CHAPTER - II

2.0 PHYSICAL AND BIOTIC ENVIRONMENT

The physical and biotic environmental characteristics of the littoral region are discussed in this chapter. Physiography, ground water, climate, soil and vegetation are the main components, which have been discussed in detail in different sections of this chapter. In the concluding part of this chapter, the synthesis of all these parameters is arranged in the form of matrix, which has been called the 'Environmental System Matrix'. As the whole tract is a flat terrain devoid of any significant relief feature, the discussion regarding physiography mostly concentrates on drainage condition and depositional activity. Based on these two parameters, physiographic sub-regions are demarcated. For all the environmental components, the characteristic features are discussed for the whole terrain and also for each physiographic sub-region. Environmental system matrices have also been prepared for each sub-region.

2.1. PHYSIOGRAPHIC PARAMETERS

This section includes depositional characteristics: drainage, geosstructure, tidal effects on island and channel geometry and physiographic sub-regions.
2.1.1. Depositional Characteristics

The study area is situated in the West Bengal portion of the coastal fringe of the Ganges delta. The suspended run-off in this delta face is to the tune of 1451.5 million tonnes per year against a run-off of 1210 km³ supplied by the Ganges-Bramhputra system (UNESCO 1975). According to the hydrological character, the whole delta has been divided into three tentative divisions: Moribund delta, Mature delta and Active deltas (Bagchi 1944), which have already been mentioned. The natural hydrological changes as well as human interference have obviously modified the original situation (Bagchi 1978). Still depending on the depositional environment, three morphological zones can be recognised in the Ganges delta as follows (Fig. 8).

(1) The zone of fluvial deposition - the upper part of the delta from the northern skirt of the marshy chain to the delta head, also identified as the moribund delta.

(2) The transitional zone - marshy chain or zone of unfinished deposition (Chakraborty 1970).

(3) The fluvio-estuarine depositional zone - area lying south of the marshy chain, located in the active delta and partly in the mature delta.
The fluvio-estuarine depositional zone, already identified as the littoral tract is clearly demarcated by the marshy chain extending from the vicinity of Calcutta on the Hooghly to Barishal on the Padma.

This marshy chain has been described as the area deprived of silt from the river flowing through the region and hence ceased to be in active phase of land building particularly in the stretch between the Bidhyadhari and the Madumati (Bagchi 1944). These salt marshes, supposed to define the boundary between the upper delta (moribund) and the lower delta where land building activity proceeds by tidal channels (Majumdar 1942), are situated in the Midnapur tidal plain which is delineated by interpolating the lagoons according to their alignment. It is also interesting to note that the shoreline of 6000 B.P. interpolated by Niyogi (1975) more or less follows the same alignment (Fig.8) which also defines the boundary of the younger deltaic plain in the north and recent plain formation in the south (Niyogi 1975). The recent plain or the lower part of the Ganges delta has been deprived of the requisite fluvial deposition due to the moribund conditions of the silt bearing rivers, caused by the disconnection of the Ganges offshoots in between the Bhagirathi and the Padma (Hirst 1916, Chakraborty and Basu 1972) as well as diversion of the main flow of the Ganges from the Bhagirathi-Hooghly course to the
Padma course (Bagchi 1944). All these findings lead to the conclusion that the southern part is dependent upon tidal deposition for its development.

2.1.2. Drainage

The whole area is interspersed with an intricate network of criss-cross channels and creeks, big or small, dividing the area into a large number of islands. These channels ultimately find their way to the Bay of Bengal through one or other of the principal estuaries. Starting from the Hooghly, the main estuaries are the Baratala (a distributary of the Hooghly) the Saptamukhi, the Thokuren, the Matla, the Gosaba and the Raimangal. The Hooghly estuary receives flow of freshwater through the Bhagirathi. The Raimangal, the upper course of which is known as the Ichamati also gets some freshwater in the monsoon months. All other estuaries are beheaded and entirely dependent upon tide water. These estuaries or sea arms were the lower courses of the Ganges off-shoots in different times. Though the upper part of the river has decayed, these lower courses remain active with the help of tidal flow.

All these estuaries are interconnected by cross channels. These channels are generally developed at right angle direction to the flow of the main estuary. As delta building activities advance, the old cross channels are choked up and new ones
develop. The stages of the cross channels are also the indicators of land building. Obviously, the modified situations are marked due to human interference in different places.

Analysis of the drainage map (Fig. 9) makes it clear that the estuaries in the western part barring the Hooghly, are smaller in length, only 15 kms from the sea face in Hamsadwip while the eastern part it is much longer, nearly 60 kms in Hingalganj-Hasnabad area. The inland extension of active cross channels are narrower in the western portion than the eastern portion. The drainage regime can be divided clearly into two parts considering Matla as the axis. The Matla is a very wide estuary comparable with the Hooghly near the sea face. It is very turbulent in monsoon months. But the upper course of the Matla from Canning to Basanti is seriously affected by silt deposition. The Bidyadhari, the Karati and the Atrabeki which have joined the Matla at Canning are completely in decadence. Atrakati, which was once a connecting channel between the Matla and the northwestern channel of the Raimangal has now ceased to be active. The Hariabanga-Jilla-Raimangal system has become hydrologically more efficient particularly in the upper course. Flow tides even in the Haro Ganga are progressing via the Jilla-Raimangal creek. The tract lying between the Saptamukhi and the Hariabanga i.e. the forest area is truly in active phase where
continuous deposition is in progress. It is apparent from the drainage map and confirmed by field survey that there are three types of channels as follows:

1) Dead channels - The channels which have lost their connection with one of the main river systems in either side. Some of these channels are completely choked up without supply of tide water except monsoon. Channels like Giapati - Piyali, Bichadhari, Atrakshil, Ghugudanga blind creek etc. are the examples.

2) Decaying channels: The channels are considerably silted up but have regularly recorded tidal fluctuations. The Saptamukhi estuary in its upper course, Hatiani-Doani cross channel, Hana channel etc. are the examples.

3) Active channel: All the channels which do not fall in above two categories having pronounced tidal action.

The dead and decaying phase attained by the various channels are not solely due to natural hydrological system. Deterioration has been accelerated due to considerable human interference. It has already been mentioned that to reclaim an appreciable portion of the prematured land, embankments have been constructed extensively. These embankments have prevented the tidal insurgence over the island. It has a very serious repercussion on the depositional activity in
the whole tract. Due to the sudden reduction of the natural spill area the tidal silts are confined to the river beds. It causes gradual upraising of the thalwegs, which again result in rise of tidal level both vertically and horizontally (northwards). Rise of tide level in Matla at Canning, Raidighi river at Raidighi, Ichhamati river at Basnabad and in other places is conspicuous. Due to the increasing lateral erosion, in a number of places like Maszidbati, Basanti and in some parts of Sandeshkhali the original embankment has to be replaced by other embankment much inside the island. It has been pointed out (Bagchi 1978) that the high tide level in most of these channels is much higher than the adjoining lands (even low tide level is also higher in some cases) and protection from saline water encroachment is a serious job. As a whole, for most of the islands artificial aids are needed to drain out the accumulated rain water (Chatterjee 1946, Mukherjee 1976).

Due to regular siltation within beds, the cross section of the channels is decreasing faster. Studies of River Research Institute (1968) and the present author reveal that in some places of Saptamukhi creek the reduction is in the order of 25 percent to 28 percent in a six years span. Past studies of Majumder (1942) also reveal the same fact for the Bidyadhari river.

The study of River Research Institute (RRI) also shows that the water bearing capacity of the Saptamukhi as a whole has reduced 5 percent in volume from 1961 to 1966. This
reduction is less (2 per cent) in the east gully of the Saptamukhi, which has indicated its higher hydraulic efficiency than the west gully and the upper Saptamukhi. In the case of cross channels, this siltation problem has also become acute even in the undisturbed area. It is also a process of land development in delta face. The tide water from two creeks flowing into a cross channel meets at a distance proportional to the length of the cross channel between two main estuaries. At this zone, the silts are suspended and deposited within the channel bed. At the time of ebb tide, these shoals are seen below water. Gradual rise of this shoal will deteriorate the whole system. These features are very prominent in the Matla, south of the Basanti island, and in the Dutta's Gang below Hamilton abad.

The Namkhana creek (Hatiani-Doani), which connects the Bartala and the Saptamukhi generally flow towards the Bartala. The share of flood flow in the Namkhana creek from both ends as estimated by R R I (1967) is given in the Table 8.

<table>
<thead>
<tr>
<th>Junction between rivers</th>
<th>Approximate percent age distribution of flood flow</th>
<th>Approximate combined flood volume in million cubic meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bartala-Namkhana</td>
<td>99:1</td>
<td>350</td>
</tr>
<tr>
<td>Saptamukhi west gully - Namkhana</td>
<td>82:18</td>
<td>55</td>
</tr>
</tbody>
</table>

Source: River Research Institute (1967)
eH—Naga-Lushi folding (Eugeosynclinal areas)
mH—Miogeosynclinal areas
--- International Boundary

Source: Geological Survey of India, 1963
A series of islands in the west of the confluence of the Namkhana creek with the Bartala, point towards this restricted flow mentioned in Table. The mean tidal range in the west gully - Namkhana creek junction and the Bartala-Namkhana creek junction are 3.25 m and 3.22 m respectively. The west gully is already in decaying stage. The Namkhana creek is also heading towards the same end.

Though the three stages of the rivers mentioned in this discussion can be recorded side by side, it is observed that the eastern part particularly south-eastern part of the Matla is in active phase. A small southern tract between the Thakuran and the Matla is also in active phase. The tract between the Hooghly and the Bidhyadhari - Thakuran has received considerable silt in the early date (Bagchi, 1944) and land building activities are in advanced stage than in the eastern part.

The difference in the degree of maturity of the landscape is partly attributable to the geostructure of the Bengal basin, which is discussed below.

2.1.3. Geostructure

The study area is located in the western part of the Nagalushi geosyncline separated from the transitional zone (between shield and geosyncline) by hinge in the basement complex and slopes towards east (Fig. 10). The transitional
zone between the shield and geosyncline is also separated from the buried shield zone by a similar hinge. This hinge zone passes through Calcutta - Ranaghat line trending N 50°E (Sengupta 1970) and represents a sharp change in depositional environment from stable shelf to deeper basin (Chakraborty, 1970). Morgan and McIntire (1959) have identified a number of enechelon faults in the lateritic Barind plain, which surrounds the Bengal basin. They also believe that this area has experienced upward movement in different geological era which is evidenced by a number of terraces. Hirst (1916) suggested that both the Barind and Madupur jungle areas were elevated as compensation to a line of subsidence passing approximately from Jalpaiguri to the sea down the alignment of the present Meghna river. Due to this subsidence Bengal basin slopes towards south east. This direction has also been followed by the Basement Complex of this tract. It may also be noted that the rate of subsidence along hinge zone (Calcutta-Ranaghat hinge zone) is less than the deeper part of the basin (Chakraborty, 1970). So the western part which is adjacent to the hinge zone is relatively matured than eastern part. Longer extension of estuaries in the Ichhamati belt than the Hooghly belt may be attributed to the above mentioned facts. Subsidence along the Meghna may also be taken as a cause for the distributaries of the Ganges to be beheaded from the original channels, and hence fresh water silt deposition has been restricted. The tract between the Bidhyadhari and the Ichhamati is a part of intermediate sagged zone which is yet to receive enough deposition to get maturity. So the structural control in the context of
broad regional setting provides considerable impact on landscape maturity in this part of the delta.

