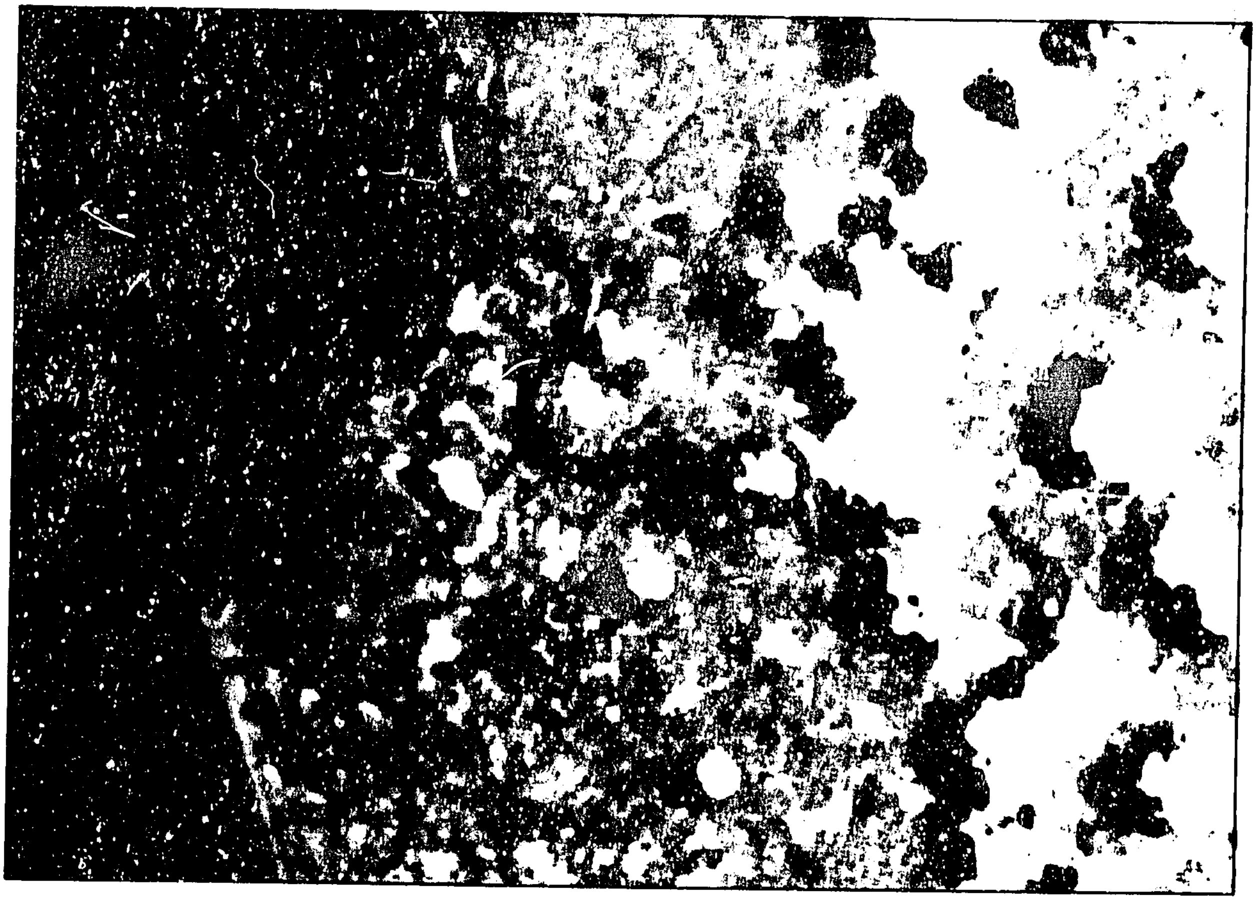
COASTAL CHANGES OF CROW ISLAND AND ITS ENVIRONS



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COAST CONSERVATION DEPARTMENT

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PREFACE

The research studies that led to this publication were undertaken at the request of the Coast Conservation Department of the Ministry of Defence (formerly of the Ministry of Fisheries). The bulk of the field investigations were carried out during 1984 and early 1985.

The field work, laboratory analysis and the tabulation of data was undertaken jointly by a team of researchers who collaborated with the author. Special mention should be made of the following for their contributions:

Dr. P. Wickremagamage for sedimentological studies,
Mr. W. N. Wilson for cartographic and aerial photo analysis,
Mr. S. N. Wickremaratne for studies on biotic aspects, and
Mr. M. D. Nelson for collection of historical information.

In addition to the research team Eng. K. M. W. Bandara assisted in the field investigations by surveying the beach of Crow Island. Mr. K. Bawa together with Mr. Bandara spent long hours in the laboratory analysing samples of sediment. Mr. S. M. B. Amunugama and Ms. Swarna Seneviratne produced the cartographic maps which form an important part of the historical analysis of Coastal changes. I thank them for their respective contributions.

The Director, Coast Conservation, Mr. S. R. Amarasinghe was primarily responsible for approving the project and for providing the necessary funds.

I wish to record with gratitude the encouragement and assistance so generously given by Ms. D. Sadacharan presently Manager, Projects and Planning and Mr. H. J. M. Wickremaratne then Manager Projects and Planning of the Coast Conservation Department who at all times took a keen interest to see the project through. The editing and preparation of the final draft of this report for printing was to a great extent facilitated by the recurrent curfews, both official and unofficial, in the latter half of 1988.

C. M. Madduma Bandara

University Park,
Peradeniya.
November, 1989.

CHAPTER 1

LOCATION AND ENVIRONMENTAL SETTING

1.1 Location

Crow Island is a tiny islet on the mouth of the Kelani Ganga, which is connected to the mainland as a result of recent reclamation activities on its southern and eastern margins (See Fig. 1). As it is today the island covers an area of approximately 29 hectares. In

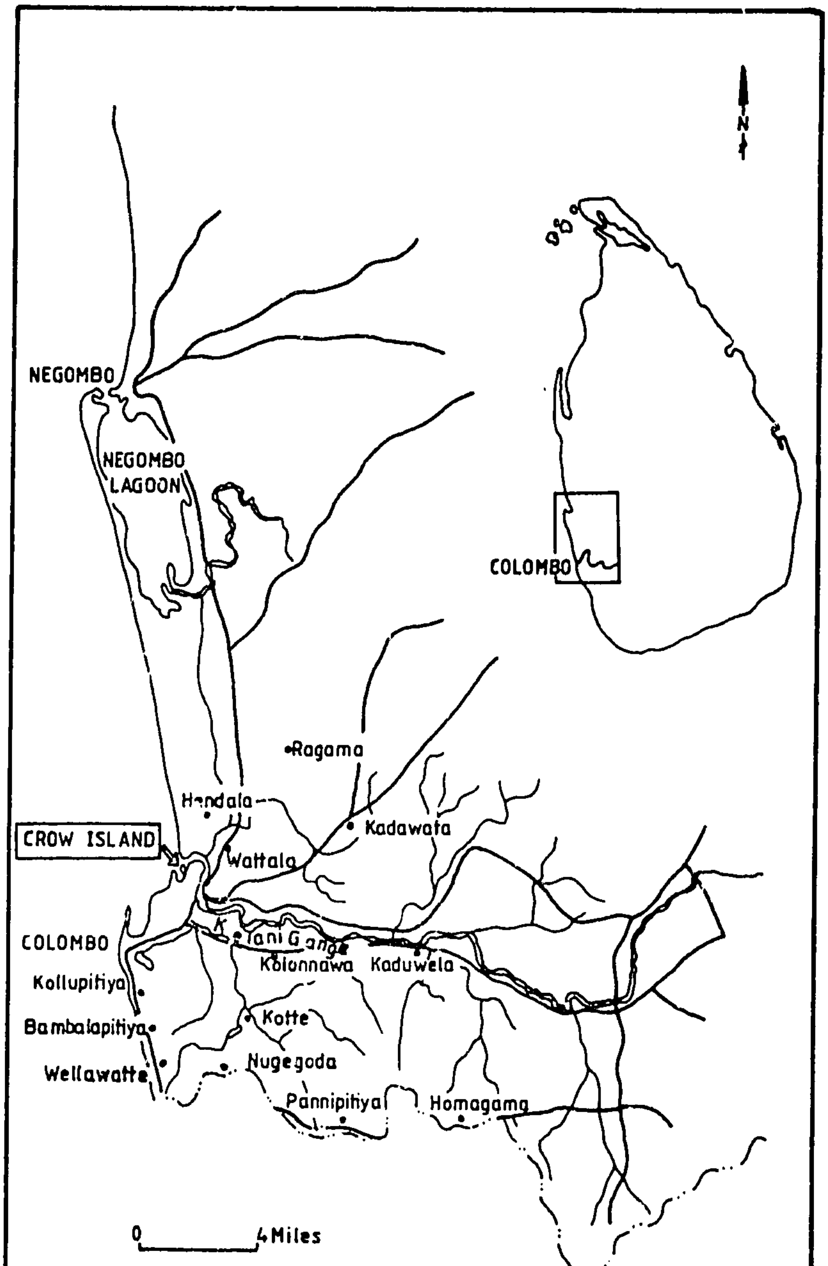


Fig: 1. LOCATION OF THE CROW ISLAND

addition to its geographical setting on the Kelani Ganga estuary, another site factor which has obviously influenced the shaping of the present Crow Island is its location on the northern outskirts of the urban sprawl of the City of Colombo. In particular, the urban area located to the east of Crow Island is one of the most congested parts of the City where residents of the lower income groups are predominantly concentrated. The increasing pressure of population and the concomitant demand for residential land has compelled the authorities to accord high priority to reclamation activities in the recent past.

1.2 Physical Environment

Crow Island can be characterised as a relatively unstable estuarine land form. It is located at the interface of two different environments; the littoral and the estuarine or riparian (See Fig. 2). Its surrounding area as well as the island itself is more or less flat lowlying terrain, heavily subjected to the influence of the river on one hand and the sea

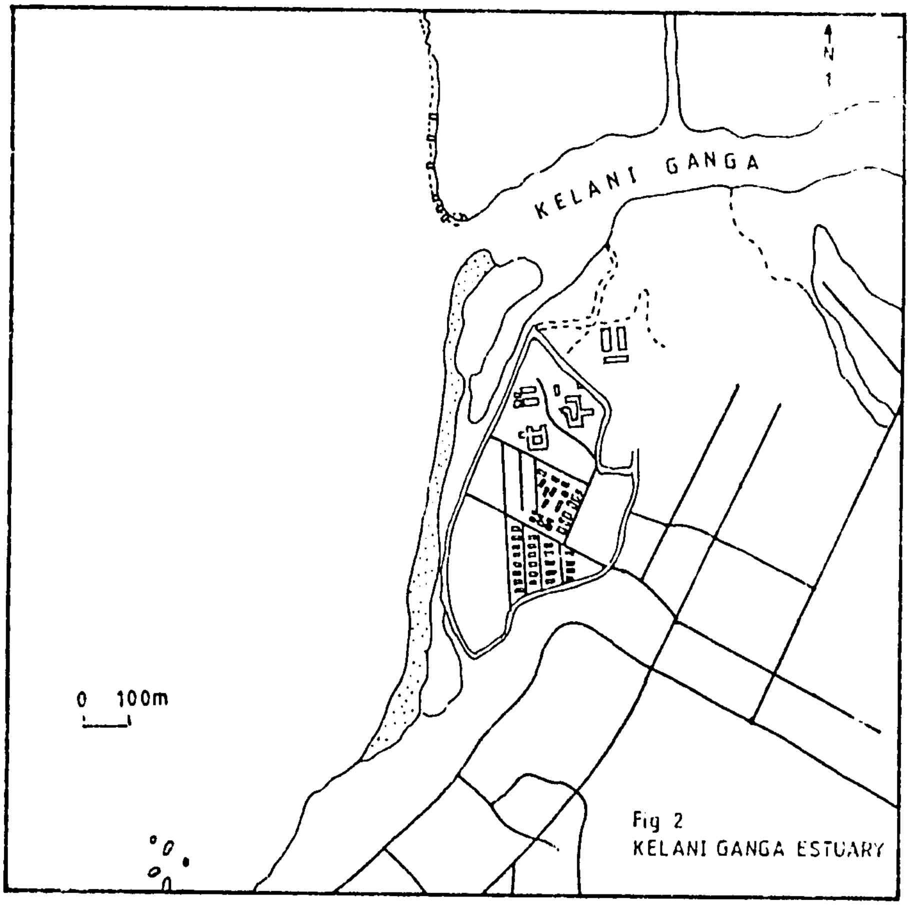


Fig 2
KELANI GANGA ESTUARY

on the other. About four kilometers to the north of Crow Island lies the Muthurajawela swamp – a wetland ecosystem with peaty conditions and brackish characteristics – covering an area of over 30 square kilometers. The name Muthurajawela denotes the existence of a paddy field in the past which subsequently converted itself to a swamp. The meander spectra of the river in its lower reaches clearly indicates its aggradational character providing a broad depositional environment. According to older maps of the area, on the left bank of the lowest meander, there existed two fresh-water bodies known as Kimbulawala (or the pond of Crocodiles) and Koraliyawala (or the pond of *Etropus surafensis* - Koraliya fish) colonised by freshwater aquatic life. It is possible that these two aquatic habitats are relict ox-bow lakes of a former river course.

1.2.1 Geology

The country around Crow Island is underlain by an ancient crystalline basement complex. The rocks which constitute this basement belong to the lower Pàlaeozòic and Pre-cambrian era (Cooray 1967). The two main groups of rock in the area, namely, gneisses and granites were formed by the processes of regional metamorphosis.

The deposits of unconsolidated material which consist mostly of beach sands cover a small belt along the coastline. Fluviotidal deposits cover much of the Crow Island area, and they are often underlain by blown sands. Large deposits of alluvium can be observed along the Kelani river. These are mostly flood-plain material on which much of the present day cultivation areas are located.

The subsurface of most highlands in the area consists of laterites. At present these appear as erosional remnants but occasionally they extend beyond sea level.

Table I

Geological Formations around Crow Island

Era	*Period*	*Formation*
Quaternary	Holocene	1. Unconsolidated sand 2. Alluvium 3. Laterites
Pre-Cambrian		Granitic gneiss

Source: Cooray, 1967.

1.2.2 Geomorphology

Physiographically, the Crow Island area belongs to the coastal plain and the flood plain of the river. Therefore, much of the area is less than 5 metres above sea level. The physiography can be described in terms of its dominant landscape units according to their possible origin. At least three such units could be identified in the immediate environs of Crow Island namely, coastal, fluvial and denudational (Fig. 3).

The coastal unit consists of landforms that were evolved by marine agents such as waves, currents and tides. It is mainly a sandy formation. In some places however, mixed features that were formed by the combined action of sea water as well as fresh water could be seen. Within the coastal unit the following features can often be observed.

i. Sandy beaches, berms, and low sea cliffs
ii. Tidal creeks
iii. Salt marshes
iv. Mangroves
v. Submerged coral reefs
vi. Beach rocks

The actual sandy beach in the area falls into three parts.

(a) The beach with irregular shapes extending from the Fisheries Harbour to the border of Crow Island.
(b) The beach parallel to Crow Island up to the mouth of the river.
(c) The straight coastline extending northwards from the estuary.

In the first of these three segments, which exhibits a curved and irregular shape, there are no exposed actual beaches. In the second segment, there is a wider and clearly demarcated actual beach. The length of this section is about 250 metres and the width is about 125 metres. This section is mostly of a straight form and displays the characteristics of a sand bar. The beach extending to the north of the river mouth is more or less a broad one but as a result of severe erosion its width is very much limited at present.

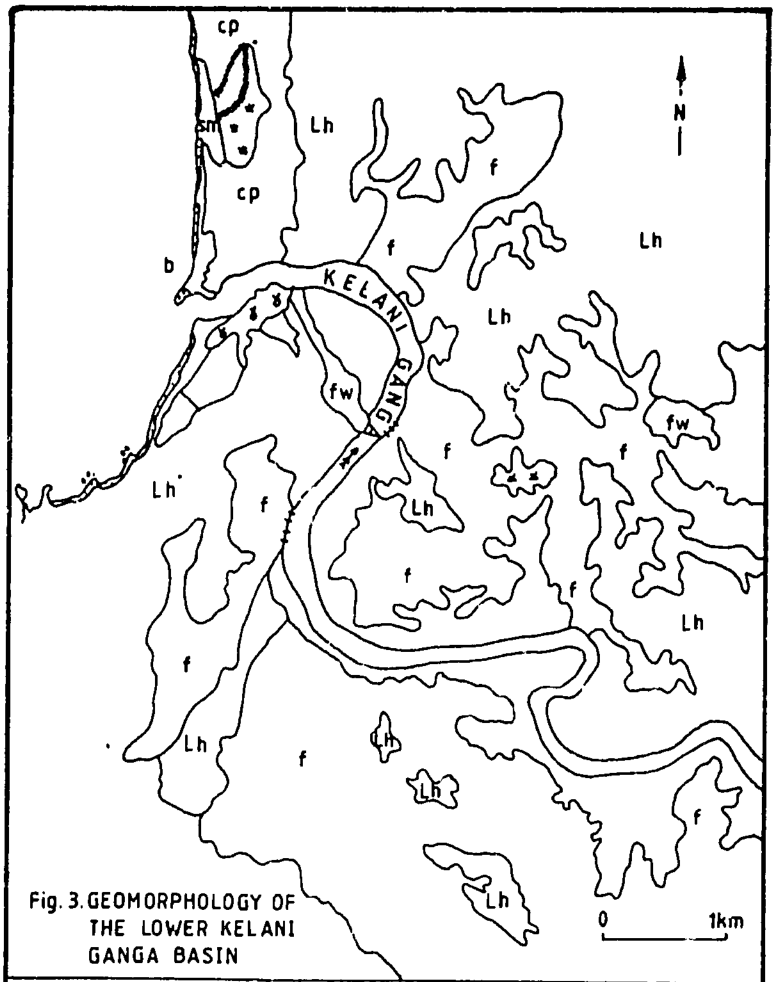


Fig. 3. GEOMORPHOLOGY OF THE LOWER KELANI GANGA BASIN

GEOMORPHOLOGICAL UNITS

COASTAL UNITS
b-beach
s-shifting sand bar
cp-coastal plain
tidal creeks
submerged reef
rock outcrops
mangrove
sm sand mantle
FLOOD PROTECTION BUND

FLUVIAL UNITS
river
f- flood plain
fw-fresh water body swamp

DENUDATIONAL UNIT
Lh-low relief highland

Tidal creeks are water courses in the form of gullies that have been formed by tidal action. These tidal creeks can be seen mostly in the southern part of Crow Island and about 3 kilometres away from the northern part of the river mouth. The average width of these creeks is about one metre and the maximum depth is about 1½ metres. Most of the salt marshes and swamps in the area around Crow Island have been formed by the circulation of brackish water through these creeks which results in floods in the low-lying areas. The type of salt marshes and mangroves created by these processes can be seen in Crow Island and in the coastline to the north of the river mouth.

