Vuma cliffs looking north

THE COASTAL ENVIRONMENT

PHYSICAL CHARACTERISTICS

CLIMATE

The Kenyan coast runs in a southwesterly direction from the Somalian border in the north, at 1º 41'S to 4º 40'S at the border with Tanzania. It lies in the hot tropical region where the weather is influenced by the great monsoon winds of the Indian Ocean. Climate and weather systems on the Kenyan coast are dominated by the large scale pressure systems of the western Indian Ocean and the two distinct monsoon periods.

From November/December to early March, the Kenyan weather, particularly at the Coast, is dominated by the Northeast Monsoon which is comparatively dry. During March and April the wind blows in an east-to-southeasterly direction with strong incursions of maritime air from the Indian Ocean bringing heavy rains. During the months of May, June, July and August, the Southeasterly Monsoon influence gradually sets in and the weather becomes more stable with dull and comparatively cooler temperatures. Between September and November, the Northeast Monsoon gradually re-establishes itself and by December the northern influence is dominant once again.

Rainfall

A relatively wet belt extends along the entire Indian Ocean coast of Africa and annual rainfall on the Kenyan coast follows the strong seasonal pattern outlined above. The main rains come between late March and early June with the rainfall decreasing from August. Some rain occurs between October and November but from December, rainfall decreases rapidly once again to a minimum during January and February.

Mean annual total rainfall ranges from 508mm in the drier, northern hinterland to over 1,016mm in the wetter areas south of Malindi. Relative humidity is comparatively high all the year round, reaching its peak during the wet months of April to July. However, there is a marked diurnal change particularly in Mombasa where it is around 60-70% during the afternoon, rising to 92-94% during the night and in the early morning.

Records kept for Mombasa and Malindi indicate that both are generally sunny throughout the year. The average number of daily sunshine hours at Mombasa are 8.4 in July and 8.9 in February, October and November. The corresponding values for Malindi are 7.3 in July and 9.3 in December.

Evaporation at Mombasa increases from a low of 138mm in July to 221mm in March. Whereas in Malindi the low in July is around 128mm, rising to 193mm in March.

Wind

The windiest time of the year at the Kenya Coast is during the Southeast Monsoon from May to September, while the calmest months are March and November when the winds are also more variable in direction.

Wind records from Lamu, Malindi and Mombasa show a consistent daily pattern whereby wind strength (in knots) drops during the night and is always less at 0600 than at 1200. This pattern is less pronounced in Lamu which also tends to be the windiest place on the Coast at 0600. Overall, it would seem that Mombasa is the windiest, but the strongest winds are likely to be experienced in August in Malindi.

Table 1 : Seasonal wind speeds on Kenya coast

wind speed (knots)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
at 0600	**LAMU**	5.6	5.3	3	6	8.3	9.6	9	10	8.6	6.6	4.3	5
	MALINDI	4.3	3.6	1.6	6.3	6.6	8	7	7.3	7.6	6	3	3.3
	MOMBASA	5.5	5.2	1.2	8	8.5	8.7	8	7.7	7.7	5.7	2	4.5
at 1200	**LAMU**	9.3	10.6	8	9	10	10.3	10	10	9.6	10	7.6	9.3
	MALINDI	10.6	11.3	9.3	10.6	10.3	10.6	11	12.3	10.6	10.3	8.3	9.6
	MOMBASA	11.7	11.7	10	10.7	10.5	11.7	11.2	11.2	11	11	9.7	10
overall average for coast		**7.8**	**7.9**	**5.5**	**8.4**	**9**	**9.8**	**9.3**	**9.7**	**9.3**	**8.2**	**5.8**	**6.9**

Figure 4 : Temperature, humidity and rainfall averages for Mombasa

Figure 5 : Average monthly wind strength and direction recorded at the fishing grounds along the Kenya coast between 1979 - 1981 on board "R.V. Ujuzi".

GEOLOGY AND GEOMORPHOLOGY

The Kenyan coastal environments are set in a passive continental margin, the evolution of which was initiated by the break-up of the mega continent Gondwanaland in the Lower Mesozoic. The initial opening of the Indian Ocean was preceded by doming, extensive faulting and downwarping similar to that observed in the modern Great Rift Valley of East Africa. These tectonic movements formed a North-South trending depositional basin. During the Mesozoic, this basin was exposed to numerous marine incursions and by the Jurassic, purely marine conditions are thought to have existed. The coastal range running parallel to the coastal zone appears to have been uplifted through faulting during this time.