2.1.4. **Tidal Effect on Channel and Island Geometry**

Tidal range and the tidal current have the broadest effect in determining the geometry of channels and islands particularly along the coast (Hayes 1975). Other parameters like storm action and wave conditions are also significant but tides are more effective as they are regular phenomena throughout the year occurring twice a day, whereas storm action is an occasional phenomenon.

The Ganges delta is dominated by the macrotidal estuaries where tidal ranges vary from 4 to more than 4 metre. The prominent feature is the overwhelming dominance of tidal currents. Development of flood tidal and ebb tidal delta are conspicuously amalgamated. To differentiate those two with their own characteristic features, detailed and in depth study is needed which is beyond the scope of this investigation.

It appears from the surface morphology that except the Hooghly estuary all other estuaries (within West Bengal) receive silt deposition from flow tide only. In the Hooghly estuary, the river water flowing in opposite direction to that of flow tide cause modification in silt depositional pattern. The shoals in the estuaries of the Hooghly,
Bartala, Saptamukhi and Thekuron-Matla are normally concentrated in the central part of the estuaries in a linear fashion parallel to tidal currents.

The flow directions of the flow and ebb tides, which are north-west and south-east in the study area (Fig.11) have significant role in shaping the islands and shoals particularly in the delta face. The alignment of the long islands, the southern part of the Mehismari, Fresherganj islands, island chains east and west of the Saptamukhi, the seaface of the Kalas island on the Thekuron, Bangadhuni in front of the Gosaba and Machuna island in the east of the Gosaba estuary are parallel to the direction of the tidal current. The significant difference is marked in the Hooghly estuary. The sand bodies within the Hooghly estuary follow the direction of the river banks. It is imperative that once the tidal bores enter within the estuaries leaving the sea face, the direction of tidal currents is principally modified by the direction of the existing channels. So the alignment of shoals within the water bodies further inland from the sea face does not necessarily follow the original direction of the currents, which are also evident in the study area particularly in the Hooghly estuary. The sinuosity of the channels over the emerged island is not controlled by the tidal directions but the initial development of channels due to emergence of sand bodies in the sea face is controlled by the tide direction.
2.1.5. **Physiographic Sub-Region**

The land building processes, discussed above, have been modified diversely due to human interference, which is already mentioned. The landscape system (Fig. 12) with its components under purely natural process and man-nature combined process show a considerable variation in morphological characteristics, which support to analyse the region in micro level.

The whole littoral tract has been divided into three zones as follows:

Zone 1. The area lying north of the northern embankments covering Kulpi, Mandir-Bazar, some parts of Mathurapur, Joynagar, Hasnabad and Haroa Police Station.

Zone 2. Area enclosed by the embankments or the embanked tract - the whole reclaimed Sunderbans.

Zone 3. Seaface area lying south of the southern boundary of the embankment - the Reserve forest area.

Landforms of these three zones have their own speciality. Zone 1 can be further divided into two separate units - (1) Kulpi - Mandir Bazar and adjoining tract, adjacent to the Hooghly river (2) Haroa - Hasnabad tract adjacent to the Ichhamati river.
These two separate units have received considerable river deposition to attain maturity. The intermediate sagged area between these two units has been deprived of normal siltation due to the faster deterioration of the Bidhyadhari. Moreover, the salt lake marshy area separates these two units. These two micro units are included in the mature delta.

Within the reclaimed area of Sunderbans, channels and estuaries show different degrees of maturity. In the southwestern part, estuaries are mostly silted up, cross channels are in decayed stage and land building process has ceased (Bagchi 1978). But in the eastern and south-eastern part, the condition is different. Cross channels are still operative though pockets (Malta - Bidhya cross channel in Canning border) of deterioration are not uncommon. Three micro regions are identified within this embanked tract or reclaimed Sunderbans. Only the reserved forest area is in an active phase, where regular tidal invasion is going on. The characteristics of each sub-region are studied to make their position clear.

2.1.5.1. Characteristics of Sub-Regions

The northern tract outside the Sunderbans - 24 - Parganas embankment or zone 1 may be considered as naturally matured delta. Two micro units, already mentioned, have been recognised and now their characteristic features are discussed to provide complete idea.
2.1.5.1.1 North-Western Plain (Kulpi - Mandirbazar Plain)

This plain lies between the Hooghly river and the ancient course of the Ganga (Adi-Ganga) traced within Joynagar, Hothurapur and Kulpi police stations. The ancient Maghurat marsh, which is now reclaimed and drained by different canals, marks its northern border. It has been established by Bagchi (1944) that the main flow of the Ganges - Padma system once follows the line of Tolly's Nala (Adi-ganga course) through Baruipur, Joynager and Kulpi to the Bay of Bengal. This plain has the opportunity to receive sufficient amount of riverine deposition to have maturity. The highest elevated (4-6 meter) zone within the whole littoral fringe has been marked in this plain.

Chatterjee (1946) considered this area as a portion of Diamond Harbour - Kulpi and Baruipur - Joynager plain. According to him, this area has been developed not only by Ganges silt but also by Damodar - Rupnarayan silt. "The Damodar is the first important river to join the Hooghly in the lower reaches and is partly responsible for raising the southern flood plains of the Hooghly higher than those of the north" (Chatterjee 1946). Presence of course sand in its soil composition also indicates the contribution of plateau rivers in depositional activity. This plain is completely encircled by embankments in the south-western, southern and south-eastern border to get protection from saline water ingress. The major portion of the plain is drained into the Hooghly river. Area under Khal bil and river is only 1.22 per cent of the total area.
Kulpi as a settlement site has been marked in the maps of Bengal prepared even earlier than Rennel (1773). This also indicates its relative maturity over the surroundings.

2.1.5.1.2 North-Eastern Plain - (Haroa-Hasnabad Plain)

This plain occupies parts of the southern portion of the highlands along the Ichhamati river and marshy tract. Slope is generally towards southeast. Highlands along the Ichhamati represent the levee sites, which gradually flatten towards south and southwest. The Haroagang demarcates the southern face and is the only draining channel of the intermediate marshes. Haroa portion of this plain is partly occupied by bil like the Panchalbaria and the Padma. The eastern portion of this plain is drained by the Gobra Khal, which issued from the Jamuna river near Hasnabad and later joins with the Bidhyadhari in the south of Sandeshkhali. Haroa plain is drained by braided river system locally known as gangs which eventually merge into one channel. This channel is known as the Haroagang, which afterwards diverges into the Bidhyadhari.

The Panchalbaria and Padma bils are the sites where fresh water silt deposition is totally restricted. Now for the cultivation of tiger prawn (Bagda), canals have been constructed from the Gobrakhal to bring saline water in these areas. Field investigation reveals that continuous silt depositions through these artificial canals lead to fill up the depressions fast. In rainy season, water table comes over surface which reflects its marshy character. Though relics of marshes are not uncommon, still
the tract is matured one as is evidenced by the old human settlements and crop culture.

2.1.5.1.3 South-Western Plain (Western Sunderbans Plain - Kakdwip - Sagar Plain)

This plain is the Hooghly Thakuran inter riverine tract. Elevated lands are marked along the Hooghly river. Elevation of land drops from 5 meter (beside Hooghly) to 3 metre (beside Thakuran), that is, 2 metre in about 50 kms; though the range is small yet it is remarkable as the whole tract is totally flat without any significant gradient. In the western tract of the Thakuran, active channels are also in a decaying state. More than 10 per cent of the total area is under river. Slope is generally towards south-east. But a considerable portion is drained through the Hooghly river, which is flowing along western margin. Adjoining parts of the Hooghly river are higher representing ancient levee sites. Spot heights of 3 metre are common. The embankments along all channels and estuaries are the positive evidence of the reclamation. The Hooghly, Bartala, Septamukhi, Thakuran are the main outlets. The whole plain becomes water logged in rainy season and in summer, ground water goes down to 3 metre from the surface. The ground water level goes down by even 5 metre in a small tract in Kakdwip. This plain being adjacent to the Hooghly river (which is still active) is more matured than other plains of the embanked zone.
2.1.5.1.4 Central Plain (Canning - Basanti Plain): This plain covers the drainage area of the Bidhyadhari - Matla river. The Bidhyadhari river, now in decaydence, once carried fresh water silt, which has developed this plain. The Western part is more matured than the eastern. The active cross channel will be met in the lower part of Basanti police station. Marshy lands like Payana bil is a conspicuous feature which seems to be developed due to breach of embankment (Chatterjee 1946, Mukherjee 1976). The Matla river is getting silted up very fast from Canning to Golabari (Chatterjee 1948, Ichiri 1958). Once Government proposed to develop Canning town as a substitute of Calcutta Port, but later it was abandoned. Due to heavy siltation, thalweg of Malta is higher (about 4 metre) than the surrounding lands (Chatterjee 1946). So it is enclosed by artificial embankments. This is a serious problem for drainage and protection of embankment. Area under Khal, bil and rivers amount to 12 per cent of the total area.

2.1.5.1.5 South-Eastern Plain (Sandeshkhali - Hingalganj Plain):

The whole tract is lowlying and comparatively immature in nature except a strip of land along the Ichhamati in Hingalganj police station. Instead of a large river, a thick network of channels is the conspicuous feature. More than 13 per cent of the total area are under waterbodies. Almost all the villages are a sort of island surrounded by embanked channel. Settlements within the islands have developed along embankments. Patches of highlands are marked within these islands. Salinity of water is slightly
higher in and around the Bidya and the Malta. Ground water table is at a very shallow depth and most of the area gets water logged in rainy season.

From the above discussion it now emerges that five micro plains may be identified within inhabited portion of the littoral fringe (Fig. 13). The study will be confined to these plains. The islands without embankment are given to forests. This tract has been considered as true active delta where deposition is going on. It is beyond doubt that instead of riverine deposition estuarine silts are the only constituents that matter here.

2.1.5.1.6. Area lying South of the Embankment (Reserve Forest area): This area is now in active phase and is restricted to the forest area. The embanked area though reclaimed in premature state has to be considered matured as it is managed by human being. Tidal deposition is going on in this area. Cross channels are active due to regular tidal flushing. It has already attained stable conditions as is indicated by vegetation of salt water heritiera type. Information regarding vegetation will be more elaborately discussed in the concerned section.

Morphologically, most significant feature of this area is the sand dunes. These dunes are formed along the coast line in a single alignment. In the western part particularly in
Frasserganj Bakkhali area, those dunes are studied. Dunes of other islands are not accessible as all of them are in reserve forest and most of them are covered by the tiger project area. So far very little work has been done regarding these dunes. The author has elaborated further the informations provided by a previous study by Betal (1973) and Ray and Baksi (1980).

