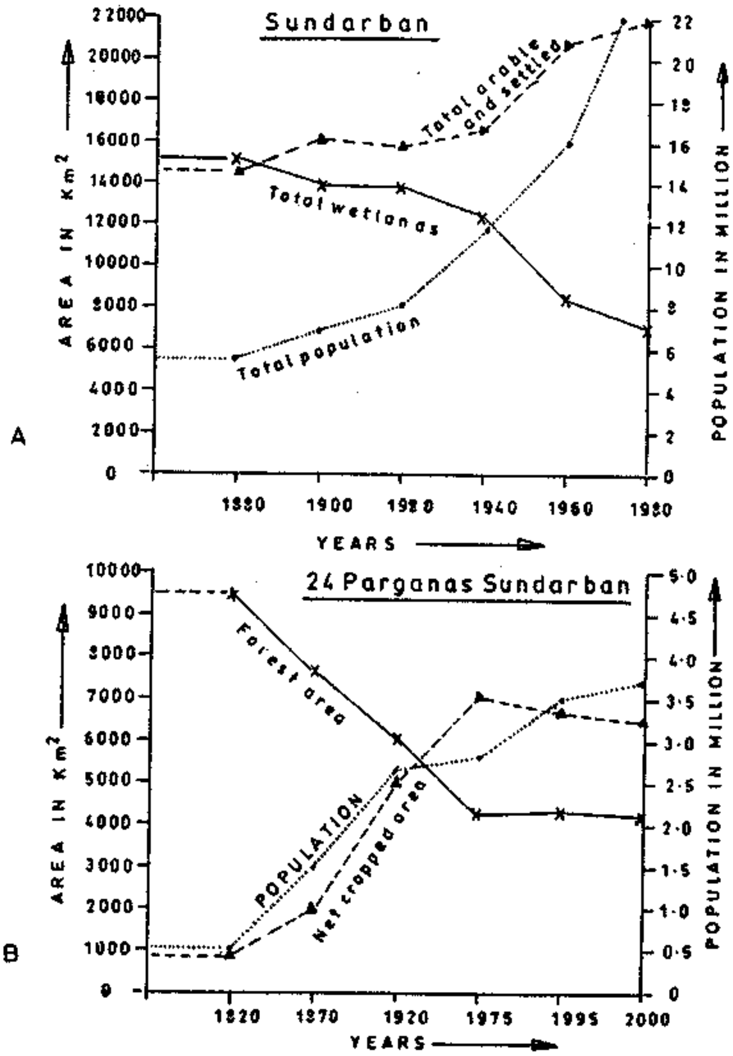

Figure 7-9 Changing land use patterns in the Sundarban and 24-Parganas Sundarban through the historical period and present period (Based on available data from Government records)

land are now selected for the growth and expansion of another city, to the northeast of present Calcutta. Large spill basins and lowlands may be occupied by such expansion of built up areas at the upper catchment of Matla complex, and the risk factor of inundation will be increased at the same time with drainage obstruction and lowland filling (Figure 7-9).

Polderization of the landscape

People of the lower Bengal encroached the premature lands of the active delta region during some historical land reclamation projects in the Sundarban tidal forests. Entire forest belt was cleared from the reclaimed areas except the remaining woodland patches along the existing channel banks, and the extreme lowland of soft alluvium surface even below the tidal level was polderized with the construction of earthen embankments to isolate the premature surface from tidal spill waters, as well as from further sediment distribution process of the flood basins. Such land space used traditionally by the Sundarban people for settlement, agriculture, roads and other transport systems, technical infrastructures, and other forms of resource extraction enhance several possible risk factors of the hazard prone zone. The natural land building process has been obstructed by such shift in landuse patterns in the Sundarban lowlands under the influence of intricate water courses, unpredictable behaviour of the sea, tidal waves, currents, sediment distribution and high groundwater level. Vulnerability of erosion, shifting water courses, tidal breaches into the protective embankments, saltwater inundation have increased rapidly in such reclaimed lowlands particularly at every monsoon season, Highest Astronomical Tidal phase and cyclone. Reclaimed wetlands and lowlands of Sagar, Pathar Pratima, Raidighi, Canning, Basanti, Gosaba, Hingalganj, Sandeshkhali, Hasnabad areas to the immediate north of the existing mangrove forest belt are devastated by destructive activities (current scour, wave dash, erosion and inundation) on several occasions in the decades of seventies, eighties and nineties of the last century. At present there are 56 polders out of 104 islands in the Sundarban.

References :

Mukherjee, K. N. (1976) : Harmonious solution of the basic problems of Sundarban reclamation. Geog. Review of India. Calcutta. Vol. 38 No. 3 PP. 311-315.

Mukherjee, K. N. (1984) : History of Land Reclamation in the sundarban. Journal of Landsape Ecology and Ekisticks Kolkata. Vol. 10 Bo. 1 PP. 1-35.

Paul, Ashis Kr. (1998) : Morphoecological management of the sundarban, India. Symp. Vol. Geom. Env. Management, Allahabad Geog. Soc. Allahabad, PP. 668-682.

Book list :

Paul, Ashis Kr. (2002) : Coastal Geomorphology and Environment. Sundarban coastal Tract, Kanthi coastal plain, subarnarekha Delta plain. AcB Publications. Kolkata 582P.

Mandol, Debabrata (2007) : Man in Biosphere- a case study of sundarban Biosphere Reserve, New Delhi : Gyan Publishing House.

Danda Anamitra Anurag (227) : Surviving in the sundarbans Threats and Responses. Unoversity of Twente, Ntherlands P. 199.

Question Bank :

1. Explain the impact of premature land reclamations in the sundrban.
2. Give an account of the management types of reclaimed coastal areas with special reference to Indian sundarban.
3. Describe the historical land reclamation stages in the Sundarban.

Unit-4 ❒ Management of geomorphic hazards

Structure

4.1. ❒ Management of Landslides With Special Reference to Northern West Bengal

A Landslide is the downhill movement of material. It is a common and usually harmless events. However, there have been notable landslides which have caused loss of life and a great deal of damage.

As a landslide involves the movement of material (soil, debris, rock) downhill, a slope is essential. Most of the time material on a slope will remain stable; if the slope becomes unstable a landslide results.

There are many factors which may make a slope unstable. The sleepness of the slope may be increased as debris is dumped on it of part of it is excavated. It houses are built they will exert a downward pressure and it vegetation is removed the binding of a soil by root will not longer occur. Weak or saturated material such as clay or he coal waste at Abertan will move easily.

Although there are many factors which encourage landslide it is usually 'treiggering off factors that actually start & landslide. Figure shows a hill side that is very likely to have a landslide.

There has been much concern, over recent years, about land use change and land degradation in high mountain regions. Mountains are naturally high energy environments. Steep slopes, rapid river incising and continuing uplift and seismic activity in many high mountain areas lead to a characteristically high incidence of slope failures and high soil erosion and river sediment yields (Gerrard 1990). When these characteristics are combined with increasing population pressure, land use change and intersive cultivation, this natural high rate of activity is, most probably increased. Thus,, there have been many claims for the role of human activity in increasing the incidence of slope failures and rates of soil loss. The Himalaya is one of the mountain ranges for which these claims have been made (Eckholm 1975; world Bank, 1979). In fact, it was the degradation seenario for the Himalaya that drew attention to this issue in other mountain ranges. The essence of this degradation seenario is that detorestation and the cultivation of slopes, in response to population pressure have destablished the slopes, creating increasing numbers of landslides, and increasing soil and water runoff. This scenario hs come to be known as 'the theory of Himalayan Environmental Degradation. It has sight positive feedback components that whimately lead to several land degradation. It has been summarised by Ives and Messerli (1989) who have also subjected it to severe criticism. The crux of their argument is that many of the eight components, however logical they might appear, have not been subjected to careful field tesging. At the time of writing their book. Ives and Messerli (1989) asserted that there was little quantitative information available eigher to substantiate or reture the scenario. Since then, a number of studies have been conducted to try provide rigorous, quantitative information with which to assess the Himalayan degradation scenario.

The soil erosion results have been reported elsewhere (Gardner and Gerrard, 2001, 2002, 2003) and a summary of both slope failure rates and soil loss and water runoff is provided in Gerrard (2002). In this account, the basic slope failure information is presented first followed by an attempt to produce a slope failure hazard assessment for the different combinations of land use and topographic factors.

This examination of landsliding in the Himalaya with respect to land use and rainfall events allows a number of general conclusions to be made:

1. Landsliding is a ubiquitous feature and a considerable hazard in certain areas. But its influence is speatially variable some areas are hardly affected.
2. Much large scale landsliding is 'natural' and seem not to be related to human activity. Most medium to large landslides exist for to 10 years.
3. Smaller scale superficial events do seem to be related to human activity because most occur in materials affected by cultivation and within the depth of the average cultivated terraces. However most of these failures

are usually repaired within 6 months of occurrence.

4. In general, sediment delivery rates from landslides are low (usually less than 50%)
5. There is little quantitative evidence to show that the incidence of landsliding has been increasing over the last twenty to thirty years apart from that associated with the construction of new roads.
6. Most landslides are related to monsoon rainfall but only when antecedent moisture has built in the surface materials. Thus, most failures tend to occur towards the end of the monsoon period.
7. Deforestation is only significant in increasing the susceptibility of slopes / < to failure if followed by poor land management. The change from forest to intensively managed agricultural terraces may even reduce the incidence of medium to large failures.

A great amount has been written about the suppossed devastation being cavised by landsliding in the Himalaya. Many of these statements have been based on limited information from locaised areas. There is still no definitive study or statement concerning the significance of landsliding in the Himalayan landscape. However, on the basis of this review, landliding, both in terms of number and size of tailures, does not appears to be a general major uncontrollable hazard. This does not mean that there are not areas where landliding is a concern, along roads and where rivers undercut slopes are two areas of concern, but the evidence does not suggest that the Himalaya are facing an 'environmental crisis' with respect of landsliding.

Can landslides be prevented ?

There are a number of ways in which potentially hazardous slopes can be stabilised. The type of method used depends on the costs and benefits that is, how much damage might be caused by a landslide. Some methods are listed below:

1. Surface drainage : diversion of surface streams from the slope.
2. Groundwater drainage : pipes will drain soil and prevent saturation.
3. Artificial structures: building of terraces or walls to prevent major slides bothing of rock of stop rockfalls for example, the Avon gorge at Bristol.
4. Planting vegetation; binds soils together.

For planning, a landslide hazard map is useful as if outlines a danger zone. Such a hazard map is drawn up by examining historical records of land slides and looking for the sorts of factors likely to encourage landslides.

LANDSLIDES IN DARJEELING TOWN OF NORTH BENGAL

Landslide is perhaps the most rampant environment hazard threatening the Darjeeling Town itself. During or after every monsoon, landslips create' havoc in and around the Darjeeling township area. Numerous slips have occurrent in the post however, the intensity, cause and serveity of the slided are being recorded only since 1899. From the records of the recent landslide events, it is clearly revealed that the frequency of landslips is increasing year after year. In order to have an insight into the probable causes of such increased vulnerability of the Darjeeling town it is necessary to trace the cause of events from the very inception of the town.