Throughout the Tertiary, the coastal areas experienced further faulting and extensive continental erosion. The older Cretaceous deposits were totally removed in many areas. The present coastal configuration, however, evolved during the Pleistocene to Recent times, a period marked by numerous fluctuations in sea level.

Three physiographic zones are observed on the Kenya coastal zone. The Nyika lies at 600m above the present sea level and represents the higher ground covered by the Duruma sandstone series and older rocks to the west. The Foot Plateau occurs at an elevation between 140m and 600m above the present sea level. This coincides well with the relatively younger Jurassic rocks. The Coastal Plain, the lowest step, rises from sea level to 140m. On average, this belt increases from a few kilometres wide in the southern sector, to over 40km in the north. The geomorphology of the Coastal Plain is dominated by a series of raised old sea level terraces. Most of the coastal environment and the modern shore configuration, follow the 0-5m and the 5-15m sea level terrace complexes.

Due to its evolutionary history, the principal rocks observed along the Kenyan coastal margin, are of sedimentary origin and range in age from Triassic to Recent. The Duruma Sandstone series, the oldest formation, is represented by the Mariakani and the Mazeras sandstones which were deposited under sub-aqueous, deltaic, lacustrine or possibly neritic conditions that prevailed before the opening of the Indian Ocean. The Upper Mesozoic is represented by marine limestones and shales with occasional horizons of sandstones and early limestones. Cenozoic to Recent rocks comprise mostly of marls and limestones, and are represented by the sandstones, clays, conglomerates and gravels such as the Marafa beds. Quaternary representatives include windblown Magarini Sands, limestones, cemented sands and coral sands. Recent unconsolidated windblown sands, beach sands and clays overlie the older units.

Kenya has a coastline of over 600km, but the exact figure depends on the extent to which small islands are included in the measurements. The Kenyan coastal region is generally low-lying and characterised by the extensive fossil reef which lies a few metres above present sea level. The coastal plain is backed in the interior by a line of hills that rarely exceed 300m except in southern parts where the Shimba Hills reach an altitude of around 1,000m above sea level. Further inland the Taita Hills rise to an elevation of 1,500m above sea level.

Soils of the coastal region show considerable variety. The porous parent rocks of sedimentary origin, generally give rise to soils of low fertility. However, patches of highly productive soils have been observed in areas of alluvial deposits. The principal soil types in the region include a narrow strip of coastal sands towards the north where it is permeated by narrow bands of grumosolis brown clay soils. The soil south of Lamu is composed of bi-alternate bands of loams beyond which the grumosolis are permeated by thick bands of ash and pumice soils.

The shoreline in most of the region apart from the Malindi area, is receding as a result of coastal erosion. Sand supplies from rivers and coral reefs are not sufficient to keep up with the rise in sea level and the problem is further exacerbated by coastal development.

Shipwrights, Mombasa

Classification of the Kenya Coastline

Many attempts have been made worldwide to classify coastlines. Usually, these classifications are meant to reflect the coast's vulnerability to oil pollution damage and are based on the geomorphology and degree of exposure of a particular stretch of coast. While providing some assistance to those dealing with an oil spill emergency, such classifications do not convey any information on the ecological value or sensitivity of the coast.

The classification adopted for this Atlas is also based on coastal geomorphology and degree of exposure but, in addition, it also takes into account the ecological value and biodiversity of the particular stretch of coastline. This classification is comprised of ten categories or types, each of which is described in Table 2 in terms of its ecological value, vulnerability and sensitivity. However, in determining the classification of a particular stretch of coast, it must be remembered that there is no definitive and precise measure of qualities such as value and importance. Neither is there an accurate measure of vulnerability. The classification is therefore a comparative one and one which is derived from the collective opinion, experience and technical judgement of experts from the region.