Several micro-relief features that have developed on the beaches can be identified more clearly by field investigations than by air-photo or map interpretation. These include low sea cliffs, mini-sand dunes, berms and spit bars. While sea cliffs that have formed through the action of waves could be detected in the lateritic areas, certain micro-sea cliffs which change seasonally due to wave action could be observed in Crow Island. Berms can be observed in the clearly developed beaches, but these are only transient phenomena that change throughout the year through wave action. The southern part of the river mouth does not appear to be a conducive environment for the formation of sand dunes when compared with the northern part where small scale transgressive dunes are seen.

The landforms created by the action of running water are observed within the fluvial unit. The following are more prominent in the Crow Island area.

(a) the course of the river
(b) marshy areas, and
(c) the flood plain

As noted earlier, the lower course of the river is entirely of a meandering type. The average length of the meandering segments of the river is about 32 kilometres. At least four clearly developed 'meanders' can be seen in the lower course. The basic dimensions of these meanders as determined by air-photographic analysisare given in Table II and Fig. 4.

Table II

Data on hydraulic geometry of the Lower Kelani Ganga (See Fig. 4)

Width of the river mouth – Inner mouth	200 m.
Outer mouth	120 m.
Average width of the lower course of the river	126.6 m.
Average width within the first meander (nearest to the estuary)	168 m.
Average width within the second meander	132 m.
Average width within the third meander	86 m.
Average width within the fourth meander (furthest from the estuary)	78.8 m.
Wave length of first two meanders ( )	31.6 km.
Wave length of third and fourth meanders ( )	12 km.
Ampltitude of the two lower meanders	16.4 km.
Mean radius of Curvature (rc)	
Within the First meander	8.6 km.
Within the Second meander	7.2 km.

As in most tropical rivers there is no clearly developed natural levee system along the Kelani river. These levees, if they ever existed, may have perhaps been destroyed by human activities.

Within the fluvial unit, flood plains are the most widespread and prominent land form in the area. These areas which are subjected to periodic inundation. consist mainly of rich alluvial soil. Therefore, except for a few places which are covered with stagnant water, the rest of the area is utilized for some form of cultivation.

The highland areas which are subject to subaerial weathering processes and lateritation, fall into the category of denudational units. They often consist of somewhat irregular terrains. It is more appropriate for these landforms to be characterised as remnants of highlands that have been weathered and dissected by agents such as rain. rivers and floods. The highlands which are under laterization are around 10–20 metres in height while their slopes vary from 2 to 6 per cent.

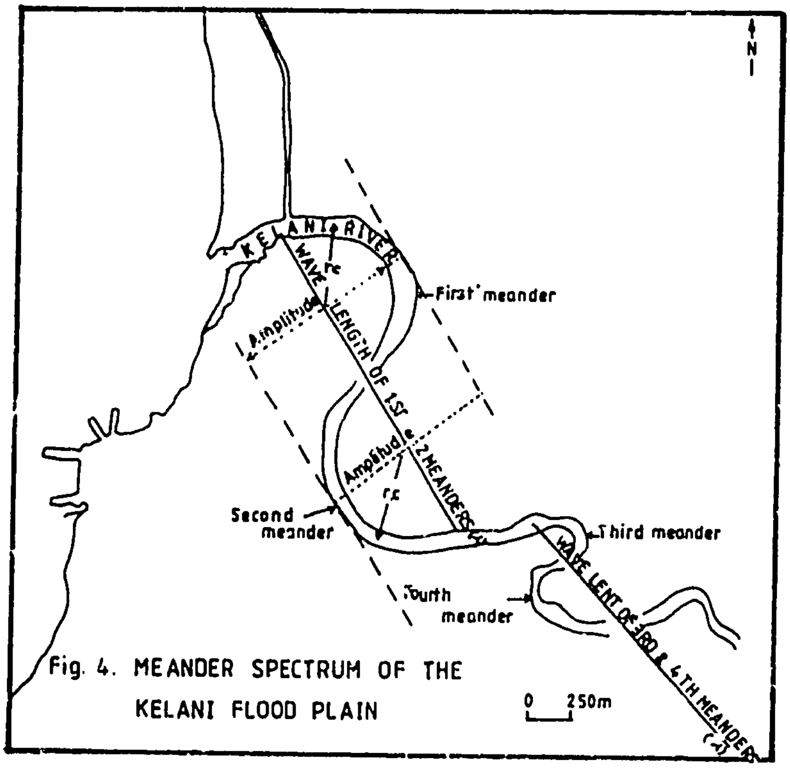
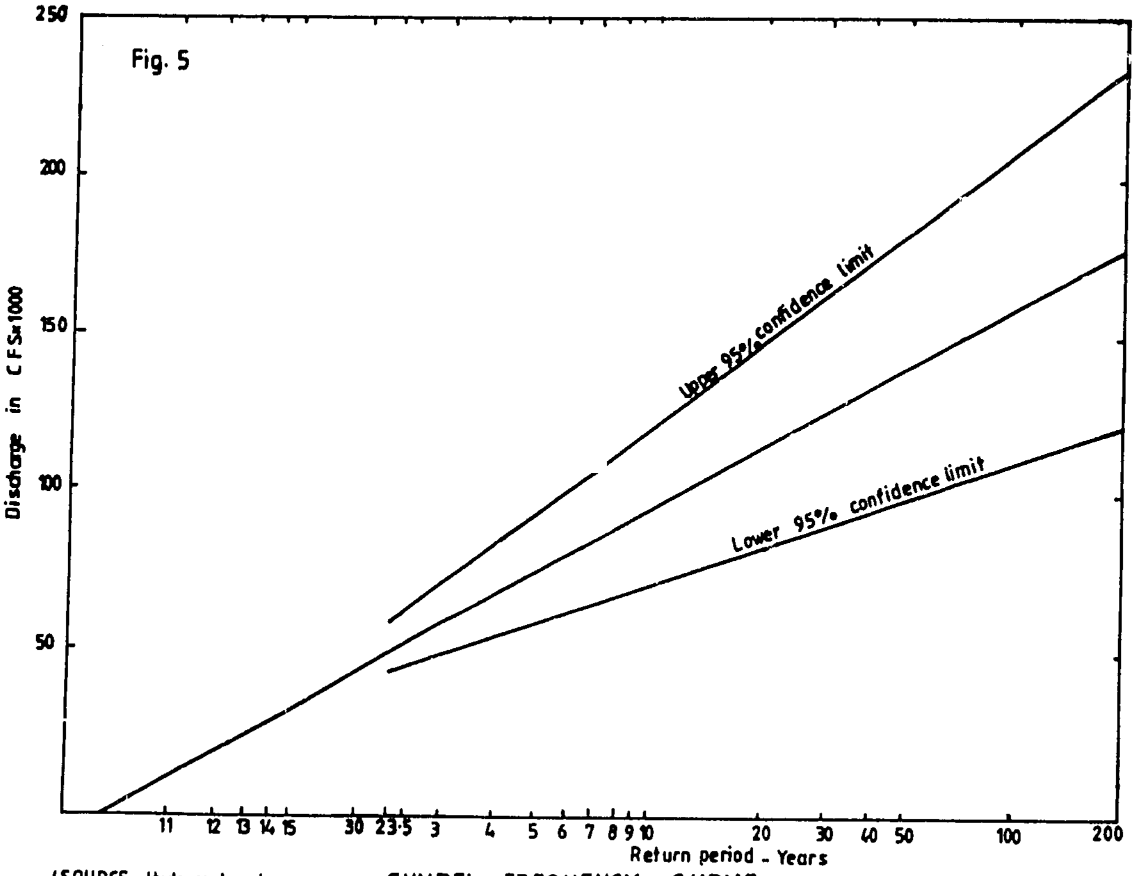


Fig. 4. MEANDER SPECTRUM OF THE KELANI FLOOD PLAIN



(SOURCE: Hydrometereology of Ceylon part II Hunting Survey 1982)

GUMBEL FREQUENCY CURVE FOR KELANI GANGA

1.2.3 **Hydrology**

The Kelani Ganga basin in its entirety comprises of 2336 km^2 of which about 80 percent lie within rugged highlands and uplands. The drainage pattern is characterised by a complex system of tributaries controlled not only by north-south trending geological structures but also by occasional fracture zones.

The average annual discharge of the Kelani river is estimated to be in the region of 4,860,000 acre feet (=585,542 Hectare metres) (Bocks, 1959). The extreme discharges from the Kelani Ganga are given by the Gumbel Frequency Diagram in Fig. 5a. This shows that while the mean annual flood is around 50,000 cusecs a flood with a recurrence interval of 100 years can be as high as 160,000 cfs (4530 cumecs).

Figs. 5b and 5c show the annual maximum flood heights of the Kelani Ganga at Nagalagam Street and Hanwella respectively for the period 1963–81. It is obvious from these graphs that the flood heights in the lower Kelani Ganga have been falling over the years. One possible factor responsible for this decline is the changes made at the river mouth for rapid evacuation of floods and the increased extraction of river sand for construction purposes.

1.2.4 **Climate**

Climatic records of Colombo indicate that over 60 percent of the total annual rainfall is received from the southwest monsoon which dominates in the period between May and September. The mean annual precipitation for the last 30 years in Colombo was 3431 mm while the mean annual temperature was 80°F (26.67°C). There is a rise in temperature from March to June. The highest recorded temperature has been 82°F (27.8°C) and the minimum temperature recorded is around 72°F (22.2°C) The average wind speed in Colombo is 5 knots, while the dominant wind direction remains southwest. (See Table III).

Fig. 5b. ANNUAL MAXIMUM FLOOD HEIGHTS AT NAGALAGAM ST, COLOMBO

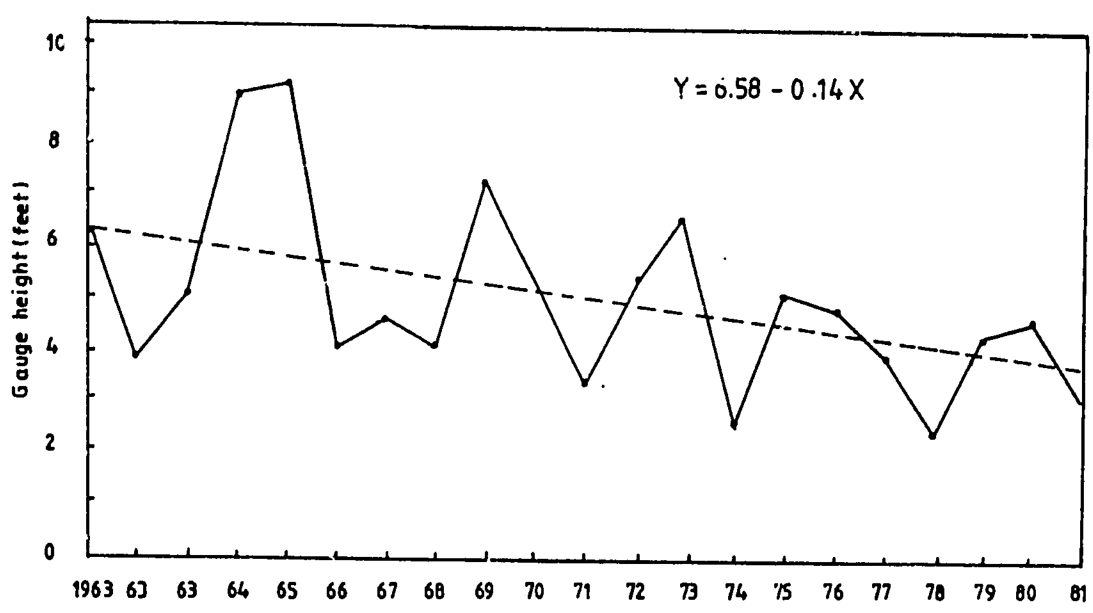


Fig. 5c. ANNUAL MAXIMUM DISCHARGE AT HANWELLA

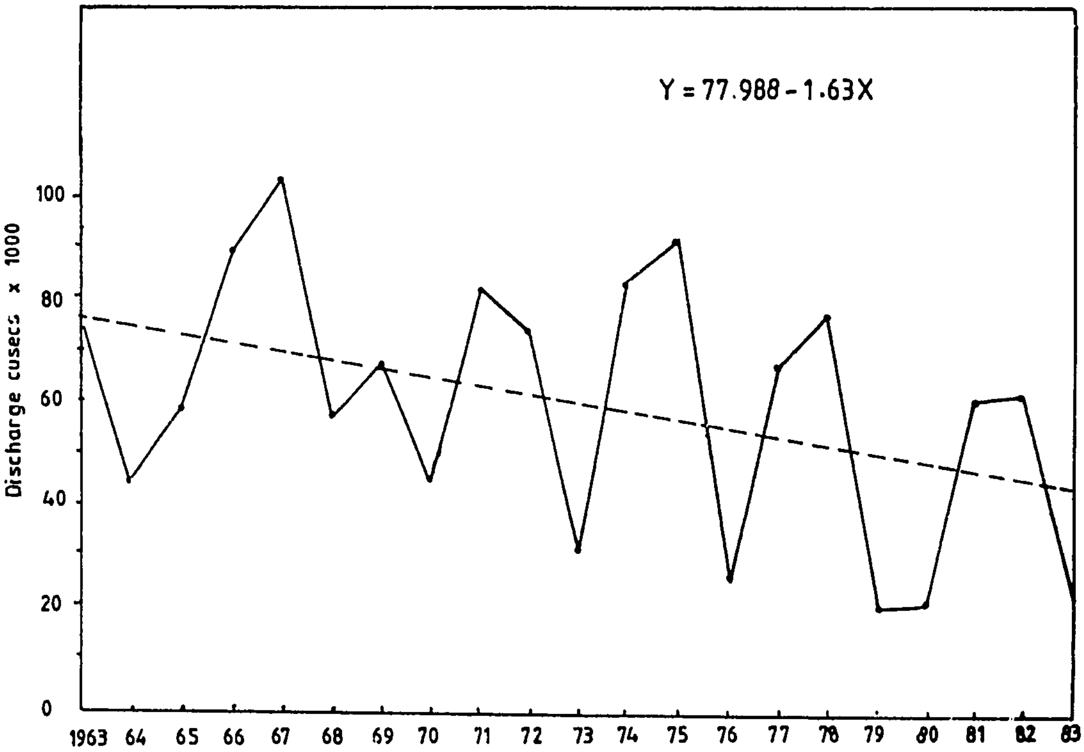


Table III
Mean Percentage Wind Directions at Colombo

Directions	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*Mar.*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
N	27	13	06	04	01	00	00	00	00	03	15	29
NE	34	26	16	06	02	01	01	00	00	04	14	31
E	01	03	02	03	02	00	01	00	00	01	03	02
SE	02	02	05	05	05	01	01	01	02	03	04	03
S	01	01	03	09	09	06	06	05	06	05	04	02
SW	04	08	19	33	57	62	59	62	62	41	14	04
W	06	16	25	21	20	24	26	28	25	24	19	06
NW	22	25	17	11	02	04	05	04	04	13	20	20
Calm	03	05	07	08	02	02	01	00	01	05	07	04

Source: Reports of the Colombo Observatory.

1.2.5 Oceanography

Two wave types connected with the wind regime can be identified in the area, namely (a) Swell waves, and (b) Local short-crested waves. Swell waves are long-crested waves generated in the sea and determined by the nature of the sea-floor and the atmospheric conditions in the area.

The swell that originates in the Bay of Bengal or in the Arabian Sea is experienced more or less throughout the year. However, as Table IV indicates, it approaches the Island mainly from a southernly direction. The heavier swell strikes the coastline obliquely and causes long shore transport of beach material despite the refraction it undergoes in shallow water (Swan 1979). In the coastal zone sheltered from the waves of the open

Table IV

Sea and Swell of Sri Lanka

Direction of Approach	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
Dominant direction Sea Swell	 NE NE	 NE NE	 NW S	 W W	 W SW	 W W	 W W	 W W	 W W	 W W	 W S	 NE NE
Next dominant Direction	N N	N N	NE NE	NW S	SW W	SW SW	SW SW	SW SW	SW SW	SW SW	NE SW	N N
Next dominant Direction	NW SW	NW S	N NW	SW SW	NW NW	NW S	NW NW	NW NW	NW NW	NW S	N W	NW S
Next dominant Direction	— S	— SW	WSW SW	-- NW	— S	— S	— S	— S	— S	— NW	NW NW	SW SW

Source: Swan, S.B. St. C. (1967).

sea and in the islands and peninsulas in the northwest,, calm conditions prevail throughout the year. In other parts of the coastal zone beaches exposed to the monsoons undergo seasonal degradation and accretion depending on whether the monsoon is offshore or onshore.

In the Indian Ocean, currents reverse their direction with the change of the monsoons. Thus there is a tendency for the water to move from southwest to northeast during the period from March to September and in the opposite direction from September to March.

Waves generated by wind often take the form of short-crested waves. These waves occasionally rise to considerable amplitudes. They often continue unbroken when they do not interfere with one another. Short-cresed waves show a dominant south-west orientation.

The southwest coast of Sri Lanka lies in a micro-tidal environment. Around the coast the rise and fall of the tide is hardly perceptible. The highest tides hardly ever exceed one metre above mean sea level. Normally the fluctuation of the tide level at Colombo lies between 0.32 and 0.38 m. Fig. 6 shows that there is hardly any change in the level of water in the environs of the Kelani river mouth. As a result most river mouths often become temporarily blocked by sand bars or sand banks. However, a combination of high tide and swell can cause severe erosion as evidenced along the western shore of Crow Island.