From the available records, it is found that the first disastrous landslip occurred on the 24th September 1899, in Darjeeling town. Unprecedented rainfall of 1065.5 mm during 23rd to 25th September (4 days) triggered about fifteen landslides in different parts of Darjeeling town willing 72 persons and causing enormous loss to land and property (Grieshach, 1899-1900). Most of these slips were confined to the soil-cap overlying the geneissic rocks. The immediate cause of the slips was attributed saturation caused by absorption of moisture and the cutting of hills lopes both form natural and artificial needs increased this instability further. Defective drainage was also considered an important factor in the absorption of moisture.

Table - Daily and cunsulative totals of rainfall during major landslips in Darjeeling town

Days	Rainfall in mm.	Cumulative total in mm.
22.9.1899	76.0	76.0
22.9.1899	291.5	367.5
24.9.1899	485.0	852.5
25.9.1899	213.0	1065.5
Total 4 days	1065.5	1065.5
10.6.1950	14.1	14.1
11.6.1950	104.0	118.1
12.6.1950	462.0	580.1
13.6.1950	254.0	834.1
Total 4 days	834.1	334.1

Days	Rainfall in mm.	Cumulative total in mm.
2.10.1968	95.25	95.25
3.101968	439.42	534.67
4.10.1968	481.33	1016.00
5.10.1968	105.40	1121.40
Total 4 days	1121.40	1121.40
Days	**Rainfall in mm.**	**Cumulative total in mm.**
2.9.1980	45.0	45.0
3.9.1980	72.0	117.0
4.9.1980	222.0	339.0
5.9.1980	5.0	344.0
Total 4 days	344.0	344.0
10.7.1993	4.0	47.0
117.1993	87.0	134.0
12.7.1993	102.0	236.5
13.7.1993	15.0	251.5
Total 4 days	251.0	251.5

Dates of major Events of landslips	Localities/Sectors affected	Remarks
22nd to 25th September, 1899	Settlement Sector : Tongsoong busti, Pradhan busti, Singamari, Hermitage, Eastern slope of the observatory hill, Jalapahar, Alubari and below the Railway stateion. Road Sector Jalapahar Road, Tenzing N. Road Birch Hill Road, Rangit Road, Hill Cart Road and Lebong Cart Road.	72 Lives lost within the town (62 Indians and 10 Europeans). The value of property destroyed amounted to lakhs of rupees. The prceipitous eastern slope from Toongsoong busti to observatory Hill experienced a series of devastaling land slips and most of the houses were destroyed.

Dates of major Events of landslips	Localities/Sectors affected	Remarks
10th to 13th June, 1950	Settlement Sector : Jalapahar cantonment; Pradhan, Moharla, Lebong, Hermitage, Toonsoong, Bhutia bustis and eastern slopes of Katapahar. Road Sector : Gandhi Road, Jalapahar Road, Convert Road, east Mall Road, Birch Hill Road, Lebong Card Road and Lebong Circular Road. Railway Sector : Large portions of Darjeeling Siliguri Railway in the vicinity of the town were washed away and not re-laid unitill late 1951.	Several hundreds of people were rendered homeless, as the whole hill sides with buildings, farms and trees collapsed. The loss of life resported was 100. The slips breached the main arterial roads and the town was cut off -for 5 days from theoutside world. Water and electricity supply stopped completely. Happy valley tea Garden sustained ravages.
2nd to 5th October, 1968	Settlement Sector : Lebong near Gompa, below Race course, Bhutia busti, Limbu basti, Toongsoong, around the jail, vineeta house (Jalapahar), Kotwali, Rajbari, Kagitora Butcher busti, Mayapuri and Manpari Buisti. Road Sector : Hill Card Road, Gandhi Road, Lebong Circular Road, Victoria Road, TenzfngN. Road, Tonga Road and Acharya Jagdish Ch. Bose Road.	The Hill Card Road was blocked at 18 different points. Heavy loss of life and property occurred especially in the neighbouring tea Gardens.
2nd and 5th September, 1980	Settlement Sector : Opposite Glenery's near planters hospital, Toongsoong, Bhutia busti, Manpari busti, near Mt. Hermon School, Butcher busti and below the Railway station. Road Sector Hill Card Road, Lebong Circular Road, Parts of T.N. Road. Tonga Road, Victoria Road and Acharya Jagadish Ch, Bose Road.	Heavy loss of life, demage to dwelling houses and disruption of communication, drinking water and electricity supply. Helicopters had to be sent to evacuate the affected people. According to the District Report (1980) the total damage to the property amounted to Rs. 647.90 lakhs.
14th to 16th September, 1991	Settlement Sector: Allmost all old sites of Landslides, near Missionary of charity, below Biroh hill near North point college, Toongsoong and Singamari. Railway Sector Certain parts of Darjeeling Siliguri Railway line.	Two people died. Drinking watersupply stopped in certain parts of the town. The Darjeeling-Himalayan Railway had to be closed for some months.
10th to 13th July, 1993	Settlement Sector : St. Paul's School behind the Padry's grave yard. Road Sector Certain parts of Hill Cart Road, Jalapahar Road, near Youth Hostel, and near Catharine Villa.	Disruption of water-pipes, as a result, certain parts of the town could not get water for more than 15 days.

The second major event of landslips in the town took place on the 15th January 1934 due to Bihar-Nepal Earthquake, which was responsible for widespread destruction though not of equal magnitude as was experienced in 1899.

On the 11th and 12th June, 1950, the hill slopes in and around Darjeeling town was affected by another disastrous event of landslips causing several deaths and heavy damage to roads, houses and public works, due to heavy shower (834.1 mm) from 10th to 13th June, 1950.

Darjeeling town and its environs was again eclipsed with large scale landslips owing mainly to very heavy and concentrated rainfall that continued from 2nd 5th October, 1968 with a total of 1121.40 mm. Such landslides caused widespread damage to human lives, properties, roads, railways and cut of the town from the rest of world for about a week.

The period between 1969 and 1979 was relatively undisturbed. But heavy and continuous rain on the 27th August and again during 3rd to 4th September 1980 triggered off widespread landslips in and around Darjeeling.

Since 1980, it has been observed that almost in every monsoon some parts of the town have been suffering from major or minor landslips causing loss of life and properties. The year 1991,1993,1995 and 1988 are the latest cases of landslips in Darjeeling town.

Tor a better understanding of the geographical distribution of landslip-prone area in Darjeeling town, a map (Fig) has been produced with the help of a check list; topographical sheets (78A/4 & 78 A/8) and direct field observations at 35 sample sites the following five categories of susceptibility zone have been put forwarded for further discussion. In this context, it is interesting to note that the map of soil erosion also shows a more-or-less similar trend,

Class -I: Extremely high slip-prone zone: Almost offer every torrential rain, these tracts experience slips. They are mostly found on the eastern slopes of Jatapahar-Katapahar ridge mainly covering the areas like Alubari, Manpari busti, Toongsoong, Pandans tea garden, Bhutia busti and Hermitage, eastern slope of leabong spur around Giving and Bannockburn tea gardens and in small pockets on western slope around Ging and Bannockburn tea gardens and in small pockets on western slope of the lebong spur i.e. Pattabong and Rangit tea gardens. It is also noticed along the western part of the town below Batasia.

Class - II : Very high slip-prone zone : These are the areas where slip occur for more than five times in ten year. They are found along both the eastern and western slopes of the ridge i.e. upper Alubari, upper Toongsoong, along the Tenzing Norge Road, C. R. Das Road, Eastern slopes of the Mall, below Raj Bhavan. It is also to be found on both sides of the Lebong spur mainly in the tea gardens of Bannockburn, Rangit and Pattabong. On the western slopes of the ridge it covers Rajbari busti, Kagihora, Victoria falls. Dr. Zakir Hussain busti. Dhobitala-around the Jail below the railway station, Lochanger, Haridas Hatta and Singamari.

Class - III: High slip-prone zone : It covers the western spur of the town along the Hill Cart Road, Gandhi Road, Nimkidara, Police line, Mary villa, Mayapuri, Upper Kagihora, below the convent cemetery. Dr. Zakir Hussain Road, along the Birch Hill spur and the Lebong spur. Here Landslips occur 2-5 times in ten years.

Class - IV: Moderate to low slip-prone zone : In this zone, Landslips occur once or twice in last ten year. It is found mostly along the ridges of Jalapahar-Katapahar up to the Mall, including the bazaar area and also along the Lebong spur including the Lebong Card Road.

Class - V : None to negligible : It is found in pockets on the ridge tops of the Jalapahar-Katapahar ridge, the Lebong ridge (Military Cantonments) and the observatory hill and on the top of Birch Hill ridge where slips occur rarely.

In view of the ever-increasing problems of landslides in Darjeeling town, man must be made aware of the possible dangers that he is inviting due to this careless dealing with nature. It is true that one has to make room for the growing population and in this pursuit, he has to utilise every piece of land available. But the precautions that have to be adopted should not be neglected. In the town, the revetments are not maintained properly, the weep-holes are choked and the drains are dumped with garbage restricting free drainage of water. Moreover, the present land use system should be properly evaluted. The construction of high rise buildings should be stopped immediately. The people should be provided with some alternate sources of energy through construction of mini hydel power projects utilising the springs, which can be an option to prevent them from cutting done more trees. But above all, it should be of ulmostr priority to develop mass awareness maong both the local people and the tourists, so that they become aware of the possible dangers they are inviting by interfering with natural laws.

References :

Basu, S. R. and Maity, R. K. (2002) : Unscientific mining and degradation of slopes in the Darjeeling Himalayas. In : (ed) S. R. Basu ; Changing environmental scenario of the Indian subcontinent. acb publications Kolkata. PP. 390-399.

Basu, S. R. and Sarkar, S. (1985) : Some consideration on recent landslides at Tindharia and their control, Indian Journal of Power and River valley Development, Oct. Nov. 1985 PP. 190-194.

Bhattacharya, S. K. (2002) : Tindharia cricket colony Landslide in Darjeeling Hills. –a comparative account 1996 and 2001. In : (ed) S. R. Basu ; changing environmental scenario of the Indian subcontinent. acb publications, Kolkata. PP. 400-405.

De, Sunil kumar. (2002) : Landslides in Balasan Basin and their control. In : (ed) S. R. Basu ; changing .... Indian subcontinent", acb publications. Kolkata PP. 406-414.

Book List :

1. Starkel, L. and Basu, S. R. (Eds.) 2000 : rains, Landslides, and floods in the Darjeeling Himalaya Indian National Science Academy, New Delhi, P. 168.
2. Valdita, K. S. 1992 : Environmental Problems in Himalaya : geological aspects. In : Himalayan Development and Environment-Problems and perspectives. Gyanodaya Prakashan, Nainital, P-161.

Zaruba, Q. and Menel, V. 1982. Landslides and their control. Elsevir scientific publiching Co. P. 324.

Questions Bank :

1. Explain why Landslides are caused by different Landuse practices on the mountain slopes and rainfall events with special reference to the Himalyan region of West Bengal.
2. Can Landslides be prevented ? Suggest various steps for the management of Landslides in the Himalayan region of West Bengal.

4.2 ☐ Management of Floods With Special Reference to Northern Piedmont Areas and Padma-Bhagirathi Intereluve of W.B.

In September 2000 Birbhum, Murshidabad, Nadia and North 24 Parganas Districts of West Bengal suffered a sudden and massive flood, together with other south-western districts of the state. The scale of damage can be judged from the fact that 20 milion people lost their homes or had them severely damage and money of these people also lost most of their farming and domestic possessions.