Living coral reefs occur all along the length of the Kenyan coast. A fringing reef colonizes the shallow parts of the continental shelf along most of the Kenyan coastline to a depth of around 45m and at a distance of between 500m and 2.0km offshore, except where river systems create conditions of low salinity and high turbidity which limit coral growth. Estuaries and deltas are characterized by extensive mangrove forests.

The width of the continental shelf off the Eastern African coast varies markedly throughout the region, but it is generally quite narrow. Kenya, with a coastline of about 600km, has an estimated continental shelf area of about 19,120km^2. Of this, some 10,994km^2 is considered trawlable. South of Malindi the continental shelf extends only 5km offshore, whereas north of Malindi, in the North Kenya Banks, the edge of the shelf is about 60km offshore.

Table 2 : Coastline classification

Type	Description	Notes
10	sheltered mangrove swamps, creeks, estuaries, marshes	*Protected from wind and wave action, highly productive environments; easily damaged physically and through pollutants; mainly intertidal - regularly exposed and submerged.*
9	sheltered tidal flats, seagrass meadows	*Mainly submerged but exposed at extreme low tides; usually subjected to medium wave energy; biological activity high.*
8	coral reefs	*Mainly submerged and subjected to significant wave action; high productivity; very susceptible to water pollution.*
7	sheltered rias, sheltered rock coasts	*Reduced wave action, mixture of subtidal, intertidal and littoral; often with extensive seaweed forests subtidally.*
6	exposed tidal flats exposed mud flats	*Exposed to wave action; relatively high biodiversity.*
5	sheltered, fine-grained sand beaches	*Generally sheltered beaches inside lagoons or behind the protection of a coral reef, subjected more to wind than wave action; productivity medium to high.*
4	exposed nearshore rocky platforms	*Subjected to increasing wind and wave action; mainly subtidal; high productivity particularly of some algal species.*
3	exposed gravel, pebble, cobbles and boulder beaches	*Exposed to wave action, usually with prominent storm ridges and steep profiles; productivity low.*
2	exposed compacted sand beaches, wind-blown sand dunes	*Generally flat and very long stretches of beach without the protection of a reef; or accumulated sand dunes which are rarely behind the protection of a reef and usually open to wind and wave action; medium to low productivity.*
1	exposed cliffs, steep rocky coasts, man-made structures	*Usually steeply dipping, near vertical walls; rocky headlands; exposed to wind and wave action; medium to high productivity.*

HYDROLOGY

Rivers and Catchments

The hydrology of the coastal region of Kenya can best be viewed by examining the drainage patterns of both perennial and seasonal rivers draining into the western Indian Ocean basin. There are two main perennial rivers namely the Tana River and the Sabaki River which also incorporates the Athi and Galana Rivers. Each of these perennial rivers has catchments extending far from the coastal hinterland into the high country of the Mount Kenya region and the Aberdare (Nyandarua) Ranges in central Kenya.

The Tana River is the longest in Kenya being approximately 850 km in length and it has a catchment area of 95,000 km^2. The Tana is regularly replenished by a number of tributaries which have their headwaters on Mount Kenya. Several hydroelectric power schemes have been constructed on its upper reaches, including those at Masinga, Kamburu, Gitaru, Kindaruma and Kiambere. In terms of annual freshwater and sediment discharges, the Tana River has the greatest volume of freshwater and the highest amount of sediment. An average of 4,000 million m^3 of freshwater are discharged annually with peak flows occurring between April and June and a shorter high flow period during November/December. The Tana River also discharges some 3 million tonnes of sediment per year. It enters the ocean about halfway between Malindi and Lamu, near Kipini, into Ungwana (Formosa) Bay. However, before it does, and about 30km upstream, it gives off a branch which leads to the complex of tidal creeks, flood plains, coastal lakes and mangrove swamps known as the Tana Delta. The Delta covers some 1,300 km^2 behind a 50m high sand dune system which protects it from the open ocean in Ungwana Bay.

Figure 6: Sand dunes at the Tana River mouth

The Sabaki River (also known as the Athi and Galana in its upland stretches) is the second longest with a length of 650km and a catchment area of 70,000 km^2 extending into the southeastern slopes of the Nyandarua Range in central Kenya. Its floodplain is less extensive than that of the Tana River and its catchment comprises important agricultural regions of central Kenya. The combined Sabaki River discharges 2,000 million m^3 of freshwater and 2 million tonnes of sediment annually into southern Ungwana Bay through the Sabaki estuary north of Malindi.

