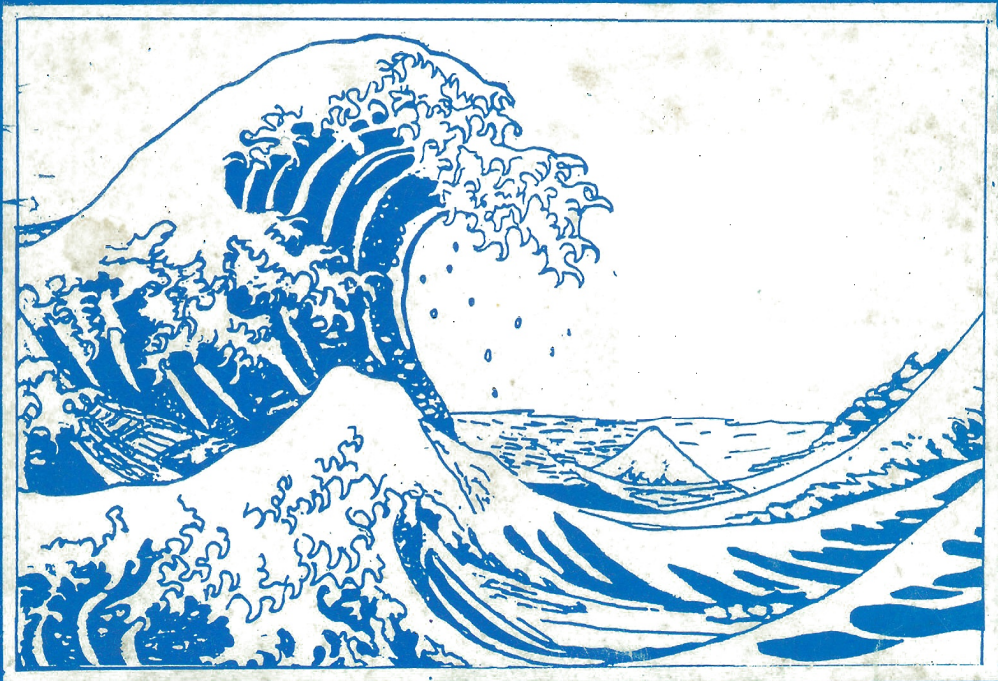


CHANGING COASTLINE
OF
SOUTHWEST SRI LANKA



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by

Upali Weerakkody

2018

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ABSTRACT

This study emphasizes the analysis of historical coastline changes during the last three centuries. The study was accomplished by the comparison of historical maps, topographical maps, sequential aerial photographs and field measurements.

The changes of the coastline that occurred during the 19 th century show that many promontories, projected land areas and capes have been destroyed and wide sandy beaches have been washed away. The coastline degradation in the study area, however, is not a continuous phenomenon as far as its changing pattern during the 20 th century is concerned. The findings on the coastline changes pertaining to the 20 th century show that the changes vary in progradation and degradation rates, in the state of equilibrium, and among the coastal compartments. The general conclusion drawn from the analysis of the net coastline changes is that the SW coast in the long-term context is degrading.

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INTRODUCTION

1.1 General context

Study of coastline changes is important for an assessment of coastal erosion hazard as well as nature conservancy, environmental management and proper utilization of resources. Thus attempts have been made to understand the diversified causative factors of coastal changes (Dassanayake, 1928; Paranathala, 1950; Zeper, 1960; Eaton, 1961; Swan, 1965; 1967; 1974; 1982; Amarasinghe, 1971; Gerritsen, 1974, Weerakkody, 1983; 1987). These studies have revealed certain short-term changes of the coast arising from seasonal or annual abrasion forces, but none of them is considered long-term or even medium-term changes.

The coastal erosion hazard of SW Sri Lanka creates some problems for the human settlements. At present, coastal erosion as well as laws banning certain economic activities that are considered damaging to the coastal environment, create socio-economic pressures on the human communities of the coastal area. Since the problem of coastal erosion has caused concern at a national level, protective measures entail increasing costs. The Government expenditure on coastal protection activities during the period between 1970 and 1982 amounted to Rs 162 million (Coast Conservation Unit, 1982). Coastal protective work has been carried out by the public sector as well as the

private sector. Specialist skills as well as unskilled labour forces have been involved in constructing defence structures since 1920's. They have been constructed along the Sri Lankan coast since that period was without proper assessment of the beach profile and other environmental factors. In fact, the construction of most defence structures was only based on information from the general public or on advice given by politicians. Since the protective measures were not based upon detailed scientific studies of coastal changes, many defence structures were erected along the coast even on places subjected to degradation during the SW monsoon and progradation during the intermonsoon periods. Gerritsen (1974, p 37) stated that 'coast protection works, harbours and outfalls are usually constructed in Sri Lanka without adequate prior study. This has often led to disappointing results and to a waste of tax-payers money'. Even though considerable resources are being allocated, coastal abrasion amounts to 0.3 to 6.0 m per annum (Swan, 1974, p3) and in some parts is even more. Because of the serious effects of coastal hazards, the concept of coastal protection has gradually evolved into a concept of conservation planning (Peoples Bank, 1980), taking into account the whole coastal environment rather than the construction of

defence structures only.

The demand for research on the coast of Sri Lanka has rapidly increased particularly since the 'Coastal Zone Management Plan' was launched by the Government of Sri Lanka. The plan was based on a survey of various phenomena, including coastal abrasion. The survey that was carried out, however, was not based on sound scientific techniques. Essential geomorphological phenomena such as the long-term patterns of changes, the seasonal patterns of beach profile changes (induced by monsoons), the classification of coastal zone according to geomorphological principles, etc, have been neglected. Coastline changes which took place during the last century were collected by Madduma Bandara (1982) with the assistance of the author and other colleagues. The study was based on evidence given by people living in the coastal areas. Although scientists and the public are generally aware that a problem exists, no detailed research on the changing Southwest coast has been carried out to date apart from the study of coastal erosion hazard. In other countries, the phenomena mentioned above rank among the most essential factors pertaining to the conservation of coasts (California Coastal Conservation Commission, 1975, p 44 , Fisher, ch 3).

1.2 Objectives of the study

The situation sketched above, indicates that the study of geomorphological development of Sri Lanka's coast is not only of academic interest, but also is of great practical importance, in the areas of coastal abrasion, management of the coastal zone, utilization of coastal resources, nature conservancy, etc. In an attempt to bridge the gap between theoretical knowledge and its application to the management of the SW coast, this study emphasises the historical coastline changes during the last three centuries with a view to assessing the coastal erosion hazard of the SW coast.

The coastline changes during the last three centuries considered is based on the study of historical maps, sequential topographical maps and aerial photographs. The analysis of the coastline changes was placed in a temporal as well as a spatial context. The final analysis of the coastline changes during the last three centuries served as a basis for reviewing the nature, the temporal patterns and the rate of the coastal abrasion of SW Sri Lanka.

METHODOLOGY

The methodology used in the survey that was carried out in this research programme falls under three categories; a) Collecting historical records and other aerial photographs for the mapping of coastline changes during the last

three centuries,

(b) Analysis of maps and aerial photographs,

(c) Examination of spatial and temporal coastline changes on the basis of available data.

The collection of data pertaining to the processes governing coastline changes of the SW coast was compared with and supported by data from earlier studies. Quantitative measured data obtained from institutions and individuals were also used.

Six chronological techniques are used in geomorphology for dating geomorphological changes, namely; radio-active determinants, dendrochronology, varves, thermoluminescence, lichenometry and historical records (Thornes & Brunnsden, 1977, p41; Goudie, 1977, p7-12). The reliable and comparatively inexpensive technique of the analysis of historical records has been used in this study in order to observe coastline changes during the last three centuries. The lack of facilities was the main constraint in using dendrochronology, thermoluminescence, etc, and thus historical records consisting of old maps and sequential aerial photographs were the only possible and suitable resources for studying the absolute chronology of the coastline changes. These records have been used in this study specifically for two reasons;

(a) Records such as ancient maps, old topographical maps (or one-inch maps), sequential aerial photographs, sequential imagery can be studied without the use of elaborate equipment by simply comparing old and new situations. Their availability and application do not involve lengthy laboratory procedures as in other techniques. The analysis of the historical records can also be easily rechecked by later researchers. The costs of collecting, processing, rechecking, etc, are minimum compared to other techniques, but evidently, the time-span covered is limited to at the most, a few centuries.

