

DYNAMICS OF MUDBANKS ALONG A COAST EXPERIENCING RECURRING EPISODES OF EROSION AND ACCRETION

Abdolhossein Parizanganeh¹, V. C. Lakhan², S. R. Ahmad²

1-Zanjan University, Zanjan, Iran

2-University of Windsor, Windsor, Ontario, Canada N9B 3P4

Abstract

The morphological states of Guyana's coastal system, at various spatial and temporal scales, are found to be influenced by the formation and migration of mudbanks. Stationary and propagating mudbanks along the coast are investigated with the use of multiple data sources, including aerial photographs, satellite imagery, GPS measurements, and a time series of coastal profile data (1941-1987, 1992-2005). Multi-temporal data from different sources are assimilated, integrated, analyzed and visualized with a geographical information system. Six mudbanks are recognized from 1941-2005. Each mudbank had a different length and moved at a different rate in a westerly direction. Mudbanks are associated with recurring episodes of erosion and accretion. Statistical analysis of variance demonstrated significant spatial and temporal variations in the patterns and amounts of erosion and accretion along the coast.

Keywords: Mudbanks, Accretion, Erosion, Propagation, Guyana

Introduction

Mudbanks are dynamical features which can affect the coastal physical environment in a significant way in terms of waves, turbidity and bottom topography [1], and also have impacts on water quality, aquatic ecology, shipping, navigation, siltation, and other coastal characteristics. While a general description of mudbanks along muddy shores has been presented [2] it must, nevertheless, be acknowledged that "our comprehension of mudshoal long-term dynamics and stability lags behind that for sandy shores" [3, p. 70]. This research, therefore, aims to provide insights on mudbanks present in a large scale, dynamic coastal system, which at the meso-scale exhibits changes in configuration and morphological stability. Focus is on the influence of

shifting mudbanks on the advance and retreat dynamics of the Guyana coast at different temporal and spatial scales.

Study Area: Guyana's Coastal Environment

The study area is a portion of the northeast coast of the South American continent known as the Guiana coast and stretches some 1600 km between the mouths of the Orinoco and Amazon Rivers. It forms the coastline of French Guiana, Surinam, Guyana, and parts of the Brazilian and Venezuelan coasts. Emphasis is on the Guyana coast which has a length of about 435 km (see Figure 1). General accounts on the nature and characteristics of the Guyana coast can be found in several studies [4] [5] [6].

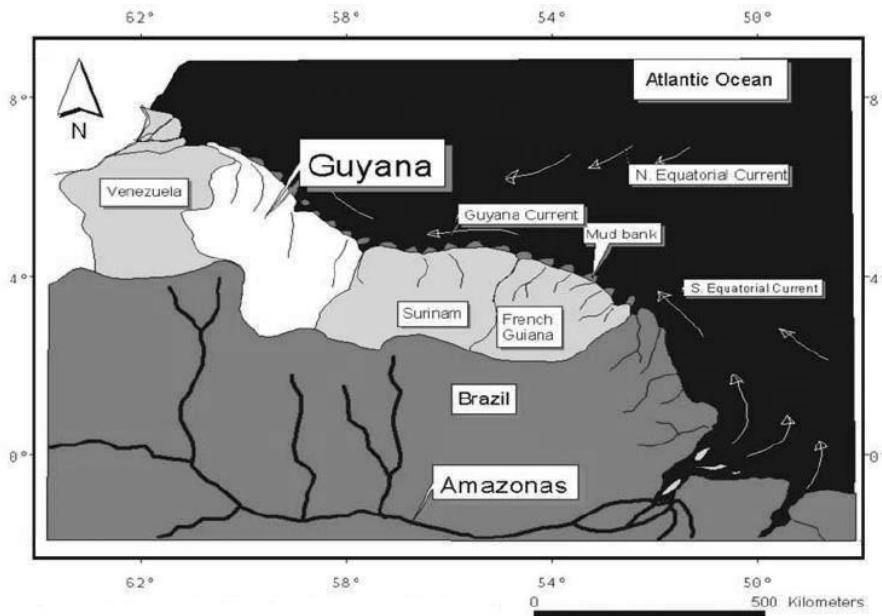


Figure 1- The study area and associated characteristics.