The high sediment loads carried by the Tana and Sabaki rivers are partly attributable to poor land use practices in their upper catchments which are important agricultural lands. Such a high rate of sediment discharge is threatening the sustainability of marine and coastal ecological biotopes such as mangroves, seagrass meadows and coral reefs. In addition, the high concentrations of silt in river water makes it unattractive for recreational purposes and limits the extent to which river water can be used for other purposes.

There are also a number of semi-perennial and seasonal rivers such as the Mwache, Kombeni, Tsalu, Nzovuni, Umba, Ramisi, Mwachema and Voi, all of which drain into the coastal region from arid and semi-arid catchments.

The Ramisi River, which arises in the Shimba Hills forested area, discharges 6.3 million m^3 of freshwater and 1,500 tonnes of sediments annually into Funzi - Shirazi Bay in the southern part of the Kenya coast. The Umba discharges 16 million m^3 of freshwater into Funzi - Shirazi Bay while the Mwachema and Mwache rivers discharge 9.6 million m^3 and 215 million m^3 of freshwater annually, respectively. Other small streams such as Mto Mkuu, Tsalu, Sinawe, Kombeni, etc, have not been gauged.

These rivers draining the coastal low plateau and the coastal ranges tend to have relatively low concentrations of silt. Since their water quality is also moderately high, these waters are normally usable for a variety of purposes with minor conventional treatment.

Coastal Lakes

There are a number of lakes in the Kenya coastal region with the greater number being found in the Tana Delta. Most of these lakes are quite small and shallow and are typical oxbow lakes, remnants of the various meanders of the Tana river. Two good examples of such lakes are Bilisa and Shakabobo. Some of the lakes, especially the smaller ones, show swamp characteristics. Examples of such lakes are Ziwa la Chakamba, Ziwa la Taa, Ziwa la Maskiti and Ziwa la Ndovu. These lakes are either recharged through ground water seepage or by the periodic flooding of the Tana River.

Apart from these oxbow lakes in the Tana Delta area, there are two larger lakes in the Mount Kilimanjaro region. These are Lake Jipe which has a maximum length of 12 km and an area of 28 km^2, and Lake Chala which is smaller than Lake Jipe and has an area of 5.0 km^2 and a maximum length of 2.2km. These lakes receive ground-water contributions from the Mount Kilimanjaro region in addition to being recharged by surface runoff.

The coastal lakes of Kenya are very important economically. They are a source of water for domestic and livestock purposes and are also important sources of fish protein. More recently, they are also becoming important for recreational activities. In general, water quality in these lakes is good since they are located some distance away from the main pollution sources.

Figure 7: Water lilies make a fine display in a small coastal lake.

Ground-water resources

The coastal region of Kenya has enormous potential in terms of ground-water resources. This is as a result of its geological structure which promotes rapid infiltration and percolation of surface runoff to recharge. Hot water springs with temperatures ranging between 65°C and 75°C are found near Mkongani and Mwananyamala in Kwale District which is also the site of other potable freshwater springs.

The rate of ground water yield varies from place to place depending on physiographic and hydraulic factors in addition to geological influences. Highest ground-water yields are experienced in areas covered with Kibiongoni beds, and Magarini and Kilindini sands on the coastal belt (for example at Tiwi). Areas covered with Jurassic shales and Pleistocene limestone of the low plateau and coastal belt tend to yield relatively poor quality water and yields are normally lower in volume when compared with areas covered with Kilindini and Magarini sands. Areas with Triassic sandstone geology also have relatively high ground-water yields.

Chemical analysis of ground-water from boreholes, wells and springs throughout the coastal area has been undertaken by the Government Chemist's Department, Mombasa Laboratory. A ground-water quality map of Kenya covering the coastal area is available.

Four main types of ground-water have been identified according to their anionic content - carbonate, bicarbonate, chloride, and sulphate.

Mixed types of ground-water composed of carbonate, bicarbonate, chloride and sulphate types, have also been reported in certain locations in the coastal belt.