(b) Historical records have been repeatedly used for this kind of study and thus there is sufficient experience. Steer (1949) illustrated the changes which occurred in the North Norfolk coast from Hunstanton to Brancaster between 1885-5 and 1935; de Boer (1964) summarized the growth of Spun Head; Kidson (1952) made a survey of erosion on Dawlish Warren covering the period between 1787 and 1949; Kidson (1963) studied the growth of sand and shingle spits across estuaries of Bridgwater bay, Somerset, using old maps and field observations. Carr (1965) analysed short-term dynamics of the shingle spits and river mouths of North Weir Point using aerial photographs aided by old maps. Changes in the spit at Gibraltar Point, Lincolnshire, have been surveyed and studied during the period between 1957 and 1969. Changes of the Puttalam spit during historical times as studied by

Verstappen (1987) is one of the good examples from Sri Lanka. Some attention has been paid to a study on coastal changes in SW Sri Lanka also by Swan, (1974, P106- 7, 1982, P 133).

Even though the historical records are widely used for this kind of studies, the technique is not devoid of possible errors. The uses, applicability, suitability, shortcomings, limitations, etc, of the historical records relating to the study of coastal changes have been treated at length by Carr (1962).

1.3.1 Historical maps and their potentialities for studying coastline changes

Many historical maps and charts of the SW coast during the last three centuries can be obtained from various sources. However, their potentialities in studying coastline changes depend on the following factors;

- a) mapping scale,
- b) cartographic deformation of the coastline,
- c) possibility of comparing with an accurate topographical map,
- d) degree of attention paid to coastal features,
- e) inclusion in the map of permanent landmarks identifiable in modern topographical maps, as well. i.e. fortress of Galle, historical temples, rock outcrops, etc.

With the above mentioned factors in mind, the available old maps are listed in a table in order to assess their potentialities (see Appendix 1), for coastal studies. Only

the most useful, reliable and accurate maps and charts have been used for this study. The selection was based on the following properties;

a) Scale; the scale of the map should be suitable/sufficient to represent the coastal geomorphological features. Further, the scale of the map had to be accurately adjusted to the scale that appears in modern maps. The scale given in units such as Rhineland rods, French leagues, etc, in old maps which are not used at present had to be accurately adjusted in order to use them in this study.

b) Cartographic deformation; The usefulness of comparing old maps and charts with modern maps depends on their geometric accuracy. If a deformed map is projected onto a modern topographical map, it can only be used with difficulty for the study.

The majority of maps and charts listed in Appendix 1 have smaller scales than the modern topographical maps. Therefore, accurate data on the coastline changes using such smaller scale maps cannot be obtained by direct projection on to a modern topographical map.

Having considered all these factors combined, three maps were ultimately selected to analyse coastline changes;

- 1) The map of the southern coast by John Fraser dating from 1840*
- 2) The map of southern coast by Joh. Fr. Lorenz dating from 1800,
- 3) The map by G.E.Schenk dating from 1790.

Four charts showing detailed coastal features also were selected, even though their accuracy do not compare with those of modern maps. They are;

- 1) The map by Valentine dating from 1663,
- 2) The map by Joanes van Keulan dating from 1660,
- 3) The map by van Dosser dating from 1766,
- 4) The map by van Ech dating from 1784.

However, when comparing them with topographical maps, some difficulties of matching have arisen. The following steps were taken to overcome these shortcomings;

- 1) The maps were projected mechanically onto the topographical map using permanent landmarks such as fortress, rock outcrops, etc.

- 2) The parts of John Fraser's map that did not coincide were not taken into account in studying changes of the coastline.

* Even though the map has been compiled in or around 1841, the year of the compilation is considered here as 1840.

In general, none of the above mentioned maps was used for quantitative measurement of the coastline changes. In addition, some parts of the historical maps which did not coincide with the topographical maps have not been used even for qualitative analysis. The historical maps which coincided with the topographical maps have been used only for qualitative study of coastline changes. These maps unravel the chronology of the coast during the period of 1660 and 1905-1917.

1.3.2 The sequential topographical maps

The topographical maps published from 1905/1917 to 1972 can be divided into two categories;

- 1) original maps based on ground survey, and
- 2) revised maps of the original maps.

Original maps are useful for measurements because the revision of the original maps was based only on changes of place names, roads, etc,. In other words, the revised maps were not based on an original ground survey.

Even though higher expenditure and more labour have been used in the compilation of these maps, some shortcomings of the maps selected for the study were noted and can be listed as follows;

- a) the graticules of the topographical maps do not coincide well with each other,
- b) the Galle area shown in all maps of the SW coast

does not match,

c) the maps published as revised maps have not been based on a ground survey. The revision has been restricted to inserting or deleting or changing of place names, roads, etc.

Considering these facts only the maps compiled under original ground survey were used in the study. They are listed below;

a) All maps published in the period between 1905 and 1918. They have been based on original ground survey.

b) The maps published in the period between 1932 and 1943.

c) The last one-inch map which was revised and published in 1972.

Some errors of the previous ground survey have been corrected in this map.

d) The 16 chain charts compiled in the years of 1921, 1932, 1933 and 1943.

Some coastline changes escape identification due to the time interval of the maps selected for the study. The time intervals of the coastline changes based on the study of topographical maps therefore are as follows; 1. The period between 1905 and 1932 (1905 or 1917/18 to 1932 or 1933 or occasionally upto 1943), 2. The period between 1932 and 1943 (1932 or 1933 or 1934 to 1943) and 3. The period between 1943 and 1972 (1943 to 1972 or 1933 or 1934 to 1972).

As both 16 chain charts and the one-inch maps had to be

utilized for the quantitative measurements of coastline changes, they were compiled into two maps on the same scale.

The one-inch maps used were mechanically enlarged using the pantograph at a scale of 2.6 cm to 406 m (one inch to quarter mile). The 16 chain charts were also blown upto the same scale. A series of sequential maps were thus compiled following this procedure. These maps cover a 67 year period (1905 to 1972) of coastline changes. Projecting the map of 1905 on to the map of 1933, for example, gives a map showing the changes that occurred in the period between 1905 and 1933. Using a planimeter, the area lost and gained during this period was measured with the help of the differences in the two maps.

1.3.3 The sequential aerial photographs

The sequential aerial photographs available for the study date from 1956, 1973/74 and 1987, and have a scale of 1:40000, 1:25000 and 1:10000 respectively. As years represented by the aerial photographs of 1956 and 1973/74 are covered by the period represented by the topographical maps of 1934 and 1972, the time period between 1956 and 1973/74 of the aerial photographs was neglected. The absolute changes of the coastline during the last 14 years (between 1973 and 1987) were studied comparing the photographs of the two later

aerial photographic coverage. The difficulties arising from the differences in scale were overcome by the preparation of a map. The relief displacement is negligible because the photographs represent low relief areas. The tilt effect was corrected by matching with the outline maps prepared from the photographs and the one-inch map with the help of pantograph. It was possible to complete sketch maps showing the two superposed coastlines. After readjustment of the scale error (see ITC, 1971), using topographical maps, the progradation and degradation of the coastline during the period between 1973/74 and 1987 were measured using a planimeter.

THE AREA AND ITS GEOGRAPHICAL SETTING

2.1 The area

The coastal area concerned under this study stretches from Ambalangoda (at Randombe) to Devundara upto the fishery harbour (Figure 2.1). This area is located in the Wet Zone of the island, and receives a rainfall that exceeds 1905 mm (75 inches) annually. The coastal belt of SW Sri Lanka faces the Lakadive region of the Equatorial Indian Ocean, as demarcated by Colborn (1975, p67). The oceanic areas off the SW coast belong to the 11 th Thermal Structural region of the Lakadive Sea of the Indian Ocean (Colborn, 1975, p31) and changes its thermal conditions in the period between May and September (Colborn, 1975, p66). The International Indian Ocean Expedition has studied the bimonthly periods as related to the monsoonal regime in the region (see Table 2.1).

Table 2.1- Northern hemisphere Monsoon seasons
(bimonthly period)

<u>Bimonthly period</u>	<u>Monsoonal regime</u>
January-February	Northeast monsoon
March-April	Decline of Northeast monsoon
May-June	Beginning of Southwest monsoon
July-August	Southwest monsoon
September-October	Decline of Southwest monsoon
November-December	Transitional, beginning of Northeast monsoon

Source: Colborn, p7 .