The coastal plain is Guyana's smallest physiographic region and has a width that varies from 16 km in the west to 64 km in the east. Much of the lower coastal plain is below sea level at high tides, and is therefore vulnerable to the potential effects of sea level rise. Along the coast, especially in riverine areas, there are large tracts of mangrove vegetation. *Rhizophora mangal* or red mangroves occupy the soft muddy soils, especially near the river banks. *Avicennia germinans* or black mangrove is one of the dominant mangrove species along the coast, and can be found in areas which have not been eroded. *Laguncularia racemosa* (white mangrove) occupies several areas bordering mangrove swamps along the coast.

More than 90% of Guyana's population lives in the coastal environment. The coast is, therefore, of immense economic, social and industrial importance. The study by [7], however, emphasized that the coastal population is plagued by a series of issues including resource depletion, habitat losses, environmental degradation, salinization, inundation and erosion. Many areas

along the coast are affected by flooding and erosion. The recent research by [8] postulated that migrating mudbanks could be blamed for exacerbating the problem of erosion along the coast of the Guianas.

Review of Pertinent Literature

The recognition of mudbanks along the Guyana coast could be traced back to 1498 when Columbus sailed along the coast but was unable to land because of inhospitable marshes and mudbanks [9]. The occurrence of mudbanks along the Guyana coast is strongly influenced by the hydrodynamic and sedimentological processes operating in the large-scale 1600 km coast of the Guianas. This coast is under the influence of massive loads of sediments discharged at the mouth of the Amazon River. The bulk of the sediments are transported from the Amazon in a northwesterly direction by the Equatorial Current, and subsequently by the Guiana Current which flows along the continental shelf. The volumes of sediment transported along the Guyana coast are found to vary seasonally from lows of 2×10^6 tonnes per month between August and

September to 25×10^6 tones per month between April and May [10]. The very fine silts and clays which are transported tend to flocculate, and when the concentrations exceed 450 kg/cm^3 it forms a coherent mass of viscous mud, and eventually settle to form mudbanks (also referred to as mudshoals) [11]. Mudbank morphological states are characterized by the formation of mudflats which could be considered the emerged parts of mudbanks. Twenty-one mudbanks are recorded along the coast between the Waini River, northwest Guyana and Cayenne in French Guiana [12].

The mudflats and associated mudbanks affect nearshore hydrodynamics, sedimentology and morphological states along the coast [13] [14] [15]. Soft mud accumulates in the nearshore areas experiencing sedimentation. The soft mud deposits become fluidized under incoming waves, and thereby have the effects of dampening the propagating waves. The reductions in wave energy initiate depositional conditions [16]. With dampening of wave energy, the process of siltation begins to occur. Hence, coastal areas directly opposite a stationary mud shoal experience episodes of accretion. Conversely, the coastal areas between the trough of two mud shoals are exposed to erosive waves. The study by [17] claimed that the influence of northeast trade winds, and associated wind-generated wave action influence the migration and displacement of mudbanks along the coast of the Guianas. Along the neighboring coast of French Guiana evidence was provided to show that a combination of hydrodynamic perturbation factors; including coastal currents, river discharges, and tidal outflows are responsible for the mobilization and displacement of mudbanks [18]. One consequence of the

immobilization and eventual migration of mudbanks is the recurrence of episodes of erosion and accretion along the coast [15].

Research Methodology

To investigate how mudbanks influence recurring episodes of erosion and accretion along the Guyana coast, this research examined evolving coastal morphology in both the spatial and temporal domains. This required the utilization of an appropriate methodological approach in order to highlight the relationships and associations existing between coastal morphological changes and the dynamics of propagating mudbanks. In addition to statistical analysis of the long-term empirical data this study employed a geographical information system (GIS) to integrate, analyze and visualize changes along the coast at various spatial scales. The GIS was parameterized with multi-temporal data representing different subsystems comprising the coastal environment. The GIS system, with its various overlay and query functions, permitted not only visualizing spatial locations experiencing erosion and accretion, but also provided the platform for modeling the migration of mudbanks in the coastal system.

Data Acquisition

A combination of archival data, published documents, topographic maps, a time sequence of aerial photographs, satellite imagery, global positioning system measurements, and field survey data are utilized to examine mudbanks. Four documents [11] [12] [19] [20] provided valuable historical information on mudbanks and their characteristics. The aerial photographs (1942, 1950, 1962/1964, 1972/1975, 1979/1980, 1984) and associated data utilized by [21] are also very useful for inclusion in

GIS database. The Landsat ETM+ image for the time period October 1, 2002 supplemented the aerial photograph data. The locations of the Albion and Melanie mudshoals are georeferenced with data from a global positioning system.