The main factors that control the quality of ground-water are the permeability of the rock, the rock type and the degree of recharge from surface runoff and rainfall. Water of the poorest quality, with high total dissolved solids (TDS), is associated with the poorly drained Jurassic shales; intermediate quality water is associated with Triassic sandstones and Pleistocene coral limestone; while the best quality is associated with unconsolidated sands (Magarini and Kilindini) that receive efficient recharge due to their high infiltration capacities.

Ground-water quality also varies depending on the depth of the borehole or well, nearness to the ocean and proximity to human settlements. Boreholes and wells located near the coast have problems with seawater intrusion and this problem is exacerbated by overextraction. Boreholes and wells located in urban areas such as Mombasa and Lamu have the added threat of pollution originating from pit-latrines and septic tank-soak pit systems which are often the source of contamination of the otherwise potable water, rendering it unsafe for drinking without disinfection.

The exploitation of ground-water resources in the coastal areas of Kenya has been haphazard with no strict government control on borehole drilling and development. With the current problems of water supply deficit and increased urban and rural populations, people of the coastal region (and especially in urban areas such as Mombasa) are increasingly relying on ground-water resources to supplement reticulated water supplies. The south coast areas of Mombasa and Kwale District depend predominantly on ground-water which comes from the Tiwi and Ukunda areas. Many of the middle and higher class tourist hotels are also drilling their own boreholes to augment the reticulated water supply system.

OCEANOGRAPHY

Coastal currents

There are four oceanic currents affecting the Kenyan coast. These are the South Equatorial Current, the East African Coastal Current, the Equatorial Counter Current and the Somali Current. The westward moving South Equatorial Current divides into two branches once it reaches the African coast at Cape Delgado. It gives off the Mozambique Current which flows southwards, and the East African Coastal Current which flows northeastwards, parallel to the coast.

The East African Coastal Current flows northwards all the year round at least as far as Malindi. During the Southeast Monsoon it continues beyond Malindi northwards, joins with the Somali Current and continues right to the Horn of