The period between May and August is the period of the SW monsoon which gives rise to rough seas with significant effect on the beach profile of the SW coast. High waves wash the beaches which are built up during the intermonsoonal period and transport beach materials along the shore. The velocity of the longshore currents increases and, in association with the rough seas created by the monsoon, large-scale beach drifting thus cause longshore transportation of materials during this period. During the intermonsoonal period that follows the beach profile is built up again due to the calm wave climate created by atmospheric conditions, which then prevails. Depressions occasionally formed in the region (Banford, 1926, 1929 a b), may temporarily change the wave climate, but cyclones such as those that occasionally hit the East and Northeast coasts of the island can hardly be expected in the SW. Features created by storm waves comparable to those of the East and Northeast coasts do not occur here.

2.2 Geological setting

The Southwestern Group, one of the Upper Palaeozoic rock formation described by Cooray (1967, p85), dominates the geology of the entire SW region of Sri Lanka. The major rock types of the Southwestern Group according to Cooray, (1967, p109), are metasediments, charnockites and allied rocks, basic rocks, migmatitic and granitic gneisses, and granites/pegmatites. The charnockites and undifferentiated

metasediments occur in the coastal plain concurrently with bands of diopside-scapolite (mainly woolsonite bearing) calc-granulites or gneiss (Geological Survey Department of Sri Lanka, 1982). Even though the hinterland contains such types of ancient rocks, the coastal area is covered predominantly by Quaternary deposits (clay, silt and sand), marine deposits (beach sand, beachrock, coral debris) and aeolian deposits (dune and windblown sand) which are Holocene while the partly ferruginous gravels are Pliestocene.

Two lithologic parts can be observed in the region: the area dominated by charnockites (hypersthene, diopside gneiss or granite bearing hornblend biotite garnet) stretches between Ambalangoda and Habaraduwa; the area between Habaraduwa and Dickwella is dominated by the undifferentiated metasediments.

At places some bands of calc-granulites protrude such as at Boossa, Gintota and the western headland of Galle as well as at Habaraduwa and Ahangama. They form headlands and rock outcrops projecting into the sea with a higher insulation on wave action as compared to similar features formed in other types of rocks. The delimitation of the boundary between Holocene and Pliestocene deposits in the SW coastal area has not been determined by geologists.

2.3 Drainage

The drainage regime of rivers, streams and lagoons of the

SW coastal zone is dominated by the monsoon rains. The peak discharge of the perennial rivers, (with ample sediment load) is in the monsoonal period. The most important perennial rivers which contribute materials to the shore are Ginganga River, debouching 13 km to the north of Galle, the Nilwala River, having its mouth in Matara, and the Polwatu River which releases its load into the Weligama bay.

Lagoons are of widespread occurrence but their contribution to the discharge and sediment yield is very limited. The outfall of the Madampa lagoon, situated at Hirewatta to the south of Ambalangoda is controlled by a bund that protects paddy fields from saline water intrusion. The mouth of the Telwatta Ganga lagoon has been cut off from the sea by the railway intersection. The Hikkaduwa Ganga lagoon and the Koggala lagoon also have their mouths blocked by man-made structures such as bridges, groynes, etc. Lagoons are very rare to the east of the Weligama bay. Only the Garanduwa lagoon situated at Talaramba and the Devundara lagoon situated at Rassandeniya stretch along the coast in these parts, but their surface area is negligible as compared to the lagoons mentioned earlier.

2.4 Human activities

The modern era of the socioeconomic activities in this area is characterized by urban development, harbour construction, etc, and the connected coral and sand mining strongly influence the coastal environment. Apart from the main commercial harbour of Galle, fishery harbours were constructed during the last decades at Hikkaduwa, Mirissa and Tangalla. Small harbours were also constructed at several places using small break-waters and groynes. There is ample evidence that some of the break-waters and groynes have caused severe erosion leading to the loss of valuable land.

The profit from the coastal resources obtained by mining, tourism, commercial harbours, etc, are probably outweighed by the high cost of coastal conservation. The damage to the coastal environments include loss of land by abrasion, decreasing land quality by coral and sand mining, destruction of natural habitat by tourism and air pollution. Several protective structures have been constructed along the SW coast including substantial and expensive engineering structures.

In fact, the hundreds of engineering structures that have been constructed even as early as the 17th century affect the natural beauty of the beaches of SW Sri Lanka. The 86 km long study area has an engineering structure per 700 meters. There is a revetment every 1260 meters and a groyne every 1720 meters. The expenditure allocated for coastal conservation was Rs 10.29 million in 1893. The future investment for coastal conservation under the

Coastal Management Plan of Sri Lanka is estimated at a level of about Rs 500-600 million. At present, Sri Lanka's coast absorbs a large amount of foreign aid and loans. For example, a Danish loan of Danish Kroner 3035000 and US aid amounting \$ 150,000 under UNDP programme have been received for coastal conservation (Coast Conservation Unit, 1980).

3. COASTLINE CHANGES AND FLUCTUATIONS OF SEA LEVEL

3.1 Coastline changes of the Pliocene and Holocene Periods

It is known from other parts of the world, that the sea level in preglacial times and during the Pliocene interglacial periods was approximately at or even well above the present sea level while significant regressions occurred during the glacial periods. The last of these during the Würm glaciation was followed by a post-glacial rise in sea level to approximately present levels. These sea level fluctuations* and their effects on coastline changes of Sri Lanka have not yet been studied extensively as compared to the studies in Europe and Mediterranean. It is evident, however, that the alternating low and high Quaternary sea levels have strongly affected the coasts of the world including those in Asian region (for details; see Goudie, p 127). Clarke et al (1978) conclude that the effect of the

* The heights of the sea levels during the interglacial periods calculated are as follows;

Sicillian (80-100 m),
Milazzian (55-60 m) between the Gunz and the Mindel,
Tyrrhenian (55-35 m) between the Mindel and the Riss,
Monastirian (15-20 m) between the Riss and the Würm,
Flandrian- the present-Würm transgression.

sea level rise due to melting of the continental ice since the last glacial maximum was not uniform everywhere because of the deformation of the Earth's crust.

Assuming that sea levels of the glacial periods had affected the Sri Lankan coasts in a manner similar to the European and Mediterranean coasts, the sea level of the SW coast of Sri Lanka may have reached the present level during the Gunz period. Subsequently, the coastal plain must have been submerged during three separate times during the Milazzian, Tyrrhenian and Monastirian periods respectively. Further, the coastline of Sri Lanka must have been situated three times more seaward, on the present continental shelf, namely during the Gunz, Mindel, Risz and Würm glacial periods when the sea level dropped because of the development of continental ice sheets at high/mid latitudes in both the northern and southern hemisphere. Finally the sea level rose during the post-glacial/Holocene to the present and at times to a somewhat higher level.

As the heights and absolute periods of these sea levels are not fully ascertained through out, the world's glacio-eustacy cannot be adopted without further investigation of the Sri Lankan coasts. The rise in sea level since the early Holocene is now generally accepted throughout the world. Geomorphological evidence for mid-Holocene maximum transgression was obtained by Weerakkody (1985, 1988) along

the SE coast. The evidence derived from the Kalametiya, Lunama and Koholankala lagoons, comprises of two sea levels respectively at 5 m and 2 m above present sea level. The shells collected from the Kalametiya 5 m beach and the Koholankala lagoon have been dated and indicate that the first one is about 3620 ± 70 BP and the second one about 3890 ± 70 BP. The heights of the sea levels pertaining to the SW coast are somewhat different to those from the other coasts of Sri Lanka and the coasts of India (Figure 3.1.1). These different elevations suggest that the SW coast subsided while the SE and NE coasts of Sri Lanka, and the Sourashtra coast of India remained more or less stable or have been submerged slightly, since the mid-Holocene time.

The fluctuations of the sea level during the Quaternary have submerged the coastal zone of SW Sri Lanka. Ancient marine landforms reworked by marine action in the immediate hinterland are the result of the last maximum rise and subsequent fall of sea level since the mid-Holocene time. The Hikkaduwa lagoonal plain, for example, exhibits varying degrees of submergence and sequential landforms, while the Ratgama-Boossa area is characterized by denudational hills and planation surfaces: (Figure 3.1.2). Figure 3.1.1 shows that the sea level along the Sri Lankan coasts has gradually dropped until 2500 BP (1000 BC) and hereafter no data is available. A slight rise of sea level was observed during the last century in Sri Lanka (Figure 3.1.3).



Figure 3.1.2- The phases of the coastal evolution along the Hikkaduwa-Boossa tract. The rise of the sea level has submerged the entire area to form a cliff coast and a baylet. Some parts of the offshore area were occupied by coral reefs. (a). When the sea level gradually dropped during the second phase, the barrier chains developed in front of the cliff coast (b). The third phase is characterized by wide sea beaches (c).