Erosional and accretional data for the time period 1941 to 1987 were obtained from the Lands and Surveys Department, Government of Guyana [22]. These data were updated to the current time period, with extensive field survey measurements obtained by the senior author [7]. Here it is worthwhile to note that in 1992 the University of Windsor embarked on a program to instrument and monitor the mudflats, mud beaches and mudbanks along the coast of Guyana. Samples on hydrodynamic and sedimentological characteristics were and are being obtained on an annual basis from the Melanie and Albion mud flats. Nearshore current data are obtained with an electromagnetic portable water flow meter [23]. In addition to current, tidal and wave data, the GIS was also parameterized on an annual basis with bathymetric, elevation, grain size, and coastal profile data relating to advance and retreat of the coastline. Other spatial and associated attribute data sets in the GIS are updated on a regular basis.

Data Pre-Processing and GIS Use

All acquired data are first pre-processed and then stored in the ArcGIS 9.0 geographical information system [24]. To obtain output results from the GIS, several extensions are used, including Spatial Analyst, 3D Analyst, and Geostatistical Analyst. For instance, the Landsat ETM+ image was processed with the IDRISI Kilimanjaro software [25], and then exported to ArcGIS 9.0. This digital dataset was overlayed on those datasets prepared from the aerial photographs.

In addition, sedimentological data were analyzed for granulometric composition with six sieves (2.0 phi, 2.5 phi, 3.0 phi, 3.5 phi, 4.0 phi, and 4.5 phi). The finer particles remaining in the pan were processed with a Brinkmann Particle Size Analyzer [26] to obtain size ranges from 4.5 phi to 8.0 phi. To investigate the spatio-temporal changes in mudbank morphology and grain size distribution, triangular irregular network (TIN surfaces) are created. The TIN model used elevation data collected at different locations from each mudbank. The area and volume statistics calculator of 3D Analyst of ArcMap are used to compute the area and volume of the TINs above zero base level. ArcScene was used to obtain the three-dimensional views of the TIN surfaces.

The mean grain size of sediments from each of the mudbanks was used to show temporal variations in size ranges. This required using Geostatistical Analyst of ArcGIS to create spatially interpolated predicted surface map of grain size distributions for all years from 1994 to 2003. The statistical interpolation method of ordinary kriging predicted values of size distribution. The layers of change in grain size distribution for different years are obtained using the raster calculator of Spatial Analyst.

Results and Discussion

Based on the processing of individual and combined datasets research findings were provided on some of the characteristics and the spatial and temporal dynamics of mudbanks along the Guyana coast. Field observations and the various data sources revealed the existence of mudbanks along the coast of Guyana. Figure 2 highlights the temporal occurrences of mudbanks along the spatial extent of the coast, stretching from the Corentyne River on the Surinam border to the Barima River near to Venezuela. Each mudbank was oriented toward the coast

with the angle between the crest of the shoals and the coast varying between 20° and 30° , with an average of 24° [11]. The wavelengths of the different mudshoals varied depending on location along the coast. With the use of aerial photograph derived data (1942, 1950, 1962/1964, 1972/1975, 1979/1980, and 1984) presented by [21], the lengths of the emerging parts of the mudbanks are plotted. Figure 3 shows wide variations in mudbank lengths for different years, with the shortest length being 4.5 km and the longest being 41.0 km. The five mudbanks for the six time periods had an average length of approximately 20 km. With the use of findings presented in [10] and selected aerial photographs, information

on the spatial locations and movements of the mudshoals are obtained. Mudshoal 1 moved westwards from Surinam (see Figure 2 for locations) after 1950. Between 1942 and 1962, Mudshoal 2 appeared in the area between the Berbice and Corentyne Rivers. The eastern part of this mudshoal became stabilized, and therefore did not emerge between 1972 and 1984. Mudshoal 3 emerged east of the Berbice River after 1950, and became very pronounced from 1979 to 1984. Mudshoal 4 occupied an area between the Mahaicony and Abary Rivers, and attained its greatest length, beginning 1962. Mudshoal 5 was located east of the Demerara River, and between 1950 and 1962 eventually migrated away from the study area.