The dune line is extended from Frasserganj in the west to the Henry channel in the east. Total extension is nearly 600 metres. The dunes are of different heights. The maximum height (20 metres) is recorded almost in the central part of the chain. The seaward sides of the dunes are steeply slopping (angle of inclination - 45° to 55°) and the landward sides are gently slopping (angle of inclination 20° to 25°). The dunes are composed of loose sand and would take time to achieve sufficient firmness and stability (Ray and Baksi 1980). It is observed that the major part of these dunes are formed by sands lifted by waves under the impact of wind. Another interesting point to note is that in the oceanward side of the dunes a clay layer is found 10 cms below the beach surface. This clay patch is intensively dotted with decayed casuarina stems. This leads to the belief that the clastic sands with clay particles clunged up at the base of the casuarina trees. This phenomenon has helped at the initial stage of dune formation. The dune sands contain well rounded quartz (75 percent - 80 per cent) sub
THE GANGES CANYON

(Switch of no ground)

[Map of the Ganges Canyon with contour lines and values in meters]

(Contour value in meter)

[Reference: P.M.S Zulfiqar 1950-51]

Fig. 14
rounded feldspars (15 per cent - 20 per cent) and sub angular platy dark minerals (analysis by the author).
The landward side of the dunes are covered with mangrove vegetation and bushes. Further north, swamps are recorded.

Patches of isolated beaches are noticed in different islands. In some portions of this zone, certain spots like 'Machua Island' beside the Hariabhanga estuary is already beyond normal high tide level. Some sweet water ponds are also marked in those elevations.

Off the Matla estuary, a submarine Canyon "swatch of no ground (Ganges Canyon) lies in the seaface (Fig. 14). According to Chakrebotry and Basu (1972), two coastal drifts, one coming along the Coromandal coast and the other along the Mortaban coast are converging near the estuary of the Matla river. These drifts are slow but persistent. This will perhaps explain why the swatch of no ground, a submarine canyon of a typo, is located at the point of convergence of these two drifts and not in the front of the arterial estuaries of the Ganges-Brahmaputra rivers. This view has however been contradicted. The geomorphologists believe that tectonics might have played a major role in the location of the swatch of no ground. So the specific reason for the development of this canyon is yet to be established.
It is also believed by some authors (Spate & Learmonth 1967, Chakraborty & Basu 1972) that the advance of the Ganges delta has been arrested. But recently it has been detected from satellite photographs that a submerged platform skirts the delta head for a considerable distance southwards, on which are emerging Jambu dwip (long island), Purbasha (Mur island) with possibility of many more being added to the list. The oceanographic chart therefore clearly establishes an advancing delta.

2.2. HYDROLOGY WITH RESPECT TO GROUNDWATER

The littoral region is interspersed with innumerable tidal channels and has no alternative source of sweet water supply in the dry period except few tubewells, ponds and tanks. The maximum depth of the ponds may reach 2-3 metres only, otherwise saline water may ingress. Average depth of fresh underground water source is above 200 metres, so deep-tubewells are required for lifting water. An interesting feature of groundwater in this area is that deep underground sweet water is overlaid by saline water. Again over this saline water a small enclave (average 2 m thick) of sweet rain water can be recorded.

This section is concerned with the groundwater, stored in the rainy season above the saline water level. The rain water enclave supplies moisture to the surface soil in one
hand, on the other, it prevents salt incrustation through capillary action for a considerable period. This water plays a major role in the pabi and pre-kharif cultivation. The agriculture in the dry period often depends upon soil moisture as the rainfall is meagre in this period. Soils having higher amount of moisture can support certain crops to attain maturity with a single irrigation. So study of this water table is essential to understand the regional character of the agriculture.

Discussion about the seasonal fluctuation of water table in the regional context will bring forth a comprehensive picture.

2.2.1. **Rainy Season**

The entire region is enclosed within 3 metre contour. It has already been discussed that the region has been prematurely reclaimed. As a result, considerable areas are below high tide level and have developed marshy character.

Very often, more than 50 per cent of the total area remain water logged in the rainy season. It is interesting to note that patches of surface saturated area are separated by lands of average ground water depth of 0.75 metres. These patches (where water never comes over the surface) are relatively higher and lie along the Hooghly, the Ichhamati and upper reaches of the Matla. These three zones actually represent the levee sites, which generally have received more
deposition.

A map (Fig. 15) for average condition of ground water in rainy season has been prepared to clarify the whole situation. Four zones are represented in the map.

### TABLE 9

**GROUNDWATER ZONE - (RAINY SEASON)**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth in metre</th>
<th>Area in per cent to total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>less than .40 metre</td>
<td>15.98</td>
</tr>
<tr>
<td>B</td>
<td>.40 - .70 metre</td>
<td>43.97</td>
</tr>
<tr>
<td>C</td>
<td>.70 - 100 metre</td>
<td>27.12</td>
</tr>
<tr>
<td>D</td>
<td>more than 100 metre</td>
<td>12.93</td>
</tr>
</tbody>
</table>

It is to be noted that these zones bear close proximity to the physiographic characteristics of the region, which will be clear from the discussion below.

2.2.1.1. **Zone A (Lying below 0.40 metre)**

Area under this category is limited. Four patches are recorded separately. In the north-western plain, a patch covers parts of the Mandir bazar and Joynagar police stations which was once occupied by the Magrahat marsh and Adiganga channel. Two other patches are located near the Pyana and Sarang bil of the central plain and near the Bhubandanga bil of the north-eastern plain. A strip of land along the Thakuran in the southern plain is also included in this
category. Elevation of these areas is low and these lands have been reclaimed from a marshy condition. Clay pan has developed below these lands, hence water cannot percolate down through soil horizons.

2.2.1.2. Zone - B (0.40 to 0.70 metre)

Greater part of the Western Sundarbans and considerable areas covering parts of Hasnabad, Sandeshkhali and Gosaba are included within this zone. Sometimes this zone also remains under water in rainy season.

2.2.1.3. Zone - C (0.70 to 1.00 metre)

Strips of land along the Hooghly and the Ichhamati are under this group. The levee sites are quite developed than the surrounding areas. The north and southern most strips of the Sagar island record this character. The area under Canning Police Station is also included in this category.

2.2.1.4. Zone - D (more than 1.00 metre)

Patches of this zone are seen in the south-western, central and south-eastern plain. Central part of the Sagar island, the Kakdwip corner, Southern part of Basanti and central part of Hingalganj exhibit this character. These patches have never been water logged in rainy season. This character indicates their relative maturity in comparison to other areas.
2.2.2. **Summer Season**

In dry period, the groundwater depth varies from 1 metre to 6 metres. During summer season four zones have been identified throughout the region (Fig. 16).

**TABLE 10**

**GROUNDWATER ZONE (SUMMER SEASON)**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth in metre</th>
<th>Area (in per cent to total area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>less than 1.5</td>
<td>8.14</td>
</tr>
<tr>
<td>B</td>
<td>1.5 - 3.0</td>
<td>39.78</td>
</tr>
<tr>
<td>C</td>
<td>3.0 - 4.5</td>
<td>46.83</td>
</tr>
<tr>
<td>D</td>
<td>more than 4.5</td>
<td>5.25</td>
</tr>
</tbody>
</table>

2.2.2.1. **Zone A (less than 1.5 m)**

Upper part of Hasnabad police station and a strip of land along the Matla in Kultali police station generally lie below 1.5 metre in dry period. A small patch in Joynagar adjacent to Magrahat police station is also included in this group. These three patches are mostly within "Zone A" for rainy season also and become waterlogged during August-September. It is noteworthy that these areas generally fall under low soil moisture regime and exhibit silty-clay-loam type of soil.
2.2.2.2. Zone B (1.5 to 3.0 metre)

Mandirbazar, Central part of Joynagar, Kultali, parts of Pathar Pratima in the western Sunderban, Sandeshkhali, Gosaba (around Bidya Kalagachi) and parts of Hasnabad (along Katshkali) are included within this zone. In rainy season, particularly during August-September, these tracts usually remained waterlogged. Soil moisture also records low value (less than 3 per cent), which indicates to the higher amount of silt than clay.

2.2.2.3. Zone C (3.0 to 4.5 metre)

This zone includes the patches covering entire Hingalgonj, police station, central plain covering Canning and Desantl and parts of Western Sunderbans covering Kulpi, parts of Mathurapur, Kakdwip, Namkhana and Sagar islands. In the rainy season also, they are grouped into Zone C. The tract has never gone under water except a portion in Mathurapur police station. The soil is silty-clay-loam to silty-clay. Moisture content is generally medium to high.

2.2.2.4. Zone D (more than 4.5 metre)

Kakdwip corner is the only patch of this zone, where water depth sometimes goes down to more than 6 metre. Soil is predominantly clay, moisture content is medium to high.

In conclusion, it may be said that spatial dimensions of different zones have a consonance with physiographic maturity of the land except in the areas under Mandirbazar and Joynagar.
police station. In Mandirbazar and Joynagar, existence of the Adiganga course and Magrahat marsh have modified the situation. Although the land is matured here, water table is low.

The following summarised table has been computed from the values of groundwater to provide a comprehensive idea.

**TABLE 11**

**GROUNDWATER ZONES AND LANDFORM**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth of Groundwater table (in metre)</th>
<th>Condition of the land</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
<td>Rainy</td>
</tr>
<tr>
<td>D</td>
<td>more than 4.50</td>
<td>more than 1.00</td>
</tr>
<tr>
<td>C</td>
<td>3.00-4.50</td>
<td>0.70-1.00</td>
</tr>
<tr>
<td>B</td>
<td>1.50-3.00</td>
<td>0.40-70</td>
</tr>
<tr>
<td>A</td>
<td>less than 1.50</td>
<td>less than .40</td>
</tr>
</tbody>
</table>

**2.2.3. Influence of River on Water Table and Salinity of Groundwater**

The littoral tract being criss crossed by tidal channels has every possibility of getting salinised even below surface. As mentioned in the earlier section, that a small rain water enclave used to develop in the immediate subsurface. This enclave plays a very significant role in
determining the salinity of soil and hence extends its influence on the agricultural landuse also.

To study the influence of tidal water on water table and salinity of groundwater two parameters, namely (1) depth of water table from ground level and (2) pH of water are considered. Data have been recorded for river water and underground water in each month of the year 1977 at Mandanagar in Gosaba police Station.