Some experts opine that sometime before the 16th century the Ganga might have had its principal discharge down the Bhagirathi-Hugli past the place where the city of Kolkata is presently situated. But there was been an ovulation of the flow of the waters eastwards, so that now the mainflow of the Ganga flows through the Padma and the Meghna. This view has its support on the episode of the filling of the underlying basement of the GBD eastward and the Ganga water had to flow according to this structural slope. The off points of south bank distributers of the Ganga with its mouth have progressively become choked-profiles which are as much as four metres above the thalweg of the Ganga itself (Basu, 1997). Thus, these rivers may receive a substantial discharge of Ganga during rains only, but they remain totally disconnected and dry during the mon monsoon months. A barrage at Farakka on the Ganga diverts lean season flow down the Bhagirathi in as attempt to flush out the sediments which have been choking the Calcutta port (Chapan, 2003)

In all part of delta i.e. Bengal there are bills otherwise called back-swamps. Some are disconnected ox-bow lakes. Others are very long linear features, which are of extensive lengths of substantially abandoned river courses. But which have flow during the wet season. There is one Gobra Nola which will be referred to in this account. It is a former course of the Bhagirathi, now separated from the river by means of an embankment running north from Murshidabad town. East of this, it has a well defined course, following to south-south, until it becomes a bil known as eventually connecting it with the Jalangi River.

A vast (42%) area of West Bengal is a risk from flooding, particularly the coastal areas and the low lying flood plains. In 2000 there were three major areas of flooding. The first was on the left bank of the Ganga in the district of Maldah. The second was in the lower Damodar Valley region. However, the biggest one affected the four districts, of Birbhum, Murshidabad Nadia and North 24 Parganas. The variety of the event is the high scale of devastation that occurred.

The location might have been unusual, but the timing of the event was 'normal'. The monsoon brings heavy precipitation from June to September, so that by the end of September rivers, bils tanks and reservoirs are usually full. The late and post-monsoon period of September-November is also the season when it is most likely that a tropical depression will move inland from the Bay of Bengal, causing heavy perception. In late September 2000 a slow moving tropical depression centred itself over the plateau areas of dharkhand. Which constitute the upper catchments for the right-bank tributaries of the Bhagirathi. The extend of rainfall with suitable comparison with other major rainfall-events in west Bengal (Rudra, 2002).

One of the authors present at Berhampore during the flood navoc witnessed the rapidity of the flood, and the plight of people suffered. Moreover, telephone lines failed, and road and rail communication breached at innumerable points isolating the flood affected districts from the rest of the world.

The surface area covered by the flood was at last 10,000 Km2. The depths of inundation in different blocks Murshidabad District. Assuming an average depth of 2 metres (as reported by local witness), the amount of water accumulated must have been at least 20,000,000,000 m3. This water was drained gradually into North 24 Parganas and finally into Bangladesh.

Recovery

For landless labourers the months after the flood provided plenty of work opportunity, though they too, needed time to rebuild their own home. They did not find their income reduced. The task of restarting cultivation required the borrowing or acquisition of plough animals or tillers. Power tillers were shared around-again it was spontaneous co-operative action that seems to have achieved most. Cattle and other animals have been replaced to some extend but not always on advantageous terms. People who previously owned milk cows may now have 'share-cropping' animals, or have fewer of them.

1 Engineering defences and an instance of catastrophic failure-

There are also some major engineering structures on some of the rivers. The Farakka barrage on the ganga has already been mentioned. On the River Mayurakshi there is the Massanjore dam, designed for irrigation purposes only, and with no flood-storage provision built into it. This means that for practical management purposes it should be filled fully as soon as possible in the monsoon, to maximise the water available for irrigation in the rabi after the monsoon is over. The catchment of dam is hardly 14% of the total basin area and the reservoir as nothing to do with the rainfall on uncontrolled lower catchment. It is that an emergency discharge from the dam aggravated the flood considerably. The River Ajoy is untamed except a small reservoir called Hinglow on a left bank tributary.

Flood protection embankments have been built along the eastern bank of Bhagirathi to protect urban areas like Berhampore and Beldanga in Murshidabad and Krishnanagar in Nadia. The eastern lands have not been subjected to flood from the Bhagirathi for more than two decades before September 2000. The lands to flood-but usually from local rain and the overflow of the distributaries like the Jalangi and the Icchamati. The usually small floods to the west and to the east of the Bhagirathi are normally not related to each other.

The flood-cum-road embankment running north out of Berhampore crosses the likely place where the Gobra Nala once channelled the old Bhagirathi southwards. The Nala is also blocked by a rail embankment as well. It was at this point at Kalu Khali that the greatest and most devastating breach happened on September 19th 2000. The current that fore through the gap has secured out a new lake, 500 metres long by more than 100 metres wide, and reputedly up to 20 metres deep. Many villagers and urban people lost-their lives and a lot of properly was lost. Farmland down stream was covered with thick deposits of sand up to 2 metres thick. The water become a major contribution to the flood that ravaged the whole of the Bhandardaha.

1 The historical record of flood :

The writings about floods in Bengal ('Bengal7 in the 19th century included Bihar and Orissa) from the last 200 years shows that large-scale-flooding is to be expected, any where in the delta. The return period of major floods in some areas may be longer than a human lifetime, so the historical record established that there are weaknesses in embankments which may lead to a repeated pattern of failure. The breach at Kalu Khali has happened before-probably because of its position across the Gobra Nala. In each event the communities are mostly left to their own devices to survive and mostly they do survive. External planning and help is minimal. Lastly the damage done by embankment in blocking lines of drainage and then in collapsing has been commented on since the first rail embankments were built.

Much of the reporting is to be found in the district volumes of the statistical Account of Bengal published in the 1870s under the direction of W.W. Hunter. In Volume IX, Districts of Murshidabad and Pabna, the following is written.

Floods are common occurrence in the District, especially in low lying Bagri or the eastern half which is situated between the Bhagirathi and the Ganga. These calamities are caused, not by excess of local rainfall, but by the rising of the rivers before they enter the District. Owing to the occurs of the rivers and the general slope of the whole of the District and the floods that occur have seldom been so serious as to cause universal destruction of the crops........The flood of 1823 is the only one that may be said to have caused general destruction of the crops. In 1848 and 1871 a great deal of mischief was done but the results were only partial.

In illustration of the flood of 1870, when the embankment on the Bhagirathi gave way, and the waters swept down on to the District of Nadia, the following description of the consequences in Murshidabad is taken from the Annual Report of the collector for that year. In the Bagri or eastern half of the District, a great portion of the has rise crop was destroyed by the floods. Much of it was carried away by the water on the bursting of the Bhagirathi embankment at Laltakuri, before it could be placed in a position of sagely; and nearly all the aman rise growing in the low lands was submerged and lost.....There was plenty of food in the District for those who could procure it. This however was by no means an cash matter for many of the suffering cultivators, who were living on machines, or bamboo platforms raised above the waters....These was exhibited during this period a spirit of mutual assistance among the people, owing to which, and to the assistance given by the relief committee, not a single death from starvation occurred. The cattle even did not suffer much during the inundation; but when the waters subsided, many of them died from being then with the rank inundation grass.......It does not seem that these floods caused any extraordinary amount of illness.

'All the rivers in Murshidabad are liable to overflow their banks firing the rains, and would annually flood the country but for the numerous funds (embankments), both Government and Zamindari, which exist throughout the District-Accidents to these bunds often occur; rats are particularly destructive to them; cattle passing and repassing cut them and the inhabitants neglect to repair the breach in time. The fishermen of the interior bils and Khals have also often the credit of coming in the night and making small cuts in them, to secure a fresh influx of fish from the large rivers to supply their fishing grounds.

Irrigation and navigation :

When the British first arrived in Bengal most transit was be water, although there was inevitably some roads. The irrigation systems of Bengal also relief upon the breaching of river leaves when the canals were in flood. These breaches fed into cannals that organised the distribution of water and incidentally of fish spawn. Writing in the 1930s W. Willeocks was of the opinion that the drawing of top wear fertilised the sold without layering it sith sand, and that the fish were deliberately cultivated in part to eat mosquito larvae and reduce the incidence of malaria.

The community based disaster preparedness :

The structural measures of flood protection have not worked to the level of expectation. The dams and reservoirs are located either along the western border of the state or within the state of neighbouring dharkhand. So these water storage structures can not accommodate the rain falling on the territory of west Bengal. The two major structural measures of West Bengal are famous farakka Barrage and Tista Barrage both had no objective of flood management or those project have any reservoir to store water.

The colonial legacy of flood control was largely limited to construction of earthern embankment along the bank of river. The total length of embankment in West Bengal now exceeds 16300 Km. This preventive measure initially controlled low intensity flood but the long term impact was the decay of rivers due to sedimentation on the river bed. The beds of many embanked rivers now stand above the objoining ground level and when the embankment is breached, the people limiting thereon are marooned fill the water evaporates or absorbed by the soil. Despite ever expanding expenditure in flood management, the flood contour has expanded appreciable during post-independence era and the number of flood victims has gone up. It is now understood that dams and embankments have impaired the hydrological balance of the delta and flood control in the low-lying tract is neither possible nor desirable.

In view of this situation a new strategy entitled CBDP has been adopted to train the people to live with flood. This has been launched in 28 blocks of Malda, Murshidabad, Nadia and North 24 Parganas under the aegis of UNICEF. The NGOs like SPADE, SMS, Ranaghat Cultural Unit, Catholic Charities, and RCHSS are deeply involved in the programme in collaboration with local panchayet Samity and District Administration. The programme has two fold dimensions-one is strengthening the early warning system and the second is community based preparedness to combat flood. The task of early warning is now entrusted to central water commission, Irrigation and waterways Directorate and Damodar Valley Corporation. These organisations receive rainfall data and massages relating to cyclone, storm or sea surge from India Meteorological Department. The early warning is generally broadcasted through radio and television and IWD maintains a website where water levels of different rivers are updated regularly. Still the warning or information does not reach many people living in the remote villages. The NGOs keep touch with district administration and share the responsibility to disseminate the early warning down to grass root level. They translate the technical language of the warning message and make it meaningful and understandable to common people. When DVC authority say that they would release 20000 cussed of water from the Durgapur Barrage that makes no sense to common people. The early warning needs to be more specific with information of areas to be marooned and possible depth of water thereon. The collaboration among IMD, CWC, IWD, DVC, District Authorities, Panchayets and NGOs can develop a good information network that would encompass very families down to farthest village.

Secondly, the preparedness is to be strengthen at both family and community level. Each family is advised to prepare a kit containing some dry food, each, valuable documents, ornaments, pass book of the bank, identity cards and some medicines so that they can shift to a safer place during the flood. The Disaster Management institute of salt Lake trained many people belonging to different districts the techniques of rescue, relief and rehabilitation. The CBDP includes the identification of high ground above highest flood level, raising of tube well, keeping the boat ready storage of flood grain in the community godown, building of new houses that can endure water logging and finally changing of livelihood pattern. Some Self Help Groups have been formed to execute the programme. The change in existing agricultural pattern is an important aspect of flood management. The introduction of Aus paddy that is sown in April the flood prone areas where Aman Paddy is washed away almost very year. The extensive area of Birbhum, Murshidabad and Nadia was covered thick deposit of sand that made it unfit for paddy cultivation. Such areas can otherwise be utilised for the cultivation of groundnut, watemelon and some vegetables. The NGOs have also introduced micro credit system for the poor families. This is expected to render necessary support to the flood-victims to revive their livelihood. Thus the objective of the CBDP is to empower rural people so that they can live with flood.