1.3 Biological Environment

The area around Crow Island is a rich biological habitat of the Kelani flood plain that has been subject to continuous replenishment of nutrients over a long period of time by seasonal flooding. However, at present most of these biotic communities have been drastically changed or replaced by agricultural and other types of land use. The following natural, semi-natural and man-made land cover types can be recognised in the immediate environs of Crow Island: (i) Littoral vegetation, (ii) Inland vegetation, (iii) Swamps and water bodies, (iv) Cropland/Homesteads, and (v) Developed land.

Fig. 6.

MEAN DAILY TIDE LEVELS IN COLOMBO, 1982

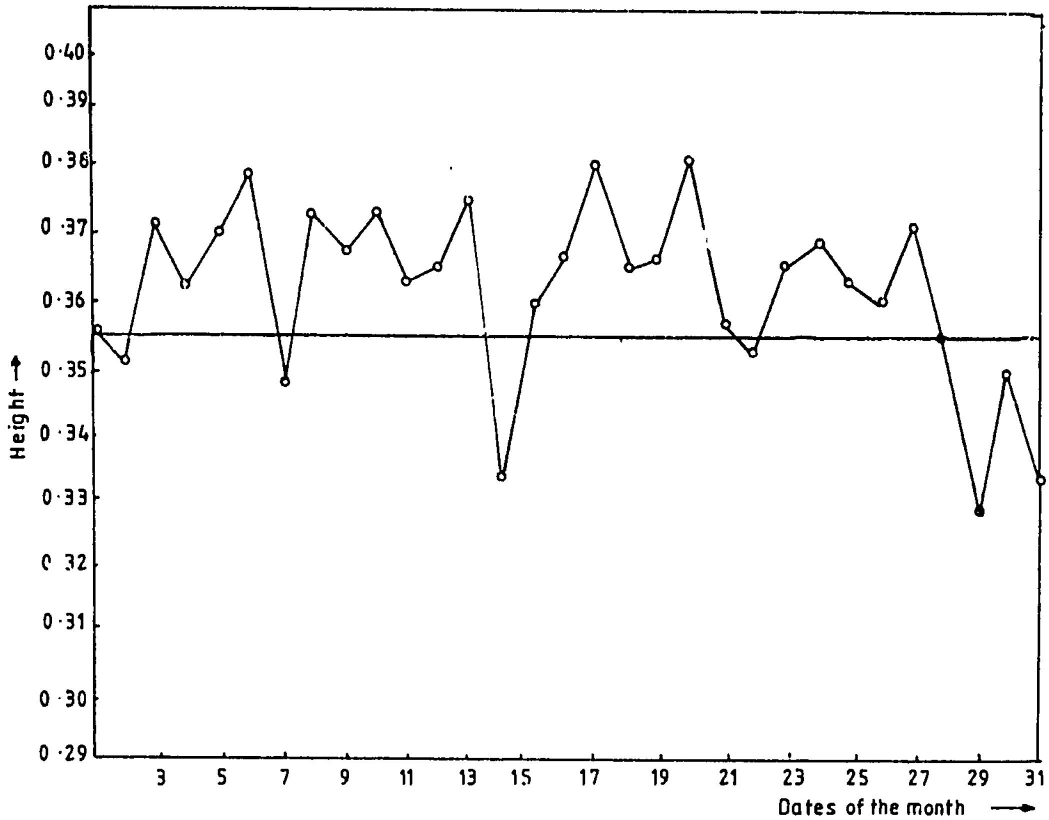


Table V

Changes in Selected Categories of landuse (1957–1972)

Vegetation/Landuse type	*% Change*
Vegetation	−35 (loss)
Lowland/Marshy	−12.5 (loss)
Crops	−55 (loss)
Buildings	+50 (gain)

1.3.1 The littoral vegetation that extends inland from the shore up to 40 to 50 metres from the shoreline is characterised by a perpetually rejuvenating sandy substrate that can be considered 'azonal' according to the classical concept of soil zones. A vegetation gradient can be observed in this zone. Close to the continually disturbed shoreline is the zone of low ground herbs dominated by the creeping species *Ipomoea pes-caprae* together with the herbs *Spinifex littoreus* and *Canavalia rosea*. Landward next to the above zone exists the zone of low shrubs with *Clerodendron* spp. and *Crotalaria* spp. whose average height does not exceed 1.5 metres. However, taller *Pandanus littoreus* that sometimes attains 4–5 metres of height could be observed here. The place name of Uswetakeyyawa located to the north of Kelani estuary indicates the widespread presence of this species in the past. This area is now being planted with coconut in some places.

1.3.2 The littoral zone gradually gives way to inland vegetation that thrive on relatively more stabilised 'Regosols' which are yet azonal. The dominant woody species of this zone are: *Callophylum inophylum, Terminalia cetappa, Barringtonia* spp. and *Pongamia pinnata* which reach above 10 metres in height. If undisturbed this vegetation community can can form a thicket with a closed canopy, but hardly any such groves are left presently.

1.3.3 In riparian bottom lands with intra-zonal subtrate (i.e. bog/half bog and low humid gley soils) swamps occur while some depressional areas are akin to fresh water lakes. Most of these swamps have accumulations of peaty material of the Muthurajawela type, which are overgrown with grasses, sedges and occasional shrubs. Common herbaceous are: *Typha angustifolia, Phragmites communis, Juncus* and *Commelina* species with *Ipomoea aquatica,* while the occasional shrubs are represented by *Hibiscus tiliaceous, Cerbera manghas* etc. The open fresh water bodies are infested with *Salvinia* spp. *Pistia* spp. and *Monochoria hastata.* Table VI gives further details of the plant species *Commelina* species with *Ipomoea aquatica.* while the occasional shrubs are represented by *Hibiscu tiliaceous, Cerbera manghas* etc. The open fresh water bodies are infested with *Salvinia* spp. *Pistia* spp. and *Monochoria hastata.* Table VI gives more details of the species found in the area.

1.3.4 Cropland and homesteads can be seen in well drained sites as well as reclaimed wetlands. In residual land the primary perennial crop is coconut. In the low bottom lands and reclaimed sites, vegetables and 'keera' (leafy vegetable) cultivation could be often observed.

1.3.5 The developed land around Crow Island includes both residential land and reclaimed areas used for buildings, parks, recreational activities, roads and various other services. Due to the urban sprawl and expansion of other human activites. vegetation and natural habitats have been encroached upon by developed land. A point sampling comparison done covering an area of about four square kilometers (from sequential airphotographs) clearly shows the reduction in vegetation cover over the years (Table VII).

TABLE VI

List of Dominant Plant Species in the area around Crow Island

Species	*Family*	*Sinhala Name*	*Life form*	*Habitat*
Annona glabra	*Annonaceae*	වල් ඇනෝදා	Shrub	Wetland/Marsh
Terminalia Cetappa	*Combretaceae*	කොට්ටම්බා/කොට්ටන්	Tree	Wide (well drained)
Calotropis gigantea	*Asclepiadaceae*	වරා	Shrub	Coastal Zone
Canavalia rosea	*Leguminoseae*	මුදුඇවර	Herb	Coastal Zone
Clerodendron inerme	*Verbanaceae*	වල් ගුරෙන්ද	Herb	Coastal Zone
C. infortunatum	*Verbanaceae*	පින්න (ගස්පින්න)	Herb	Coastal Zone
Desmodium app.	*Leguminosae*	උඳුපියලි	Herb	Coastal Zone
Clotolaria juncea	*Leguminoseae*	ඇඳන හිරියා	Low shrub	Coastal Zone
Impmea pes-caprea	*Convulvulaceae*	බිමතඹුරු (මුදු බිමතඹුරු)	Creeper	Coastal Zone
Pandanus littoreus	*Pandanaceae*	වැටකේ	Tall Shrub	Coastal Zone
Spinifex littoreus	*Gramineae*	මහා රාවණා රැවුල	Herb/grass	Coastal Zone
Callophylum inophylum	*Guttifereae (Clusiaseae)*	දොඹ	Tree	Inland
Morinda citrifolia	*Rubiaceae*	ඇහු	Shrub	Coastal Zone
Eupatorium odoratum	*Compositeae*	පොඩිසිංඤෝමරන්	Tall herbs	Widspread
Dillenia retusa	*Dilleniaceae*	හොඬපර	Tree	Inland
Commelina spp.	*Commelinaceae*	ගිරාපලා	Grasslike herb	Wetland
Cymodon dactylon	*Gramineae*	හීන් ආටවරා	Grass	Wetland
Ipomoea aquatica	*Convolvulaceae*	කන්කුන්	Creeper	Wetland
Juncus spp.	*Junaceae*	ගල්ලෑහැ	Sedge	Wetland

Species	Family	Sinhala Name	Life form	Habitat
Phragmites spp.	*Gramineae*	නලාගස්	Sedge	Wetland
Typha angutifolia	*Typhaceae*	හම්බුපන්	Sedge	Wetland
Hibiscus tiliaceus	*Malvaceae*	බෙලිපටටා	Shrub	Wetland
Carbera manghas	*Apocyanaceae*	කදුරු (ගොන්කදුරු)	Tree	Wetland/mangrove
Salvinia auriculata	*Salviniaceae*	සැල්වීනියා	Water Ferm	Wetland/mangrove
Monochoria hastata	*Pontederiaceae*	දියහබරල	Herb	Wetland/mangrove
Eichornia crassipes	*Pontederiaceae*	ජපන්ජබර	Herb	Wetland/mangrove
Pistia stratiola	*Araceae*	දියපරැල්	Water ferm	Wetland/mangroves
Terminalia arjuna	*Combretaceae*	කුඹුක්	Tree (stunted)	Water margin/Wetland
Barringtonia racemosa	*Lecythidaceae*	දියමිදෙල්ල	Low Tree	Water margin/Wetland
Pongamia pinnata	*Leguminoseae*	මගුල් කරද	Tree	Wetland
Amaranthus spinosus	*Amaranthaceae*	කටුතම්පලා	Herb	Land
Croton lactifer	*Euphorbiaceae*	කැප්පෙටියා	Shrub	Land

Table VII

Changes of vegetation and lagoonal area in the Crow Island from 1956 to 1982 (In Hectares)

Year	Total Area	Vegetation	Water (Lagoon)
1956	11.73	9.07	2.13
1960	6.62	4.27	0.43
1972	10.0	5.83	1.25
1982	12.4	2.67	1.73

1.3.6 Vegetation ecology of Crow Island

Crow Island may be considered a successional community developing on alluvium and beach deposits. As the area has been reclaimed, filled-earth overlies the alluvium, unconsolidated sand and bog soil in most places. Except in the sand, elsewhere soil drainage is imperfect to very poor. Seasonal fluctuations of the water table and occasional floods had originally created a diverse habitat that was dominated by mangroves, marshy plants, littoral vegetation and low forests, before the area's vegetation cover was denuded. The following vegetation and land cover types can be recognized within Crow Island at present, on the basis of air photographs (1982) and field observations: i. Sea-shore vegetation, ii. Low forests, iii. Mangroves, iv. Developed land, v. Water bodies.

The sea-shore vegetation community stretches inland as a narrow belt, with a width of about five metres. In some places coastal erosion has removed such herbal vegetation including the major species *Ipomoea pes-caprae*. This serial stage is gradually taken over by the low forest in the less disturbed adjacent sites. Approximately 60% of the coastal zone of the Island is covered by plants of the sea-shore vegetation type.

A remnant of the low forest can be seen close to the western (sea-side) margin of the Island, next to the shore vegetation. This patch is about 30 square metres in size, with *Cerbera manghas, Hibiscus tiliaceous* and *Terminalia cetappa* forming a close canopy with an average height of four metres.

Presently, less than 10% of the total area of Crow Island is covered with mangrove vegetation compared to nearly 40% in 1956. As observed near the southernmost end of the Island, the common species are *Rhizophora mucronata, Avicennia* spp., and the mangrove fern *Acrosticum aureas,* while *Cerbera manghas* and *Hibiscus tiliaceous* grow towards the periphery of such vegetation. The average tree height of about 5 metres suggests disturbances caused by human activities.

Presently around 70% of Crow Island's area is either built up or earth filled, and needs better means of soil drainage. Since the mangroves and other swamps have been filled up to 7 metres in depth the impact of this alteration on the area's hydrological system would have been considerable.

CHAPTER 2

HISTORICAL EVOLUTION OF THE COUNTRY AROUND CROW ISLAND

2.1 Geological History

The history of the Kelani Ganga estuary is necessarily related to the evolution of the south-west coast and the adjoining land mass of Sri Lanka. The present day geomorphological landscape of Sri Lanka is largely determined by its natural history, geological structure, lithology and exogenous processes. However, regional relationships may be interpreted in terms of morphotectonics.

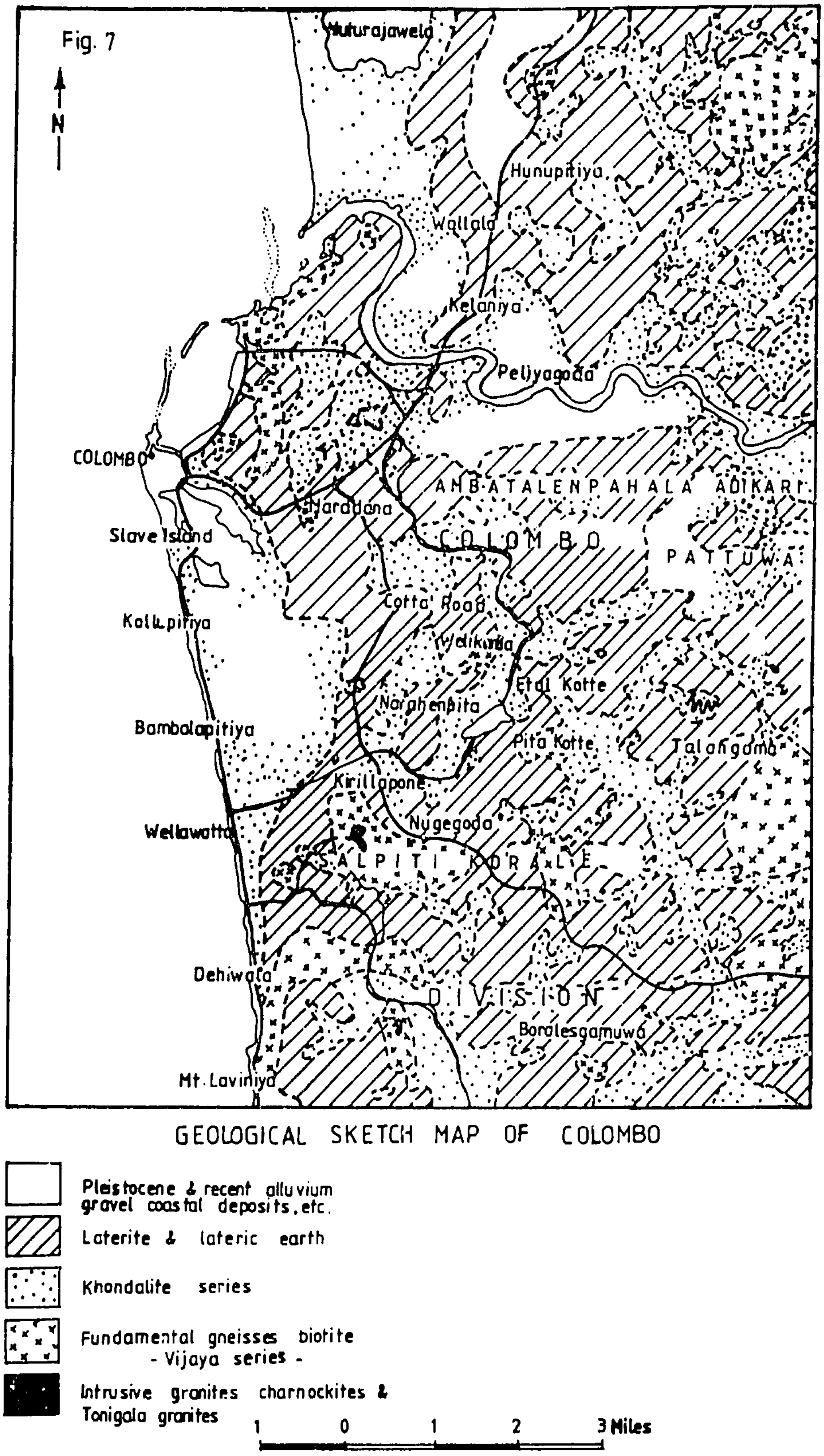
Structurally, Sri Lanka is related to the Indian subcontinent to which it was affiliated through the greater part of geological time, when both were components of the super-continent of Gondwanaland, which included the adjoining land masses of Antartica, Australia, Madagascar, Africa and South America. Gondwanaland began to disintegrate in Jurassic times or approximately 135–180 million years ago. The disruption of Gondwanaland and the movement apart of its component parts was accompanied by phases of sea-floor spreading which were responsible for the creation of the Indian Ocean (Stonely 1974, Swan 1985).

The first signs of an Indo-Lankan rift also appeared in Jurassic times, opening an ancient pre-cambrian fault (Katz, 1978). This separation from India resulted in the creation of the Palk Strait, and the Gulf of Mannar Zone. The latter was infilled with Jurassic and Miocene sediments which attain thicknesses exceeding 300 metres at certain locations. Further evidence of the eastward and southward movements of Sri Lanka are indicated by the steep gravity gradients along these coasts, where continental rocks of the Island were once thrust over the thin oceanic crust. Despite these early events, Sri Lanka has tended to remain comparatively stable through most periods of its more recent geological history. The earliest phase of the evolution of the southwest coastline was the result of the separation of the Island from South India and its conjectured drift in an anticlockwise manner (Kularatnam 1959). If the theory of continental drift in the context of Sri Lanka is reasonably valid, then, before the separation of the Island, the southwestern coastline should have formed part of the continuous landmass of Gondwanaland. However, the sedimentary evidence related to the Gondwana period in Sri Lanka is limited, and confined only to a few Jurassic deposits near Tabbowa and Angidama, not too far inland from the western coast.

In terms of lithology, rocks are mainly pre-cambrian over 90% of the present area of the Island. They consist of ancient crystalline formations unaffected by volcanic activity and mountain building processes for over a period of one thousand million years (Crawford & Oliver 1969). The remainder of the Island includes sedimentary deposits which are mainly Miocene and quarternary and located principally in the North and North-west.