### TABLE 12

MONTHLY RECORDINGS OF PARAMETERS

<table>
<thead>
<tr>
<th>Month</th>
<th>Depth of sub-tidal soil in G.L. (m)</th>
<th>Mean difference in depth of sub-tidal soil and river water current from G.L. (m)</th>
<th>pH of sub-tidal soil</th>
<th>pH of river water</th>
<th>Ratio of pH of soil to pH of river water</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-1.35</td>
<td>-1.92</td>
<td>7.2</td>
<td>7.6</td>
<td>0.947</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>-1.50</td>
<td>-1.92</td>
<td>7.2</td>
<td>7.6</td>
<td>0.947</td>
<td>51.5</td>
</tr>
<tr>
<td>March</td>
<td>-1.95</td>
<td>-1.95</td>
<td>7.4</td>
<td>7.4</td>
<td>1.00</td>
<td>97.7</td>
</tr>
<tr>
<td>April</td>
<td>-1.87</td>
<td>-1.95</td>
<td>7.8</td>
<td>7.5</td>
<td>1.04</td>
<td>5.1</td>
</tr>
<tr>
<td>May</td>
<td>-1.52</td>
<td>-1.82</td>
<td>7.8</td>
<td>7.8</td>
<td>1.00</td>
<td>145.8</td>
</tr>
<tr>
<td>June</td>
<td>-1.17</td>
<td>-1.82</td>
<td>7.4</td>
<td>7.6</td>
<td>0.974</td>
<td>200.5</td>
</tr>
<tr>
<td>July</td>
<td>-0.13</td>
<td>-1.85</td>
<td>7.3</td>
<td>7.5</td>
<td>0.973</td>
<td>540.9</td>
</tr>
<tr>
<td>August</td>
<td>+0.15</td>
<td>-1.92</td>
<td>6.5</td>
<td>7.2</td>
<td>0.925</td>
<td>482.4</td>
</tr>
<tr>
<td>September</td>
<td>+0.10</td>
<td>-1.95</td>
<td>6.4</td>
<td>7.1</td>
<td>0.201</td>
<td>236.5</td>
</tr>
<tr>
<td>October</td>
<td>+0.12</td>
<td>-1.92</td>
<td>6.8</td>
<td>7.2</td>
<td>0.944</td>
<td>201.7</td>
</tr>
<tr>
<td>November</td>
<td>-0.20</td>
<td>-1.90</td>
<td>6.7</td>
<td>7.3</td>
<td>0.918</td>
<td>3.3</td>
</tr>
<tr>
<td>December</td>
<td>-0.82</td>
<td>-1.80</td>
<td>7.2</td>
<td>7.3</td>
<td>0.986</td>
<td>6.6</td>
</tr>
</tbody>
</table>

(-) indicates below ground level (G.L) (+) indicates above ground level (G.L)
RELATIONSHIP OF GROUND WATER AND
RIVER WATER

Soil pH
River Water pH
River Water Depth

Fig. 17
The monthly recordings on water tables have indicated that the two levels are separated by more than 2 metres in August, September, October and almost converge in March and April (Fig. 17). Considerable water logging is observed in August to October due to heavy downpour. This substantiates that over the saline water table a sweet water enclave of rainwater develops in each year. This accumulation increases rapidly from June-July as a consequence of monsoon. In August it reaches its maximum width of 2.07 metres, which gradually decreases to nil in the month of March. It indicates that the enclave of sweet water is completely dried up in the month of March. pH value of 7.4 for both the water is a positive indication of their uniform characteristics. From the month of April, the rain water enclave starts to develop. The incrusted salts over the surface in the dry months are diluted by rainwater and accumulate at the groundwater level which is indicated by the higher pH value (7.8) of sub soil water. But as the monsoon approaches and establishes, the pH value of sub soil water gradually decreases. The pH value of 6.4 is marked in September for sub surface water when pH value of the river water reaches 7.1. The considerable difference between the sub soil water and tidal river water as is evident from the monthly pH recordings needs to be explained.

It is a fact that tidal water is denser (density $\rho = 1.025 \text{ gm/cm}^3$) than fresh water ($\rho = 1.000 \text{ gm/cm}^3$). So the rainwater can possibly be accumulated over saline water with marginal mixing at the interface.
In the estuarine deltas, the seasonal fluctuation of tide water pH is a regular phenomenon as a consequence of seasonal fluctuation of riverine discharges. In this area, the peak upland discharge is attained in the month of September.

It is likely that a part of the upland precipitation flows into this area through the fresh water aquifers at deeper layers of the sub soil. As a result, the saline prism is pushed back towards the sea front (Herman 1978). This saline prism will again advance inland as soon as the hydraulic pressure in the fresh-water aquifer declines. Such advances begin by November and reach its peak in the month of May (Chattopadhyay 1930).

The accumulated rain water column in the embanked islands develops a constant hydrostatic gradient which prevents the sub soil water to get salinised by the river water appreciably.

The fluctuation of salt water wedge in the estuaries, hydrostatic gradient of the accumulated rain water and the low density of the rain water combinedly control the hydroecological dynamics of this littoral tract.

It is observed that the process of reclamation is not likely to be jeopardised by salinity of tidal flow. The level of salinity of groundwater is found to oscillate within permissible limits.

2.3. CLIMATIC CHARACTERISTICS

In general, the study area lies within the tropical monsoon belt. Being located at the head of the Bay of Bengal, it is
conveniently placed to receive the full thrust of the south-west monsoon advancing over this region. The whole region is separated from the northern tract by 1650 mm isohytes with few exceptions like Hasnabad - Haroa area where rainfall is recorded to be less than 1650 mm. The climate is humid tropical (An of Trewartha). Maritime influence is recorded both in range and absolute temperature. The average annual rainfall in this region is 1650 mm. In some abnormal years this may be even a little over 2000 mm and in some subnormal years it is as low as 1500 mm. About 75 per cent of the annual rainfall occur in the months of June to October. Cyclonic storms are also frequent in the months of June to October.

2.3.1. Pressure

Surface pressure of 1003 mb separates the region from the rest in the summer season. The convex shape of the curve towards north-west for the whole of Bengal points to the dominance of the low pressure over the north-western part of India. Study of Koteswaram (1956) regarding the jet streams over the tropics indicates that the westerly jet stream at 1030 mb level is displaced to the north of the Himalayan block and the elongated trough extends from the north-western India to the eastern India following the latitude of 20°N in the monsoon months. In the way of fluctuation, this trough sometimes advances towards this region. An easterly current over southern Bengal is experienced in mid-June to September which...
concentrates along 15°N (Newell et al 1922). It generates some wave-like secondary wind maxima, which again in the form of jetlets traverse the region and inevitably claims utmost importance in the genesis of the climate of the region (Chatterjee 1972).

The direction of the pressure line is reversed to some extent in the winter season. It is dominated by anti-cyclones. Barometric pressure is generally below 1016 mb, which gradually increases to the north. Pressure gradient is lower in this season than that of summer.

2.3.2. Temperature

Temperature, as an essential element of climate, exerts influence on the agrarian economy of the region. Temperature is not uniform throughout the region. It is lower in the southern part in comparison to the northern. Lower temperature of the southern tract is associated with the maritime influence.

The month of January is the coldest when the isotherm of 13°C can separate the whole region from the rest of the delta. In this month, Sagar island registers a mean daily minimum of 16°C and the northern part records 13°C. This region experiences cold weather with minimum temperature of 6°C in some winter days when the western disturbance passes through. The estuarine influence over the region has also been manifested through higher temperature in winter compared
to the inland tract, though latitudinal difference is not high.

Temperature begins to rise from the month of February and reaches its maximum in the month of April-May. It is interesting to note that isotherms, which used to be convex to the region in January, become concave in May and the gradient changes from north to north-west direction. The southern most tract experiences the mean daily maximum temperature of 32.2°C whereas northern part records 35.3°C in the month of May. The maximum temperature of Sagar islands may go above 37.8°C in some abnormal summer days and then the temperature trend changes from south-north to north-south. Occasional drop in temperature in this season is evident due to the influence of Norwesters which cause rainfall and thunderstorms in the afternoon hours. It has also been observed that intra-regional variation of temperature is higher in the summer than in the winter. The estuarine influence on summer temperature is also indicated by the westward trend of temperature gradient. The seasonal variation of temperature in the Sagar island is less than that in the northern fringe.

2.3.3. **Sunshine**

Along with the temperature and rainfall, the factor that is expected to contribute significantly to the performance of crops is the amount of sunshine. Separate figures for the intensity of light or hours of bright sunlight for any other weather
station than Chinsura (which is 60 km north of the region) is available. The duration of actual hours of bright sunshine increases gradually from 8.9 in January to 9.6 in May. Thereafter, the hours fall rather rapidly down to 4.7 in July rising again gradually to 9.2 in December. This actual trend is much dependent on the character of the monsoon and associated cloud formation. It will be evident from the table given below that possible hours of bright sunshine may greatly vary from the trend described above, for example, a drought in July (in an unusual year) may extend the bright sun period to 13.5 hours as against the actual 4.7.

**TABLE 13**

<table>
<thead>
<tr>
<th>Month</th>
<th>Bright sunshine Possible</th>
<th>Bright sunshine Actual</th>
<th>Evaporation in mm West Bengal average</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>13.2</td>
<td>9.1</td>
<td>131</td>
</tr>
<tr>
<td>June</td>
<td>13.5</td>
<td>6.2</td>
<td>118</td>
</tr>
<tr>
<td>July</td>
<td>13.5</td>
<td>4.7</td>
<td>95</td>
</tr>
<tr>
<td>August</td>
<td>13.0</td>
<td>5.0</td>
<td>78</td>
</tr>
<tr>
<td>September</td>
<td>12.4</td>
<td>5.9</td>
<td>73</td>
</tr>
<tr>
<td>October</td>
<td>11.7</td>
<td>7.4</td>
<td>83</td>
</tr>
<tr>
<td>November</td>
<td>11.1</td>
<td>9.1</td>
<td>85</td>
</tr>
<tr>
<td>December</td>
<td>10.7</td>
<td>9.2</td>
<td>77</td>
</tr>
<tr>
<td>January</td>
<td>10.8</td>
<td>8.9</td>
<td>81</td>
</tr>
<tr>
<td>February</td>
<td>11.3</td>
<td>9.3</td>
<td>98</td>
</tr>
<tr>
<td>March</td>
<td>11.9</td>
<td>9.3</td>
<td>184</td>
</tr>
<tr>
<td>April</td>
<td>12.6</td>
<td>9.6</td>
<td>203</td>
</tr>
</tbody>
</table>

Source - ICAR Hand Book of Agriculture 1967
2.3.4. Wind and Storm

The plants are also benefited by winds as they bring moisture from water bodies and make the plants alive. The direction of wind is usually guided by the monsoons and north-westers. Wind direction is south-westerly in the monsoon and it is northerly in the winter.

Two full fledged meteorological stations are situated at the southern tip (Sagar Island) and northern adjoining areas (Alipore). The annual march of wind velocity shows the minimum in winter and with the advent of summer the velocity increases having the maximum in April. In the coastal areas, the velocity is higher ranging from 16 to 25 km/hour for at least five months.

2.3.4.1. Cyclonic Storms

A number of studies have been done regarding the cyclones and depressions in the Bay of Bengal (Mukherjee et al. 1982). In the norwester period i.e. from mid-April to mid-June, sudden storms are generated in the evening. Cyclones may occur in October-November in some years. In the Bay of Bengal, several tropical storms are cyclonic in character. The most important factor which favours the development of cyclonic storms is the prevalence of moist warm winds. These storms grow gradually till the maximum intensity is reached; some storms extend over wide areas with low pressure gradient, but some are concentrated over small area with steep pressure gradient outside the centre. Wind velocity is the strongest in periphery
but within the centre it is mild. The western part of the region is sometimes totally covered with depression and experience high wind velocity.