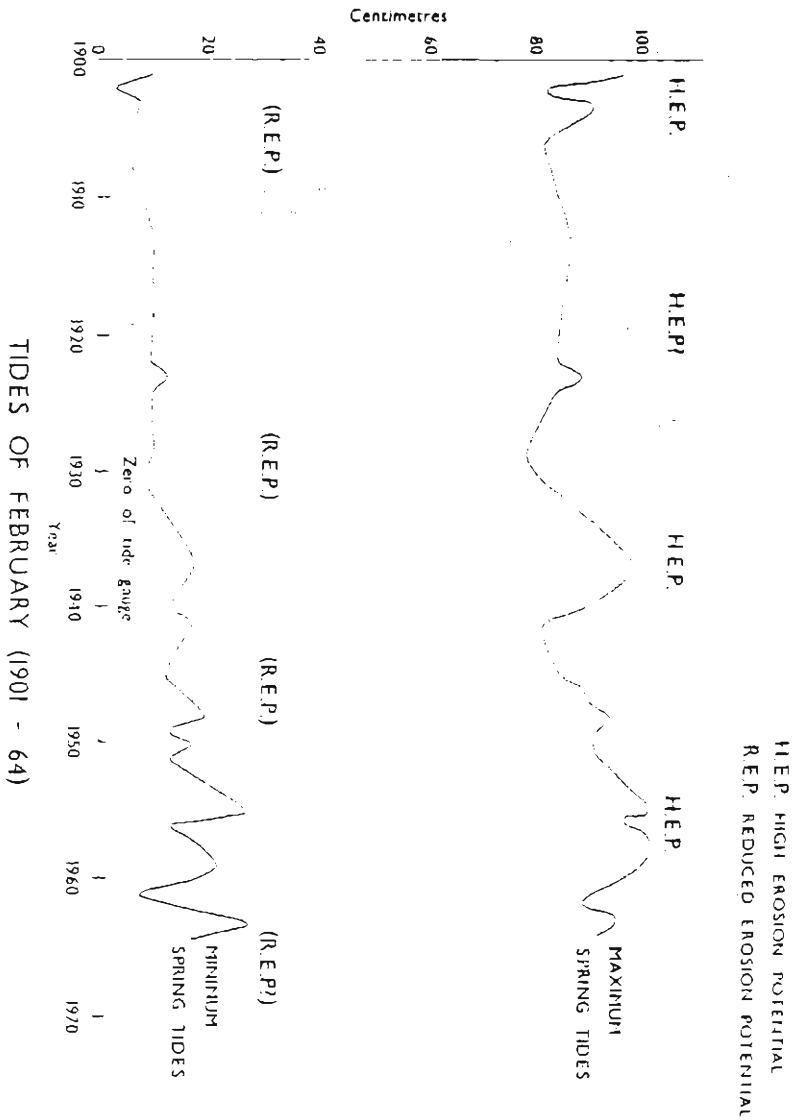


Figure 3.1.3- Available data suggest that tidal cycles occur. Period of higher tides are associated with potentially greater erosion. Source: Swan (1974, p24).

3.2 Sea level changes in the Indian Ocean

The Geodetic and Research Branch of the Survey of India has been systematically computing the values of monthly and annual mean sea level in recent years at various parts of the Indian Ocean. Based on records for a number of years, Gulatte (1950) observed that progressive changes of mean sea level relative to the land are noticeable in Calcutta and Port Blair (Andaman Islands) and that an upward trend of the mean sea level of the Arabian Sea exists at Bombay from 1930 onwards. Swan (1974, p24) mentions that a slight rise of the sea level over the last one hundred years or so is regarded as the most general tendency in Sri Lanka.

4. HISTORICAL COASTLINE CHANGES OF SW SRI LANKA

4.1 Changing processes and their effects on coastline changes

Evidence for generally stable climatic conditions without frequent drought and famines from the 7th to 13th century AD in Sri Lanka has been collected by some authors (Verstappen, 1987), which is in line with global conditions. This period is called the 'little optimum' (750-1300 AD) and was characterized by relatively warm atmospheric conditions which had not been equalled since the climatic optimum of the mid-Holocene (Goudie, 1977, p 119). Therefore some environmental changes may have taken place in Sri Lanka as well as in the rest of the world. For Sri Lanka on the basis of the development of a new spit at Kalpitiya, Verstappen suggests that the south winds which prevailed upto the climatic deterioration of the 'little ice age' around 1500-1800 were replaced by the abrasive southwest winds. The peak stage has probably occurred around 1700. The later centuries have been associated with somewhat drier climatic conditions. The dendro-chronological evidence collected by him suggest that somewhat wetter climatic conditions resulting from the south winds have gradually been replaced by the drier conditions associated with the

later dominant southwest winds. These changes have introduced considerable fluctuations of the process along the study area.

The change of the earlier established north bound littoral drift to a south bound one from Hikkaduwa to the south and southeast coastal tracts is proved by the changing direction of the sand spit at the Nilwala River mouth. The spit was at first rather square-shaped as shown by the maps of 1766 and 1784 (Figure 4.1.1). On the map of 1840 the spit has been drawn as an elongated one, and in later topographical maps with a slightly recurved tip. The recurved tip towards the east has been formed due to the newly established east-bound drift. The other evidence pertaining to such changes of the wind direction can be observed at the bay of Galle. The shoals and beaches which existed in 1660 as shown in Figure 4.1.2 were destroyed around the late 18 th century. Many traces of the shoals were not recorded in the map of 1790 which shows many coastal details (see also Weerakkody, 1987).

Barrier chains, extensive sandy beaches, sand spits, etc, preserved in the coastal zone are other landforms which have been subjected to changes. The changes of the base level induced by the slightly rising sea level indicate clearly the elevated wave-cut terraces between 0 to +2 m MSL along the barrier chains of the SW coast.

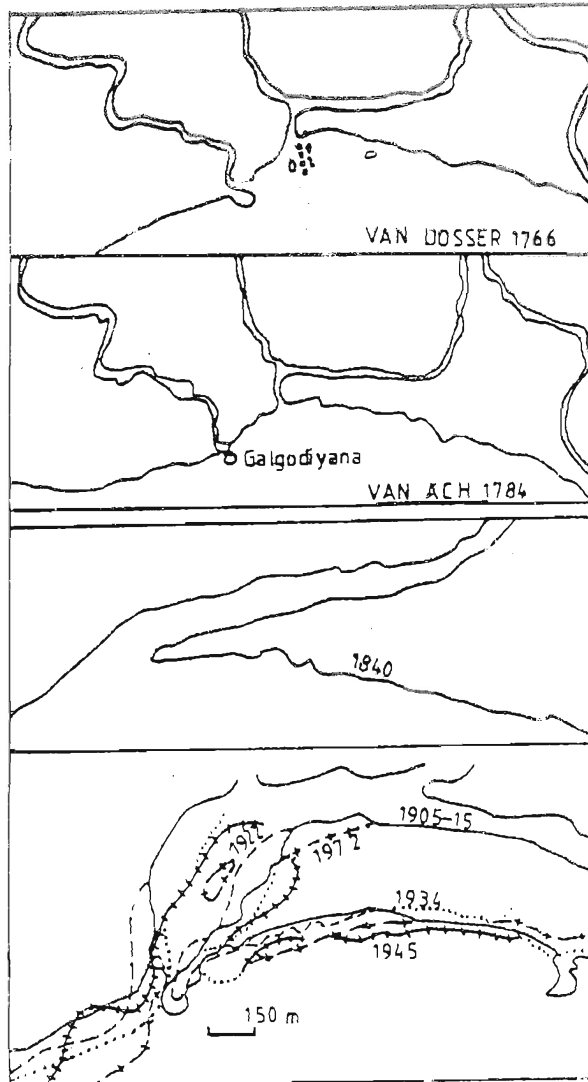


Figure 4.1.1- Coastline changes of the Nilwala River mouth between 1776 and 1972. Note the square shaped sand spit at the mouth in 1766 and 1784 and the recurved sand spit in 1905-15 and 1972.