The southwestern region has many geomorphological features common to those in the 'highland' series (Cooray, P. G. 1967). The predominant rocks of these formations are charnockites and gneisses, but there are other metasediments and granites as well. Geological structures and relief are related to those of the highland series. Thus prominent ridges and valleys run parallel to one another, and sub-parallel to the coast. Thus the southewestern region differs from the Vijayan region in terms of its geological structure and relief.

The deposits of shale at Tabbowa belong to the Cretaceous period which is assumed to be of some 135 million years. The sandstone formation near Minihagalkanda on the



GEOLOGICAL SKETCH MAP OF COLOMBO

southwestern coast is assumed to have been formed around 25 million years ago. The Miocene marine transgressions in the North and Northwest (circa 25–40 million years) did not leave much evidence along the southwestern coastline. Some initial efforts to reconstruct the coastline of Sri Lanka during the Pleistocene period were made by Deraniyagala (1960) (Fig. 7). The origins of most superficial deposits such as alluvium, beach sands, gravels and laterites which are readily observable in the area around Crow Island are not older than the Pleistocene period.

2.2 Evolution of Crow Island

Crow Island is essentially a creation of the Kelani Ganga and its alluvial load. Therefore, historically its origin may not extend beyond the Pleistocene period. The borehole data

Table VIII

Depth of weathered rock from the surface (Ref. Figs. 8 & 9)

Bore Hole No.		*Depth (m)*
1	.. ..	13.5
2	.. ..	13.5
3	.. ..	15.0
4	.. ..	19.0
7	.. ..	13.9
Mean	.. ..	14.98

Source: Records of the National Building Research Organisation.

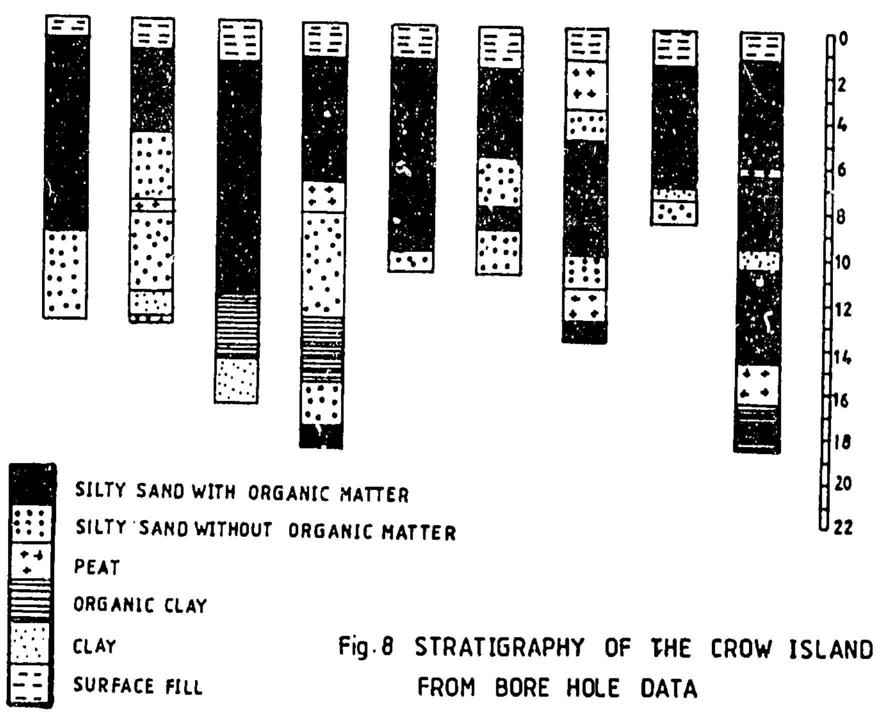
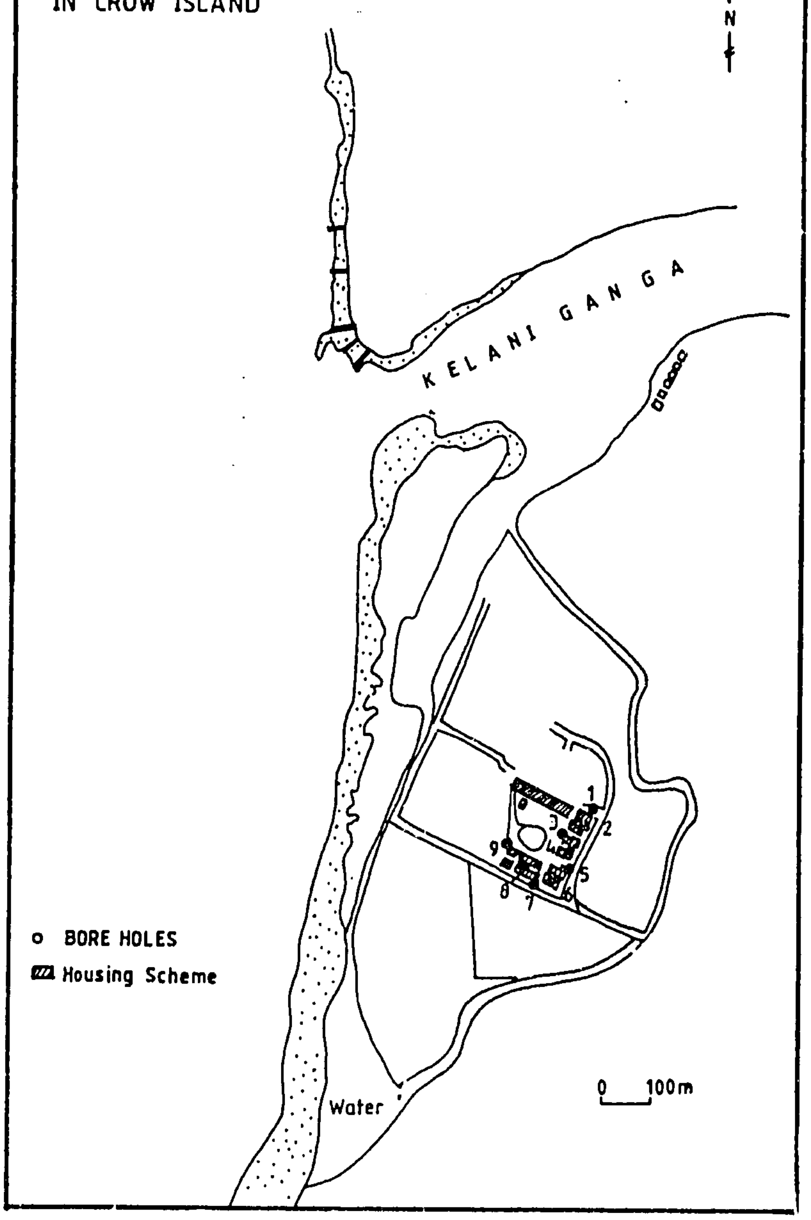


Fig. 8 STRATIGRAPHY OF THE CROW ISLAND FROM BORE HOLE DATA

available for this area helps to establish the stratigraphy of Crow Island at least in a tentative way. These borehole records indicate that the bed-rock is considerably deep below the surface of Crow Island. The depth of the boreholes varies from 10 to 19 metres. None of them reach the bedrock. However, five of them (out of nine) have reached the weathered zone of the bed-rock. The depth of the weathered rock from the surface varies from site to site as can be seen in Table VIII, Fig. 8 and Fig. 9.

Fig. 9
LOCATION OF BORE HOLES IN CROW ISLAND



It is clear from Table VIII that the sediment layer in Crow Island extends well below sea level. Over the weathered bed rock it has a layer of silty sand with organic matter in most bore holes. Organic clay has been observed in three sites with thicknesses ranging from 2 to 3 metres. In a few locations peat formations were observed at depths ranging from 7 to 13 metres; their thickness varies from 0.5 metres to 1.8 metres. The natural surface layer of many of the sites is silty sand with or without undecomposed organic matter, possibly indicating their fluvial origin.

The presence of organic layers well below sea level indicates that they were laid down in a calm environment, possibly lagoonal or estuarine. Existence of peat and organic material below the present sea level indicates that Crow Island remained a marshy area during recent periods of geological history. It is therefore reasonable to infer that anaerobic conditions prevailing in a marsh were favourable for the accumulation of peat. It is also possible that subsequent filling of the marsh with alluvium and other deposits could have led to a gradual subsidence of these organic layers. The depositional environment of the estuary could also have been affected by the post-Pleistocene sea level changes. The relict vegetation communities that existed at the time of deposition of subsurface organic material indicate that the diversity of species of Crow Island was higher and more stable in the past than today.

The submerged reef, as observed at a distance of 0.6 km. from the present coastline indicates that the superficial deposits in and around Crow Island were in fact, laid down in some form of a sheltered basin-like environment provided by the reef. Even a slight negative change of sea level could expose the reef. Since the bed-rock appears to be deeper than 15 metres in most bore hole sites in Crow Island it is possible that the bed-rock is covered by a thick accumulation of superficial material. Crow Island thus rests on a cushion of superficial deposits, therebv creating an unstable geomorphological environment. The sediment load of the Kelani Ganga kept on adding material of fluvial origin to the sheltered environment of Crow Island. It must be admitted that the above attempt at reconstruction of the geological past of Crow Island and the conceptual stratigraphic model of the Kelani estuary as presented above are based on limited available evidence and therefore open to revision if further evidence becomes available.

Historical Period

The earliest historical records relating to the environmental history of the Kelani estuary and its immediate upstream area go back to the period of King Kelanitissa (185 B.C.). The Mahawamsa makes references to marine transgressions of considerable magnitude during this period. It appears that human settlements in this area had existed even before the period of Kelanitissa as evidenced by the visit of Lord Buddha. If the visit of Lord Buddha had actually taken place, such settlements were there around 500 to 600 B.C. From the distant historical past the area around the Kelani estuary formed an amphibious landscape with water bodies and marshy lands interspersed with highlands with lateritic caps. At the time when the capital of Sri Lanka was shifted to Kotte this area should have had a considerable density of population. It is possible that some of the present day marshy areas such as Kaduwela and Muthurajawela were lands under some form of paddy cultivation.

Cartographic records on the evolution of Kelani estuary

The earliest map of Sri Lanka by Ptolemy (Circa 200 AC) does not include much detail of the Kelani estuary and its immediate environs. Therefore, it does not throw much light on the history of the area in and around Crow Island at that time. It is from the Portuguese period that historical maps tend to convey some idea as to the evolution of the area around the Kelani estuary. A list of maps depicting this segment of the coastline is given according to their chronological sequence in Table IX. (See also Fig. 10).

Interpretation of Historical Maps

In spite of the fact that there are questions of originality, accuracy and dating of available historical maps, they do provide information which cannot be obtained from other sources.

Table IX

List of Historical Maps and Aerial Photographs (in chronological sequence)

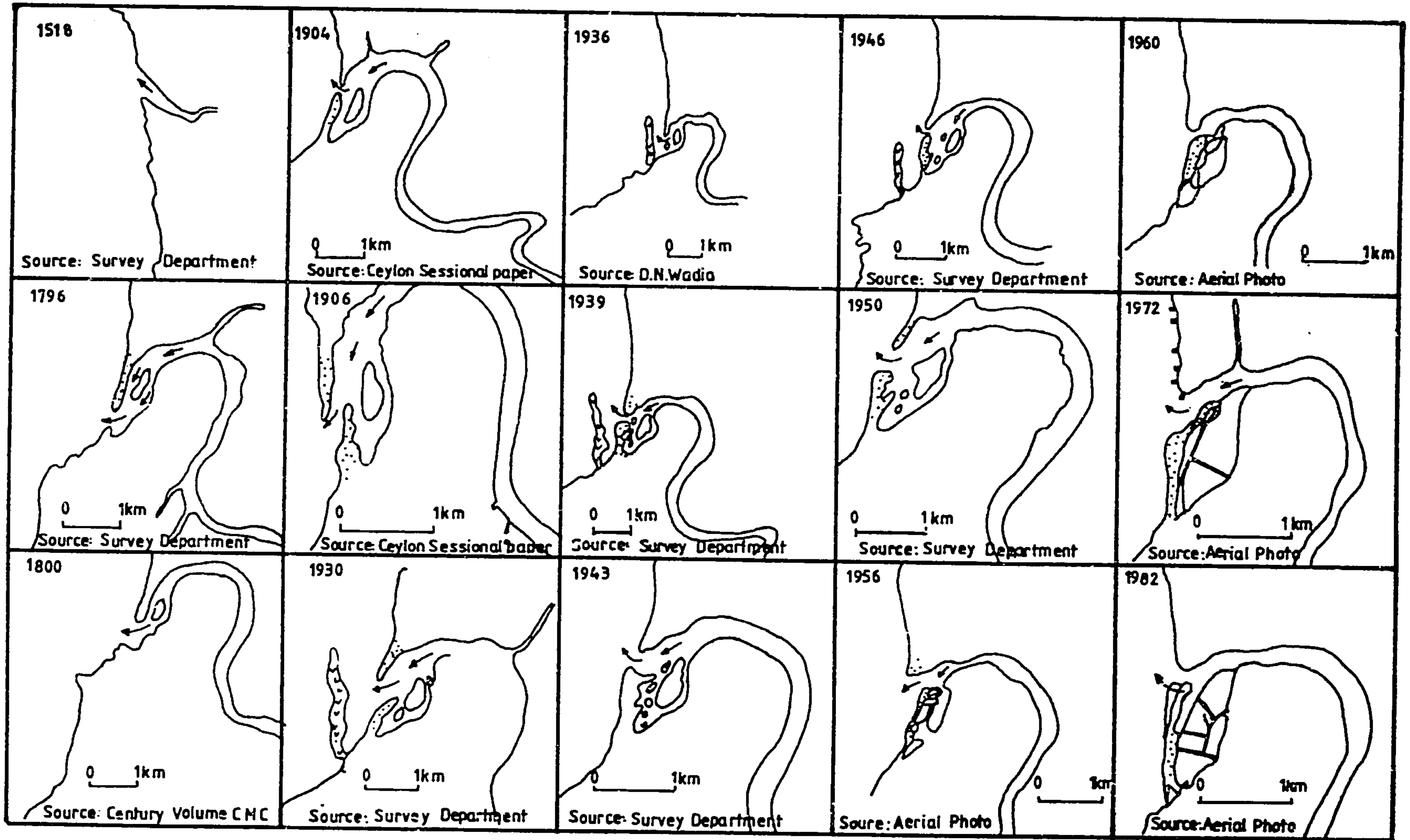
Year	*Name of Map*	*Publisher*
1518	Colombo	Surveyor General – Historical Details by R. L. Brohier
1656	Map of Colombo in the Portuguese Era	Surveyor General – Historical Details by R. L Brohier
1796	Fort of Colombo	Surveyor General – Survey Dept.
1800	Colombo in 1800	Rev. James Cordiner
1904	Colombo Showing Flood Area in 1904	Sessional Papers
1906	Colombo Harbour, Ceylon	Coode, Son & Mathews, Consulting Engineers
1906	Colombo Harbour (Admiralty)	Admiralty Chart
1930	Colombo North	Surveyor General – Survey Dept.
1936	Geological Sketch Map of Colombo	D. N. Wadia
1939	Colombo	Surveyor General
1943	Colombo	Surveyor General
1946	Colombo	Surveyor General
1950	City of Colombo	Surveyor General
1950	Tourist Map – City of Colombo	Surveyor General
1956	Aerial Photograph	Survey Department
1960	Aerial Photograph	Survey Department
1972	Aerial Photograph	Survey Department
1982	Aerial Photograph	Survey Department
1982	Urban Plan	Urban Development Authority

Information depicted on the historical maps could be classified for convenience into three major groups.

(i) changes that have taken place at the river outlet.
(ii) changes of shifting sand bars near the river mouth
(iii) changes in the shape and area of Crow Island.

The changes of the river mouth and its distributaries

The maps of 1518 (Portuguese period) do not show clearly the upstream course of the Kelani Ganga except at its mouth. According to Fig. 10 the river at that time reached the sea without encountering barriers or islands. The river mouth was fairly wide, and the coastline extended south without any irregular morphological features. This situation had obviously changed by the end of the Dutch period in 1796. As depicted in Fig. 9, the river by this time shows a clear meandering pattern and falls into the sea with a small island near its mouth. At this stage, the mouth of the river seems to have developed two outlets on the sides of the island. During this period the main river outlet was very narrow due to a long northerly spit-bar. By the year 1800 the river seemed to have remained the same as what it was in the year 1796. However, the river outlet seems to have moved slightly southwards. By 1904, the river outlet had migrated to the north and a lagoonal environment had formed near the estuary. The formation of a spit-bar has significantly contributed to the creation of this lagoonal environment. Unfortunately, hardly any historical maps are available for the period 1800 to 1904. Since 1904 the river mouth has moved to the south and it has stabilished itself at the centre of the thalweg with an equal distance from both migratory spit-bars.



HISTORICAL CHANGES OF KELANI GANGA ESTUARY (1518 - 1982)
Fig.10

Maps of 1936 also show the position remaining almost unchanged. Within a short period of 3 years the outlet has moved northwards again in 1939. This northern outlet remained unchanged even in 1946. However, the outlet has shifted between 1950 and 1956 back to the position of 1906 and 1936. Since 1956 and to date the outlet is located slightly to the north of its position in 1906.

The formation and shifting of spit-bars

The sand bars formed at the river mouth can be identified as distinct but transitory morphological features. In most maps since 1796 there were two spit-bars at the river mouth, one extending northwards and the other southwards. These maps also indicate that significant changes have taken place in the length and position of these river mouth bars from time to time.

In 1518 there was no spit-bar extending from the tip of the northern river bank. However, a sandbar which extends southwards could be observed in the map of 1796, making the river outlet somewhat narrow. This situation can be seen up to the year 1800. However, from 1904 to 1939 this northern sandbar had become shorter and shorter. As a result the outlet has shortened northwards while a southern spit-bar has developed. It is therefore obvious that there is an inverse relationship between shortening of the northern sandbar and the development of the southern sandbar. Thus when there was no southern sandbar from 1518 to 1800, the northern sandbar remained dominant (Fig. 10).

A well developed southern river mouth sandbar could be seen in 1904 (Fig. 10). This southern sandbar is generally oriented in a north-south direction. The neck of this sandbar is quite narrow and it is wider at its northern end. During the period 1906–1936 (Fig. 10) the length of this sandbar has been slightly reduced, and it has moved towards the land compared with the earlier periods. Besides that, the width of the neck of the sandbar has increased while the width of its northern part has decreased.