The tidal water swells up due to high wind pressure and occasionally it crosses over the anticipated high water level. Cyclonic storms and the resultant storm surge levels are very important from the hydraulic point of view in as much as they influence the levels upto which river water may rise and the levels upto which protection is desired. It is observed by the MONEX (Sivaramakrishnan 1982) in the month of August (20th to 22nd) 1977 that the average height of the swells may go upto 3.8 metre at 20/21° latitude. Coincidence of this height with the high tide in the estuarine region may over flow the embankments.

An analysis of 60 years climate data collected from the Indian Meteorological Department gives an idea regarding cyclonic frequency in different months and their related characteristics. The most severe cyclone occurred in October, 1942 when maximum wind speed was recorded as 225 km/hour and high water level was about 3.5 metres, 2 metres above the anticipated level.

Monthly summarised note: Cyclonic frequency and characteristics are discussed for all the months to have a comprehensive idea.

January : No Cyclone
February : No Cyclone
March : No Cyclone
April : South west winds occasionally advance across the entrance of the bay and then retreat
May: Cyclonic storms are of comparatively frequent occurrence in the Bay during May (two times in every three years) and are occasionally of exceptional strength and vigour. They usually travel in a northerly direction and turn to the north-east in the later stages of their journey.

June: This is the month of monsoon when cyclonic storms usually come from north of latitude 19°N. It occurs once or twice every year.

July: The monsoon has already set up well, so winds blow steadily and strongly. Cyclonic storms though frequent, twice or thrice every year, are of low intensity.

August: The south-west winds blow less steadily than in July and show characteristics like that of July.

September: Cyclonic storms are usually originated further south near about 16°N and have low intensity. These cyclonic storms resemble the storms of July and August in general character. Occasionally, storms of higher intensity may also occur.

October: This is the month of retreating monsoon when north-west winds prevail to the northern part of the Bay, whereas south-west winds still persist in the southern part of the Bay. This is most dangerous for the region because a marked tendency of cyclonic storm formation is always present.
Many of the storms originated in this month develop cyclones. Its direction may also fluctuate.

November: The south-west winds retreats cyclones generally originate south of 16°N latitude and are less frequent over the land. The chances for a storm to develop into a cyclone are about two to one.

December: In this month south-west winds retreat considerably and within the third week of this month the winds are totally withdrawn and storms are of rare occurrence.

2.3.5. Thermal Efficiency Index

Thermal efficiency index is relatively more important than absolute temperature from the stand point of agriculture. But data of evapo-transpiration are not available for all the stations. Hence a simplified formula used by Thornthwaite (Klages 1942) is followed here. According to Thornthwaite temperature efficiency index or thermal efficiency index (I) can be represented as:

\[ I = \frac{12(T - 32)}{4} \times N \]

where:
- \( T \) = Average temperature of each month in °F
- \( N \) = number of months

This index has been calculated for different stations (Table 4 Appendix - 1) and it is observed that the highest value of I (143.63) is recorded in the Hasanabad plain and
MONTHLY DISTRIBUTION OF T-E VALUE
the lowest (137.74) is in Namkhana - Kakdwip plain. It is 142.34 in Sagar island. According to this index there is no specific drought condition in this region (Fig.18). But due to salinity of soil edaphic drought is evident.

2.3.6. Precipitation

Rainfall is undoubtedly the most important constituent element of climate. The region experiences 1750 mm rainfall on an average with a decreasing trend from south to north (Fig.19). The highest rainfall (1802.7) mm has been recorded in Gosaba village. The greater part of this rainfall is concentrated in the four months (June, July, August and September) of the south-west monsoon, when about 75 per cent of the annual rainfall occurs. Besides this, rainfall is caused in the summer by the norversters and in the winter from the western disturbances. Rainfall caused by the norversters is always more than that of the western disturbances.

The south-west monsoon usually arrives at the region by the second week of June. Arrival of monsoon is few days earlier in Sagar island than in the rest of the tract. Southern part of the region receives more rainfall in the monsoon than the rest, but in winter and summer the northern part receives more rain than the south. Total rainfall in the region in four monsoon months (June, July, August and September) is more than 1400 mm. On an average, the region experiences 75 rainy days in a year. This average number varies from place to
place. It is 71 days in the northwestern plain whereas in
the northeastern plain it is 78 days.

2.3.6.1. Seasonal Distribution of Rainfall

Distribution of rainfall may be studied in seasonal
context also. The monsoon usually bursts into the region in
mid-June. Heavy shower starts from this month and prolongs
upto September. In the month of October and May, a consider­
able amount of precipitation may also be marked due to the
norwesters and other tropical storms. Three different seasons
have been identified within a year.

1) Wet season - June, July, August, September and October
2) Nor-westers - March, April and May
3) Cold season - November, December, January and February

TABLE 14

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Recording station</th>
<th>Rainfall in different seasons</th>
<th>Month and amount of rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>Cold</td>
</tr>
<tr>
<td>North-Eastern</td>
<td>Basirhat</td>
<td>1294.9</td>
<td>58.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(80.02%)</td>
<td>(3.61%)</td>
</tr>
<tr>
<td>North-Western</td>
<td>Diamond Harbour</td>
<td>1415.8</td>
<td>90.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(81.89%)</td>
<td>(5.24%)</td>
</tr>
<tr>
<td>Central</td>
<td>Canning</td>
<td>1325.2</td>
<td>35.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(82.60%)</td>
<td>(2.2%)</td>
</tr>
<tr>
<td>South-Western</td>
<td>Sagar</td>
<td>1505.4</td>
<td>49.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(86.89%)</td>
<td>(2.88%)</td>
</tr>
<tr>
<td>South-Eastern</td>
<td>Gosaba</td>
<td>1572.1</td>
<td>41.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(84.40%)</td>
<td>(2.20%)</td>
</tr>
</tbody>
</table>

Source: Table 4 Appendix - 1. Figures in the bracket are the percentage share.
More than 82 per cent of total rainfall occurs in the wet season followed by the norwesters (13 per cent) and the cold season (3 per cent). December and January are months of the minimum rainfall (2-14 mm), and the maximum rainfall is recorded in the months of July and August. Three stations (out of five) record the highest rainfall (344.9 mm to 375.4 mm) in July the rest two in August (324.4 - 462.4 mm).

2.3.6.2. Regional Profile

Intra-regional variation of rainfall is also evident from the Table 10. Southern part of the study region receives more rainfall than the north. 80 per cent of the total rainfall occurs in the wet season in the northern part and it is round about 85 per cent in the southern part. The northern part receives more rainfall (round about 15 per cent) than the southern part (round about 10 per cent) in the norwester's period. Rainfall due to the norwester's is caused by the western disturbances. Since this rain bearing wind approaches from north-west, the north-western part of the region receives heavy down pour. But this rainfall variation has little impact over the crop production.

**TABLE 15**

<table>
<thead>
<tr>
<th>Season</th>
<th>Sagar</th>
<th>Basirhat</th>
<th>D. Harbour</th>
<th>Canning</th>
<th>Gosaba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>5.81</td>
<td>-8.93</td>
<td>-4.48</td>
<td>-6.85</td>
<td>10.50</td>
</tr>
<tr>
<td>Norwesters</td>
<td>23.52</td>
<td>14.28</td>
<td>-3.97</td>
<td>5.18</td>
<td>7.51</td>
</tr>
</tbody>
</table>

Source - Table 4, Appendix - 1.
It is clear from the above table that the intra-regional variation of rainfall is more in the norwester period than in the wet season. Sagar island, the southernmost point of the study region, receives the lowest rainfall in the norwester's period and it records the second maxima in the wet season.

2.3.7. Ombrothermic Analysis

This analysis is carried out to get a climatic pattern, which emerges from a combined graph of rainfall and temperature (Fig. 20). Superimposition of rainfall and temperature curves for a whole year taking a common base line has resulted in identifying three periods namely; dry period, wet period and a transition.

The dry period starts from November and lasts till 1st half of April in Sagar island. 165 days out of 365 days in a year are dry with bright sunshine of 9 hours/day on an average with a temperature fluctuation from 20\(^\circ\)C to 26\(^\circ\)C. Preceding and following the wet period two transitional periods of short duration may be recorded. The 2nd half of April to 1st half of May and 2nd half of October may be considered with different thermal efficiencies, which are indicated by the rate of evaporation of 203 mm and 83 mm respectively. Though rainfall starts in the end of April, temperature continues to be high resulting in the maximum evaporation. Duration of bright sunshine per day is less (7.4) in October than in the coming months. Moreover, due
to heavy rainfall just in the preceding months, the moisture in air is slightly higher. This combinedly results in less evaporation (88 mm) inspite of high temperature (27.6°C).

The wet period actually starts with the onset of the monsoon. It covers about six months when bright sunshine is available for 6 hours/day on an average. Evaporation in this period is naturally less. September, the month of lowest evaporation (73 mm) rate, receives 273.3 mm rainfall with average temperature of 23.6°C.

The dry period starts slightly earlier in the northern part of the region than in the south. It also prevails upto the end of April, but the transitional period is shorter than that in the south. It has already been discussed that the northern part receives more rainfall from the norwesters. Following this rainfall, monsoonal rain comes which makes the climate wet. But it is also to be noted that temperature in the dry period is slightly lower in the southern part than in the northern tract. The pattern of rainfall curve in the northern part is also different from that of the southern. A sharp drop from the maximum, particularly from September to October has shaped the northern curve somewhat different compared to the curve at Sagar where the drop is not so sharp.

In fine, it can be said that though climatic characteristics of the micro-regions do not vary conspicuously they however, permit construction of an ombrothermic diagram for facilitating conclusions.
2.4. SOIL

The soil of the tract in general may be termed as "Salinised new Ganga alluvial". The silt and clay roods carried down into the sea undergo partial transformation in their exchange complex due to the exchange reaction with salts of the sea water. These partially transformed soil constituents are carried with tidal water and are deposited in the flood plains.

2.4.1. Soil Association

The salinised soil, thus deposited are subjected to two principal soil forming agencies: (1) rain water and (2) sea water (Mukherjee 1970).

Due to rain water, the following changes are recorded in the nature of the deposits:

(a) The soluble salt in the soil is partially leached away. If this leaching process acts over a soil whose original deposit does not contain dolomite, and sodium ion enters into the exchange complex in presence of excess salt, saline alkali soils are produced.

(b) When the soluble salts get completely leached away and the exchange complex is filled up by sodium ions, non-saline alkali soils are produced.

(c) If this process takes place in presence of buried half decomposed organic matter then degraded alkali soils or saline turf soils may be produced.
When sea water takes part in the leaching process sodium ions enter into the exchangable complex of the saline soils and also form saline alkali soils. Hence four types of soils may be recorded within the coastal soils (Fig. 21) of tidal origin (Mukherjee 1970, Bhattacharya 1972).