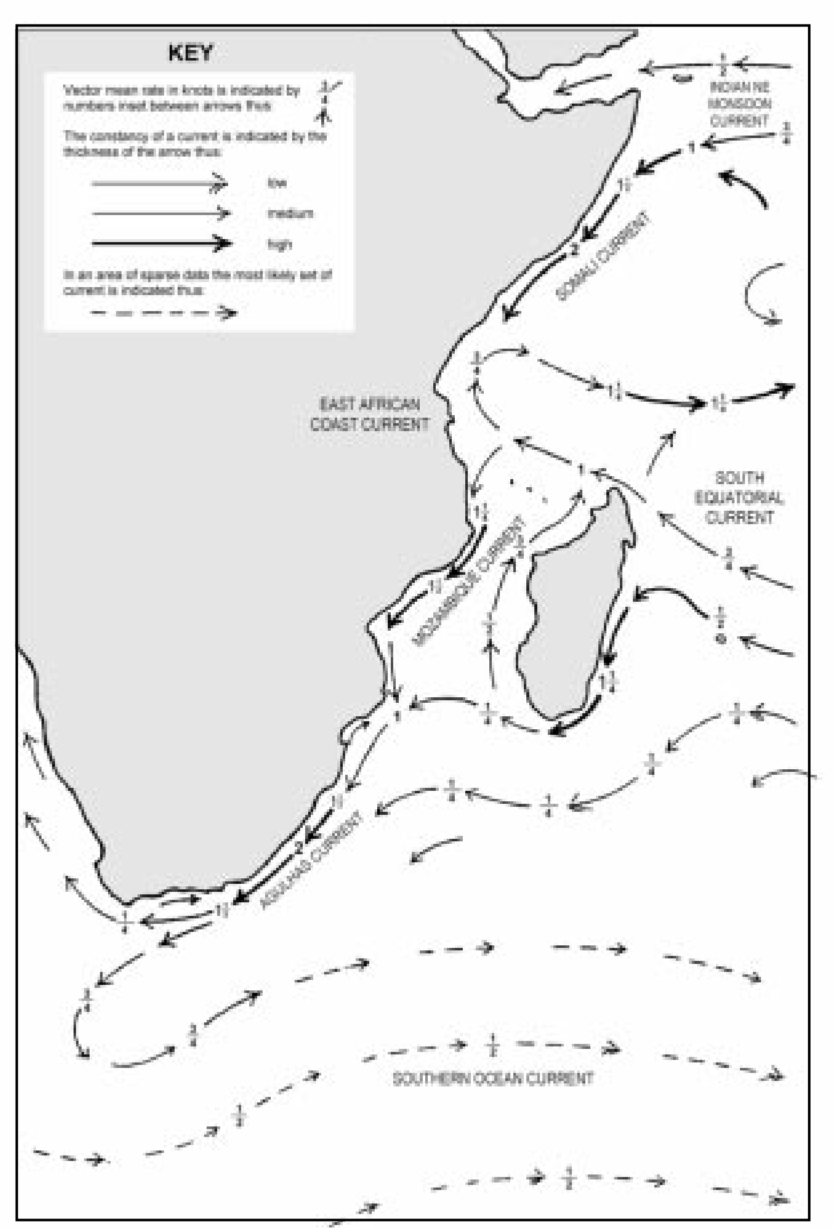

Figure 8a : Vector-mean currents for January

Africa. During the Northeast Monsoon (November to March), however, the northward extent of the East African Coastal Current is more restricted. At this time it meets and joins the southward flowing Somali Current (which changes direction under the influence of the monsoon) with this convergence taking place anywhere between Malindi and north of Lamu, depending on the strength of the monsoon in any particular year. The two streams then turn eastward and flow offshore as the Equatorial Counter Current.

The Somali Current is the only one that reverses its direction of flow under the influence of the monsoon. It flows in a southwesterly direction at about 1.5-2.0 knots with the Northeast Monsoon (November to March). While during the Southeast Monsoon (April to October), the Somali Current reverses its flow and increases its velocity to around 2.0-2.5 knots. It now appears as the northwards extension of the East African Coastal Current which still arises from the onshore