Further changes can be seen in sandbars during the period 1939–1950 leading to the creation of a lagoonal environment at the river mouth. Besides these changes several hook-shaped and other forms of secondary sandbars have formed towards the land side. In 1956 the southern sandbar has shifted landward and merged with Crow Island. This position continued to remain up to the present day. Therefore, the lagoonal environment has almost disappeared and several marshy tracks have appeared in its place.

The changes in the form of sandbars and their inverse relationships are undoubtedly related to the sediment budget of the estuary. It is possible that the sediment budget of the Kelani Ganga would have largely been affected by the changes that took place in its upstream watershed areas consequent to the opening of plantations since the latter part of the 19th century. The higher sediment load of the river during the period 1870 up to around 1940 due to expansion of tea plantations would have created an ideal environment for deposition of sediment at the estuary. It is also possible that the sediment yield of the river had reached some steady state after full establishment of the tea cover.

Changes in the 'Islands'

The first map which shows the formation of an island in the estuary of the Kelani Ganga dates back to 1796. It is possible that this island would have been the remnant of a former delta. As a result of occasional floods two distributories with an island in between could have been developed near the estuary. In 1904 Crow Island seemed to be an isolated land mass near the river mouth (Fig. 10) benefitting from the sheltering effect of a well-developed southern sandbar. Another distinct character of the Crow Island environment is the gap between the mainland and the island which has narrowed over a period of time due to the continued deposition of river sediments. By 1930, while Crow Island appears to have retained its original form, three smaller islands had been added to the estuary. This is likely to have been the result of a higher sediment yield possibly resulting from an accelerated rate of erosion in the upper catchment where large scale tea plantations were opened during the previous 50 years. These islands were separated from one another by a myriad tidal creeks. After 1930 the estuarine area evolved itself into a terrain with marshy lands probably as a result of the landward movement of the sandbar. The recent land reclamation work for housing development and for other building projects has virtually converted this area into a unique man-made terrain unit.

Recent Morphological changes (1956–1982)

The first air photographs of Crow Island became available in 1956. Since then air surveys have been conducted sporadically in 1960, 1972 and 1982. These photographs provide a useful source of information on coastline changes during the recent past.

An analysis of air-photographs indicate changes in the following prominent morphological units during the last four decades.

(i) Coastal Zone
(ii) Estuary
(iii) Crow Island
(iv) Sand bars
(v) Shore line.

(i) Coastline changes

Various changes in the coastline that have taken place during the last 30 years could be identified and estimated on the basis of 1956 air-photographs. The coastline that has been affected by these changes can be divided into 3 segments.

(i) from the Mutwal fisheries harbour to Crow Island
(ii) from Crow Island to the river mouth, and
(iii) from the river mouth to the north

When 1972 photographs are compared with those of 1956, recession of the coast-line towards the land can be clearly seen. This is obviously a result of severe erosion. As a preventive measure several groynes have been constructed on the northern side of the estuary and these are clearly depicted on the photographs of 1972. Besides these, several specific areas threatened with severe erosion can be identified (See Fig. 11). On the other hand when compared with the 1983 photographs the beach areas developed as a result of the construction of groynes are insignificant.

The coastline around Crow Island is an area which has undergone considerable changes. During the 1950's the coastline receded towards the land because of erosion and in 1970 it developed towards the sea and once again in the 1980's the Island is faced with an acute problem of erosion. These shifts of the coastline can be explained in terms of the changes of the shifting spit-bars situated near the river mouth.

A few other changes along the coast in the northern part of the estuary can also be identified. Here, the coastline which was of a straight and less irregular shape in 1956, has changed to a more irregular shape in 1972 and 1983. This irregular shaped narrow beach, is a result of the erosion of former beaches and the adjoining lands. On the photographs of 1980's these characteristics could be observed more clearly. It is possible that these changing processes would have started during the 1960s.

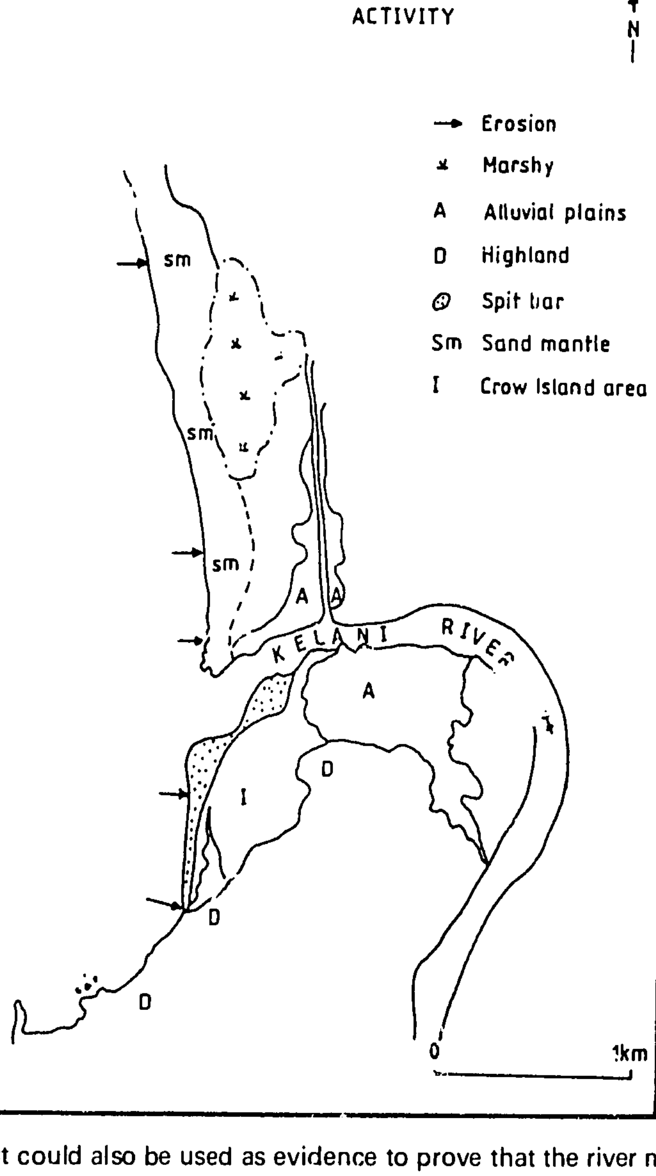
(ii) Changes along the estuary

A study of 1956, 1960, 1972 and 1983 photographs indicates clearly that, it is the estuary that has undergone some of the most significant changes.

The width of the estuary has become narrower during the 1980's but it had widened during the 1970's; again in 1980's it has become narrower. Obviously the formation of a sand bar on the shores of the northern bank of the river outlet has contributed to the narrowing of the river mouth. With the formation of that northern spit-bar at the river mouth the simultaneous formation of a semi-circular sand barrier in the sea in front of the river mouth can also be seen. This formation could be the result of an increased supply of sediments to the sea by the river in the 1960's than in the 1950's.

The changes in the regime of sediment transport are reflected in the tone of airphotographs in 1960 when compared with those of 1956. The general tone of the 1960 photograph is lighter. This reflects the increased suspended load transported by the

Fig 11. LOCATIONS OF SEVERE EROSIONAL ACTIVITY



river. Besides, it could also be used as evidence to prove that the river mouth had become a dominantly depositional environment instead of an erosional one. However, in the 1970's this situation had changed significantly, and the river load which would have deposited, was carried away off shore by the waves and currents. Sometimes this can also happen as a result of the increased velocity of the river current. These sediments would have normally been deposited in the southern part of the river mouth by the long-shore drift thereby resulting in the formation of a spit-bar parallel to Crow Island.

The increased transportation of sediments from the river mouth to off shore areas after 1970 has probably influenced the acceleration of erosional processes along the beaches of Crow Island. Some extraneous factor is responsible for the increase in the transportation of sediments to the off-shore areas. Since the detection of the possible cause from air-photographs was difficult, a field investigation was undertaken. According to field evidence the submerged reef situated about ½ km away from the beach has apparently been destroyed partly through human interference, and partly by undermining and consequent subsidence as reported by divers. If some reduction in the elevation of the reef has occured, through natural or man-made causes, then the finer sediment could pass through the gaps in the reef to the deep sea. Hence the sediments available for the replenishment of the beach becomes inadequate, leading to an acceleration of erosional processes.

Air-photographs indicate that no significant sand deposition has taken place on the spit-bar during the 1970's. Instead, severe erosion of the spit bar has taken place. Evidence for severe erosion is shown by the exposed root zone of mangroves along the spit bar. On the other hand the river mouth seems to have slightly narrowed in the 1980s as a result of transportation of an increased sediment load and its deposition at the estuary.

In addition to the changes referred to above, some distinct changes can also be detected in the area extending upstream from the river mouth. Thus photographs taken in 1956 and 1960 indicate the gradual development of pools upstream along the left bank. However, these pools show a shrinking trend by 1970. Again in 1980 this feature becomes more complicated and the left bank becomes more irregular in shape. But the right bank which was more irregular in shape during the 1960s than in 1956 has taken a more regular form by1979 and 1980. This can be a result of the construction of groynes in 1970 for the prevention of erosion.

Changes in Crow Island

The various changes that have taken place in Crow Island during the last thirty years can can be considered in relation to two time periods, namely: i. the changes before 1970 and ii. the changes after 1970. The photographs of 1956 and 1960 show Crow Island almost in its natural state. However, after the 1970's as a result of the filling and reclamation of the area, Crow Island could be seen as a unit of man-made terrain. According to the aerial photographs of 1956 and 1960, the estuarine area of the Kelani Ganga consisted of four small islands. These islands were separated by creeks and the whole area was covered by mangroves. The extents of these four islands in 1956 and 1960 are given in Table X.

Table X

Land Area of Crow Islands

Island (as in Fig. 12)	*Area (acres/hectares)* 1956		1960		*Difference*	
	Acres	*Hectares*	*Acres*	*Hectares*	*Acres*	*Hectares*
1	29.90	12.10	29.00	11.74	–0.90	–0.36
2	5.12	02.07	5.00	02.02	–0.12	–0.05
3	3.50	01.42	3.30	01.34	–0.20	–0.08
4	7.30	02.95	7.00	02.83	–0.30	–0.12
Total	45.82	(18.54)	44.30	(17.93)	–1.52	0.61

In spite of a slight reduction in the total extent, there was no distinguishable change in the area of these islands between 1956 and 1960. However, there had been a significant difference in the extent of water-logged areas adjoining the islands. These changes would have occurred as a result of seasonal changes in the river regime. The changing velocity of the current of the Kelani river flowing through the creeks would have caused changes in the area under water-logged conditions. Furthermore, the shifting of the sandbar formation bordering the Crow Island area could also have influenced the changes occurring in the water logged areas.

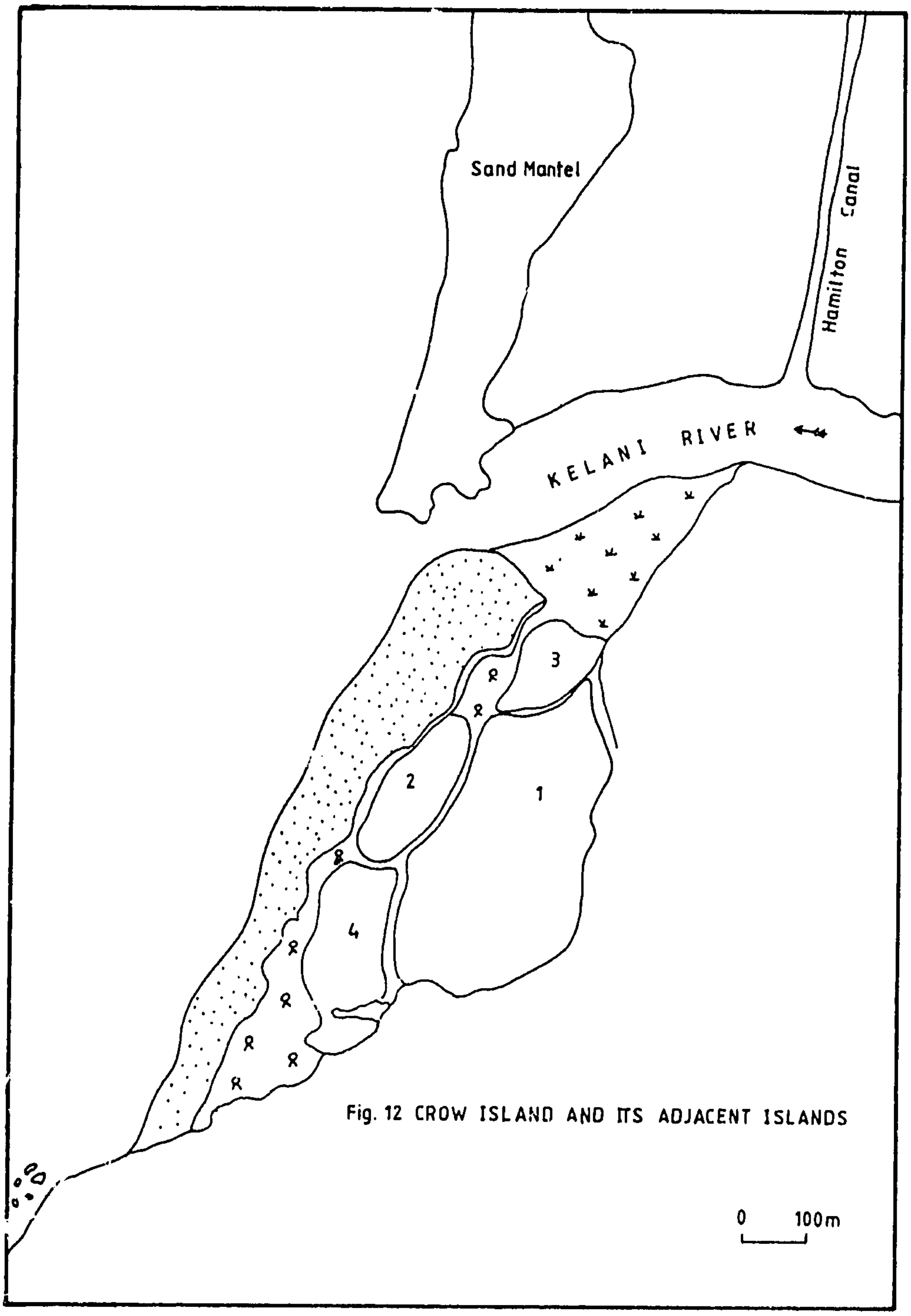


Fig. 12 CROW ISLAND AND ITS ADJACENT ISLANDS

Changes in spit-bars

Spit bars are the most prominent coastal landforms which have undergone spectacular changes. When 1972 and 1983 photographs are compared with those of 1965, it becomes clear that the most significant changes that have occurred have been those in relation to the southern spit bar. This spit-bar extends northwards from a line parallel to the southern boundary of Crow Island. At its beginning the spit bar is very narrow and at its tip it becomes quite broad. However, its width is not constant as it changes seasonally. Table XI, gives the measurements of the southern spit bar.

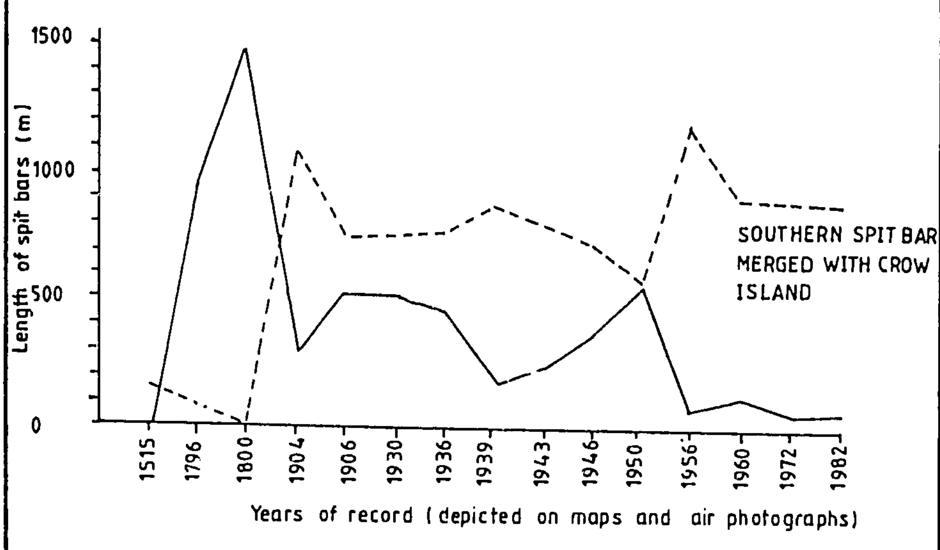
Table XI

Changing Dimensions of the Southern Spit-bar

Width of the spit-bar	1956–1960 *(m)*	1972–1983 *(m)*
Southern part	14	12.5
Middle part	24	19.5
Northern part	30	20.75
Total lenth of the spit bar	358	82.5

These changes also compare well with those shown by historical maps, depicting particularly the period before 1956 (Fig. 13). The most significant change associated with the southern spit-bar is its landward migration and its eventual merging with Crow Island. These changes indicate some disturbance in the sediment budget of the estuary which has undoubtedly resulted in the acceleration of the erosional processes.