**TABLE 16**

SOIL ASSOCIATION AND THEIR CHARACTERISTICS

<table>
<thead>
<tr>
<th>Association</th>
<th>Salt (in per cent)</th>
<th>Exchangable sodium in per cent</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saline soil</td>
<td>more than 0.15</td>
<td>less than 15</td>
<td>less than 7</td>
</tr>
<tr>
<td>Saline alkali soil</td>
<td>more than 0.15</td>
<td>more than 15</td>
<td>more than 7.5</td>
</tr>
<tr>
<td>Non-saline alkali soil</td>
<td>more than 0.15</td>
<td>more than 15</td>
<td>more than 8</td>
</tr>
<tr>
<td>Degraded alkali soil</td>
<td>...</td>
<td>more than 15</td>
<td>more than 4.6</td>
</tr>
</tbody>
</table>

2.4.1.1. Saline Soil

Saline soils are largely found in the flood plains of the rivers and in depressions. This type of soil has developed in the north-eastern plain, the tract bounded by the Donsa in the east and Chotokalagachi in the south and in the marshy chain in Haroa. In the central and south-eastern plains, a tract bounded by the Matla in the western and southern side is also found to have the same type of soil.

2.4.1.2. Saline Alkali Soil

This soil is also found in depressions and river beds, but the interaction between the present deposit and the saline tidal back rushes are yet to be completed. The south-eastern plain (Sagar, Kakdwip, Namkhana and Pathar Pratima)
and a part of the north-western plain (in Kulpi and Mathurapur) are the major areas of this soil group. In the central and south-eastern plains a considerable coverage may also be marked.

2.4.1.3. Non-saline Alkali Soil

A considerable portion of the adjacent areas of the three plains and portions in the west of the Matla (Mathurapur) are under non-saline alkali soils. This patch is surrounded by the saline soil boundary and cannot be traced anywhere else.

2.4.1.4. Degraded Alkali Soil

Leaching of these soils, especially in presence of decomposed vegetation within 4 to 6 feet below the surface, has led to the formation of organic acids. The combined action of organic acids and excess salt upon tidal deposits has given rise to this type of soil. The eastern part of this tract bounded by the Hana, Char Baidya Khal Attharabanka and Tushkhali Khal is constituted by this type of soil.

The table (No. 16) given above will bring clear idea about the exchangeable sodium and pH value of the soil. This slightly acidic soil does not pose any hindrance to the cultivation for aman paddy. This region has an extra advantage of heavy rainfall which washes out the salt incrustation. This salt is incrusted over the land surface due to capillary action in the dry period of the year.
2.4.2. Soil Texture

The coastal soil consists mostly of silt, clays and fine sands; coarse sand is almost absent. Therefore, the texture is fine. Soils of this region may be divided into six textural categories, namely, clay, silty clay, clay loam, silty loam, silty clay loam and sandy soil (Fig. 22). This classification is according to the percentage variation of the soil components. Clay loam, silty clay loam and silty loam have the maximum coverage though other categories are also present. Predominance of clay is mostly seen in the mud flats and in saline marshes. Normal estuarine depositions are characterised by silty soils.

TABLE 17

SOIL TYPE - THEIR MECHANICAL COMPOSITION

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(in per cent)</td>
<td>(in per cent)</td>
<td>(in per cent)</td>
</tr>
<tr>
<td>Clay</td>
<td>less than 40</td>
<td>less than 40</td>
<td>more than 40</td>
</tr>
<tr>
<td>Silty clay</td>
<td>less than 20</td>
<td>20 - 60</td>
<td>40 - 60</td>
</tr>
<tr>
<td>Clay loam</td>
<td>20 - 45</td>
<td>15 - 55</td>
<td>27 - 40</td>
</tr>
<tr>
<td>Silty Loam</td>
<td>less than 50</td>
<td>50 - 88</td>
<td>less than 27</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>less than 20</td>
<td>40 - 72</td>
<td>28 - 40</td>
</tr>
<tr>
<td>Loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy Soil</td>
<td>more than 85</td>
<td>less than 15</td>
<td>less than 10</td>
</tr>
</tbody>
</table>

Source - Thompson L M & Trosh F.R. (1979)

2.4.2.1. Clay Soil

Clay percentage is more than 40 and fine sand is less than 40. In the north-eastern plain, this soil is mostly found in the marshy lands adjoining Haroa plain. Similar soils have also occupied a considerable area in the south-western plain over the Kakdwip mud flats. A high
percentage of clay particle makes the soil sticky in wet period and hard in dry period. Due to the high plasticity of clay soil, tendency towards water logging in rainy season is a regular phenomenon here. In the summer, mud cracks are conspicuous features of the landscape. This type of soil is not very suitable for agriculture.

2.4.2.2. Clay Loam

It comprises 27 per cent to 40 per cent clay, 15 per cent to 55 per cent silt and an insignificant amount of sand. In the central plain near the Matla, a patch of typical clay loam is seen. Its coverage is insignificant in comparison to other soil groups. Moisture rententive capacity of this soil is high and it contains low organic matter.

2.4.2.3. Silty Loam

This type of soil is predominant in the riverine tracts of the Ichhamati and Hooghly. Usual sites are Nadia-Bangla, Hingalganj and Kulpi - Mandir Bazar plains, where landforms are matured. The percentage of silt is 50 or more, of clay is 20 and of sand is 15 to 20. This soil is not rich in organic matter but is agriculturally very productive. A variant of this soil is found in the old beds of the Ganges.

2.4.2.4. Silty Clay Loam

This type of soil has the maximum coverage. It bears a close similarity with silty loam in properties. Only a higher percentage of clay characterise this soil. This type is largely found in the south-western and south-eastern plains. This also shows a tendency of water logging. The presence of organic matter in this soil is less than that in the silty loam hence agricultural productivity
2.4.2.5. Silty Clay

Soil that contains 40 per cent to 60 per cent clay and 20 per cent to 60 per cent silt comes under this group. Coverage of this soil group is also very insignificant.

2.4.2.6. Sandy Soils

This type of soil has developed along the sea coast. Its coverage is limited in Sagar island, Fresherganj, Kalas island etc.

2.4.3. Taxonomical Classification

Five family classes are present in this region (Fig. 23). Their identification is based on the particle size (Johnson 1981).

2.4.3.1. Sandy

This is a fine earth, whose texture is defined by presence of loam in coarse sand. It can also be composed of coarse sand alone. Very fine sand is conspicuously absent. The clay fraction is less than 10 per cent. Areas along the sea face of the islands such as Sagar, Fresherganj and Kalas are normally covered by this soil.

2.4.3.2. Coarse Loamy

By weight 15 per cent or more of the particles are fine sand (diameter 0.25 - 0.1 mm) including fragments up to 7.5 cm in diameter. Clay proportion in the fine earth fractions is less than 18 per cent. This type of soil has been developed in the north-western plain and is also found
in parts of Joynagar, Natrapur and Mandir Bazar. The water holding capacity of this soil is not very high. Agriculturally, the soil is productive one. Different types of crops usually grow in the area under this soil.

2.4.3.3. Fine Loamy

By weight 15 percent or more of the particles are fine sand (diameter 0.25 - 0.1 mm) including fragments upto 7.5 cm in diameter. Percentage of clay in the fine earth fraction is 18 to 34. This type of soil has the maximum coverage. The whole western part of the region more or less is covered by this fine loamy soil. A part of the Hasnabad-Haroa plain is also under this type of soil.

2.4.3.4. Fine Silty

A small patch of this soil is seen in Joynagar police station at the northern periphery of the north-western plain. It contains less than 15 per cent of fine sand (diameter 0.25 - 0.1 mm) and 18 per cent to 34 per cent of clay. This soil is also productive, its moisture retentive capacity being high.

2.4.3.5. Fine

This soil contains clay percentage of 35 to 59 in fine earth fraction. A strip of land along the upper reaches of the Thakuran and around the trijunction of Kakdwip, Kulpi and Pathar Pratima show development of this
soil type. The whole of the south-eastern plain lying
south of the Dansa River and along the Haroa Gang includ­
ing marshes of Haroa is covered by this soil. This soil
is characterised by a good moisture retentive capacity.

2.4.4. **Soil Moisture**

Soil moisture is an essential determinant of soil
quality. The moisture retentive capacity of a soil is a
function of the amount of clay it contains. Short duration
crop may be cultivated in the dry period with the residual
moisture. In this region, the air dry soil moisture varies
from 2 per cent to 6.9 per cent. The whole region is classi­
fied into three categories (Fig.24): high (more than 4 per
cent) medium (3 per cent - 4 per cent) and low (less than 3
per cent).

2.4.4.1. **Regional Distribution**

In general, the moisture content of the soil is low.
Isolated patches of high moisture regime are marked in almost
all micro regions. A high moisture regime is experienced in
Kakdwip, Kulpi, Pathar Pratima and adjoining tracts, where the
clay proportion is more. Such a high moisture regime can also
be seen in the southern parts of Sagar island and the Hasnebad -
Hingalganj tract along the Ichhamati. But it is interesting to
note that the Matla and Kalagachi riverine tracts, though
covered with mostly fine textured soils, have a low moisture
regime. A positive relationship between clay and moisture
content exists in the matured delta areas (Fig.25). Tracts
DISTRIBUTION OF CLAY

DISTRIBUTION OF SOIL MOISTURE

GRAPHICAL CORRELATION OF CLAY AND A.D.M. IN DIFFERENT PLAINS ALONG DEPTHS (upto 125 cms.)
with high moisture regime lie in relatively high levee areas where delta building activities have ceased.

### TABLE 18
**SUB REGIONAL CHARACTERISTICS OF SOIL MOISTURE & CLAY CONTENT**

<table>
<thead>
<tr>
<th>Micro regions</th>
<th>Soil moisture (in per cent)</th>
<th>Clay content (in per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North eastern plain</td>
<td>2.3 to 5.1</td>
<td>28 to 52</td>
</tr>
<tr>
<td>North western plain</td>
<td>1.0 to 6.9</td>
<td>16 to 42</td>
</tr>
<tr>
<td>South western plain</td>
<td>2.1 to 5.6</td>
<td>24 to 47</td>
</tr>
<tr>
<td>Central plain</td>
<td>2.6 to 4.4</td>
<td>30 to 49</td>
</tr>
<tr>
<td>South Eastern plain</td>
<td>2.9 to 4.7</td>
<td>38 to 50</td>
</tr>
</tbody>
</table>

Source: Table 5 Appendix - 1

The natural process has been disturbed to a considerable extent in the reclaimed area, therefore a clear cut relationship between soil moisture and clay content is not evident. The maximum moisture content of soils in the north-western plain is 6.9 per cent but the maximum clay content of the same soil is 42 per cent whereas in the south-eastern plain, soils of maximum clay content (50 per cent) have moisture potentiality of 4.7 per cent only. In the elevated tracts along the Ichhamati, soils containing 50 per cent clay have 4.3 per cent to 4.7 per cent moisture. In the Sagar island, soils having 4.5 per cent to 5.5 per cent moisture contain 43 per cent to 47 per cent clay. Soils of silty clay texture contain higher moisture in general.
2.4.5. Soil Fertility

Soil fertility depends largely on the distribution of nitrogen (N), Phosphorus (P₂O₅) and potassium (K₂O). In general, the region is included in the zone of low nitrogen, medium phosphorus and potassium as is indicated by the report of the National Commission on Agriculture. It is obvious that the report considers only district level averages. When a part of the district is separately studied, the picture may be quite different.