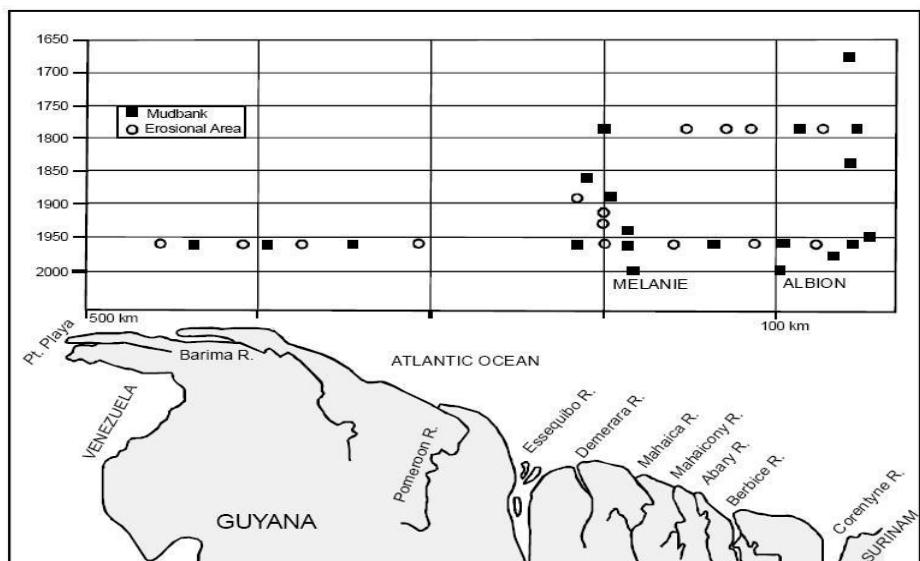


Figure 2- Representation of mudbanks along the Guyana coast Data source: field work, and [11]

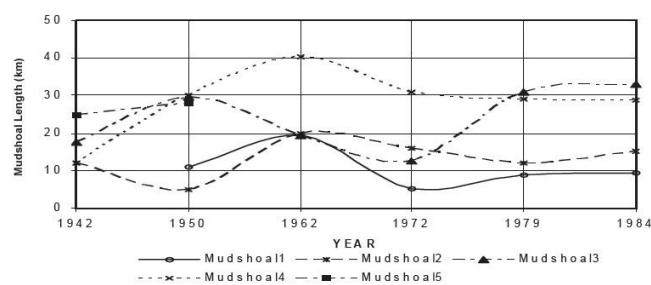


Figure 3- Lengths of emerged portions of mudbanks. Data source: [28]

The length of the mudbank at Melanie (see Figure 2) in 1992 was approximately 7.5 km. This mudbank was considerably longer but it was displaced by nearshore erosional processes during the period of field surveys. A three-dimensional plot (Figure 4) of the surveyed portion of the Melanie mudbank reveals a well-defined mudflat which was pronounced at the low tide level. The dewatering channels within the mudscape could be explained as being indicative of operational degradational processes initiated by the complex interplay between sediment supply and hydrodynamic forcing functions. While findings on mudbank displacement are presented elsewhere [17][18][27][28][29] it could, nevertheless, be worthwhile to note that as a mudbank started to migrate westwards the mudscape environment became exposed to erosive waves. The removal of mud deposits, which previously damped the effects of incident waves, resulted in increased impacts of wave-induced erosion. Erosion intensified in those areas along the coast opposite the troughs which are

situated between two adjacent mud shoals [15].

The increased displacement of the mudbanks resulted in alterations of the surface morphological characteristics, and quantifiable changes in sedimentological properties. The surficial sediments collected on an annual basis from across the length and width of the Melanie and Albion mudbanks are analyzed, graphed and represented as TIN surfaces in ArcGIS 9.0. Figure 5, a TIN representation of the temporal variations in grain size from the eroding Melanie mudbank, demonstrates that with degradation of the mudbank there was a gradual and progressive removal of the bulk of the finer sediments. Over time (1994-2003), the grain size decreased from sizes in the fine range (4.5 phi to 8.0 phi) to those in the coarse range (< 3.5 phi). This occurrence permits the advancement of the claim that an erosional mudbank is characterized by comparatively higher concentrations of coarser sediments. The aggrading mudbank at Albion was found to have a far higher percentage of finer sediments [27].