Fig. 13 CHANGES IN THE LENGTH OF SPIT BARS



Shoreline changes

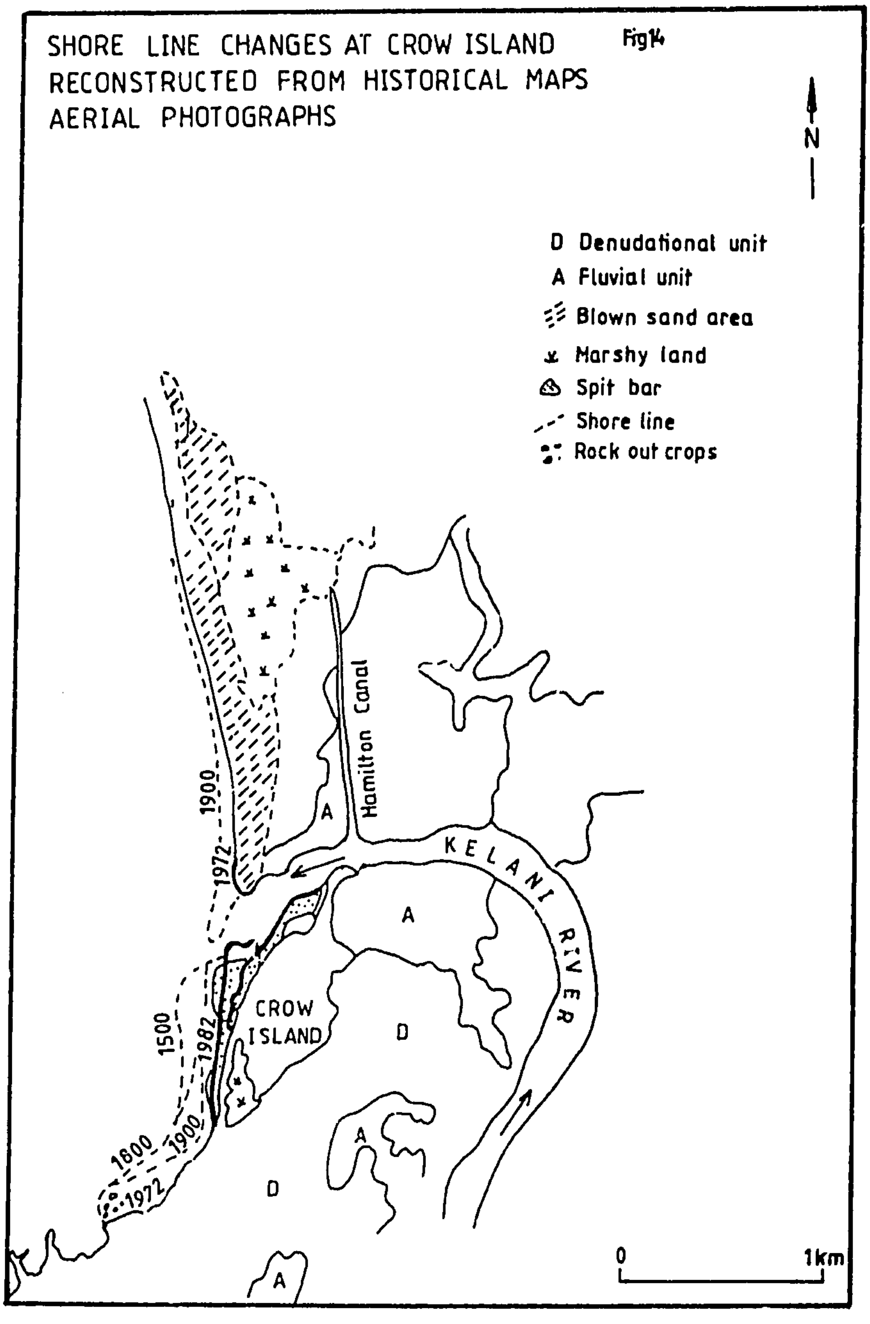
In addition to the morphological changes in the Kelani Ganga estuary, the shoreline has also undergone several changes. This is borne out by the following evidence:

(a) In the map of 1518 A.C. both coastlines extending from the river mouth to the north and south were less irregular.

(b) Since 1800 A.C. the southern shoreline has become increasingly irregular. This irregularity appears to have been accelerated after 1906. After 1950 the shore line has receded landwards quite rapidly.

(c) Accordingly to many topographic maps and oral evidence of local residents, prior to 1956 there has been a playground called Alexandra Park at the beginning of the southern sand bar. This does not appear in the maps compiled after 1956. A remannt of a circular swing can still be seen near the shore line of the truncated spit bar.

(d) The former shoreline which was cartographically reconstructed with the aid of aerial photographs and field evidence, is presented in Fig. 14. When different lines of available information are pieced together, a general picture emerges of heavy loss of land through erosion.



CHAPTER 3

A HISTORY OF DEVELOPMENT ACTIVITIES ON THE KELANI GANGA ESTUARY

3.1. The natural environment of the Kelani Ganga estuary began to change rapidly due to a variety of development activities since the latter part of the British period as a result of the development of Colombo as the capital city and the major port and harbour. In order to understand the impact of these activities on the Keani Ganga estuary, available historical documents and other sources of information were collected and analysed. The bulk of this information came from various Government institutions such as the Irrigation Department, the Colombo Port Authority, the Land. Reclamation and Development Corporation, the Urban Development Authority and the National Housing Development Authority, as well as from interviews with people residing in the Crow Island area. An examination of the information obtained from these sources indicates that the Colombo Harbour and Fisheries Harbour development, irrigation and flood protection activities and the city development programmes had a significant impact on the changes that have taken place in the environment of the Kelani Ganga estuary.

3.2. **Harbour Development**

The beginnings of the evolution of Colombo Harbour can be traced back to the Portuguese period (Fig. 15). The gradual development of the Harbour continued during the Dutch period and the early period of British occupation. It is said to have afforded safe anchorage to an aggregate of some 20,000 tons of shipping even as far back as 1830.

However, the development of the Colombo harbour reached a significant level only after the construction of the breakwater during 1875–1885. This breakwater was 1285 metres long and 15 metres wide and stood 3 metres above the level of the breaking waves. The other breakwaters in the Northeast and Northwest were completed in 1898. The 'Island Breakwater' which was completed by 1900, gave the harbour adequate shelter for an enclosed area of about 260 hectares.

In addition to these major activities, there were also some minor construction works in the harbour enclosure during this period For example in 1902, 18 jetties were built up in front of the coaling depots. Thereafter, no major activities had taken place until the 1950's. The modern developments were in fact incorporated in the original Harbour enclosure. These major structures included Northeast Quay, Delft Quay, and Queen Elizabeth Quay which were added later and which reduced the area from 260 hectares to 243 hectares. Since then there have been hardly any development activities except the recent construction of a container terminal. However, the inner Harbour area was dredged to specific depths from time to time to cope with the problem of siltation. Thus it has been estimated that between 1880 and 1930 nearly 10 million cubic metres of material have been dredged from inside the harbour basin (Godage 1983). This change is clearly brought out by the submarine contours within the Harbour as depicted in the maps of 1803, 1840 and 1931 (Fig. 15A).

The Fishery Harbour development project was started at Mutwal beach in 1902. The main purpose of this project was the construction of a breakwater in the N-E direction to provide shelter for more than 700 fishing boats. The breakwater was 245 in length and built of rubble stones mainly from the Mutwal Quarry.

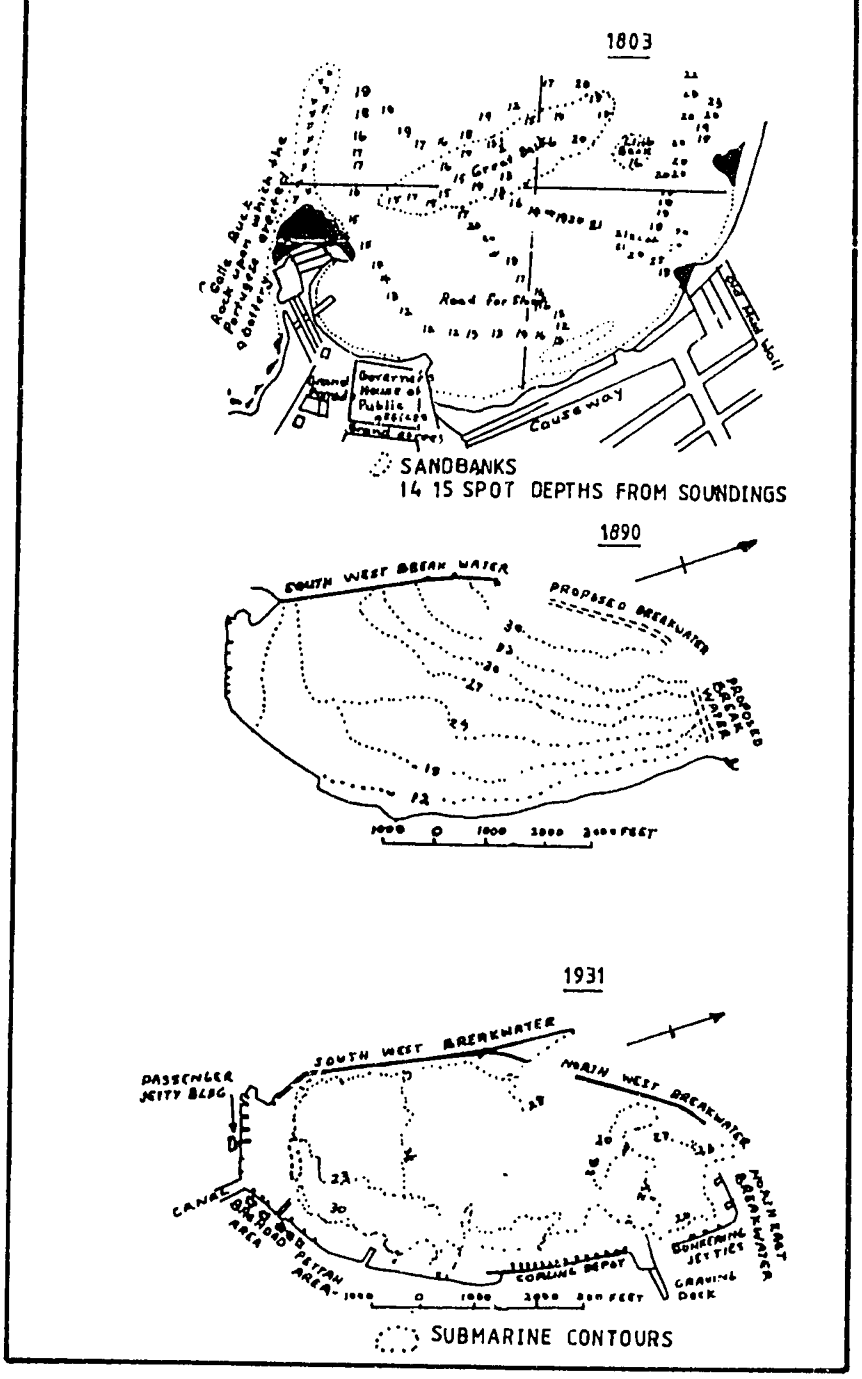
Fig. 15 · **Portuguese map of Colombo** page 9
(Translation of Inscription on the Map. "This fortress was erected by Governor Lopoz Soarez and was demolished by Governor N O Da Cunha by Order of the King Our Lord")

The building of the breakwaters in the Colombo Harbour as well as in the Fishery Harbour may have affected the transport of the beach sands from the southern coastal areas by the longshore currents. On the other hand the dredging could have affected the sedimentation processes in and around the Kelani Ganga estuary.

3.3. Urban Development Activities

During much of the Portuguese period and in the early Dutch period, the Crow Island area remained almost completely abandoned and was covered by littoral forests and marshy lands. Later, the Dutch developed the road system, dug canals and cultivated cinnamon on the higher terrains. The Kelani Ganga and its distributaries were linked together by the canal system. The Dutch canal which begins from Puttalam runs through Negombo and joins the Kelani Ganga near its estuary and finally ends up in the Beira Lake in the City. With the development of the harbour and other urban functions the northern part of the city became more densely populated. Thus the 'Kotanchena' ward which covered the area up to the Kelani estuary at that time recorded a population increase from 16,322 in 1891 to 20,260 in 1901. By 1981 the population in the wards

Fig 15A EVOLUTION OF THE COLOMBO HARBOUR (1803-1931)



which now fall within the former Kotanchena ward had increased to 106,777 giving a a crude density per acre of 6.6 persons or nearly 70 times the national average density. At present one of the most serious problems in the area is the scarcity of land for housing and construction. In order to solve the problem of land scarcity at least partly, the Ministry of Housing, the Urban Development Authority and the State Engineering Corporation have made some attempts at large scale reclamation of land since the beginning of 1970. As a result 'Crow Island' was reclaimed by dredging sand from the Kelani Ganga estuary and transporting soil from other parts of this area to fill the low-lying parts of the Island. It has been estimated that the total extent of reclaimed land was around 8 hectares and that nearly half this area was filled with river sand. In 1979 the buildings of the National Aquatic Resources Agency (NARA) constructed on this land and two adjacent housing schemes established.

In spite of the reclamation of lands and the construction of housing sites, the people residing in the area complain that coastal erosion in the southern part of Crow Island beach caused by high waves during the monsoon period is seriously affecting the land and threatening some of the buildings For example, an old house, a recreational park, some valuable land and many coconut trees have been completely destroyed recently by the high waves. In order to check erosion a rubble stone groyne has been constructed on the Mutwal beach.

Sand mining is the other major factor that affects the sediment balance of the estuary. Large quantities of river sand are being removed from various sites along the river to distances as far away as Avissawella. The increased mining of sand reflects the expansion of construction activities which reached a peak in recent years stimulated by the growing urbanization. It is obvious that mining of sand directly affects the transportation of the bed load in the river. It could also weaken the process leading to beach replenishment in the Crow Island area. In 1984 a survey was carried out by the People's Bank to estimate the amount of sand removed from diferent locations along the Kelani Ganga. This survey arrived at an average figure of 1349 m^3 per day giving an annual mining rate of around 222,771 m^3. It should be noted that this estimate does not however, include the large amount of sand removed from the river by mechanical means for the development of the new capital of Sri Jayawardenepura, Kotte.

3.4. Flood Protection and Drainage Activities

Since the Dutch period (18th century) flooding of the low lying areas, particularly of the northern banks of the river such as Peliyagoda and Petiyagoda, had been a serious problem. During this period a flood protection bund 7.61 kilometers long was cons-constructed. The problem of floods however, remained largely unsolved. During the monsoonal period of high rainfall some of these areas continued to be flooded causing a number of other problems Thus from time to time several attempts were made by the Local Government and Irrigation Departments and other concerned agencies to mitigate the effects of floods. These activities included:

(a) construction of flood protection bunds on the northern and southern banks of the river,
(b) building of culverts at the confluences of tributaries with the main river, and
(c) reclamation of marshy lands.

Details of these activities are given in Table XII. The environmental impacts of flood protection and drainage activities on the estuary of the Kelani Ganga have been many and varied. For instance the immediate result of constructing the 6.6 km. long northern flood protection bund by the Dutch would have been an increase in both the velocity of discharge and the sediment load of the river. At that time while the deposition of finer sediment on the flood plain areas may have decreased, it would have increased in the downstream river channel towards the estuary. Therefore the impact of the northern flood protection bund should have been felt in the Dutch canal and in the Crow Island area. Large scale flood protection and drainage engineering activities have both beneficial and adverse effects. It is possible that the necessity for desilting the river mouth arose at least partly as a result of upstream flood protection works. The cumulative result of all river training exercises would thus have been manifest in the Crow Island environment in the form of development, migration and disappearance of river mouth sandbars, and in the creation of marshy water-logged lands. As indicated by the air-photographs it is also possible that the problem of siltation of the Colombo harbour which is open to the north and north-east is not unrelated to the sediment discharge of the Kelani Ganga.

Table XII

A Chronological Record of Development Activities on the Kelani Ganga Estuary & its Environs

I. Port and Harbour Development

Type	*Duration & Time*	*Nature of Work*
1. South-western Breakwater	1875–1885	1285 metres long. Constructed with 30 ton concrete blocks set in sloping land on a prepared rubble base deposited on sea bed and within a mass concrete capping on top at a level of 3.36 metres above Low Water Mark.
2. North-eastern Breakwater	Completed 1898	335 metr's long. Rubble bank protected on the seaside by 5.10 ton armour stone. Some 215,000 tons of rock were deposited.
3. North-western Island Breakwater ..	Completed 1906	814 metres long. Similar to South-western Breakwater in construction.
4. Dredging of Harbour	1880–1990	Land 8 metres below Low Water Mark, reclaimed along the harbour frontage.
5. Dredging of Harbour	1892	Dredged deepening to 8.5 metres.
6. Dredging of Harbour	1896–1906	Dredging the harbour upto 9 metres.
7. Coaling jetties	1902–1912	18 jetties were constructed along the reclaimed foreshore south of the Graving dock.
8. An extension Arm to the South-western Breakwater	1907–1912	500 metres long. An effective wave trap.
9. Wave Breaker	1912–1913	Some 1590, 30 ton pell-mell concrete blocks were deposited on the outer berm of the breakwater.
10. Total dredging in 50 years	1880–1930	10 million meters of material have been removed by the dregers from within the harbour basin.
11. Construction of Quays	1950–1956	Prince Vijaya, Delft and Queen Elizabeth Quays.
12. Dredging	1973–1981	1.9 million cubic metres of spoil. The dredger 'Diyakawa' carried out 220,000m of reclamation in the new new container terminal.
13. Building a Container Terminal ..	1980–1985	300 metres long container terminal built.
14. Ongoing projects		Dry Dock Harbour Project.
II. Flood Protection and Drainage		
1. Flood protection bund	Dutch period (18th century)	7.6 kilometres long Kelani North flood protection bund constructed by the Dutch along the North bank of river.
2. Dutch Canal	Dutch period (18th century)	A canal was built from the Kelani river mouth (Mattakkuliya) to Negombo.
3. Railway Embankment Bund ..	1922–1924	3.47 kilometres long, from Wellampitiya to Mahawatte along the railway line.
4. Flood protection bund	1922–1924	0.81 kilometres of Kolonnawa bund.