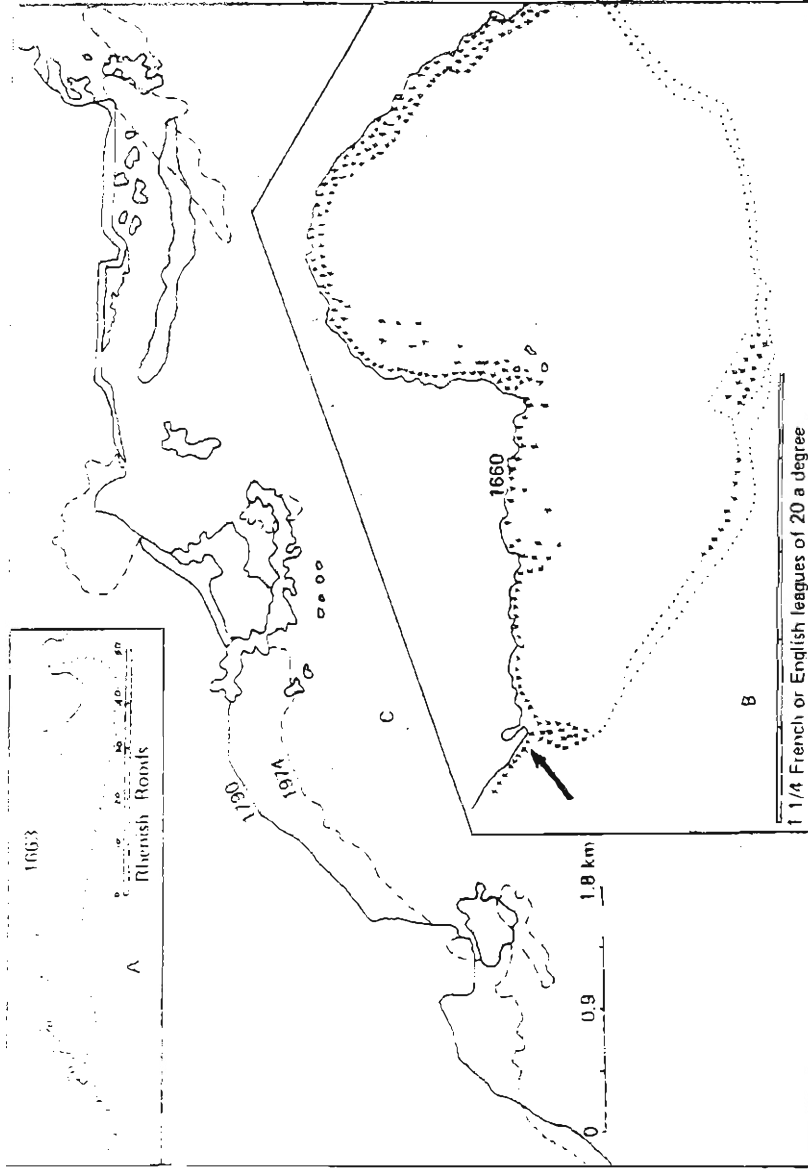


Figure 4.1.2- The east coast of the bay of Galie, in maps of 1660, 1663 and 1790. The extensive beaches and shoals (in cross and dots) of 1660's were destroyed. Between 1790 and 1974, segments were subjected to progradation and local degradation. (A) extracted from Valentine map of 1663; (B) extracted from John van Keuian's map of 1660. Note the sand spit at Gintota (arrow). The dashed-line represents the 1974 coastline drawn from aerial photographs (Source: Weerakkody, 1987).

This means that the beaches which formed during the ultimate recession of sea level, followed by the formation of the barrier chains have been sapped by the inundated beach-rocks which have been formed underneath the barrier chains. The well surveyed and mapped beachrocks along some coastal tracts by John Fraser in 1840 suggest that they have been exposed even before the early decades of the 19 th century. The abrasion phase of the SW coast as evident by these tracts, therefore, may have started during the 17 th century when the strong southwest winds* influenced the marine processes in later times.

The concept can be elaborated using field evidence and facts derived from aerial photographs and topographical maps. It can be assumed that at least their remnants of some formations developed during the lowest sea level have been preserved along some coastal tracts of Southwest Sri Lanka until the early 19 th century while many landforms have been washed away by the changing marine processes caused by a rise of sea level possibly since the 18 th century

* The SW winds reach the study area as a west component as far as the coastal orientation is concerned. Hereafter, the SW winds therefore will be termed as western winds.

and during the last century. Such preserved landforms (or their remnants) can be seen on maps dating from the early 19 th century.

Changes of the processes also included changing longshore currents in the study area during the first decades of the 20 th century. This is evident, for instance from the changes that took place along the Seenigama coast. Before 1840, the Seenigama coastline was protected by a large headland with a wide sandy beach. The southern part was demarcated by the Hikkaduwa Ganga outfall. Northward sand bearing longshore currents were introduced at the Seenigama cape. The existing sandy beaches and some parts of the barriers near the cape were removed and their materials redeposited at the northern end of the coast. As revealed on the one-inch map of 1917, the northern and southern parts of the headland were eroded. It could be believed that erosional processes were intensified between 1915 and 1921. This situation has been well documented by Dassanayake (1928), a pioneer coastal engineer of Sri Lanka (Figure 4.1.3 a & b).

This process gradually accelerated between 1920's and the early 1930's. Hard rocks which had been attached to the early coastline were cutoff and converted into islets. Between 1932 and 1943, the ruined promontories of the defunct headland of the Seenigama coast were completely destroyed. A large portion of land was lost by the intensified

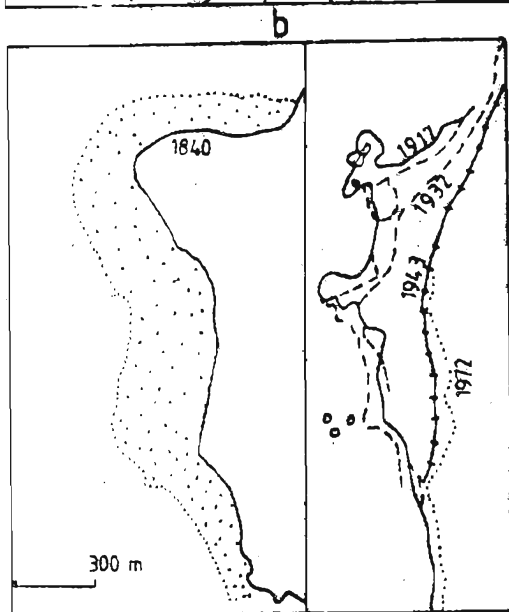
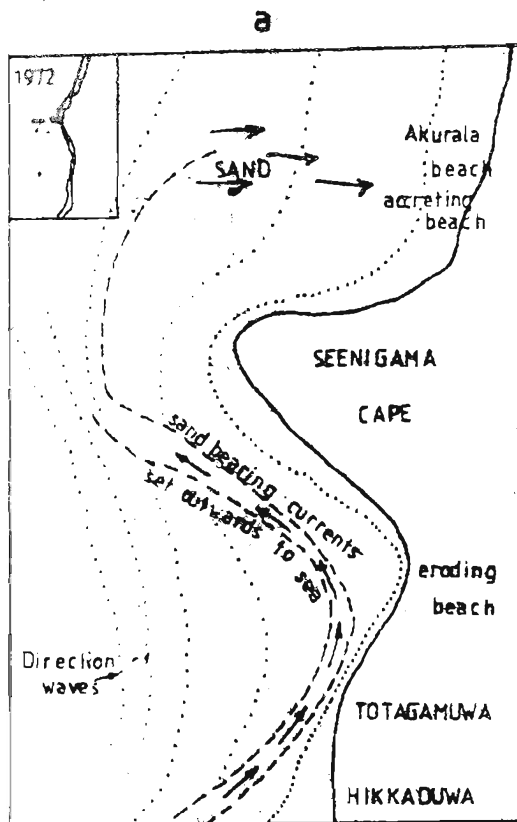


Figure 4.1.3- Diagram drawn by Dassanayake (1928) illustrating beach erosion and accretion as observed near 60 th mile, Colombo-Galle road (or compartment 4.1) during the period 1915-21 (a). The coastline changes of Seenigama since 1840 shown by (b) unravel that a huge land portion has disappeared during the last century. Orientation of the diagram (a) was readjusted by the author. Diagram (b) was taken from Weerakkody (1983).

wave action during this period. Only some minor changes took place during forties to seventies. Today, it is protected by a revetment and the northern part of the defunct headland is covered by small groynes.

The changes that have taken place in the Hikkaduwa Ganga outfall and the Dodanduwa coasts are shown in Figure 4.1.4. During the early decades of the 19th century, the northern and southern parts of the Hikkaduwa Ganga outfall were rich in extensive sandy beaches as well as hinterlands. During the late 1880's, these landforms were destroyed and the outfall was barricaded by a sand spit. Between 1934 and 1943, the southern portion of the spit was eroded. Subsequently, the sand spit was also destroyed. Now the coastline with the outfall appears as a complex field of groynes and revetments connected to each other.