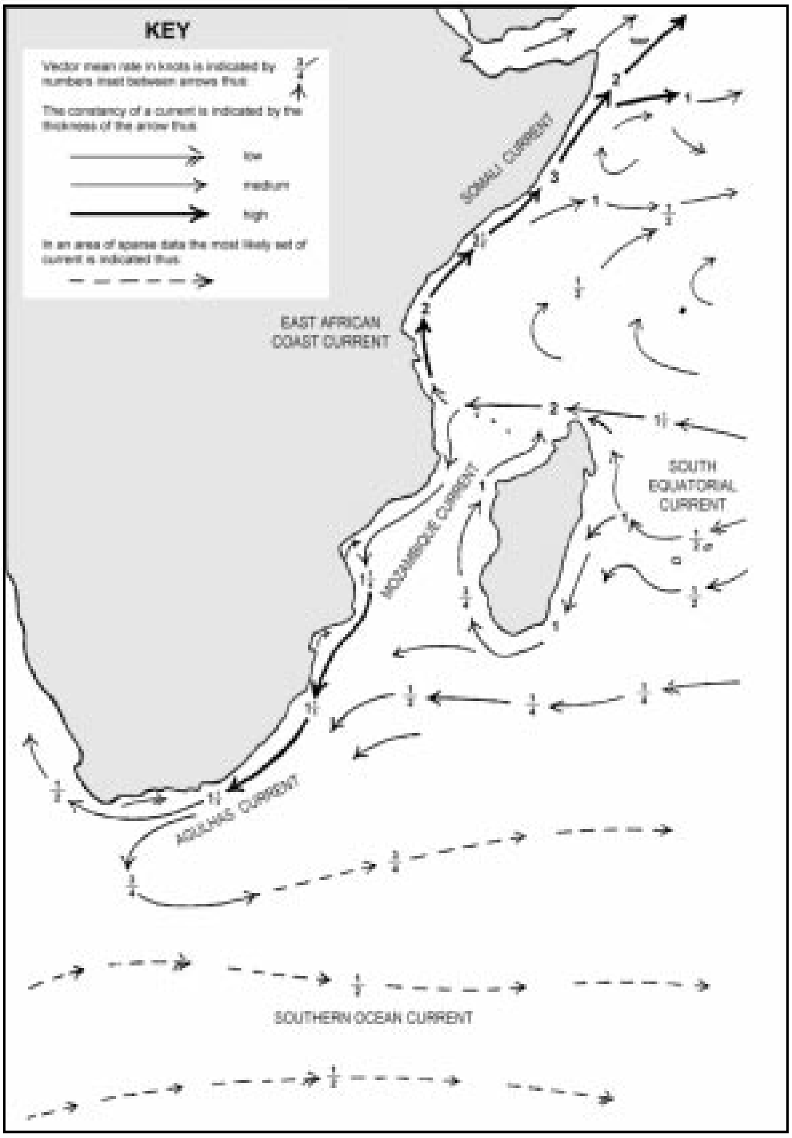

Figure 8b : Vector-mean currents for July

South Equatorial Current. At this time of the year, the Equatorial Counter Current is not so distinctive from the general Southwest Monsoon Drift at the lower northern latitudes of the Indian Ocean.

The net onshore currents result in the sinking of surface waters along most of the Kenyan coast. The exception is near Kiunga where some mild upwelling is thought to occur during the Northeast Monsoon.

Tides

Kenyan coastal waters are characterized by semi-diurnal tides - approximately two tidal cycles for every 24 hour period. Except for limited periods in the year, however, the levels of high and low water of each successive tide differ appreciably from the corresponding tide before and the tide following. The tides can therefore be designated as mixed semi-diurnal tides.

The reference port for tidal observations in Kenya is Kilindini (Port Mombasa) where the maximum tidal range does not usually exceed 3.8m but may occasionally go beyond this. Tidal range for Malindi is 2.0m for neap tide and 2.9m for spring tide. There is a lag in the tidal state which increases with distance north along the Kenyan coast. Malindi is normally 5 minutes after Kilindini while Lamu is about 40 minutes behind.

Deviations from the predictions in tide tables are influenced by barometric pressure, onshore winds and oceanic swell. However, the lowest tides occur persistently during the Northeast Monsoon since they combine with the prevailing winds to drive water offshore.

Figure 9 : Southermost mouth of the Tana River

Sea temperature and salinity

Sea surface temperature and salinity also vary with the monsoon season. The highest temperatures of 28-29^{o}C occur following the Northeast Monsoon in the months of March and April. On the other hand, the lowest sea surface temperature occurs in August and September with a minimum of 24^{o}C.

During the Southeast Monsoon the shifting of ocean currents brings Pacific Ocean water of high salinity into the South Equatorial Current while during the Northeast Monsoon the South Equatorial Current draws water of low salinity from the Malay Archipelago. These changes in turn result in higher and lower salinities of the East African Coastal Current waters. A further influence on salinity is the incidence of rainfall, especially the heavy rains of March to May when the discharges from all major river systems as well as all the more minor seasonal ones are at the maximum. As can be expected, offshore waters are influenced mainly by the oceanic currents and surface water salinities in Kenyan coastal waters vary from a minimum of 34.5‰ to a maximum of 35.4‰. The influence of the river outflow is contained mostly in inshore areas by the prevailing wind conditions and much wider variations in salinity do occur at the local level.

Concentration of Chlorophyll-a

A measurement of the concentration of Chlorophyll-a is used as an indicator of ecological productivity.

As can be seen from Table 3 below, the concentration of Chlorophyll-a in Kenyan surface waters is highest during the Southeast Monsoon and at this time of the year, the concentration decreases with depth. However, during the Northeast Monsoon the gradation in concentration is exactly reversed with the highest levels found at 50 metres and decreasing towards the surface. If the average for the whole water column is considered, concentration is highest during November to April. On the other hand, there is a tendency for Chlorophyll-a concentration to increase northwards along the coast during May to October. This is thought to be the result of the Somali upwelling.

Table 3 : Concentration of Chlorophyll-a in Kenyan coastal waters (mg/m^3)

Depth	May to October (South East Monsoon)	November to April (North East Monsoon)
Surface	0.30 to 0.50	0.10 to 0.20
At 25 metres	0.20 to 0.30	0.30 to 0.50
At 50 metres	0.10 to 0.20	0.30 to 0.50