Type	Duration & Time	Nature of Work
5. North lock		Lock gate concrete structure 33.5 metres long and 4.8 metres wide, crest level 19.3 metres above mean sea level controlled by three wooden gates.
6. Urugodawatte Road gap		Length of gap 6.5 metres Crest level of bund 21.6 metres above mean sea level.
7. Urugodawatte main line gap ..		Length of gap 8.7 kilometres, Crest level of bund 21.6 metres above mean sea level.
8. Waragoda Harbour line gap ..		Length of gap 16.2 metres, Crest level 20.6 metres above mean sea level.
9. Victoria Bridge Road gap		Length of gap 6.5 metres, Crest level 20.4 metres above mean sea level.
10. Main Drain		3.1 metres wide Channel from Prince of Wales Avenue to Mutwal.
11. Nagalagam Culvert		A concrete structure 4.1 metres long with two wooden gates.
12. Bloemendhal Road Culvert.. ..		A concrete construction 4.6 metres long with two openings.
13. Aluthmawatha Road Culvert ..		A concrete construction 4.8 metres long with two openings and concrete tunnel 1.8 metres diameter and 566.5 metres long.
III. Coastal Development		
1. Fishery Harbour	1902	250 metres long breakwater extended in a North by East direction from the rocky edge at the Mutwal coast.
2. Sewerage outlet	1926	1.8 metres diameter concrete lined 593.7 metres long drainage outlet at the Mutwal beach.
3. Breaching of the sand bank at the river mouth	1950	A sand bar extending from the northern tip of the river mouth was destroyed by the Port Authority in connection with the flood protection scheme in Colombo North.
4. Construction of Groynes	1964	Constructed two rubble base deposited groynes at the northern tip of the river mouth and the rocky edge of the Mutwal beach.
5. Ongoing projects		Constructing a sewerage outlet about 3.2 kilometres away from the Mutwal beach. Construction of a petroleum pumping station at Mutwal by the Sri Lanka Petroleum Corporation.
IV. Urban Development and Land Reclamation		
1. Colombo Municipality area extended ..	1865	The Colombo Municipal Council area extended to the southern bank of the Kelani Ganga.
2. Land Reclamation	1902	The harbour foreshore area west of the Reclamation road from Pettah to Mutwal was reclaimed from the sea.

Type	*Duration & Time*	*Nature of Work*
V. Urban Development and Land Reclamation		
		The subsequent land reclamation activities in Colombo were particularly concentrated in the Beira lake and in the Eastern part of the city.
3. Reclamation of Crow Island ..	1979	The swamps in and around Crow Island were filled partly with sand dredged from the Kelani estuary and spoil from other parts of the city. The total reclaimed land area is approximately 8 hectares.
4. Crow Island Housing Scheme ..	1980	A two-storyed housing complex was constructed by the National Housing Development Authority partly on the reclaimed land.
5. National Aquatic Resources Agency ..	1980–1982	Two building complexes were built by the Ministry of Fisheries in the northern part of Crow Island.
6. Ongoing projects		Some reclamation and housing activities are in progress. . .

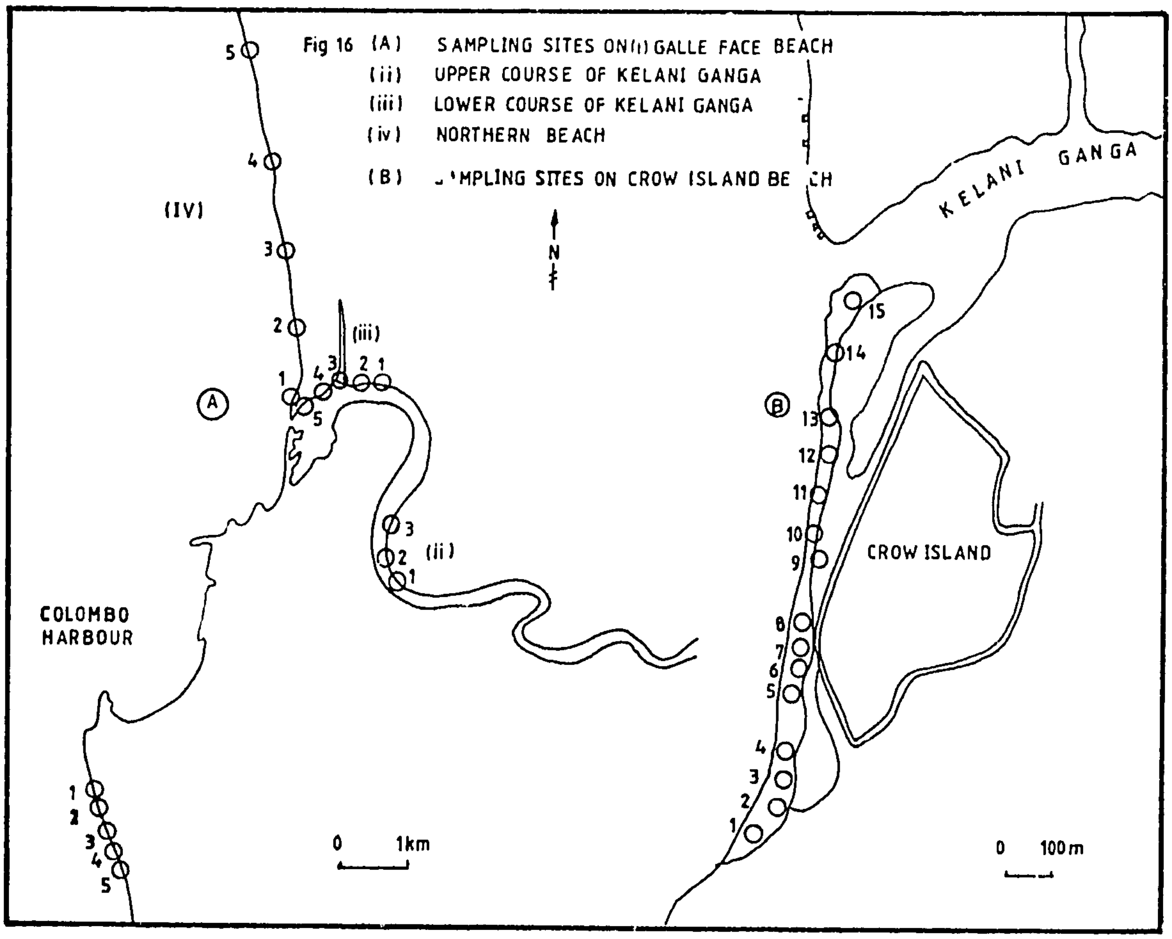
CHAPTER 4

AN ANALYSIS OF BEACH SAND & RIVER SEDIMENTS

4.1. The reconstruction of the historical evolution of Crow Island and its environs as attempted in Chapter 3 has clearly indicated the importance of sedimentological considerations in understanding the coastal dynamics of Crow Island. Therefore an attempt was made to trace the sources of sand to the beaches of Crow Island and their distribution. Sand samples were collected at 20 metre intervals from four locations, namely (a) Galle Face beach, (b) Crow Island beach, (c) beach north of the Kelani Ganga mouth and (d) the bed of the Kelani Ganga (Fig. 16). The beach samples were collected along the high water mark. This was roughly taken as the seaward limit of creeping vegetation or any natural or artificial feature such as a cliff face or a sea wall limiting the extension of beach. All samples were taken after removing loose sand from the surface.

4.2. Analytical Procedure

Most sand samples collected were free from shell fragments except those from the Galle Face beach which contained a considerable amount of shell fragments. They were removed by acid treatment, before drying for sieving. Sub-samples of 50–150 grammes of sand were used for mechanical analysis. The sets of sieves discribed in Table XIII were used and the samples were shaken for 10 minutes in a mechanical sieve shaker.



The sand fractions remaining in the sieve pans were weighed and percentages were calculated using the following standard procedure.

Table XIII

Sieves used in the mechanical analysis of sand

Sieve No.	*Sieve Size (mm)*
8	2.380
14	1.410
18	1.000
20	0.841
35	0.500
60	0.250
80	0.177
100	0.149
230	0.063

The data obtained from the mechanical analysis was used to construct cumulative frequency diagrams from which median grain size (Md) and quartiles were obtained. Parameters like median grain size and sorting coefficient were used to compare sands sampled from the four selected localities. The following two parameters were calculated as coefficients of sorting:

(1) Trask's sorting coefficient So,

$$So = Q_3/Q_1$$

where Q_1 is upper quartile (75 percent greater than)

Q_3 is lower quartile (25 percent greater than)

$\log_{10}$ So is considered to be more useful for comparative studies (Krumbein and Pettijohn 1938)

(2) Graphic Standard Deviation (Folk and Ward 1957)

$$1 = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$$

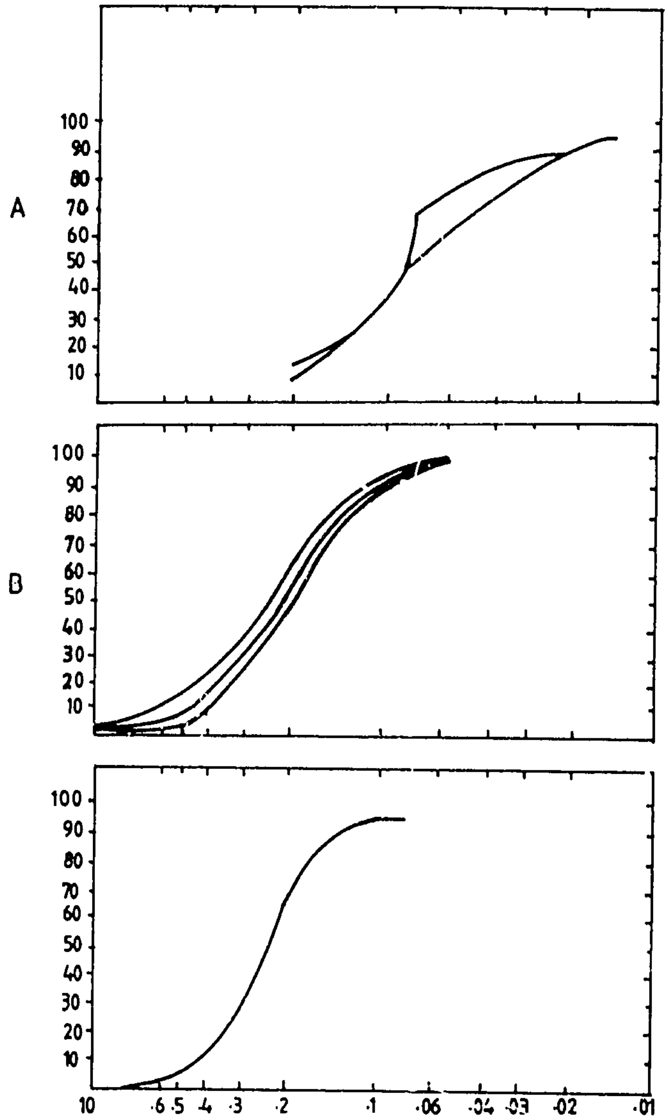
The second method is accepted as being more accurate since it takes the entire distribution of particle sizes into consideration. It has also been found to provide a value close to the mathematically determined standard deviation. Trask's So does not take the standard deviation into abbount and therefore it is mathematically less sound.

4.3. Results of Grain-Size Analysis

The shape of the cumulative frequency curve is an important diagnostic factor in the identification of sedimentary environments (Krumbein and Pettijohn 1938). (S' shaped cumulative frequency curves are characteristic of sedimentary formations with a high degree of sorting. Beach materials very often tend to have a high degree of sorting due to the energy! of ocean waves. Therefore, the dominance of a single grain-size band containing a fairly high concentration of heavy minerals is characteristic of wave sorted materials.

The grain size characteristics of sediment of the four locations are illustrated in Fig. 17, A, B, C. The Galle Face sands have a well balancld distribution approaching an 'S' shaped curve indicative of a high degree of sorting. Sand from Crow Island North bank of the Kelani river and the northern beach show very similar distributions. They are less well sorted, and are all dissimilar to Galle Face beach samples (Table XIV). In most of the beach samples, grain size range is restricted to less than 1.00 mm fraction. The cumulalative frequency curves drawn for Kelani Ganga bed materials are very different with respect to the shape of the curves and also to the grain size range which is generally coarser (side) than the beach sands. These differences are well illustrated by median grain diameter (Md), sorting coefficient (So and $\log_{10}$ So) and graphic standard deviation listed in Table XIV.

Fig.17 PARTICLE SIZE DISTRIBUTION OF SEDIMENT SAMPLES.



A KELANI GANGA

B CROW ISLAND

C GALLE FACE

Table XIV
Textural parameters of the sands

Sample	M_d	*So*	log_{10} *So*	Q_1
Galle Face	0.256	1.266	0.102	0.505
Crow Island	0.270	1.490	0.173	0.960
N. Bank	0.210	1.440	0.158	0.830
N. Beach	0.220	1.460	0.164	0.780
Kelani Ganga	0.910	2.290	0.360	0.098

According to Table XIV, the sorting coefficient is lowest for the Galle Face beach sands and highest for the Kelani Ganga bed materials. Other locations have values in between but closer to the Galle Face value. All beach materials are similar with respect to the median grain size but the river bed sands are much coarser than the beach sands.

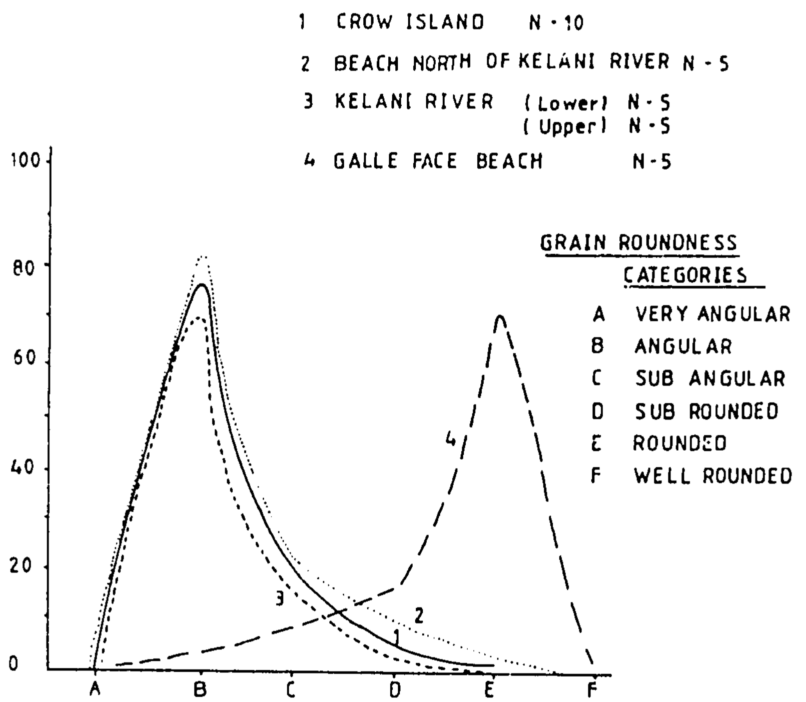
4.4. Grain Roundness

Roundness was determined on two selected minerals, namely ilmenite and magnetite, for they occur in the source rock as angular grains. Rounding of these minerals may easily be attributed to their transport history and mechanics. The grain roundness of these minerals was determined under a binocular microscope by comparing with a chart containning grains of six roundness classes varying from very angular to well rounded (King 1975 after Shepard and Young) For this study 100–300 grains from each sample were used.

The mean values were calculated for sands from all four locations and the percentage for each roundness class was calculated. These values were plotted as a frequency distribution (Fig. 18).

From Fig. 18, two well defined peaks can be identified in B (angular class) and E (rounded) classes. This shows that the sediment analysed in this study can be divided into two categories namely those with angular grains and those with more rounded grains. Galle Face sands represents the latter and sands from the other three locations represent the first category. It is interesting to note that sands from the Kelani river bed and those from the Crow Island area are similar in respect to grain roundness characteristics (Fig. 18).

Fig 18 MEAN PERCENTAGE PARTICLE ROUNDNESS



4.5. A cursory mineralogical analysis was caried out on sand samples from the Crow Island beach. The presence or absence of certain minerals in Galle Face beach samples is also indicated in Table XV for comparison.

Table XV

Mineralogical Analysis

	Galle Face	*Crow Island*	*S G.*	*WR*
1. Zircon	×	×	4.68	A
2. Ilmenite	×	×	4.7	B
3. Magnetite	×	×	5.18	A
4. Rutile		×	4.18–4.25	A
5. Quartz	×	×	2.65	A
6. Monosite	×*	×	5.0–5.3	Q
7. Muscovite		×	2.76–3.1	E
8: Hornblend		×		E
9. Garnet	×	×		E

* *Rare*

S.G.: Specific Gravity

WR: Weathering resistance

A: Greatest resistant to weathering

B: Resistant to weathering between A and B

E: Least resistant to weathering

The conspicuous absence of Muscovite Garnet, Rutile and the scarcity of Monazite in the Galle Face sands is interesting. The presence of Mica near river mounths has also been reported by other writers (Swan 1983). Muscovite is a highly unstable mineral that cannot persist in marine environments. It is therefore, generally absent in beaches away from the river.

4.6. **Discussion**

In a study of the evolution of Crow Island, and in understanding its present morphological instability, it is pertinent to determine the sources of sediment supply for the Kelani Estuary.

There are three possible sources of sand supply to the Kelani Estuary, namely, (a) the Kelani Ganga, (b) the longshore drift and (c) beach erosion.

It may be expected that a greater part of the sediments coming into the estuary is supplied by the Kelani Ganga. There is evidence to support the existence of a northerly drift of sand in the western littoral zone, but the Colombo harbour is likely to act as an effective barrier depriving the Kelani estuary of sands coming from the south. This is well illustrated by the results of the sedimentological investigations reported above (Section 4.3 and 4.4). Amongst the three parameters (i.e texture, mineralogy and morphology) mineralogy and grain roundness have provided some guidance to differentiate sands which have different histories and origins. Those sands which have travelled long distances tend to have more rounded grains. Furthermore they tend to be lacking in easily weatherable minerals.

The sands of the Galle Face beach should have been derived from a source further south, most probably from the Kalu Ganga since there are no important streams draining into the sea between Kalutara and Galle Face. Therefore, sand grains probably travelled with the littoral drift tend to show an increase in roundness due to (a) selective transport of more rounded grains and (b) further rounding during transportation. Therefore, as can be expected, the Galle Face sands contain more rounded grains. By contrast, sands near the Kelani mouth contain more angular grains because in river transportation sand grains do not seem to get rounded as much as during marine transport. Examination of river bed-load sands close to the Kelani mouth showed that grains were very rare.

Mineralogically, the Galle Face beach sands can be differentiated from the others by the relative absence of muscovite, hornblende, and rutile which were present in the Crow Island samples. Muscovite and Hornblende are highly unstable minerals which tend to weather very soon. They are abundant near river outfalls but not present in beach sands away from them (Swan 1983). This therefore indicates that Crow Island and the sand bars were formed primarily with sands brought in by the Kelani Ganga.