The promontories of the study area degraded continuously during the 19th century, as a result of severe erosion processes. The protruded land masses that were very wide spread during the first decade were washed away during the second decade. During the early decades of the 19th century, Unawatuna composed of a small baylet instead of the present zeta-curved beach. A large portion of land which projected to the sea on the eastern side forming the baylet was completely destroyed. Furthermore, this destruction led to a state of inequilibrium of the coastline.

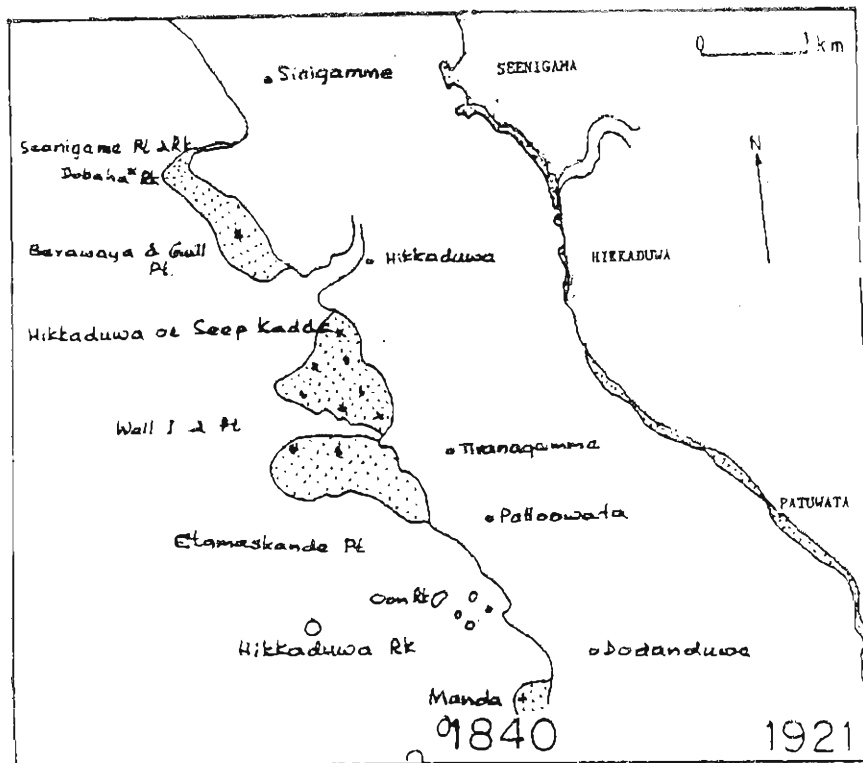


Figure 4.1.4- The landforms of the Seenigama-Dodanduwa coast in 1840 and 1921. The coast mapped in 1840 by John Fraser, shows large land portions projected seaward. The dotted areas apparently are wide beaches while the asterisks indicate emerged ledges.

As shown by the first topographical map of 1918 of the area, the headland was completely destroyed. Nowadays, its ruins can be observed offshore. The ultimate result of the changes is the conversion of the baylet into a log-spiral shaped coastline (Figure 4.1.5 a).

Unlike Unawatuna, the Kataluwa and Piyandigama coastal segments were protected by projecting land masses in 1840. The western land mass which was called Gonagallepara, was completely eroded between 1840 and 1905 and there is no trace of it today. During this period of destruction, the eastern land mass was gradually shaped by wave action and given a westward tip (Figure 4.1.6). Not only the headlands but also the river mouths and lagoonal outfalls have been changed by the altered processes along the SW coast.

The most important feature of the river mouths and outfalls is the growth of spits during historical time. The largest among the smallest sand spits that developed during historical times is the elongated sand spit in front of the Gin River mouth. This first appeared in the map of 1660 (Figure 4.1.2). The spit changed considerably during the last century (Figure 4.1.5b).

The coast of the Nilwala River mouth lost a considerable portion of land in the late 18th century and the changes which took place during the later period have been restricted to the sand spit (Figure 4.1.1).

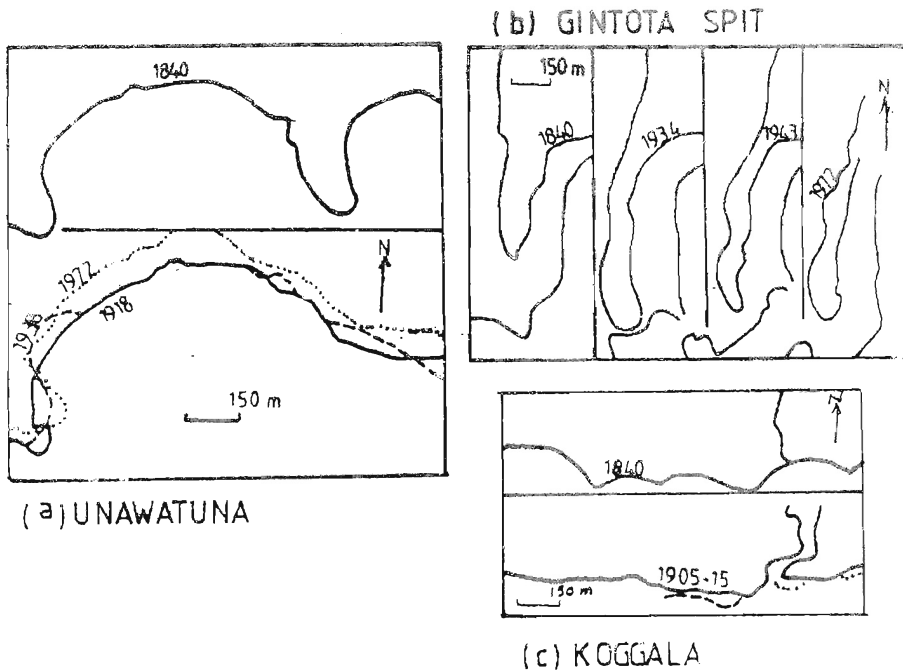


Figure 4.1.5- The Unawatuna coast of 1840 was a baylet protected by two headlands. As shown by the topographical map of 1918, the eastern headland was destroyed(a). The Gin River mouth is occupied by a sand spit which has changed its length and width during the period between 1840 and 1972 (b). However, the map of 1840 does not show the present small spit in front of the Koggala lagoonal outfall. It first appeared in the map of 1905-15 (c).

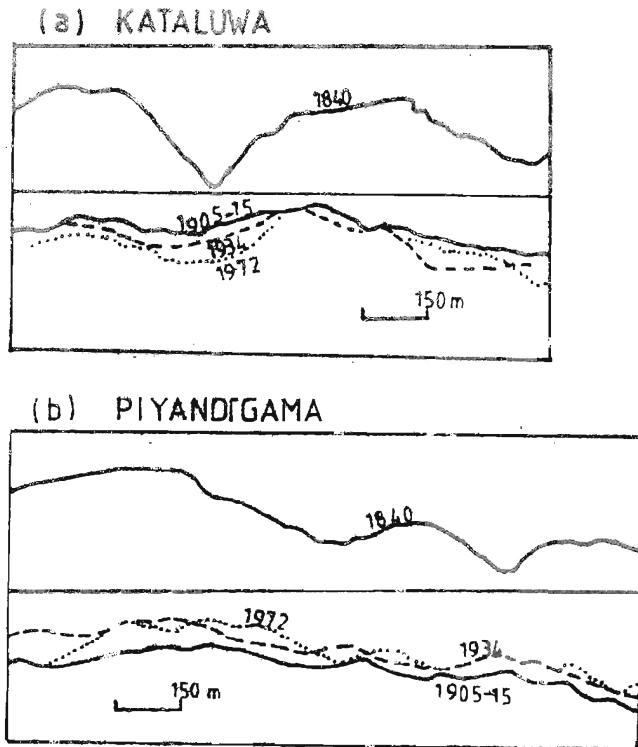


Figure 4.1.6- The Kataluwa coast of 1840 reveals that it had a huge protruded land mass. As shown by the topographical map of 1905-15, this land portion has been washed away and slight accumulation has been taken afterward(a). The Piyandigama coast (b) also occurred as a headland coast. The protruded land portion has been washed away during the period between 1840 and 1972.