Rferences :

Rudra, K. (2002) : The flood in West Bengal : September 2000. NAPM, West Bengal. 37P.

Sen Sarma, Sunil (2002) : Floods in West Bengal-Nature Analysis and solution. In (ed. S.R. Basu) Changing Environmental Scenario of the Indian Subcontinent. acb publications. Kolkata. PP. 315-325.

Book list :

Agarwal, Anil and Chak, A. (ed) 1996 : Flood plains and Environmental Myths. CSE P. 146.

Majumder, S. C. (1942) : Rivers of Bengal Delta. C.U. PP. 16-22.

Dasgupta, A. (2000) : Rajyer Banya : Byapak Khoykhati. (in Bengali) Gangashakti (3.11.2000)

Questions :

1. Explain the various causes of floods in northern piedmont areas and Padma-Bhagirathi interfluve of W. B.
2. Describe the preventive methods floods so far as adopted in the flood affected areas of west Bengal.
3. Give an account of the management of floods with special reference to Padma-Bhagirathi Interfluve, W. B.

4.3 ❑ Management of River Bank Erosion With Special Reference to Ganga Bhagirathi in West Benga l

Alluvial channels as they flow in easily erodible and easily adjustable sediments are characterised by time-dependent stability factor. Instability is often accentuated by changes in sediment load, discharge, flow pattern and channel geometry. Energy disequilibrium thus generated gives the system entropy a tendency to increase with immediate behavioural responses in the form of braidation, avulsion, thalweg shift and bank erosion (Schumn, 1977). In the lower reaches of the large alluvial rivers like, Rupnarayan, Ichhamati, Bhagirathi and Padma, Channels are charactersed by fluctuation flow regimes, effect of tides, huge sediment content very low channel slope and winding courses. They continually change the ir appearance as bar and islands shift, disappear or form during high flows. As bars grow, flow is deflected towards the bank, eroding them and introducing coarse meterial into the channel (Schumn, 1981) The ultimate manitest is bank erosion at an alarming rate at some points affecting the geomorphic stability of channel bank to the adversity of living things.

1 Ganga river is eroding its bank @ 10 m a day on an average in the Manikchak (Gopalpur to Gangabhawan), Kaliachak II and Kalichak-III (Pardeonapur) block of Maldah,. Even the 6th retired embankment has been almost consumed. In the last decade, hundreds of acres of land with fertile topsoil and orchards and thousands of houses have been lost, that together has given rise to thousands of environmental refugees.

1 Erosion by Padma river near Akheriganj area was devastating, especially in 2000-01, with padma sawllowing up 149m of the metalled road connecting Behrampur, At places like, Alarpur, Kharibona and Shibnagar, local people are fed up with the patehy and faulty repair work by the PWD of the State Govt. the boulders are washed away every year and fresh ones are pitched in routinely. The vilages like Madhugari, Bousmari, Chamna, Checkania, Nasererpara and Hugulberia could be wiped out from the map any day.

1 At Fazipur, downstream of the Jangipur barrage, the gap between the Padma and Bhagirathi has sarrowed down to about 600m from 1400m in 20 years. At an average rate of erosion of 350m per year, there is every likelihood of this narrow strip of landmass being eroded in about 2-3 years and the Padma joining Bhagirathi.

Bank failure and Flood Hazard in Ganga-Padma-Bhagirathi River System:- The lateral migration/oscillation of the Ganga-Padma river down the ages, both prehistoric and historic period may be considered as a natural phenomenon is geological time scale. But in human orientation, this shifting of the river occurse is causing large scale disaster, flooding and bank failure in Malda and Murshidabad districts, West Bengal India.

Upstrem of Frakka Barrage

In Manikchak-Gopalpur area active zone of bank erosion is present along the left (eastern) bank of the Ganga river (about 700m shifting of river bank between April '97 and Nov. '97). Morpho arrangement of older meander scrolls are indicative of further eastward extension of this zone up to Pagla Nadi. The Pagla Nadi, an offshoot of the Kalindri/Fulhar river from southeast corner of the bhutnir char was flowing in a curvilinear fashion up to Gopalpur and then flows in two branches with broad meandering. Presently the upper portion of Pagla Nadi is cut off from the Kalindri river but remnants of abandoned channel course is well documented in the satellite imagery. South of Gopalpur the Pagla Nadi splits into two branches and now receives water from the Ganga-Padma river.

Further downstream up to Farakka barrage the Ganga river has straightened to a large extent and engulfed the meander loop of the Pagla Nadi. The latter may act as a distributary channel in near future of the Ganga river and may cause flooding in the Kaliachak-Malda area which is originally the flood pair of the Ganga system. In this context, the recent flood of September, 1998 in an around Kaliachak-Malda area is the best example.

Down Stream of Farakka Barrage

In this stretch/ in general, the Ganga-Padma river becomes a braided river with fabrics of channel bars and the main flow is in the right side of the river. In response to that the shifting of river course or bank failure zone are along the right bank of the river in comparison to the upstream of the Farakka barrage. The possible spatial reason is the presence of comparatively hard 'Barind formation7 (in Bangladesh) almost all along the left bank of the river. The most vulnerable areas within the West Bengal are :

(i) **Teghari - Oaharpur area, Murshidabad district** : Well marked southward migration of the Ganga-Padma river between 1947-1997; if this tendency prevails it may capture Bhagirathi river near Teghari destroying the present embankment.

(ii) **Akherigang area, Murshidabad district**: migration of main flow of the river is towards south and there is a tendency to capture the older meander scrolls. It is interesting to note that the Ganga-padma river is flowing in NW-SE direction (up stream of Akheriganj) maintaining a straight course before taking its east ward turn around Akheriganj. This particular alignment is largely controlled, with all possibilities, by one lineament along which the Mahananda river also flows (in the north) and joins Ganga-Padma river. In this respect, it is presumed that the Mahananda river discharge is also a major factor of Bank erosion in the Akheriganj Sector. The earlier branch off point of Bhairab river (as shown in sol toposheet, 1974) is now well with in the Ganga. Padma river, about 6 Km. North of the present mouth which rejuvenates only in the rainy season with increase in discharge level.

(iii) **Jalangi area, Murshidabad district**: the bank line shifting of the Ganga-Padma is towards west (i.e. right side of the river) and capturing the old scrolls in the south near the branch-off point of matabhanga river. In this tendency of smoothing of curvature prevails. Jalangi river may rejuvenate. Study of the natural section of the Ganga-Padma river both in the upstream and downstream reveals the presence of fine sand partings within the salty clay sequence and exemplifies the recent flood plain materials in geological terms. During high discharge time, removal of this fine sand/silt parting also accelerates the process of bank failure.

In this context, it may be mentioned with pragmatism, that the terrain conditions and the river behaviour do not support the existing method of engineering activities of check/reduce the bank failure phenomenon vis-a vis flooding. Rather it may be considered as 'ad-hocism'. A regional outlay for the whole stretch of the ganga-Padma river including the Phulhar and Mahananda rivers may be termed based on the reports of the expert committees so far held and the spatial database of the present day scenario generated by the DST and NES, Govt. of the West Bengal (1998). In order to achieve the outcome of such regional activity, move emphasis is to be given on social adoptions to avoid the predicaments in the sensitive zones.

Mitigation of the bank erosion disaster :

River bank erosion and shoreline erosion are chronic problem for the low-lying coastal floodplain of the sundarban, estuarine floodplain of the Hugli, Saptamukhi, Matla, Raimanagal, Rupnarayan and Subarnarekha river and the sandy shorelines of the coastal belt. This is the most unpredictable and damaging disaster which occurs in the coastal region. The following mitigation process can be suggested for the victims of erosion disaster :

(i) Rehabilitation of the victims on the stable ground;

(ii) Awareness among the people of disaster affected areas about the protective function and ecosystem function of the mangroves along the island margins, river banks and fioodplains;

(iii) 'Erosion impact analysis" is necessary for the river training structure which increases erosion elsewhere;

(iv) Bank stabilization by planting mangroves can be implemented to minimize the flow velocity of high water levels and wave dash activities;

(v) Control the "development intervention" along the bank of river and estuaries.

(vi) Dune stabilization by planting long rooted grasses, sand binding creepers and indigenous scrub can minimize the shoreline erosion along the sandy coast;

(vii) Coastal buffers (against waves, currents and storms), i.e. dunes, mangroves and saltmarsh areas should be strictly protected from the intervention of people;

(viii) There should be co-ordination between Forest Department, irrigation Department and Resource Users of the coast in bank protection works;

(ix) Victims of the disaster affected areas should be involved in the newer occupations of pond fishing and farm forestry on the rehabilitated grounds;

(x) Introduction of such environmental issues in the school syllabus can build the awareness among the new generation about the conservation of Mangroves and other vegetation on the unconsolidated alluviums of the Low-lying coastal plain.

(xi) Rehabilitation problems of the erosion victims can be solved with the generation of funds at the local level, active participation of 'Sundarbans Biosphere Reserve' Programme in scientific co-operation dealing with people-environment interaction in this situation, and with the utilization of the 'Rural Development Aids' from the national Government, (xii) There shonld be a regional policy on the management of erosion disaster. Ministry of Environment and Forests (MOEF), State Pollution Department and Department of Environment of the State Government should play a significant role in the preparation of such 'regional policy on the disaster management;

(xiii) Polluters and Developers should contribute tunas for such regional disaster management.

Erosion victims of the coastal floodplains are funds as environmental refugees. In future, the rehabilitation problems can share the major development funds of the sundarban region. Scarcity of the rehabilitation ground in this geographic situation may generate a new conflict of resource use. Yet the issue of environmental refugees is ignored in the region probably because they fall under different categories of disasters (Such as cyclone disaster, flood disaster erosion disaster.).

Disaster management is a process of action in the disaster affected areas. It is the people who experience disasters. Thus participation of the people is necessary in the long term management of the disaster proneareas with the various NGOs and the local Government bodies. Disaster Development and Environment are critically linked. Thus, the development interventions should be controlled with scientific assessment of development activities in the most fragile environment of the country.

References :

Chakrabrti, and chandhuri. B (2002) : The application of satellite data in moniforing the Bhagirathi-Hugli River system and its estuary. In. (Ed. S.R.B. Basu) : Changing scenaria........... Indian subcontinent. acb publications. Kolkata-PP. 191-197.

Paul, Ashis Kr. (1995) : Coastal Erosio in West Bengal. MAEER'S MIT PUNE. Special Vol. Journal of science Technology and Humanity. Vol. IV/NO. 15 and 16 PP. 66-84.

Basu, S.R. (2002) : River bank erosin in W.B.

Sarkar , Ashis (2002) : Problems of Riverbank erosion.

Suggested Reading :

In (ed) Felicitation Vol. of S.R.Basu. Geomorphology and Env. acb publication. Kolkata.

Paul, Ashis Kr. (2002) : Coastal Geomorphology and Environment. AcB Publications. Kolkata P. 582.

Questions :

1. Describe the causes of river bank erosin with special reference to Ganga-Bhagirathi and Hugli estuary regions in W. B.
2. Give an account of management of river bank erosion with special reference to Ganga-Bhagirathi in W. B.

4.4. ❑ Management of Coastal Erosion With Special Reference to Digha Township and Sagar Island of W.B.