Absence of sand bars and the erosion in Crow Island and the beaches around indicate that the balance that existed between various factors and forces has been affected due to natural or man-made causes. While there is hardly any evidence of changes in natural environmental factors since the 1940's, there is some evidence to suggest that human interference with this delicatrely balanced environment has increased in recent decades. Several important human activities which could have had a bearing on sediment balance can be identified. Flood prevention works, land reclamation programmes, harbour construction activities and increased extraction of sand from the river are some of them. Amongst these factors, sand extraction would certainly have serious repercussions in the estuarine environment. In this context it may not be an exaggeration to state that the entire city of Colombo has been built by the sands brought down by the Kelani Ganga. Sand extraction from the Kelani Ganga may have been going on for a long time, but earlier it would have been on a smaller scale. After independence these activities would have been accelerated to meet the growing demand from the increasing housing stock of the city of Colombo.

The present rates of sand extraction from some of the major rivers of the South-western coast of Sri Lanka have been quoted in a People's Bank Study (1984). Table XVI lists these figures together with the annual total discharge of these rivers.

Table XIV

The Annual Total Discharge of some Major Rivers of the South-West Sector of Sri Lanka and the Volume of Sand Extracted Annually

Name of River	*Annual Discharge (Million m³)*	*Volume of Sand Extracted per year (Cubes)*
Nilwala Ganga	1380	2005
Gin Ganga	2180	21563
Kalu Ganga	8187	46563
Kelani Ganga	5582	222771
Maha Oya	1485	111720
Deduru Oya	1130	22896

(*Source:* Peoples Bank, 1984; Irrigation Department Records).

According to these figures the volume of sand extracted from the Kelani Ganga is 4.8 times greater than from the Kalu Ganga, which has the highest discharge and perhaps the highest sediment yield. According to Swan (1983, p. 52), the Kelani Ganga is ranked third in the production of sand but it has the highest sand extraction. This may be attributed to the greater demand for sand in the Colombo area particularly in the recent past and during the current boom in the construction industry. It is not known what percentage of the river load is removed by people but there is hardly any doubt that it constitutes a substantial portion of the river's natural load which could well exceed the threshold that maintains the natural balance. Removal of such a large volume of sand, which would otherwise have replenished the estuary has created a sediment deficiency in the Kelani Estuary. This factor alone could be responsible for changing a predominantly depositional environment into an erosional one.

It has been argued by some writers, that the sand supplied by the Kelani Ganga does not play an important role in the sediment budget of the estuary because the greater part of the river load escapes into the offshore zone. The presence of a sediment flume on aerial photographs extending towards the offshore zone has been used as evidence for the above argument. But it is a well-known fact that such features on aerial photographs represent mostly the suspended load and not the bedload which can be seen on the river mouth in the form of ripples and sand waves when the sea is shallow. The sediment flume that appears in aerial photographs should be made up of finer grade materials transported in suspension and they may be undoubtedly responsible for the silting up of the Colombo Harbour. The coarser materials brought in by the river are deposited in sand bars and a part of it is carried away by northerly currents produced by waves approaching obliquely. The north-south extending submerged reef may effectively obstruct the escape of bed materials into the offshore zone.

Geological History

On the geological time scale the depth of sedimentary deposits in Crow Island seems to point to a possible change in the sea-level off the western coast. Evidence for sea-level changes have been traced by Wadia (1941), Cooray (1967), Sommerville (1908), etc. This information can be summarised as follows:

(i) Beira Lake (Wadia 1941). Several episodes of sea-level fluctuations are indicated by the stratigraphic evidence of Beira Lake.

(ii) Presence of laterite below sea level, as at Hendala; total thickness around 15 metres. Out of that at least 8 metres below MSA (Herath and Pattiarachchi 1970).

(iii) Laterites occur in the flood plain of the Kelani Ganga under the marshes adjoining Kolonnawa. Grandpass, Wellampitiya, Kelaniya, etc. These laterites extend 4.5–13.7 metres below MSL (Seneviratne 1970).

(iv) The terrace gravels eg. Malvana formation lie about 15.2 metres above the present river level (Coates 1913 quoted by Cooray 1967).

(v) A submerged forest of dictyledonous trees exists at 45 metres below MSL west of the Colombo–Kandy road between the 4th and 5th milestones. These trees are covered by peat and river-borne sand indicating marshy conditions (Deraniyagala 1958).

These pieces of evidence according to Wadia (1941) and Cooray (1967) show sea level oscillations of around 12.1–15.1 metres during the quaternary period. However, Cooray (1967) suggests that the sea-level of the western coast of Sri Lanka remained relatively static during the last 3000 years. This is indicated by the presence of a coral reef in Hikkaduwa about a foot above sea level which has been dated to be 3000 years old.

If the theory of sea level changes is accepted, the origin of the Crow Island may well be related to fluctuations of the sea level. The bottom layer of sand found on Crow Island may well have been laid down by the Kelani Ganga when it was at a higher elevation. Organic clay deposits may represent a lagoonal environment which may have been created by a sandbar formed on the seaward side cutting off the lagoon completely. The presence of peat layers in certain locations at the centre of Crow Island indicates marshy conditions created possibly at a higher elevation that at the level at which they are found today.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1. The major focus of this study constituted an investigation of historical changes in Crow Island and its immediate environs. An attempt has been made to collect information related to this theme from a variety of sources. These included historical maps, air-photographs, and published and unpublished data from Government departments and other institutions. The proximity of the Kelani Ganga estuary to the city of Colombo and its harbour is one of the reasons for the availability of much of this historical information. Admittedly historical data in the form of maps are not always a dependable and accurate source of information. The scale of the maps, their cartographic presentation and the authenticity of the map makers do not always make these maps amenable to precise cartographic measurements. The more one goes back into history the more difficult becomes the interpretation of maps. For example, the earliest available map of Colombo (1518) "combines the medieval attempts to produce effect by both 'symbol ' and relief in pictorial Cartography" (Brohier 1948).

On the other hand it was surprising to discover such a wide range of maps made at such distant points of time in history. Most countries, except perhaps those in Europe, do not possess this wealth of historico-cartographic information that we have here in Sri Lanka. Therefore, in spite of the limitations inherent in early maps, and of the absence of other sources of information on coastline changes, one has to fall back on the qualitative information decipherable from them. Thus although one may not be able to measure accurately the precise dimensions of a coastal feature such as a spit-bar, the very presence or absence of it may prove to be an extremely useful piece of information.

5.2. In our quest for information in records and files maintained by various institutions we have come across some useful sets of data which are more reliable than historical maps. Bore-hole data, hydrological records and information given in Admiralty Charts fall into this category. We are inclined to suspect that further sets of similar data may exist in scattered sources which we could not trace during the limited period of our investigations.

5.3. In addition to the available historical maps and other literary sources, we have also made some attempts to collect information by direct field observations, measurements and collection of sediment samples and their subsequent laborarory analysis. It is admitted that much of the field observations are of a qualitative nature, such as interviews with elderly coastal residents or occasional visits to the study area to observe seasonal changes. However, the surveying of the area and the collection and analysis of sediment samples were based on standard procedures and techniques used in the relevant fields.

We do not consider that data we have generated are adequate for the purpose of precisely reconstructing the past history of the Kelani estuary. Therefore, we are inclined to believe that what we have attempted constitutes nothing more than a reconnaissance survey. Our field investigations have in fact opened more vistas for future research and raised more questions than what have been actually answered. Nevertheless, considering the constraints of available time and resources we feel that we have achieved much more than what had been originally anticipated.

5.4. While keeping in mind the limitations and reliablity of information we have collected and generated we shall now attempt a reconstruction of the past history of Crow Island.

The story of the evolution of the Kelani Ganga estuary and Crow Island begins in the most recent geological period–the Pleistocene, which is dated to be around one to two million years. The post-Pleistocene period in most parts of the mid-latitudes was marked by the recession of ice sheets which accompanied significant fluctuations of sea level. Although these changes were not experienced with the same magnitude in tropical areas, there were changes of sea level which could have significantly affected coastline changes. Deraniyagala (1958) has compiled a list of evidence for both emergence and submergence of coastlines in Sri Lanka since the Pleistocene period. Subsequently more evidence of coast line changes were brought to light by Cooray (1958) and Swan (1964). These writings throw some light on the evolution of the Kelani Ganga estuary. Most writings on sea level fluctuations on the western coast tend to interpret the raised beaches, and inland deposits as witnesses of the interglacial period while the post-Pleistocene period is marked by phenomena related to submergence Thus Deraniyagala (1958) makes an attempt to reconstruct the former beaches of the western coast on the basis of submarine contours. The deposits and duricrusts which are observed below the present sea level (eg. organic clay in Crow Island and laterites below sea level) indicate the possibility of submergence of coastal areas during the post-Pleistocene period.

An examination of the submarine contours indicatesthat the 10-fathom contour is the most crenulated contour. Some of the laterite deposits are also reported to be 45 feet below sea level. Thus if the 10 fathom contour is taken to indicate a former sea level during the Pleistocene, the coastline at that time could be reconstructed as indicated in Fig. 19.

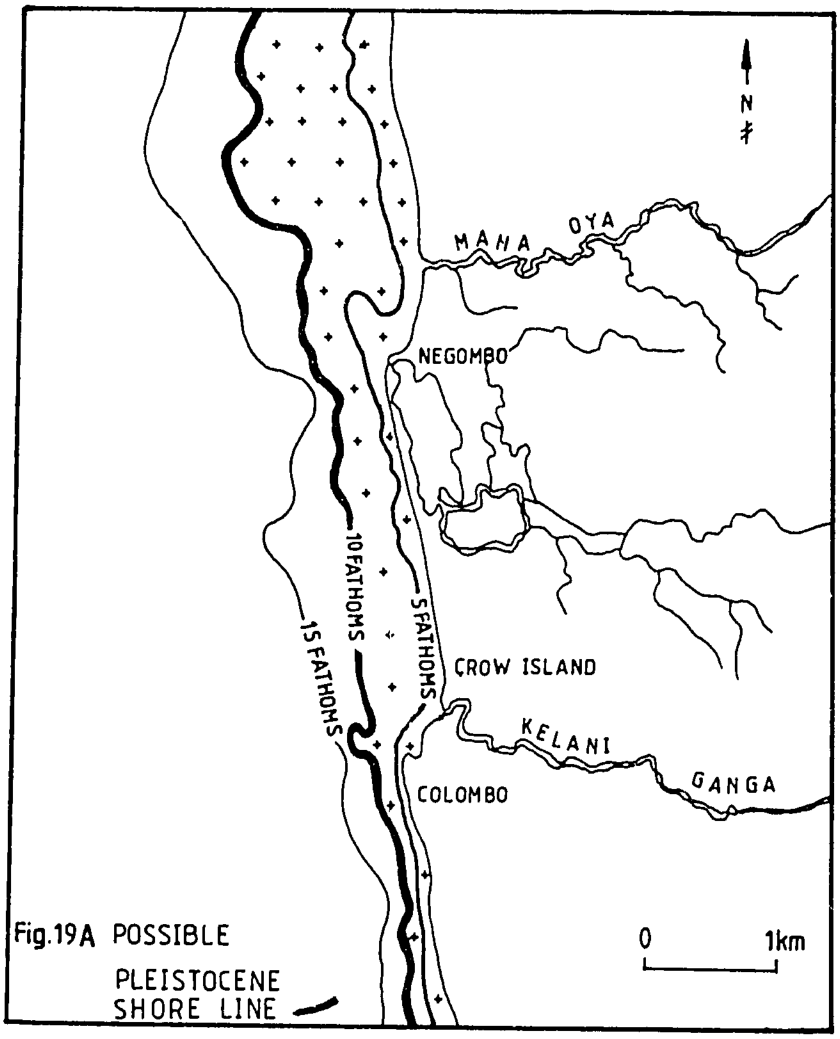


Fig.19A POSSIBLE PLEISTOCENE SHORE LINE

5.5. It could be reasonably assumed that significant changes in the natural setting of the Kelani Ganga estuary resulting from human activities began to occur after the 16th century with the arrival of the European naval powers. Before this period, historical records indicate occasional marine transgressions and early human settlements in the lower Kelani basin. However, large-scale human settlements and the spread of agricultural landuse became more pronounced only after the shift of the capital to Kotte. Some toponomical and linguistic evidence indicate that much of the low-lying areas around the Kelani estuary were cultivated with rice and that some of the water bodies which are now brackish were fresh water lakes at that time.

5.6. Some of the most significant changes in the coastline around the Kelani Ganga estuary after the arrival of the Portuguese were associated with the gradual development of the Colombo harbour The earliest Portuguese map of Colombo indicates the natural state of the Colombo harbour except in the Colombo Fort area where some buildings had been erected by that time. In general, the changes in the Kelani estuary and its environs during the Portuguese period were insignificant compared with activities during the Dutch and British periods that followed.

5.7. During the Dutch period much attention was paid to the construction of canals and flood protection works in which the Dutch had considerable expertise. Thus the canal connecting Beira Lake with Negombo Lagoon stretched across the Kelani estuary possibly affecting the adjacent low-lying areas. Similarly, the 7.6 km long Kelani North Flood Protection bund could have had considerable repercussions on the discharge of water and sediment into the Kelani estuary.

5.8. It was during the British period that large-scale changes in the coastal environs of Colombo began to appear. At least three major development activities during the British period could have affected the natural equilibrium of the Kelani Ganga estuary. First and foremost of these activities was the development of the Colombo harbour, particularly the construction of the northern breakwater during the period 1875–1885, and the subsequent dredging and desilting of the inner harbour from time to time. It is possible that the northern breakwater has effectively deflected the northward movement of littoral sediment by longshore drift reaching the offshore area of the Kelani estuary. The desilting and dredging which resulted in the removal of some estimated 10 million cubic metres of material would have created an artificial deficiency of sediment in the inner harbour which is directly open and aligned towards the mouth of the Kelani Ganga. It is likely that this has led to increased siltation of the harbour by the material discharged through the river, thereby affecting the sediment budget of the estuary. The aerial photographs indicate that this process of siltation is still active. It should also be noted that the submerged reef in front of the mouth of the river could have acted as a trap for coarser sediments, while the finer sediments escaped across it.

5.9. The period of development of the plantation industry in the upper reaches of the Kelani Ganga basin which broadly coincides historically with the development of Colombo and its harbour could have had a positive impact on the sediment budget of the estuary benefitting the formation of spit-bars in the sheltered environment of the Kelani estuary. Thus it could be seen from historical maps that the maximum development of the two spit-bars on the river mouth was around 1904 by which time plantation agriculture covered large extents of land. This situation continued to prevail during the first half of this century.

5.10. When the city of Colombo map of 1950 (16 chains to one mile) is compared with subsequent aerial photographs of 1956, 1960, 1972 and 1982, it appears that the greatest changes in the sedimentary environments of the Kelani Ganga estuary have actually taken place during the last 35 years. The well developed spit-bars depicted on the 1950 map are almost totally absent in the aerial photographs of 1956. We learn that, in order to ease the flood problem in low-lying areas of the lower Kelani basin, the submerged reef in front of the river mouth was blasted open during this period as a simple solution in flood-control engineering. The gaps in the reef created by this blast would have definitely enhanced the escape of finer sediment into the open sea and towards the Colombo harbour as indicated by air photographs of 1956. Once the sheltering effect of the reef was disturbed, the sediment budget and the associated coastal features on the estuary are likely to have begun to change. Thus the southern spit-bar has migrated eastwards and merged with Crow Island to form its present sandy beach, while the northern spit-bar disappeared almost totally. The beach of Crow Island itself continued to diminish in width as witnessed by the residual stumps of littoral shrubs on the beach still seen today. During the last few years the river has taken a new course through this creating a small island in the estuary.

5.11. It is possible to explain the changes that have taken place in the Kelani estuary in the last three decades largely in terms of removal of sand from the river for various purposes. The population in the city of Colombo nearly doubled itself during this period and the demand for housing and other building purposes has proportionately increased. We should not forget the fact that almost the entire city of Colombo is built with sand from the Kelani Ganga. An estimate made by the People s Bank in 1984 shows that some 222,771 cubes of sand are removed from the river annually. As part of our field programme, a survey map of the sandy beach of Crow Island was prepared and the volume of sand on it estimated by trapezoidal approximation. This shows that the total volume of sand on Crow Island beach above sea level is around 75,600 cubic meters. It must be noted that a comparison of figures given by the People's Bank Survey, with our estimates is beset by problems of conversion. However, this clearly brings out the seriousness of the adverse impact that sand mining can have on beach replenishment in Crow Island.

5.12. It is difficult to subscribe to the view that the bulk of the sediment discharged by the river escaped to the open sea to be transported to unknown destinations. Our investigations on the origin of beach sands in Crow Island as well as in the adjacent coastlines, indicate that, the sands of Crow Island are derived mostly from river sediments. It is possible that a portion of finer sediments does escape to the sea as indicated by some photographs and satellite images. On the basis of available evidence it appears reasonable to arrive at the conclusion that much of the coastal problems experienced by Crow Island are either directly or indirectly related to the disturbances caused by human activities to the sediment budget of the estuary.

5.13. In our endeavour to understand the historical changes and the coastal dynamics of Crow Island, we have deliberately and persistently taken a diagnostic approach rather than a diagnostic approach rather than a prescriptive one. It obviously lies within the domains of coastal engineering and landuse planning to devise ways and means of combatting coastal problems in a given locality and the Crow Island is no exception in this respect. However, on the basis of our experience in conducting this study, it is pertinent to express a few thoughts that frequently crossed our minds, related to planning of the future of the Crow Island area.

5.14. In the first place we believe that every attempt has to be made to maintain the natural sediment balance of the Kelani Ganga estuary without serious disturbance. This may prove to be a wiser option in the long-run, although some hard engineering solutions may be deemed necessary to overcome some of the urgent problems faced by Crow Island at present. Secondly, we feel that the root cause of some of the problems experienced in this area today can be traced to the broader question of urban landuse planning. Areas such as that of the Kelani Ganga estuary which are ecologically delicate have to be handled with greater care in landuse decision making. More vulnerable areas could best be allocated for uses such as recreation (i.e. playgrounds, recreational beaches, etc.) than for those involving heavy investments and construction activities such as housing and other building. Thirdly, in view of the difficulties we ourselves have experienced in locating reliable historical records relating to the more recent periods, we feel that there is a need to systematically monitor the developments in estuarine environments such as that of the Kelani Ganga. Such vigilance is bound to pay dividends and may not be that difficult in this age of remote sensing and computer data banking.

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