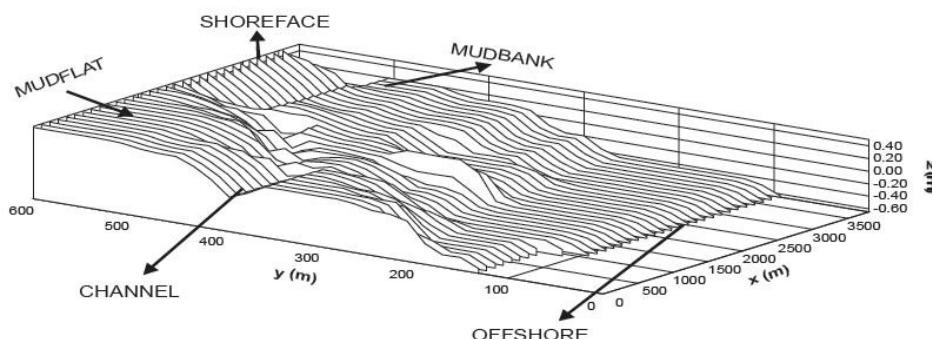


Figure 4- Three-dimensional plot of the eroding Melanie mudbank.

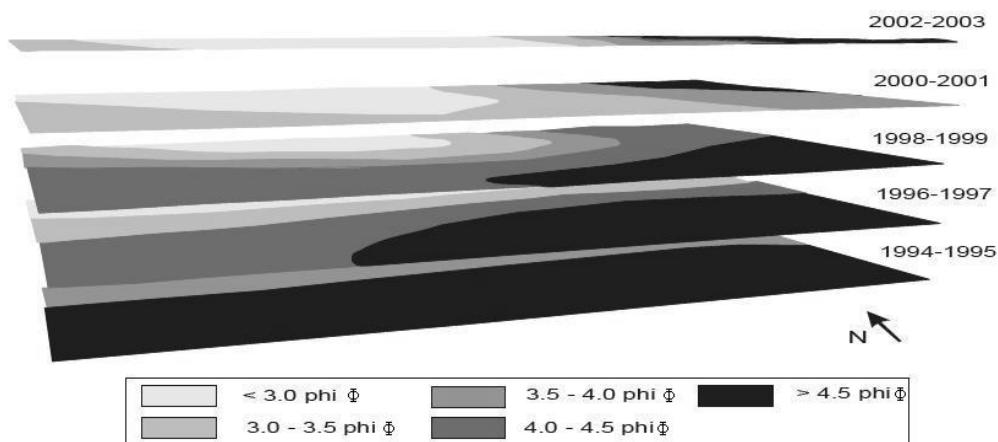


Figure 5- TIN representation of temporal variations in grain size of Melanie mudbank

The GIS results substantiated the field observations that the migration or displacement of a mudbank was generally associated with erosion of the coastal section that was protected by the mudbank, especially if the mudbank was once attached to the shore. Instead of the mudbank attenuating the impacts of shoreward propagating waves, the exposed coast experienced the effects of concentrated erosive energies. Hence, the movement of mudbanks along the coast of Guyana was accompanied by a pattern of erosion and accretion of the adjacent coast. This situation was also observed along the neighboring coasts of Surinam [28], and French Guiana [29]. To statistically investigate the influence of mudbanks on the temporal variability of erosion and accretion patterns along the coast of Guyana, advance and retreat coastal data collected by [22] for the time period 1941-1987 were analyzed. The advance or retreat (AOR) rate method was utilized and AOR rates are calculated for nine time periods (1941-46, 1946-51, 1951-56, 1956-61, 1961-67, 1967-72, 1972-77, 1977-82, and 1982-87) for 86

coastal profile sections. Distinctive erosional and accretional cycles could be observed from the plot (Figure 6) of the AOR data. An established accretional pattern could be observed in 1941 and then again in 1977. Within the 36-year cycle there are evidences of pseudo-cycles for the period 1941-46 and 1961-67, and also for 1961-67 and 1977-82. There was also clear evidence of a defined erosional cycle, especially for the period 1946-51 to 1972-77. A pseudo-cycle could be noticed for the period 1972-77 to 1982-87.