Seasonal variations of along have sediment drift and offshore sediment drift are estimated by Bhandari and Das (1998) with the mathematical model study of beach dynamic around Digha coast. The study shows that the net alongsh are sediment drift is from west to east in the monsoon season and it follows reverse direction, from east to west in the winter season along the same cost. However, the amount the monsoon sediment drift (19000-234000 cubm/ month) is comparatively high at every section of the shoreline that the amount of winter sediment drift (10200-12700 cub. in month). The net annual sediment drift is recorded from west to east and the amount veries from 85160 cub.m/ Year to 128000 cub.m/ Year along the shoreline. There is also the variations of offshore and unshore sediment drift (12.0-30 cub.m/ month in the monsoon season and it is 10.7-15.7 cub./month in the winter season) in the cost, but the net annu sediment drift is from oushore to offshore (122.8-195.2 cub Year) direction.

The result of the study proves the presence of a dronglongshore current from the southwest to northwest in the monsoon season and also a less powerfuU longstore current from northeast to southeast in the winter season particularly due to the seasonal variation in wind direction in the region.' Thus the linear depositional features (spits and bars) are developing and extending around Talsari-Jatranala sector in the extreme west and Pichabani mouth-Junput sector in the extreme east along the coast in response to the alongshore sediment drift supported by longshore current cells and significant cell boundary zones. Hugli mouth and Subarnarekha mouth and two significant sedement input zones in the coast. However the erosive shoreline sector is situated in between old Digha and Dadanpatraban in which the annual offshore sediment drift is significant due to the presence of active rip current cells or the significant cross shore sediment transport cells in the period of high weaves.

There are 4 opr 5 categories of energy variations in the cost. Such type of energy variation phases include mouse waves, winter waves, tidal waves (H.A.T. phase), high magnitus cyclone waves and low magnitude cyclone waves. The parameters of significant wave hight, significant wave length, significant cell circulation system, as well as the amount of alongshore sediment drift and onshore-offsho sediment drift are changing in the different energy variation phases. Thus application of any mathematical model for studying beach dynamics must include the energy variation phases and changing parameters to get the complete idea of sediment drift variations for a dynamic sondy coast.

The study of wave refraction pattern over the innershed off the north western shoreline of the Bay of Bengal by S.C. Chatterjee and B.N. Ghosh (1998) with the help of Indian Naval Hydrographic chart (No. 851 Approaches to the Sandheads, 1982) indicated a significant idea of a probable erosional factor along the sandy shoreling. The result of such study shows that wave orthogonals are found to converge in between old Digha and Digha Mohana and diverge on all the other places between New Digha and Dhamra-Maipara river in the southwest and from shankarpur to Rasklpevr river in the northest. The converging wave orthogonals are producing erosive energy but the diverging wave orthogonal are contributing energy conditions favourable for the deposition of sediments along the shoreline. However, erosion is also significant along the shoreline sector between Sankarpur and Dadanpatra in which the wave orthogonah are not found to converge. Thus it is proved that no single factor is responsible for such shoreline erosion in the low-lying sandy west. Other local factors are also responsible for the beach depletion and cut-back process of the cliff line along the dune bodies.

Shoreline water table alteration, development intervention, other human induced land use changes, sediment characters and the high water level situations on the seaward side include in other factors of the shoreline erosion. Further research will produce significant data bank on the shore line changes which may be considered by the planners for better costal zone management in the region.

Coastal Erosion

In the 1995 coastal floods swhich were caused by the combination of surge tide (over 6 m in amplitude) and gale force winds (120 km/hr), waves smashed through seadykes, guard walls and rivers over-topped their banks. A number of West Bengal coastal areas were devastated in this May cyclone. Other notorious cyclones of last century (1942,1970,1989 etc.) associated with surging tides , waves, and strong wind forces devastated the coastal zones of West Bengal in terms

Rates of river bank erosion and shoreline recession in West Bengal and Orissa coastal plains:

Table 1 :

Name of River	Areas affected	Extent and rate of erosion
Bidya-Hogol,	Kumirmari, Basanti	2 km in the last 6 years
Gomor,	Rangabalia, Dulki,	(1990-1995)
Durgadaoni	Sonaga, Birajnagar (1990-1995)	2 km in the last 6 years
Matla River	Sonakhali, Basanti, Kanthalberia	3.2 m/yr. (1921-1968)
Thakuran River,	Kultali, Chakirmore	5.02 m/yr. (1921-1968)
Saptamukhi River	Lothian Island, Bhagbatpur	2.3 m/yr. (1921-1968)
Dasa River-Goureswari River	Hingalgunge-Rupmari	1 km extent of the bank between 1942 and 1995(18.9 m/yr)
Ichhamati River	Taki-Hasnabad	402 m from 1942 to 1993 (7.9 m/yr)
Muriganga-Baratala River	Kachuberia, Sumatinagar Sikarpur, Ramkrishnapur Boatkhali and Mahisani island	500 m in between 1968 and 1995 (18.5 m/yr)
Hugli River	Ghoramara island Khasimara, Suparibhanga, Lohachara island	1.7 km extent of land at 63 m/yr. 100m/yr.(1968-1988)
Rupnarayan River	Tamluk, Uttarchara	1219 m in the last 3 months, 1995.
Haldi River	Nandigram-Mangalkhali	1931 m in between 1930 and 1995 (30 m/yr)
Subarnarekha River	Amchua-Dagara banks	500 m (1965-1991) at 19.2 m/yr.
Burabolong River	Balaramguri	460 m (1965-1991) at 17.7 m/yr

Name of District	Shoreline	Rate ofreccession
Brahmani-Baitarani River	Patabaria, Talchua	5 to 8 m in 1989 (May)
	And Dhamra	Cyclone
South 24-Parganas	Fresargunj	9.7m/yr (1930-1970)
	Bakkhali	5.4 m/yr-8.5 m/yr(1971-1995)
	Dublat-Shibpur	25.8 m/yr (1942-1992)
	Beguakhali	23.1 m/yr (1942-1992)
Medinipur Dt.	Digha shoreline	11m/yr(1866-1965)
		17.5 m/yr (1965-1995)
	Ramnagar Digha Mohona	3.95 m/yr (1930-1995)
	Jaldah Mohona	5.14 m/yr (1930-1995)
Balasore District	Chandipore	2.5 m/yr (1988-1995)
	Chaumukh	3.79 m/yr (1988-1995)
	Satbhaya	2.8 m/yr (1988-1995)

of human lives, property damage and the erosion or loss of coastlands. During the storm events the raised water levels and high energy wave environment or extreme wave events affected the upper shores and inland river banks. Thus, shoreline recession and river bank erosion are triggered-off by such storm events. In the year a loss of large tracts of lands is recorded in the coastal areas of West Bengal due to the retreat of land margins in the shorelines and river banks. Micro-cliffs in the intertidal deposits, in the seafront dunes, and in the river banks indicate a progressive long term retreat without any intetvening cyclicity in this study areas.

Coastal defence structures of the post management systems are more or less damaged and show a complete failure to protect the coastal change from the events of overtopping waves and surge tides. One can see the present conditions of guard walls, guide walls, seadykes, and the riverside earthen embankments and may appreciate the high cost of maintenance of damaged structures.

Table 2: Shoreline surface configurations recorded from the beach-dune-marsh profiles of the entire Coastal sectors of the study area(1993,1996 and 1999):

Coastal station	Beach width	Dune barrier width (cross sectional)	Dune heisht	Surface heisht of the marsh
Subarnapur	120 m	120 m	6.2 m	2.5 m
Talsari(Barrier spit)	190 m	210m	4.5 m	1.8 m
Jatranala (Digha west)	130m	149 m	8.9 m	2.8 m
Gangadharpur (Digha east)	110m	80 m	7.5-10 m	2.8 m
Shankarpur	150m	130 m	7.6 m	2.6 m
Dadanpatrabar (eastern part)	210m	78 m	8.3 m	2.5 m
Dadanpatrabar (western part)	190 m	110m	8.5 m	2.6 m
Beguakhali (Sagar Island)	100 m	110m	5.3 m	2.4 m
Beguakhali (Sagar Island)	96 m	90 m	5.2 m	3.0 m
Burirkhal complex (Sagar Island)	200 m	78 m	5.4 m	3.0 m
Ganga Sagar	240 m	65 m	5.2 m	2.8 m
Shibpur	120 m	72 m	7.2 m	3.0 m
Dublat	120 m	90 m	10.2 m	3.0 m
Dublat	140 m	88 m	11.0m	3.0 m
Bakkhali	170 m	70 m	5.4 m	2.8 m
Fredrick Island	130m	100 m	6.0 m	2.8 m
Henry's Island(near Bakkhali creek)	330 m	79 m	7.2 m	2.6 m
Henry's Island(Saptamukhi bank)	210m	48 m	6.8 m	2.6 m
Henry's Island(Saptamukhi bank)	218m	45 m	6.8 m	2.6 m
Chuksar Island (Northwestern side)	54 m	96 m	6.05 m	1.48 m

The failure of the hard defence structures proves that they are constructed without knowing the reasons for coastal change. On the beach side of Digha sea wall, wave reflection is transporting material seaward. Thus, beach lowering is actively taking place in this area with associated sinking rate since the early seventy. The landward side of the sea wall is not adequately drained, thus impeded the groundwater flow and ultimately raising static water pressure and causing the guard wall to fail by bursting forward. Pressure over the landward side of the sea wall is also created by the construction of concrete jungles, especially in Old Digha. Also local piezometricpressures have been affected by huge extraction of groundwater and eventual collapse took place in the months of June and August, 1992 and successive cracks also have developed over the seaward side of the wall near Sea Hawk hotel. In 1995, a developed surge tide of May cyclone overtopped the sea wall and gushed into the Old Digha township and inundated large areas under 3 m depth of water. At present, the shoreline recession is significant especially in the unprotected areas with the concentration of wave energy and toe scour by waves. Sea walls are damaged in such a way to the east of Digha that any high magnitude cyclone may wash out the township by overtopping the walls in near future. Sea walls of Fresargunj were already destroyed in the late seventies and erosion has extended about 1 km inland from the initial brick wall in the last 7 years(Table 1).

Sundarban is compared with polderland as all the reclaimed areas are lying below the level of high tide water which enters into the interior parts of the Sundarban delta plain twice daily through the embanked-jacketed courses of tidal channels and rivers. The weaker structure of the embankments is affected each year by the cyclones which exceeds 50 km per hour. Many channels are choked with the high rate of siltation in the channel beds thus unable to hold the massive ingression of seawater in the cyclones. Normal current scour takes place at the toe of the embankments in the rising and falling tides. Moreover, partially damaged embankments and the weaker structure of the embankments are promoting bank erosion in many areas of the Sundarban especially in the period of cyclones by high energy tidal and wave environment.

The coastal zone acts as a buffer zone for the wave energy both wind and tidal, which is generated over large areas of ocean. The passive acceptance of this energy leads to erosion which sets up morphological changes in the coast (Pethick,1992). The high energy wave environment of southwest monsoon brace and tidal energy variations over a short period(spring-neap cycles), medium term (summer and autumnal equinoxes), and a long term period (yearly tides), are absorbed by the coast of West Bengal in expense of morphological changes by normal erosion process. Some bank erosion is quite usual or an episodic phenomenon on rivers, and under natural conditions is controlled to a large extent by the bankside vegetation loss. In the mangrove.