As unraveled by the maps of 1766 and 1784, the eastern part of the river mouth has been drawn as a protruded land mass with an extensive hinterland zone. In the mid-decades of the eighteenth century land mass gradually receded, and this change gave rise to the formation of two islets which are situated on either side of the river mouth today. These are known as Pareyduwa and Galgodiya. The eastern part of the river mouth was subjected to severe erosion during the second and third decades of the 20 th century. These stages were illustrated by Dassanayake in 1928 (Figure 4.1.7). Between the second and seventh decades of the 20 th century, the sand spit has changed its mass but has remained in its original form. We note that in 1920's and 1930's the estuarine beaches were subjected to a high rate of mobility due to fluctuation of the sand supply by the river.

A small spit developed in the same period in front of the Koggala lagoonal outfall and still persists notwithstanding considerable changes (Figure 4.1.5 c). At present, many lagoonal outfalls of the SW coast are protected by two parallel groynes preventing the formation of barrier spits in front of them as can be observed at Hikkaduwa, Madampe, Goyyapana, etc.

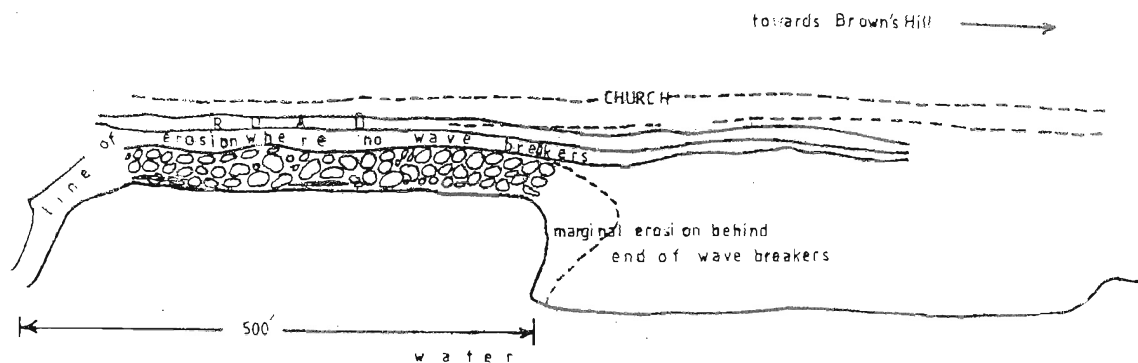


Figure 4 1.7- The continuous changing processes have washed away even the well prograded beach at the river mouth of Nilwala (16.2) during 1915-21. The revetment that was constructed to cope with erosion problems at that time is covered by sand at present. It is now situated 100 m inland.

Since 1977 the author has frequently observed the changes of processes in the study area. The Akural point, Kahawa, Hikkaduwa, Ahangama and Polhena are major areas where severe abrasion of beaches has occurred. In addition to the natural processes, the Hikkaduwa lagoonal outfall has been affected by refracted wave energy induced by the break-water (or large groyne) of the fishery harbour.

4.2 Quantitative aspect of the coastline changes

The coastline changes that occurred during the 20th century were studied quantitatively by measurement on sequential topographical maps and aerial photographs. Three periods could be distinguished because of the age/years of the available topographical maps and aerial photographs; First period covers 29 years (1905 to 1934) for the coast between Koggala and Devundara and 14 years (1917 to 1934) for the coast between Ambalangoda and Koggala. The second period covers 38 years (1934 to 1972) for the entire coast except for a few segment. The first and the second periods are based on old topographical maps while the third (1973 to 1987) is based on aerial photographs. The phrase 'coastline changes' includes both degradation and progradation. The spatial variation of the coastline changes is shown according to the coastal compartments given in Table 4.2 and Figure 4.2.1.

Table 4.2 Coastline changes and coastal compartments of the SW coast of Sri Lanka

No given for the identity	Place name	Length of the coastal compartment in km	Coastal degradation (-) and progradation (+) in '000m.		
			First * period	Second ** period	Third ** period
1.1	Randombe-Harakgala	2.08	-8.88	0	NA
1.2	Harakgala-Pattigala	1.04	+10.4	-6.4	-1.56
1.3	Pattigala-Wellameda	2.65	-8.80	+31.20	-83.75
2	Wellameda-Kahawa	1.97	-9.20	-27.20	-0.75
3	Kahawa-Seenigama	2.05	NA	NA	-48.75
4.1	Seenigama-Totagamuwa	1.20	-5.40	-213.75	-27.50
4.2	Totagamuwa-Wellawatta	0.92	-19.12	-3.60	-20.61
4.3	Wellawatta-Waal island	0.97	-1.60	+36.00	+11.87
5.1	Waal island-Patuwata	4.05	-132.80	+119.20	+95.62
5.2	Patuwata-Degalla	0.85	-12.40	-13.6	-3.70
6.1	Degalla-Gin River mouth	5.65	NA	+87.20	NA
6.2	Gin River mouth-Gintota	0.85	NA	+67.20	NA

continued

No given for the identity	Place name	Length of the coastal compartment in km	Coastal degradation and progradation (-) in '000m.		
			First period	Second period	Third period
7.1	Gintota-Osangoda	2.80	NA	NA	NA
7.2	Osangoda-Galle Town Hall	1.60	NA	NA	NA
8.1	Galle Town Hall-Old jetty	2.30	+69.69	NA	+31.81
8.2	Old jetty-Gibbert island***	1.05	-1.60	NA	+ 1.87
8.3	Gibbert island-Rumassala	2.90	+46.23	+48.70	-38.12
8.4	Rumassala-Watering Point	1.50	0	-50.37	-56.25
8.5	Watering Point-Unawatuna	2.25	0	NA	0
9	Unawatuna-Wella-addaragoda	1.75	-21.85	NA	-52.50
10.1	Wella-addaragoda-Talpe	2.14	-11.63	NA	-25.62
10.2	Talpe-Katukurunda	4.40	+172.96	NA	-11.87
11.1	Katukurunda-Koggala	3.20	+29.21	NA	-48.72
11.2	Koggala-Kataluwa West	0.50	NA	NA	-8.12

No given for the identity	Place name	Length of the coastal compartment in km	Coastal degradation (-) and progradation (+) in '000m.		
			First period	Second period	Third period
12.1	Kataluwa West- Atadahewatugoda	1.22	-25.3	NA	+48.12
12.2	Atadahewatugoda- Piyandigama	1.40	+48.76	NA	+21.87
12.3	Piyandigama- Goyyapana	1.00	-10.12	NA	- 9.37
12.4	Goyyapana- Denuwala	1.33	- 4.60	NA	+25.00
12.5	Denuwala- Midigama East	0.77	- 9.20	NA	- 5.00
12.6	Medigama East- Mempitiya	2.08	-24.84	NA	-28.12
13.1	Mempitiya- Walliwela	2.08	-21.16	NA	+ 8.55
13.2	Walliwela- Mirissa	6.25	+89.47	NA	NA
13.3	Mirissa- Pemuyana	2.94	NA	NA	+14.70
14.1	Pemuyana- Bandaramulla	1.15	-4.60	NA	+ 0.60
14.2	Bandaramulla- Talaramba	2.94	-27.17	NA	-23.10
14.3	Talaramba- Godakanda	2.05	-11.73	NA	- 4.30
15	Polhena	3.53	+56.35	NA	NA
16.1	Polhena- Meddewatta	1.30	+84.15	+22.54	-29.30
16.2	Meddewatta- Rassandeniya	2.65	-27.31	-21.62	+28.35
16.3	Rassandeniya- Devundara	2.25	-26.45	-37.49	+25.26

* first period= 1905/15/17/18 to 1932/33/34; ** second period= 1932/33/34 to 1943; *** third period=1973 to 1987.