A national level chart of fertility grading has been prepared by I.C.A.R. It is admitted that nutrients are not interchangeable with one another. If a parcel of land is deficient in Nitrogen then extra phosphorous or potash cannot overcome that deficiency, so also for others. Hence high, low and medium categories of each nutrient are treated separately.

TABLE 19

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Nitrogen</td>
<td>less than 250</td>
<td>250-500</td>
<td>more than 500</td>
</tr>
<tr>
<td>Available Phosphorus</td>
<td>less than 20</td>
<td>20-50</td>
<td>more than 50</td>
</tr>
<tr>
<td>Available Potash</td>
<td>less than 125</td>
<td>125-300</td>
<td>more than 300</td>
</tr>
</tbody>
</table>

Source: Soil testing in India (1966)
From this table percentage figure can be calculated taking one acre of land with 6 inch depth containing 2,000,000 lbs of soil.

**TABLE 20**

**FERTILITY GRADING CHART BY PERCENTAGE FIGURE**

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Nitrogen</td>
<td>less than .013</td>
<td>.013 - .25 more than .025</td>
<td></td>
</tr>
<tr>
<td>Available Phosphorous</td>
<td>less than .001</td>
<td>.001 - .003 more than .005</td>
<td></td>
</tr>
<tr>
<td>Available Potash</td>
<td>less than .006</td>
<td>.006 - .012 more than .012</td>
<td></td>
</tr>
</tbody>
</table>

This chart has been prepared on an all Indian basis, for a particular region this range may not be ideal for classifying lands. A modified gradation chart has therefore been prepared for the study area.

**TABLE 21**

**FERTILITY GRADATION FOR THE STUDY AREA**

![](values are in percentage)

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>less than .05</td>
<td>.05 - .10 more than .10</td>
<td></td>
</tr>
<tr>
<td>Phosphorous</td>
<td>less than .10</td>
<td>.10 - .15 more than .15</td>
<td></td>
</tr>
<tr>
<td>Potash</td>
<td>less than .90</td>
<td>.90 - 1.30 more than 1.30</td>
<td></td>
</tr>
</tbody>
</table>

NPK value obtained from the sample study indicates the total amount but not necessarily the available amount. The whole
region is deficit in nitrogen—It is very rich in K$_2$O followed by P$_2$O$_5$.

2.4.5.1. Distribution of Nitrogen

The alluvial soil contains little amount of nitrogen. Its distribution is also variable (Fig. 26). Four patches of low nitrogen can be identified on the map and it is interesting to note that their sites are located in the zone of higher elevation having some degree of maturity in landform than the surrounding regions. The Mandir bazar police station contains low nitrogen. Soils of the Joynagar Police Station contain high nitrogen and so also Hasnabad, part of Basanti, Sandeshkhali and Hingalganj Police Stations.

2.4.5.2. Distribution of Potassium

Soils of the region are very rich in K$_2$O (Fig. 27). The north-western, south-western and north-eastern plains contain very small amount of K$_2$O. Higher proportions are recorded in parts of the central and south-eastern plains. Major parts have the value lower than .90 per cent. Along the eastern border of the western Sunderbans a strip of land having medium grade value separates the patch from the western parts of Canning with high K$_2$O and the western Sunderbans with low K$_2$O. In Sagar island, a small patch has a medium status.
2.4.5.3. Distribution of Phosphorus

The region is rich in P₂O₅ in the Indian standard but most of the areas have medium grade status. Four isolated patches of higher grade can be marked (Fig. 28). The maximum coverage of the high grade lies in the north-western part. A considerable area around Canning has also high grade status, so also for a strip of land in southern Hingalganj and southern most islands of Pathar Pratima. In Haroa Police Station, the marshy land sites register low grade status. The northern tip of Sagar island also lies in the low category.

2.4.6. Study of Some Typical Soil Sections

Soil sections have been examined in five micro regions (Fig. 29). Considerable variations are marked (Table 6, Appendix 1) in their characteristics. The following discussion will bring forth the micro regional variation in soil characteristics.

2.4.6.1. North-western Plain

The texture of the studied soil section in this plain is Sandy loam. Proportion of fine sand, silt and clay in the first 25 cm depth are 66 percent, 19 per cent and 15 per cent respectively. Coarse sand is almost absent. Percentage of fine sand gradually decreases from 66 per cent in the upper part to 46 per cent at the bottom of the section. With the gradual increase of clay, soil
CHARACTERISTICS OF SOIL SECTION (SELECTED)

SAHDESHKH ALI
JL No 44

REFERENCE
N
P2°l
K,0
wss
A DM
CLAY
SILT
SAND

KAKOWIP
JL No 27

HASNABAD
JL No 35

SANDESHKHALI
JL No 44

SAGORE
JL No 121

KULPI
JL No 69

Fig. 29
moisture increases. Below 25 cm the soil is moist one, though it is dry over the surface. pH value of the soil gradually becomes lower at increasing depths and water soluble salt increases from 0.32 per cent to 0.35 percent. Nitrogen content of the soil is also reduced and uniformity is marked in the case of $P_{2}O_{5}$ and $K_{2}O$ distribution. The soil has an alkaline tendency resulting in low productivity of rice.

Average depth of sub soil water is 1.5 metre and in rainy season water comes over the surface for some time. This lower depth of water and state of submergence for some period bring about some changes particularly in Oxygen compounds.

2.4.6.2. South-western Plain

The section is located at Ganespur in Kakdwip police station. The site of the section is flat and is situated on a matured land. Soil texture of the upper layer is loamy with pH value of 8.6. In the intermediate depth of the section, proportion of silt and clay increase and at the bottom, percentage of silt decreases with increasing clay percentages. Texturally, the profile is of silty clay loam at the sub-surface. This plain has been developed with riverine - estuarine deposits.

The moisture content of air dry soil increases with depth corresponding to clay proportions. pH value decreases with depth and so also the water soluble salts. Fertility of the lower layer continues to be the same.
2.4.6.3. Central Plain

This plain is characterised by silty clay type of soil. Percentage share of fine sand, silt and clay in the upper layer is 8 percent, 51 percent and 41 percent respectively. Percentage of fine sand and silt gradually decrease and clay material increases with depth. At a depth of 100 cms, clay records higher percentage than silt. Coarse sand is almost absent up to 50 cms, but afterwards, it may be detected to the extent of one percent only. The Bidhyadhari-Matla was once an active stream and carried riverine deposits, which are now overlapped by estuarine deposition. Soil moisture increases with depth corresponding to clay materials. pH value of soil drops to 4.4 at the bottom from 8.0 at the upper layer, though percentage of soluble salt increases by 0.46 percent to 0.62 percent.

Fertility status of the soil is more or less same with slight rise in nitrogen. Micro nutrients like $\text{Fe}_2\text{O}_3$, $\text{Al}_2\text{O}_3$, $\text{CaO}$, $\text{R}_2\text{O}_3$ are higher throughout the section.

Depth of water level is about 3.4 metres in summer and round about 1.0 metre in the rainy season. Water never comes over the surface. So the area is not depleted of Oxygen. Colour of the soil varies from grey to dark grey, softness increases correspondingly.
2.4.6.4. North-Eastern Plain

The sample site is located at Haroa. The soil sample comprises fine sand, silt and clay in the proportion of 12:41:46 respectively. Coarse sand is also present. The texture of the soil at the bottom of the section is loamy with 27.30 per cent of clay and 30.61 per cent of fine sand. Percentage share of silt is almost same throughout the section. Colour varies from Olive green to Olive yellow. Soil moisture decreases with the decrease in clay percentage. Upper layer marks neutral reaction but it, alkaline with depth. Water soluble salt increases from 0.16 percent to 0.18 per cent. The soil is rich in $\text{P}_2\text{O}_5$ and $\text{K}_2\text{O}$ nutrients, both of which show increasing value with depth. The fertilizers used by the farmers are mainly nitrogenous compounds, because the whole tract is deficit in nitrogen.

Like sections of other tracts, this profile is also rich in $\text{R}_2\text{O}_3$ and $\text{Al}_2\text{O}_3$. $\text{Fe}_2\text{O}_3$ is also present almost in equal proportion to other samples.

Depth of underground water level in summer is 0.4 metre and in the Rainy season, water logging condition is a common phenomenon during some of the rainy days.

The area was once under marshy condition hence clay content of the upper layer is more. The depressions allow accumulation of washed out materials from the surroundings. The result is that a higher percentage (0.65 percent) of coarse sands is met within the upper layer compared to that in the lower layer.
2.4.6.5. South-Eastern Plain

The section is located in the western side of the Bara Kalagachi river. This is a part of the intermediate sagged zone between two inter riverine tracts. Landform is at a very premature stage. Fine sand, silt and clay are in the proportion of 9:20:21 in the upper layer and 5:15:15 in the lower layer. This represents a texture varied from clay loam to clay. Clay fraction increases with depth, so also the soil moisture. It is interesting to note that soil texture varies from clay to clay loam or loam in the northeastern plain and in the south-eastern tract it is clay loam to clay. It indicates a reverse texture compared to the previous section. An idea about the depositional characteristics of these two areas may be obtained from the textural composition of soils. Marshy area, which has no outlet to get drained, allows deposition of the suspended particles within the depression on the basis of fractionation due to density. But for an area of tidal deposition, the picture is quite different. Back tides push back the flocculated materials produced as the result of solifluction. From a study of about 60 profiles a situation can be visualised in which the upper layer of deposition having clay moves with water keeping higher amount of silt back. As a result, lower layers are rich in clay but upper layers are rich in silt.

pH value gradually decreases to less than 5 indicating high acidity with tendency of degradation of soil status. In the central plain, the representative section also shows this character. Water soluble salts increase with depth.
The upper layer is usually found to be very rich in K$_2$O; P$_2$O$_5$ is also high but nitrogen is less. Amount of nitrogen and K$_2$O increase with depth but the amount of P$_2$O$_5$ decreases. Soil profile is very rich in R$_2$O$_3$, Al$_2$O$_3$ and Fe$_2$O$_3$. CaO is present almost in same proportion as in other sections but records decreasing value with depth. Water logging condition prolongs for considerable period in a year, and below 100 cm the soil profile is always invaded by water.

2.5. VEGETATION

Vegetation is the cumulative product of edaphic and climatic conditions; coastal soil with moist tropical climate allows to grow a special type of vegetation which is known as Mangrove.

Two main groups of plants develop in estuarine environments, namely, (1) marine plants which grow in the water including seaweeds (algae) generally develop on the surface of stable mud flats. (2) Maritime land plants, which are profoundly influenced by saline water but do not live in areas permanently covered with water. Within the estuarine environments, these maritime plants are typical in the salt marshes. Most salt marsh plants are flowering plants and they are known as halophytes (Salt loving plants).

In general, the area is famous for its beautiful mangrove vegetation. This 'mangal' or mangrove community can
be regarded as forming a distinct sub-group. Here the saline water estuaries and swamps influenced by the monsoonal and snow melt floods from the Ganges-Brahmaputra virtually become fresh water for some parts of the year. These conditions favour the development of Heritiera minor groups, which occupy large areas and are commercially valuable.