Table 3: Fishing trawlers, gaslight ships and iron made buoyas drifted onshore by surge waves at the storms:

Year of cyclonic storm	Type of the floating object drifted on the shoreline beaches from the off-shore stations	Name of the island on which the material is drifted and sunk	Place of the Island
1988	Gas lightship or Gaspar light	Bakkhali seabeach	Lowtide shoreline around Bakkhali creek
1989	Large size trawler of iron body	Sagar Island seashore	Near old seamaphore station at Beguakhali
1989	Large iron made buoy	Henry's Island	On the beach ridge surface at the western bank of Saptamukhi river
1989	Large iron made buoy	Sagar Island	Beach ridge surface around Burirkhal
1995	Large iron made buoy	Sagar Island	Sand flat surface around the Ganga Sagar beach near the creek bank
1995	Large iron made buoy	Ghoramara Island	Eastern bank of Ghoramara Island at Khasimara village
1997	Gas lightship or Gaspar light	Sagar Island	Western bank of Ganga Sagar creek

dominated river banks the roots of the plans hold the soil together and maintain the bank's stability. The equilibrium of this natural process is disturbed with the removal of bankside vegetation by Sundarban people to increase the space available for agricultural use simply in a misguided attempt to 'tidy' the landscape. Thus in many areas of the Sundarban, river banks are eroding away at an alarming rate.

Natural erosion process may be increased rapidly to adjust the morphological changes of coastal zone with the rising sea level. The coasts of Bangladesh and West Bengal are already vulnerable to flooding from cyclone events and some of the most extreme catastrophes of modem times have occurred there. The frequency of cyclones has been increased as sea level rises (Pugh,Gaur,1992). Topography of the intertidal deposits is changing in the island coasts due to natural erosion at present.

Beach and dune erosion are most significant event in the recent decades, so far as recorded in the coast of West Bengal. The large beach plain (800-1200 metres wide inl930-31) and wide dune field (1000-1200 m wide in 1930-31) of Digha coast has been sufficiently narrowed (120-150 m wide beach plain and 88-149 m wide dune field in 1993) at present due to the erosion at an alarming rate. Thus, the existing soft defences (beach and dune) are unable to protect the inland areas from flooding in cyclone events. Erosion in the upper shores by high energy wave and tidal environment, flattening of the beach plain, formation of micro-cliffs over the intertidal deposits, toe scour and associated crestal slumps of the frontal dunes, removal of dune barrier by shoreline recession, reduction of dune height by wind erosion, cliffing at the seaward side of dune barrier, and flattening of the dune field by northward marching are important morphological changes of beach and dune topography of West Bengal coast at present (Table 2). These are nothing but the adjustments of coastal front topography with the recent phase of high energy waves and tides developing in the bay head coast of India.

Since 1982 the author has been visiting the coastal areas of West Bengal and part of Orissa intensively (more than 100 times till July 1995) to observe and record the changing coastal topography under high energy waves, tides and winds. This observation is based on experiences in the field, and on research work.

EROSION DUE TO STORMS

It is observed that the coastal erosion has been increased by specific cyclonic storms (in the year 1943, 1950, 1965, 1970,1982, 1984, 1988, 1989, 1991, 1993, and 1995,) in West Bengal, Bangladesh, and in the parts of Orissa. Surging waves, strong winds and torrential rains are associated with the cyclones. Areas lying below 3 and 5 m surface heights are liable to coastal floods during high magnitude cyclones. Lower part of the Sundarban delta plain, Subarnarekha delta plain, western bank of Hugli estuary (eastern Medinipur Plain), and Digha-Ramnagar coastal plain are lying below 3 rn surface height from the mean sea level. Remaining areas of the Sundarban delta plain (northern and central parts) are lying below 5 m surface height, and they are mostly reclaimed at present by earthen embankments. All these lowlands of coastal West Bengal are fed by large estuaries, tidal inlets, and channels which help a surge originating in the bay to penetrate deep inland during larger cyclones. In the last 105 years 24 parganas districts (Sundarban areas in West Bengal), Medinipur district (Kanthi coastal plain), and Balasore districts (Orissa coastal plain, northern part) are visited by 23 large cyclones (1 in 4.6 years), 12 cyclones (1 in 8.8 years), and 14 cyclones (1 in 7.5 years) respectively. Most of the severe cyclones visits the coastal plain in the pre-monsoon months (May-June) and in the months of retreating Monsoon (October-November).(Table 3)

During storms the high tide line over the raised water level goes right upto the base of the dune cliff. Surging tidal waves broke the barriers of earthen embankments, and sand dunes and flooded human habitation in the coastal lowlands in 1995 (May, 16), when the cyclonic storm coincided with the spring high tide. In this single storm, the dune cliff or the bank receded by 8-10.5 meters at Sagar Island (Shibpur-Dublat areas) and by 2.5 to 3 meters at Digha (Gangadharpur-Atili areas). The storm sea level touched the base of high dune cliff and the entire cliff retreating rate was triggered off due to wave scours and crestal slumps. Thus, the loose and unconsolidated materials of the sand dunes are easily eroded in such a single storm.

River bank erosion was also pronounced in this cyclone by high energy current flow and wave dash activities. It is observed that damages of river banks and adjacent embankments by wave dash was far less than the magnitude of destruction caused by currents at the bed of a river. High wind speed caused by cyclone, increases wave dash activity and changes the current pattern of rivers. Thus, unconsolidated materials produced by fresh silt accumulation over the river banks are easily erodible by wave dash and changing current pattern in the cyclones. River Rupnarayan was in spate when the pre-monsoon cyclone (May, 1995) was crossing over Tamluk (Rupnarayan Plain). A large portion of the riverbank had been damaged due to erosion in Uttarchara village (over a charland), and the bank erosion extended inland by 1219 meters within three months (May 14-July 14) after the cyclone. In the single storm the western and eastern banks of Ghoramara island had been scoured by storm water level in Hugli and Muriganga rivers. Bidya, Hogol, and Gomor rivers of the Sunderban engulfing large areas of Basanti, Rangabelia, and Gosaba after the cyclones of 1988-89 and 1995. Ghoramara island of the Hugli estuary will be wiped out of Western Bengal's map within the next 8 years if the present erosion rate continues with the frequent cyclones in this region.

EROSION DUE TO ENGINEERING STRUCTURES

Digha coast of West Bengal is partially protected by boulder paved sea walls to prevent the erosion. Sea walls also existed in Fresargunj coast in early sixties and around the tidal semaphore station in Beguakhali (Sagar Island) in early seventies. Sunderban rivers and tidal channel banks were protected by 3500 km long earthern embankments. Much of the estuarine bank and island bank of the Sunderban have the structure of brick-pitching walls, high enough to prevent flood from the normal high tides. The orthodox engineering view is that the construction of embankments along both sides of mighty rivers like Hugli, Saptamukhi, Thakuran, Matla, Ichhamati-Raimangal, and Rupnarayan, by concentrating their flow , increases their erosive capacity (thus exposing the embankments to a greater risk of breaching) and increases the flood hazard in downstream areas. The recent floods indicated the embankment problem of the region, where large part of landmass was ravaged by floods for several days from May, 14,of 1995.

"Tide rose to menancing heights, swallowing one village after another and rendering at least 50,000 helpless. The gushing waters found every possible breach in the embankments, too frail to withstand pressure, before running havoc in the localities. Embankments, worth crores, were washed away in minutes."-(The Statesman News, June 3, 1995)

Embankments along the major rivers are subject to erosion by shifting river channels, as has, the fragile embankments may crumble at the slightest pressure even in the normal high tides, happened in the case of Hugli-Muriganga left bank embankment and the embankment of Sagar Island. With Raimangal,Kalindi, Dasha, Ichhamati, Hugli,Muriganga, Saptamukhi, Thakuran, Matla and Bidya in spate, atleast 155 kms of the embankments were washed away in the last major cyclone (May 14-16, 1995). The river beds have been sufficiently raised by siltation due to the presence of earth banks along both sides of the rivers. Many sand bars are eventually developed over the river beds, as the natural spill areas of normal high tide water are protected by vertical walls. Thus, the present behaviour of Sunderban rivers

- their current flow, silt content and changes in course—actively control the fate of erosion at different spots. Dasa river is going to be merged with another river (Goureswar River) by lateral shifting in the northern Sunderban after the recent tidal waves. The river bank has moved one kilometer inland by wave dash and current scours in the cyclone. Many areas had been flooded for several months, because of the ponding effect of breached waters in the lowland. At the high-water level, the pressure exerted over the earthen embankments causing normal scours in the river side of the earth walls. Thus, the fragile embankments may crumble at the slightest pressure even in the normal high tides.

Historical records show that during the period 1877 and 1965, Digha shoreline moved inland by 970 m with an average retreat of 11 m per year. However, the rate of shoreline retreat has been increased sufficiently within the short term period between 1965 and 1995 by 525 m with an average retreat of 17.5 m per year. To prevent such increasing erosion rate, the West Bengal Govt. constructed 3.7 km long sea wall with an apron of laterite blocks in between 1972 and 1982 in the eastern part of Digha. Later the stretch of 1 km more sea wall (lkm + 3.7 km =4.7 km) constructed to the western end of existing sea wall by 1988 to cover the shoreline of Digha from average storm level erosion. The initial sea wall was gently inclined to the beach plain at an angle of 12 degree from the standing guard wall (1.7 m high) over the shore-front. The sloping face of the sea wall touched the upper part of beach plain and protected the bankline behind the long sea wall from open wave attack. As a center of tourist attraction, Digha has gradually developed and the area witnesses an unprecidented construction boom just within the range of few hundred metres behind the sea wall. Many multistoried hotels sprung up within the shorter range sea wall especially in Old Digha. The indiscriminate digging of heavy tube wells into the dune bank has led to the collapse of subsoil layers and the resultant seepage of saline water into the drinking water. Another important feature is that the sea wall does not cover the most erosion prone ea wall, though protecting the bank, is unable to stop the active beach lowering at the rate of 15-20 cm per year (Irrigation Deptt., W.B.). The downward force of reflected waves rapidly scour the sand from infront of the wall, along with the breaking up of the laterite apron and displacement of the laterite blocks.

A sectional subsidence of the sea wall took place just infront of the Gangadharpur village (Digha east) in July 1992 and the sea has advanced inland by as much as 83 metres in this period.

Sinking and collapsing hazards of the sea wall after each monsoon show the absence of a firm foundation of the wall to a reasonable depth below the ground level. That's why the sea wall is unable to withstand the impact of the crushing waves in the normal Southwest monsoon brace. Many cracks and scars have developed on the infront of sea wall due to gradual sinking process. Displaced boulders are thrown upward by wave breakers at the high spring tide level all along the sea wall. The presence of older laterite blocks at the depth of 5 m below the present beach level proves the pressure and sinking rate of laterite boulders in the seafront slope of the wall. Each year new boulders are being dumped over the sinking boulder slope by local development authority. From 1993, angular Khondalite boulders were introduced over the laterites to facilitate better packing by prevention of rounding of edges. Sand bags were also introduced behind the wall to support the damaged guard wall from tidal breaches. This, however, yielded little result.

The storm surge of 1995 (May 14-16), damaged the guard wall by overtopping effect and breached into the Digha township, rendering the whole area prone to flood. Frequent cyclones and associated surge waves have been damaging the guard wall at an alarming rate and the destruction of Digha township in near future by a storm comparable in magnitude with the storm of 1943 that lashed this area, is not ruled out. The 1943 storm surge breached and partially washed away the much higher (3 m) sea dyke (earth bank) running north of Digha estuary.