****Galle harbour is neglected.

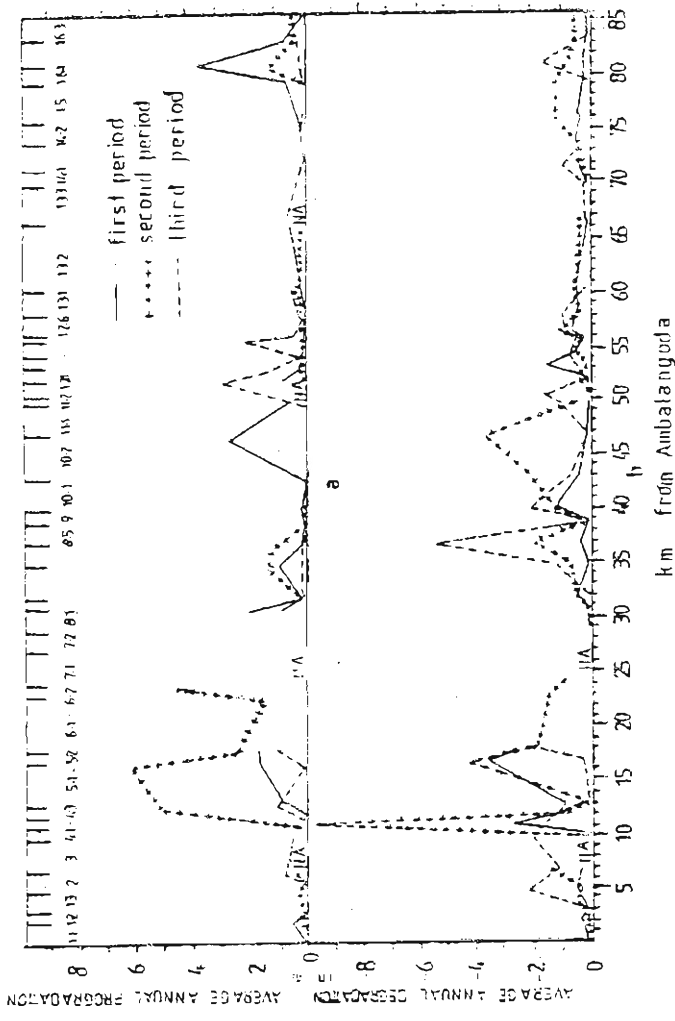


Figure 4.2.1- Average annual coastal degradation/progradation in the study area for the three periods distinguished during the 20 th century. The fluctuations in degradation and progradation indicate that the coastline was not characterized by continuous abrasion. (Average annual progradation/degradation for a period was obtained following the formula: $\frac{D_p}{Y_p} = Lc$, where D_p = degradation for the period progradation for the period, Y_p = years covered by the period, Lc = length of the coastal compartment. (The place names of the compartments appear in Table 4.2)

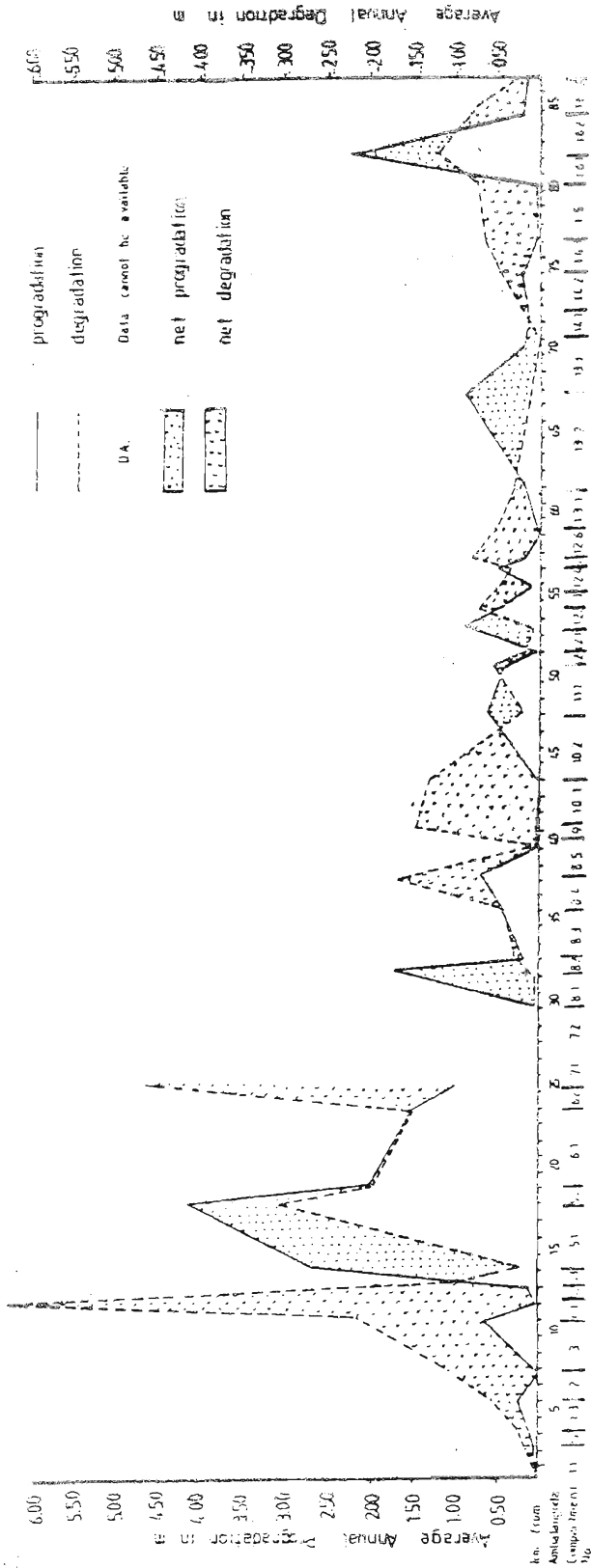


Figure 4.2.2- Average annual changes of the coastline of the Southwest during the 20th century. The differences between the progradation rates and degradation rates reveal the net degradation or progradation (The average values have been obtained by dividing the total of the degradation/progradation values by the years of observation and by the length of the compartment. The place names of the compartments appear in Table 4.2.

The data of the coastline changes reveal strong fluctuations in degradation and progradation during the 20 th century. The situation is summarized in Figure 4.2.1. The high progradation rates occurred along the coast from Narigama to the Gin River mouth (from 4.3 to 6.2) along the bay of Galle (8.1 to 8.5), the eastern and western sides of the Koggala outfall (10.2 to 11.2) and near the Nilwala River mouth (16.1, 16.2 and 16.3). All coastal compartments, however, exhibit changes during the 20 th century. The coasts NW of Galle have experienced total degradation during the first, second and third periods. Considerable progradation took place along the coasts only during the second period. The coasts SE of Galle have, except for a few segments (10.1, 10.2, 14.2 and 14.3), have been subjected to progradation at varying rates during the 20 th century. The progradation rate of the compartments near the Nilwala River mouth (16.1 and 16.2) exceeds degradation rates during the three periods. Figure 4.2.2 shows that in many compartments degradation exceeded progradation during the 20 th century. Considerable progradation only occurred along the coasts stretching from Waal island to Degalla (4.3 to 5.2), in some parts of the bay of Galle (8.1 and 8.2), Katukurunda-Piyandigama (10.2 to 12.2), in the bay of Weligama (13.2 to 13.3) and at the Nilwala River mouth (16.2).

5 CONCLUSIONS

Even though the coastline changes during the last three centuries are within the time span covered by the study, evidences pertaining to sea level fluctuations prior to the last three centuries are of interest as they assist in understanding the coastline changes of the Pleistocene and Holocene periods. Important effects of sea level changes in the study area relate to the mid-Holocene. The Holocene marine transgression maximized around 6 th millennium BP. It continued submerging the coast during 1000 year period or until the beginning of the 6 th millennium. Thereafter, the sea began to regress from the submerged areas (Figure 3.1.2). Differences in elevation of the raised beaches of the SW coast as compared to other coasts of Sri Lanka and the coasts of the islands in the Indian Ocean as well as the coasts around the Indian Peninsula give rise to various Neotectonic hypothesis; (i) the SW coast has subsided, (ii) the SE, NE coasts of Sri Lanka and the NW coast of India have remained stable or (iii) emerged slightly or subsided at a lower rate than the SW coast, since the mid-Holocene.

The period concerned under the historical coastline changes is divided into two sections namely; (i) changing processes and their effects on coastline changes, (ii) quantitative aspects of the coastline changes. The

information derived from previous studies (Verstappen, 1987) and from the (few) historical documents available give only an indication of the beginning of the abrasion phase. It appears that the abrasion phase of the SW coast has probably begun around 1700 as a result of the changing wind direction and later has accelerated by a slight rise of sea level. More research is necessary, however, to get detailed information about the beginning of the abrasion phase.

The changes of the coastline that occurred during the 19 th century show that many promontories, projected land areas and capes have been destroyed and wide sandy beaches were washed away. The facts pertaining to the 20 th century confirm that the changes of processes have being continued until the present decade (Figures 4.3.1 and 4.3.2). The coastline degradation in the study area, however, is not a continuous phenomenon as far as their changing patterns during the 20 th century are concerned (Figure 4.1.1). Even though it is generally believed that the coastline degraded continuously the findings on the coastline changes pertaining to the 20 th century show that the changes vary (a) within the periods and (b) among the coastal compartments. Some coastal compartments have remained in the state of equilibrium within the progradation and degradation rates .

Prevention of building unnecessary structures in compartments which are in a state of equilibrium/high rate of progradation would improve the quality of the coast and minimize the cost incurred by the coast protection works.

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