2.5.1. Vegetation Type and Characteristics

According to Champion (1936) two types of vegetation are recognised in this area: 1) Beach forest (2) tidal forest; Tidal forest is further sub-divided into (c) Low Mangrove forest, (b) Tree Mangrove forest, (c) Salt water Heritiera forest, (d) Fresh water Heritiera forests;

In the delta coast, beach forest is confined to a very narrow belt along the coastline particularly where sea sands comprise the major ingredient in the soil. Casuarina is the normal characteristic species and spinifex is the common maritime grass.

Sea face of the Sagar island near Ganga Sagar; Bakhali-Freserganj in Namkhana; 'Kalas' island at the Saptamukhi and Mechua island near the Raimangal are the places where sandy beaches have been formed and are the appropriate places of beach forest development.

Different sub-types of tidal forests have been developed according to the duration of tidal water over
the island. The locality factor and type of vegetation are provided in the Table 22.

At the time of reclamation, trees were so ruthlessly cut down that not a single species is seen. So demarcation of a particular zone of a special sub-type is quite difficult. But the presence of the species along creeks and channels outside the island and in the backyards of settlements have helped to some extent in this respect.

The vegetation type changes with distance from the sea face. But this change is not abrupt. From the seaface towards north, Low Mangrove, Tree Mangrove, salt water Heritiera and fresh water Heritiera are normal chronological order. After the zone of fresh water heritiera non-tidal forests appear. It indicates a separate geocological system. The study area is confined within littoral ecosystem and hence fresh water heritiera zone constitutes the northern boundary, which is already discussed in the delimitation section. Each sub-type is discussed below. Local names of the plants are used in the discussions and the botanical names are given in the Table 2, Appendix 2.

2.5.1.1. Low Mangrove Forest

Recently deposited soft tidal muds, submerged by every tide, may be considered as the normal sites for low mangrove forests. Along the delta face and within the estuaries, where new depositions become stable, this sub-type grows gregariously. Dense garaon (1 to 2 metre) dotted with
genwa (3 to 6 metres) form the basic mosaic of the submerged islands. They are all evergreen with leathery leaves. At the time of high tide, only upper parts of genwa are seen.

2.5.1.2. Tree Mangrove

Baen, kankra, dhundul, poohar, garan are the normal species with undergrowths of golpata, gulga and gabua where salinity of water is high and soil remains permanently wet. Stable mud banks of the delta stream, tails of islands near sea face where accretion is in progress this type has developed as closed evergreen forest with leathery and vivipary leaves.

2.5.1.3. Salt Water Heritiera

This type has been developed in brackish water zone where fresh water silt deposition occasionally intervene with tidal deposition. Stiff clayey soil with low humus content is much suited to this type. Forest is fairly dense with frequent stilt roots. Typical pneumatophores are also marked. The common species are sundri (though not seen in the study region) genwa, goren in the upper tier and dhundul, poohar, baen and kankra in the next. Golpata is not marked in this zone.

2.5.1.4. Fresh Water Heritiera

Where fresh water deposition is common, this type develops much. The Sunderban bile or marshes along the northern skirt of the region are the ideal sites of this transitional forest community. Beyond this, nontidal forest occurs. The stilt roots are rare but pneumatophores are much.
Complete three storied forest with different heights are common. Dhudul, poohar, kakra, baen and keora from the upper story followed by gongwa, hintal, goran, amur group. Harkuch kanta and panlata are also found.

2.5.2. Regional Distribution

It has already been discussed that the whole region was reclaimed by preventing tidal invasion and cutting down of forests. The southern part outside the embankment, that is, present reserve forest area shows the development of beach forests and three sub-groups (Low Mangrove, Tree Mangrove, Salt-water Heritiera) of tidal forests. The stable major islands are the sites of tree mangrove and salt water heritiera forests. The newly deposited sands at the delta face as well as within the estuaries are the sites of low mangrove forests. This reserve forest area once supplied all the fire wood and charcoal needed for the Calcutta region. Golpata are largely used for thatching the mud built houses. It is also used for preparing a special type of mat which is locally used. The different types of tidal species grow depending on (1) the degree of maturity of the islands, (2) salinity of the estuarine water and (3) the period of tidal inundation.

It is also a fact that tree mangrove, low mangrove and salt water heritiera may grow side by side according to their relative positions with respect to salt water interference. For example, in Namkhana island along the Saptamukhi, salt water heritiera may survive and the islands within the
<table>
<thead>
<tr>
<th>Type/ Submerging Condition</th>
<th>Salinity Locality &amp; Zone</th>
<th>Local name of the species</th>
<th>Max. height of the Deposition upper Canopy in metre</th>
<th>Agent of Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Beach Submerged at High Sea shore, sand dune &amp; beach Bola No Kanjanka, Kat-Dhani Karanja Jhau Harkuch Ban-Jhai Gor-lish Panlata</td>
<td>High Submerged at the base of the dune</td>
<td>10-12 Marine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Tidal Forest</td>
<td>High</td>
<td>Soft tidal mud Goran Har-Dhani No 3-6 Estuarine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.a. Low Mangrove Submerged at every tide</td>
<td>High in the newly Baen kuch grass deposited in- Goran Ked (Mare-land face with- Sun-grass) in estuary below dri</td>
<td>3-6 Estuarine</td>
<td></td>
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<tr>
<td>Category</td>
<td>Description</td>
<td>Typical Locations</td>
<td></td>
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<tr>
<td><strong>2b. Tree Submerged</strong></td>
<td><strong>High</strong></td>
<td>Mud banks Tials of islands near sea face where accretion has been started. More stable islands below MSL</td>
<td></td>
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<tr>
<td></td>
<td><strong>Low</strong></td>
<td>Mud flats stiff clay in the area along estuary, connected with sweet water flow above MSL but lower than H.T.L.</td>
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<tr>
<td></td>
<td><strong>Very low</strong></td>
<td>Marshes &amp; bils where rain water is accumulated and salinised by tidal water in the Keora Sunderban bils &amp; Ora Marshes along the nor-Baen thermal boundary above H.T.L.</td>
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</tbody>
</table>

Modified from Champion (1936) N.B. Local names of the plants are used - Botanical names of the plants are provided in Table 2, Appendix.
estuary, 'Henry Islands, possess low mangrove and tree mangrove. The new depositions beside a well developed island may contain low mangrove species only.

Trees are ruthlessly felled down in the reclaimed islands. So it is not possible to discuss elaborately regarding the vegetation of the plains as such, but a brief note is provided.

2.5.2.1. North-Western Plain

This plain, being matured, lies outside the embanked portion. Soluble salt in the soil is less than the southern tract. Kulpi was already recognised as a settlement where reclamation has been done years ago. With the deterioration of the Hooghly river, upward pull of tidal water has initiated regeneration of salt water plants along river side. In general, the plain show the character of fresh water plant sites. Few horkoch kanta with dwarf sized garcan are marked along the small tidal inlets. Panlata as a climber may be frequently noticed.

2.5.2.2. South-Western Plain

Low mangrove, tree mangrove and salt water heriteria all are seen in this tract. Though the whole plain is now inhabited, some reserve forest areas can be seen here and there. Plants have also developed along water courses outside the embankments. Lothian and Henry islands are fully forested. Newly deposited sands along the delta head also
shows the development of low mangrove forests. Sea beach with small dunes in Sagar island and Bakhali shows the development of beach forest. Most common plant casuarina, of beach forest is planted here by Government Forest Department.

Tree mangrove and salt water forests are marked throughout the plain. In the northern portion within Kakdwip, salt water heritiera are seen particularly along the Hooghly mouth. With completion of the Farakka Project, fresh water supply has been increased resulting in decrease of salinity to some extent. Besides, an extensive mud flat has developed here which also supports saltwater heritiera group.

2.5.2.3. North-Eastern Plain

Soil salinity of this plain is low. Some portion of this plain is higher than the surroundings and some portions are occupied by the 'bil' area. These bil's or depressions are the sites of seasonal fresh water deposition. Fresh water heritiera has developed in scattered areas. Tree mangrove forest and salt water heritiera are marked but low mangrove forest is rare. No specific forest area can be found in this plain. The characters stated above are mainly studied in the waste lands and along water courses.

2.5.2.4. Central Plain

Salt water heritiera and tree mangrove are found in the wastelands but low mangroves are common in the southern parts, where soil salinity is higher than the northern tract. Plants of fresh water Heritiera group are grown along the north-western border of Canning Police Station.
2.5.2.5. South-Eastern Plain

Tree mangrove and low mangrove forests are the typical vegetation. Salinity of soil is high. Hor kuch kanta has grown up in the elevated areas like Dutta Pasur in Hamilton abad. Along the Kalagabhi river, tree mangrove can be marked. Low mangrove forests are also seen beside tree mangrove in areas of low elevation. This plain is lower than the southern reserve forest area. Some of the islands possess salt water heritiria group.

2.6. PHYSICO-BIOTIC ENVIRONMENTAL MATRIX

The factors of physico-biotic environment have been discussed in detail in this chapter. This matrix has been worked out based on these discussions to understand the comparative situation of different plains with respect to the different environmental elements. This matrix will provide a comprehensive picture, which would be helpful to bring out the characteristics of the micro plains at a glance.
<table>
<thead>
<tr>
<th>Plains</th>
<th>Area under water bodies (percent of total area)</th>
<th>Stages of geomorphic features</th>
<th>Notable soil type</th>
<th>Soil salinity</th>
<th>Groundwater depth (rainy season)</th>
<th>Average No. of rainy days</th>
<th>Vegetation (Dominant type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-western plain</td>
<td>2.00</td>
<td>Completely dead</td>
<td>Old Adi-ganga channel with Levee sites</td>
<td>Clayey</td>
<td>Ganga river saline non-alkali</td>
<td>3-4 2-3 1729 70-75</td>
<td>Fresh water Heritiera occasionally low mangrove</td>
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<td>(Kulpi Joy-nagar plain)</td>
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<tr>
<td>South-western plain</td>
<td>10.00</td>
<td>partly dead</td>
<td>Mud flats sand dune along sea clay</td>
<td>Clay to Saline</td>
<td>3-6 3-6 1732 90-95</td>
<td>90-95</td>
<td>Low mangrove, Tree mangrove salt water Heritiera beach forest</td>
</tr>
<tr>
<td>(Kakdwip-Sagar plain)</td>
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<tr>
<td>Region</td>
<td>Type</td>
<td>Salinity</td>
<td>Soil Conditions</td>
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<tr>
<td>Central Plain (Canning Plain)</td>
<td>Tree mangrove, Low mangrove</td>
<td>Salt water</td>
<td>Heritiera, saline, alkaline, Alkaline turf soil</td>
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<tr>
<td>North Eastern Plain (Haroa, Hasnabad)</td>
<td>Complexly dead marshes, levees, channels</td>
<td>Saline to silty</td>
<td>Natural, clayey to silty, 0-3 salt water</td>
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<tr>
<td>South Eastern Plain (Sandesh active cross channels)</td>
<td>Tree mangrove, Low mangrove</td>
<td>Fresh water</td>
<td>Heritiera, saline, Alkaline turf soil</td>
<td></td>
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