Calcutta Port Trust constructed a 2.8 km long guide wall on the northern end of Nayachara Island in Hugli estuary for improvement of draft of Hugli river by diverting the eastern bank current to move along the Haldia bank during ebb tide flow and down flowing river current. Several cross spurs have also been constructed along the northwestern bank of Nayachara Island in the same scheme of river training works. The bank protection works on the right bank of the Hugli river or at the southwest corner of Sagar Island were introduced in the eighties. The construction of guide wall and cross spurs has led to change the current direction in this part of the estuary and is causing erosion on the right bank of Hugli from south of kulpi to Hard Wood Point and on the north-western bank of Ghoramara Island. Current scour at the high tidal level is producing toe erosion on the Hugli bank and developing bank slumps on the valley side slope. Thus, the deeper channel of the Hugli river is shifting eastward along this bank. Ghoramara Island is seriously affected by erosion after the constructionof guide wall in Nayachara Island.

The bank protection walls of Sagar Island now stand approximately 1 km into the sea and the area over which the tidal semaphore stations were situated is now submerged by seawater. The sea wall structure of Fresargunj area became susceptible to erosion in the period 1960-1961 and completely devastated after 1970 cyclone.

NATURAL CAUSES OF EROSION

Natural change in coastal landforms by erosion process may be a short term, a medium term, or a long term response to the energy variation. It is observed that the normal wave attack produces net loss of sediments by erosion in the lower part of the sandy beach in the southwest monsoon brace. In this period, a spring tide level touches the base of beach-fringed dune and produces micro-cliff by erosion or by shoreward transport of unconsolidated dune sands. Even the stratified, grass covered large blocks or chunks of unconsolidated sediments have been observed to roll down after erosion by undercutting of sand bank in Hugli estuary within a short term period tidal energy variation and wave dash activities. Thus, the nature of sediments along the sandy shoreline and estuary bank are sensitive to small scale changes even in the diurnal variation of tidal energy. Channel banks of the Sunderban sometime develop a marked resistance to wave energy when they are colonized by dense vegetations. Thus, a short term stability of the banks may be achieved but erosion will start again with the removal of vegetation from the banks.

Rhythmic shoreline changes are also recorded due to erosion process by periodic energy variations in the seasonal monsoon winds (summer and winter) and in the cyclones (May-June and October-November cyclones;). Charts of seasonal sea level variations have been prepared by J.G.Pattullo (1963) for March, September, June and December. In March, sea level is lower than the mean in the Northern Hemisphere and higher in the south of the equator. The largest deviations occur in the Bay of Bengal, where values of -40cm occur. In September, the Bay of Bengal shows positive values of +54 cm, which is partially responsible for the dominance of southwest monsoon winds over the sea surface. However, the enormous discharge of freshwater carried by Ganga-Brahmaputra-Meghna system, Hugli-Rupnarayan-Kasai-Subarnarekha system, and Baitarani-Brahmani-Mahanadi systems in the northern Bay amlify the tide and surge situations along with the seasonal high seas in southwest monsoon brace. Thus, periodic variations of tidal energy and wave events produce net transport of sediment offshore. In this period, the bank retreat of estuaries and cliff retreat of dunes increase significantly to adjust the high energy tidal and wave environment. The Bay-head coast of the region is normally prone to cyclones and directly exposed to wave attacks in the storm period. Storm waves attack the beach berm and foredune in the surging situation and attack the normal wave action in the falling stage of storm. Thus, they flatten the beach-dune profile and develop long shore bar and trough over the lower part of shore profile. The extra high-water levels in the storm of high magnitude allow waves to wash sand over the backshore zone into a lower inland, such as in a lagoon behind a barrier beach. Thus, all over the sandy shorelines of West Bengal and Orissa (northern part), coastal wetlands behind the dune barrier, are getting filled up with washover sands from the dune landscape. The coarser sands remove seawards under similar wave conditions. Net erosion is therefore significant on the shoreline just after storms.

A progressive change in cliff retreat is quite different from the cyclic change of beaches in which partial recovery takes place after each successive erosive phase. Beaches of Ganga Sagar, Fresargunj, Chuksar Island, Digha coast, Talsari, Junput, Shankarpur,and Orissa shoreline generally return to steeper reflective profile after'the high energy wave event is over. A six year periodicity is produced by the interaction of episodic toe erosion by currents triggering mass failures on the Saptamukhi river banks after the accumulation of sediments over mud flat surface exceeded the critical threshold of erosion. In Sunderban coast right from Sagar Island to Hariabhanga river mouth to the east, clay base of the beach has been exposed after the removal of sand sheet by storm level waves. Notably, micro-cliffs are produced by wave erosion over the clay banks mud flats and saltmarshes. The presence of a cliff over the Sunderban swamp deposits indicates a progressive long term retreat without any intervening cyclicity. The downward movement of cliff base sediments and beach sediments in recovering the erosional phase of sea beaches occur gradually in Sagar Island, Bakkhali, and Henry's Island, by lower beach accumulations.

Past changes in the energy of the coastal environment are associated with postglacial rise in sea level (Pethick, 1992). The accumulation of non-cohesive sediments over Kanthi coastal plain, and Subarnarekha delta are short term responses to the post-glacial rising sea level in this region. Now those sediments are gradually being moved offshore or back to the shelf by erosion from coastlines and through riverine sand drifts. Strong surges produced by storm catastrophes (1 in 4.6 year) in the Sunderban result in periodic erosional phases along the estuary shore which are showing progressive erosion without intervening recovery phase. Sea level rise over the present century will be a long term change of energy variations in the coastal environment. Thus, many areas of the present day coastline and estuary shore will be affected by erosion in response to the high energy waves and tides in the coastal zone.

In the Sunderban coastal zone, the silt carried by the rivers is deposited on the edges of the islands and riverbeds, and raising them both. Sand drift amount per year by Hugli estuary and the siltation rate over the river bed have been measured by Central Water and Power Research Station (1961). The study shows that the eroded sediments of the estuary bed and banks are mostly drifting offshore and changing the bathymetry of Hugli mouth. However, the siltation rate of the estuary bed is 22-24 million tons per year, generally distributed in different reaches of the estuary. It has been observed that there is a periodic balance between the erosion and depositional processes in response to energy variations in the estuary. Riverine silt of the Sunderban comes mainly from the interior of the islands and banks by the scouring caused by the concentrating and longer ebb tides. This continual scouring without compensatory silting during the flood tends to lower the interior of the islands and gradually form pan areas and enlarge them. Denudation also occurs on the outer bank of a meander channel but this is offset by accretion in the slack water which occurs behind the inner bank of a curved channel. Extensive new chars (sand bars) are developing in the river Hugli, Saptamukhi, Thakuran and Matla which continue to become shallower. Thus, erosion is enhanced by normal energy variations within the channel due to shallower beds and decreasing capacity of the channel cross sectional areas to hold the massive tidal invasion in the storm levels. The water level is reaching the banks of estuaries and large tidal channels, and scouring them by wave dash or current activities. Sinking of the basin floor seems to be going on even now in this part of the Bengal Basin due to auto-compaction of sediments. The sinking nature of the basin floor is reflected by the general drowned appearance of the coastline in the Sunderban. Rivers of this region are narrower inland and are discharging very little freshwater to the sea but have wider mouths in response to destructive macro-tidal energy variations. Thus, erosion is a normal process to adjust with the submerging effect of spring high tides in the wider mouths and lowlands around estuaries. Channel banks and shallower beds arw normally scoured by massive ingression of tides in the funnel shaped mouths, and by converging effect of flood tide water in the narrower inland channels. Thus, the rush of tide is also producing bores in the Sunderban rivers.The tidal current during bore tides is very strong, and enough to scour the banks and beds of the rivers.

Mild neo-tectonic activities in the northern and western basinal areas are also affecting landforms and riverine regimes in South Bengal (Das Gupta, 1994). Alignments of ground depressions in and around Hugli estuary, from Diamond Harbour to the sea, could also be a reflection of continuing mild tectonic activity in this region. Therefore, the lands on the seaface and estuarine shores are being denuded by reflecting high energy waves and tidal currents over the upper shores at present.

Erosion is also caused by nátural wave dash activities in the estuarine shores when strong southern winds penetrate inland through the estuaries in a falling stage of tides. High energy waves develop at this period due to the frictional resistance of northward moving winds against the south flowing ebb waters in the estuaries.

BEACH AND DUNE EROSION

The high energy coastal fringe sandy tract is well marked by wide beach plain and associated shoreline dune ridge around Kanthi coastal plain, Subarnarekha delta plain and Hugli-Saptamukhi complex of Sunderban deltaic shoreline. The beach fringed dune sector is under threat of rapid erosion in many parts of the sandy tract. Beaches and dunes and their nature of erosion are presented and specially analysed in this part of the chapter with a special reference to the physical background of erosion.

Beach Erosion: Steep storm waves attacking a sand beach are usually destructive in their effect, moving sand to deeper water offshore (King, 1972). In areas of estuarine shores and in the beaches of Bakkhali and Sagar Island, as a result of storm surges of 1984 , 1988 and 1989 removal of sand sheet took place, leaving the clay base of the beaches exposed. Beaches play a significant role in diminishing or dissipating the normal wave energy of open sea environment. Sandy beach always gets destroyed by high energy wave environment, leaving the coast exposed to erosion. Sandy beaches of West Bengal show the similar nature of erosive character. Coarser sand are being removed seawards by storm generated steeper waves while finer sands are being removed by wind actions when drying out at the lowtide. However, the finer sands are also transported seaward by longshore drift at the storm water level lowering the level of the foreshore surface of the beach. Thus , beach lowering is actively taking place in the sandy coast of West Bengal.

Digha beach is sinking at the rate of 15-20 cm per year. It has been observed that 30 cm of beach sinking or lowering is likely to cause 22 m of bank recession in Digha (unprotected areas) . Beach lowering during the month of September , 1965 was even by 30-5- cm around Digha due to a storm of extreme intensity (Niyogi, 1970). Another storm, September, 1967 also caused prominent erosion around the beach south of present day sea wall. The cyclone and associated tidal waves of 1995 (May) caused a significant lowering of the beach surface around old Digha. The beach south of Digha

Trial Aforestation Programme area and near the Hotel Sea Hawk were the worst victim (30 cm). For such a significant rate of beach lowering in a single storm the sea wall was partially collapsed and the guard wall was highly damaged infront of Hotel Sea Hawk. Sediments are usually washed out onshore and offshore by developed rip currents and longshore currents in the storm water level. . At the same time the extreme high-water level allows waves to transport beach sediments to the Digha saltmarsh areas through Digha estuary mouth by washover process in the storm period. Thus , the whole marsh area is now silted up and to improve the draft of Digha estuary, for usual running of the Shankarpur fishing harbour, dredging is essential at present . The westward growing spit attached with the Shankarpur sector near Digha estuary indicates the existence of a longshore current (east to west) which becomes active only in the period of storm waves (South easterly) in this area. Satellite photograph shows that there is a linear trough (SSW-NNW) in the local bathymetry of Digha offshore in which a strong littoral current runs towards Digha during southwest monsoon season. This drift current is also causing the removal of beach sands in Digha. The fine grained beach sands are unable to withstand the high energy waves produced by storms.