The AOR rates data are also subjected to analysis of variance in order to determine whether recurring episodes of accretion and erosion varied statistically in the spatio-temporal continuum. Based on the Levene's Test for Variance [30], it could be claimed that accretion and erosion varied in different spatial sections of the coast, with more aggradation occurring in those sections of the coast protected by stationary mudbanks. The Bonferroni Test [30] provided results demonstrating significant temporal variations in accretion and erosion. Evidently, as the mudbanks move through space and over time the coast responded by either accreting or eroding. Interestingly, the migrating

mudbanks along the coast have a periodicity of approximately 36 years, which is about 6 years more than that postulated [8].

cognizant of the fact that the implementation of functional coastal protection measures requires a thorough understanding of the physical processes

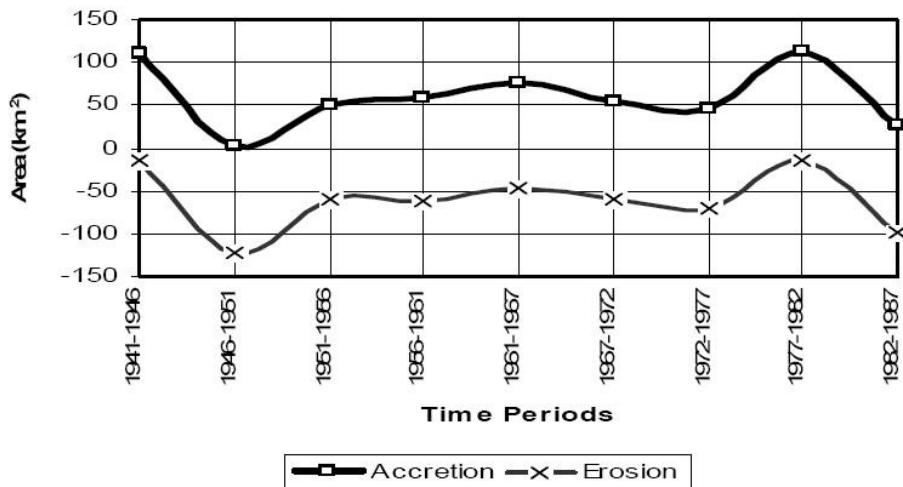


Figure 6- Plot of coastal data showing erosional and accretional cycles

Conclusion

The morphology of the coast of Guyana is directly affected by the location of mudbanks, which in turn could be associated with recurring episodes of erosion and accretion. This research permits the claim that the mudbanks along the coast of Guyana have a significant influence on mesoscale coastal behavior whereby the coastal system, at different spatial scales and at different times, responded to the presence or absence of mudbanks. The migrating mudbanks have quantifiable periodicities. Of significance is the fact that the observed aggradational and degradational sequences have different magnitudes and durations. Since it is necessary to understand the transitory morphological states in the coastal system [31], it becomes critically important to gain additional insights on how mobile mudbanks affect the morphological stability of the Guyana coast. Coastal engineers, planners, and policy managers must, therefore, be

operating in the coastal system, especially on how mudbanks initiate either accretional or erosional episodes along the coast. Additional scientific research findings on the dynamics of mudbanks will certainly be beneficial for coastal resource managers who have to address the recurring problems of coastal erosion.

References

- 1-Mehta, A.J., 2002. Mudshore dynamics and controls. In: Healy, T., Wang, Y., and Healy, J.A. (Editors), *Muddy Coasts of the World: Processes, Deposits and Function*. Elsevier Science, The Netherlands, pp. 19-59.
- 2-Flemming, B.W., 2002. Geographic distribution of muddy coasts. In: Healy, T., Wang, Y., and Healy, J.A. (Editors), *Muddy Coasts of the World: Processes, Deposits and Function*. Elsevier Science, The Netherlands, pp. 99-201.
- 3-Kirby, R., 2002. Distinguishing accretion from erosion-dominated muddy coasts. In: Healy, T., Wang, Y., and Healy, J.A.

(Editors), Muddy Coasts of the World: Processes, Deposits and Function. Elsevier Science, The Netherlands, pp. 61-81.

4-Daniel, J.R.K., 1981. Coastal processes and the dynamics of coastal morphology. The Geographical Association of Guyana Journal, III, 1-16.

5-Lakhan, V.C., 1991. Simulating the interactions of changing nearshore water levels, morphology and vegetation growth on Guyana's coastal environment. In: McLeod, J. (Editor), Toward Understanding Our Environment. Simulation Councils Inc., San Diego, CA, 13-20.

6-Lakhan, V.C., 1994. Planning and development experiences in the coastal zone of Guyana. Ocean and Coastal Management, 12, 1-18.

7-Lakhan, V.C., 2005. Proposed framework for the implementation of a spatial decision support system for coastline and flood prediction along the Guyana coast. Journal of Indo Caribbean Research, 6: 17-35.