Beaches of Sagar Island and Bakkhali are significantly being eroded at an average rate of surface lowering by 15-18 cm per year. Micro-cliffs are developed over the exposed clay base of the beach around this area. When the shore parallel steeper waves break on the cliff faces, successively at the rising and falling tides in the monsoon season, a vibration is felt over the whole area. Beaches and shores around Saptamukhi river mouth (Henry's Island) are getting lowered at such a rate that some important archaeological remains like pottery items are exposed from the clay base of the beach by wave erosion. Stumps of submerged forest trees, matured and decayed pneumatophores of Sundari trees (Heritiera fomes) are exposed vertically over the clay base, which lay below the sheet of beach sands few years back. The stiff clay bank is getting eroded by high energy foreshore waves and being flattened from the initial seaward slanting surface. Subsidence, local rise of sea level, and their impacts on energy variations of waves and currents are causing such damaging effect on the beaches around Saptamukhi-Hugli complex (Sunderban).

Between June 1985 and June 1995, beach monitoring survey in parts of Sagar Island (Shibpur, Dublat, and Beguakhali) shows that there is a significant beach lowering (159 cm to 183 cm), activity without any compensatory accretion process in this areas (except the beach around Ganga Sagar. Finer beach sands are being transported offshore by wave backwash and longshore drift currents. The shore platform has been flattened exceptionally after the last major cyclone (May, 1995) in this area. The beaches around Ganga Sagar creek mouth have a blanket of sand sheets which are often aided by biogenic activities of ghost crabs and other benthic animals. Intense burrows created by crabs in the soft sands increase porosity of the beach sediment which may be washed out by wave working process in the storm water level. Such biogenic interaction with beach sediment and energy variations in wave environment also produce erosion in the exposed clay base. The concrete platforms for the bases of successive tidal semaphore stations over the shore are now detached from the landward advancing shoreline of southwest.

Table-4: Thickness of soil removed from the foreshores recorded in three coastal stations (reference marks are based on tree stumps existing on the foreshores)

Sample nos.	Station -1		Station-2	Station -3	Thickness recorded with the fixed reference points of existing tree stumps
	(A)	Shibpur Island (B)	Sagar	Bakkhali	Henrv's Island
1	134 cm	131 cm	52 cm	48 cm	**Station-1**
2	142 cm	126 cm	90 cm	52 cm	Coconut Tress, Date Palm Trees
3	124 cm	58 cm	62 cm	39 cm	**Station-2**
4	145 cm	97 cm	63 cm	42 cm	Casuarina trees, Eucalyptus trees, Mangrove trees.
5	183 cm	123 cm	95 cm	38 cm	
6	152 cm	91cm	12 cm	29 cm	
7	148 cm	102 cm	65 cm	51 cm	
8	146 cm	159 cm	72 cm	55 cm	
9	146 cm	183 cm	76 cm	48 cm	**Station-3**
10	153 cm	152 cm	42 cm	39 cm	Mangrove trees

Corner of Sagar Island (Table-4).

Dune erosion : The sandy beach and dune forms maintain their existence because of supply of sands and variations of energy events in the seashore. There is an active symbiosis process between coastal dunes and beach systems. They react very quickly to the high energy events.

During the storm events the beach tends to be flatter and wider, so that the seaward dunes are eroded. As a result of the flattening of seabeach the foredune ridges of Digha coast, Sagar island, Fresargunj, Bakkhali and Henry's island are affected by severe erosion at present. At Sagar island and Bakkhali, total removal of foredune ridges took place after the May cyclone,1995. Dune sands are transported seaward and partially deposited on the lower beach . The beach extends landward to adjust its profile causing the recession of dune cliffs. Dune cliff recession was 8.8 to 9 m per year in mid sixties to mid seventies, and at present it is ranging from 11 to 14.7 m per year in Digha. At Bakkhali a dune ridge of 13 m was partially washed out from the seaward side in a single storm of 1984.The part of the distablized dune is now advancing inland at the rate of 17 m per year in the same area. High energy wave events in the upper shores especially in the storm period and in equinoctial tides, produce massive erosion at the base of foredune ridges. Later with the successive crestal slumps and active shoreward transport of basal sands by high-water waves and currents , the retreat of dune cliff is triggered off. The upper beach provides the source for aeolian transport of sands for the formation of dunes in the supratidal zone. At present, the exposed clay base of the beach does not provide the source of sands for the generating of dunes in the shoreline in parts of Sagar Island and Bakkhali. Thus the soft defence of the Sunderban shoreline is being removed in high energy events.

Digha beach is now backed by narrower (85 m wide) foredune ridge of 8 to 10 m high with blowout gaps, slip faces, landward serrated margins due to differential marching of the dunes, and without the presence of new dunes. The old records show that the dune ridge was 23 m high in 1877 (Quoin Hill), 20 m in 1931 (Survey of India's Topographical Map) and reduced to only 12-14 min 1965(Irrigation Department). The older dune ridges are progressively more eroded and at many places blowouts have been enlarged sufficiently by wind erosion of dune ridges. The lowering of dune surface is recorded in 3 sample areas of Digha east from March 5, 1985 to August 28, 1985 by G.S.I. The record shows that the total lowering was 7 cm, 20 cm, and 15 cm respectively in the three sample areas of bare dune surface. The seaward facing slope of Digha dune (near Digha estuary) is wave cut while the land facing slopes are more or less covered by dune grasses, *Casuahna* trees and other plants. However, the secondary eroded dunes are climbing over the stabilized surface of older dunes and are marching irregularly to the saltmarsh areas of Digha estuary. Thus the tidal saltmarsh contains some wind blown sand in this area.

Because of their coastal situation, dunes have come in for more share of human interferences. Even if they are not destroyed by housing, but their use for recreation creates great problem. The use of coastal sand dunes by a large number of people in an uncontrolled manner result in deterioration especially in Digha, Sagar Island, Kanthi, Fresargunj and Bakkhali areas. Housing over the dune rows of kanthi coastal plain, stock grazing practice over the dune ridges of Sunderban, and recreation the dune surface of Digha is destroying the dune systems by erosion.Trampling kills the vegetation and along well used paths the fragile surface protection it provides is broken through, allowing wind erosion to take place, which if not arrested can destroy dune system. At present most of the coastal dunes provide space for the practices of farm forestry in co-operative system by planting *Casuarina equisetifolia* tree species over the dune surface in West Bengal.Thus, at the scurbaceous stage of the vegetation it arrests the wind erosion, but blowouts spread over the exposed open spaces of the dune bodies when the trees are matured. In the dry period (March-June), strong onshore winds pass over the dune surface (sparsely vegetated) by developing blowouts and enlarge them gradually to destabilize the dune system. Some dunes are seriously affected by washover process of surged waves in the storm water level (low dunes).
Normal processes of erosion is causing the dune bodies to spread and flatten, and is becoming lower with age in an offshore island of Hugli R. mouth (Chuksar Island). Many fishing huts spring up on the dune ridges especially in the fishing season, and vegetation cover of the dune is removed by the activities of fisherman allowing wind erosion to take place in the hot and dry period.

Sea level rise over the next decades will lead to an increase in mean water depth in the shores, which in other way will increase the mean wave height and wave related effects. Thus, the hard defence structures (boulder paved sea walls, brick pitchting banks and earthbanks) would be affected by an increased risk of overtopping, damage and failure.

Table-5 : Coastal erosion damage potential (Case of West Bengal and Orissa)

Immediate effects (freauentlv or potentially damaging)	Areas affected seriously
1. Removal of small islands	Lohachara, Khasimara, Suparibhanga islands in Hugli estuary
2. Breaching of barrier islands	Satbhaya barrier islands in Brahmani-Baitarani river mouth
3. Loss of beach sediments	Digha, Bakkhali, Beguakhali, Dublat-Shibpur
4. Recession of dunes, bluffs and cliffs Sagar Island coast	Digha, Talsari, Shankarpur, Bakkhali and
5. Destruction of existing habitat of shores	
6. Weakening and destruction of seawalls and embankments	Sunderban,Subarnarekha delta and Brahmani delta
7. Loss of agricultural lands and gardens	Digha, East Medinipur,Sundarban islands and Talchua Island of Brahmani delta
8. Isolation of jetties, seamaphore stations from mainland Tamluk	Lohachara, Ghoramara,Khasimara,Bisal akshmipur, Lakshmipur, Begundiha and
9. Shoaling of offshore waters	Seamaphore stations at Beguakhali and jetties at Sunderban river banks. Talchua island Sagar-South and Bakkhali-South
Secondary effects (lons term damage potential)	**Areas Affected**
10. Loss of income from beach recreation	Fresargunj, Bakkhali and Digha
11. Flooding of land areas behind breached embankments	Tamluk, Nandigram, Khejuri, Sagar Island, Ghoramara, Hingalgunge, Sandeshkhali, Basanti, Gosaba.
12. Reduction of protection against future storms	Sunderban as a whole, Talchua Island.(loss of buffer)

Erosional and removal activities of soft defence structures like dunes, in the coastline, also would be increased. Present study shows that the foreshores of coastal profile in , many parts of West Bengal are now adapting a new dynamic equilibrium probably due to the changed hydrodynamic conditions and sediment characteristics. Frequency of cyclones is increasing, and changing the hydrodynamic regimes of the shores with increased wave events. Thus, the shorelines is retreating at an alarming rate in West Bengal, Bangladesh and Orissa. The risk of damages along the Sunderban river banks and in the estuarine islands has been increased sufficiently at present (Table-5).

We have to adopt a long term programme but relatively a sensitive approach in coastal management at present. The study is necessary to understand the behavior of energy variations, and the periodic adjustments of coasts to such variations of energy input for the successful implementation of management programmes. It is better to preserve the natural systems(dunes and marshes) by allowing them to adjust to the constantly varying environment in the coasts, Human use of the changing coastal zone should be more scientific.

Reference :

Niyogi, D. 1970 : geological background of beach erosion at Digha, W. B. Geol. Min. Soc. India Bull. Vol. 43, PP 1-36.

Paul, Ashis Kr. 1997 : Coastal Erosion in West Bengal. MAEER MIT PUNE JOURNAL, Vol. 4 Nos. and 16 (Special Issue on coastal Environmental Management) PP. 66-84.

Paul, Ashis Kr. 2005 : Coastal Erosion in West Bengal. in : combating Disaster. (Antara Banerjee, Bidisha Mallick, Debasish sarkar and others. eds.) AcB publications. Kolkata PP. 130-35

Paul, Ashis Kr. 2007 : Nature of erosion hazard in Indian subcontinent and various management procedures. In : Geographical disaster. ed. S. Chatterjee. Science Vision. Kolkata PP. 66-87.

Pethick, J. 1992 : Natural change. In : Coastal zone planning and management. Thomas Telford. Londan, PP. 49-63.

Suggested Reading :

- Coastal Geomorphology and Environment. Ashis Kr. Paul, 2002. AcB Publications. Kolkata. PP. 582.
- An Introduction to constal Geomorphology. John Pethick, 1984. Around-Heinemann, London. PP. 260.
- Coastal Environments. Carter, R.W. 1988 : Academic Press, PP. 688.

Questions :

- Discuss the geological back ground of constal erosion in Digha and Sagar Island.
- What is the role of human activities in coastal erosion with special reference to Digha and sagar island ?
- Discuss the problems of various erosion protection measures adopted in Digha and sagar island.
- 'Erosion is a natural change in response to energy variations in the alluvium coast'. Explain the statement with special reference to Digha and sagar island.

Notes