8-Allison, M.A., and Lee, M.T., 2004. Sediment exchange between the Amazon mud banks and shore-fringing mangroves in French Guiana. Marine Geology, 208: 193-203.

9-Irving, B. (Editor), 1972. Guyana. A Composite Monograph. Inter-American University Press, Puerto Rico.

10-Nedeco, 1972. Reports on Sea Defence Studies. Netherlands Engineering Consultants, The Hague, The Netherlands.

11-Allersma, E., 1971. Mud on the oceanic shelf off Guyana. UNESCO-FAO Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions. Curacao, Antilles, 193-203.

12-Delft Hydraulics Laboratory, 1962. Demerara Coastal Investigations. Report on Siltation of Demerara Bar Channel and Coastal Erosion in British Guiana. Delft, The Netherlands.

13-Eisma, D., and Van Der Marel, H.W., 1971. Marine muds along the Guyana coast and their origin from the Amazon Basin. Contr. Mineral. And Petrol., 31, 321-334.

14-Barreto, L.A., Milliman, J.D., Amaral, C.A.B., and Francisconi, O., 1975. Part II. Northern Brazil. In: Milliman, J.D., and Summerhayes, C.P. (Editors), Upper Continental Margin Sedimentation off Brazil. Contr. Sedimentology 4, Stuttgart, 11-43.

15-Lakhan, V.C., and Pepper, D.A., 1997. Relationship between concavity and convexity of a coast and erosion and accretion patterns. Journal of Coastal Research, 13 (1), 226-232.

16-Winterwerp, J.C., de Graaff, R.F., Groeneweg, J., and Luijendijk, A.P., 2007. Modelling of wave damping at Guyana mud coast. Coastal Engineering, 54, 249-261.

17-Augustinus, P.G.E.F., 2004. The influence of the trade winds on the coastal development of the Guianas at various scale levels: a synthesis. Marine Geology, 208 (2-4), 145-151.

18-Lefebvre, J.P., Dolique, F., and Gratiot, N., 2004. Geomorphic evolution of a coastal mudflat under oceanic influences: An example from the dynamic shoreline of French Guiana. Marine Geology, 208, 191-205.

19-Abernathy, C.L., 1980. Guyana Coast. Recommendations for a Future Sea Defence Strategy. Report No. 0D30. Hydraulics Research Station, Wallingford, England.

20-DHV Environment and Infrastructure, 1992. Sea Defence Component of the Infrastructure Rehabilitation Programme (IRP). Report on Morphological Aspects. Volume II. Amersfoort, The Netherlands.

21-Augustinus, P.G.E.F., 1987. The geomorphologic development of the coast of Guyana between the Corentyne River and the Essequibo River. In: Gardner, V.

(Editor), International Geomorphology 1986 Part I. Wiley, New York, 1281-1292.

22-Lands and Surveys Department, Government of Guyana, 1993. Demerara Foreshore Survey Data. Lands and Surveys Department, Georgetown, Guyana.

23-Marsh-McBirney, Inc., 1990. MMI Model 2000 Flo-Mate Portable Water Flowmeter Instruction Manual. Maryland, pp. 29.

24-ESRI, 2005. ArcGIS 9.0. Esri, Inc., Redlands, CA.

25-Clark Labs, 2003. IDRISI Kilimanjaro: Guide to GIS and Image Processing. Clark University, Worcester, MA.

26-Brinkmann Instruments, Inc., 1989. PSA 2010 Particle Size Analyzer: Operation Manual, Galai Production, Ltd.

27-Lakhan, V.C., Cabana, K., and LaValle, P.D., 2003. Relationship between grain size and heavy metals in sediments from beaches along the coast of Guyana. *Journal of Coastal Research*, 19 (3), 600-608.

28-Augustinus, P.G.E.F., 1987. The changing shoreline of Surinam (South America). Ph.D. thesis. University of Utrecht, The Netherlands, 232p.

29-Froidefond, J.M., Pujos, M., and Andre, X., 1988. Migration of mud banks and changing coastline in French Guiana. *Marine Geology*, 84, 19-30.

30-SPSS, Inc., 2003. Statistical Package for the Social Sciences. Version 13. SPSS, Inc., Chicago, IL.

31-Lakhan, V.C., 2004. Perspectives on Special Issue papers on coastal morphodynamic modeling. *Coastal Engineering*, 51 (8-9), 657-660.