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REGIONAL SEAS

A.L. Alusa and L.J. Ogallo:

Implications of Expected Climate Change in the Eastern African Coastal Region: an Overview

UNEP Regional Seas Reports and Studies No. 149

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PREFACE

In spite of uncertainties surrounding the predicted climate change, greenhouse gases appear to have accumulated in the atmosphere to such a level that the changes may have started already and their continuation may now be inevitable.

The environmental problems associated with the potential impact of expected climate change may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future. Therefore, in line with UNEP Governing Council decision 14/20 on "Global Climate Change", the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP) launched and supported a number of activities designed to assess the potential impact of climate change and to assist the Governments concerned in identification and implementation of suitable response measures which may mitigate the negative consequences of the impact.

Since 1987 to date, Task Teams on Implications of Climate Change were established for ten regions covered by the UNEP Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas , South-East Pacific, Eastern Africa, West and Central Africa, the Kuwait Action Plan Region and the Red Sea and Gulf of Aden). The Task Team for the Eastern African Region was sponsored by UNEP.

The initial objective of the Task Teams was to prepare regional overviews and site-specific case studies on the possible impact of predicted climate change on the ecological systems, as well as on the socio-economic activities and structures of their respective regions. The overviews and case studies were expected to:

- examine the possible effects of the sea-level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);
- examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;
- examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and
- determine areas or systems which appear to be most vulnerable to the above.

The regional overviews were intended to cover the marine environment and adjacent coastal areas influenced by, or influencing, the marine environment. They are to be presented to intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans, in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in development of policy options and response measures suitable for their region.

Following the completion of the regional overviews, and based on their findings, site-specific case studies are developed by the Task Teams and are planned to be presented and discussed at national seminars. The results of these case studies and the discussions at the national seminars should provide expert advice to national authorities in defining specific policy options and suitable response measures.

The Task Team on the Implications of Climate Change in the Eastern African Region was established and met in its first meeting in Nairobi between 21-23 June 1989, and in its second meeting jointly with the Task Team for the West and Central African Region in Nairobi between 18-21 December 1989. Each member of the Task Team was assigned a specific subject to address in detail. and the present overview is largely based on the contributions by the individual members of the Task Team as given in Annex I. The Task Team consisted of:

S.O. Allela, A.L. Alusa, M.Kh. El-Sayed, G.L. Kamukala, P. Kiguta, M. Kihu, J. Matondo, T.J. Njoka, L.J. Ogallo, V.L. Saha (Coordinator).

This publication was prepared by A.L. Alusa and L.J. Ogallo on the basis of work carried out by the Eastern African Task Team, edited by John C. Pernetta, and finalized for publication by M. Gerges (Deputy Director) and M. Kh. El-Sayed (Consultant) of OCA/PAC.

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1. INTRODUCTION

Anticipated global warming as a result of the emission of greenhouse gases into the atmosphere was the most important subject discussed during the fifteenth session of the Governing Council of UNEP and at the Second World Climate Conference. The so-called greenhouse effect is a most pressing environmental problem to the extent that it involves many scientific disciplines and hence presents major challenges. The greenhouse gases (CO_2, CFCs, CH_4, N_2O, O_3, etc.) have the effect of changing the atmosphere's radiative balance by trapping more heat near the earth's surface resulting in a rise in global mean surface temperature. It is now clear that if the burning of fossil fuel continues at the present rate, global warming is a virtual certainty.

General circulation models estimate that by the year 2030 the mean global temperature will increase within the range 0.5-4.5°C, (Bolin *et al*, 1986, IPCC, 1990). This may appear small, but even the lower end of this range, if achieved, would cause major changes in regional climate. Specifically, such regional climate change, when coupled with an increase in frequency and intensity of extreme weather events such as floods, droughts and cyclones, will have considerable impact on communities and their socio-economic well-being. The regional impacts of changes in greenhouse gas concentrations are, however, not well understood.

Present planning activities, to the extent that they are climate-sensitive, assume that past climate provides a reliable basis for future climate. With the known effects of greenhouse gases, this assumption is no longer valid. A forecast of future climate must now take cognizance of the greenhouse effect and the anticipated global climate warming. Specifically, the expected melting of ice-sheets and thermal expansion of the oceans is expected to lead to sea-level rise in the range of 20-140 cm by the end of the next century. In 1990, the Intergovernmental Panel on Climate Change (IPCC) estimated that the global mean sea-level will rise by 20 cm by the year 2030. These expected changes are important additions to the planning process in view of the increasing population and the subsequent increase in use of coastal areas for various activities such as tourism, agriculture, fishing, harbours and industries. For the Eastern African Region, the sea-level rise forecasts necessitate a serious examination of efforts towards the amelioration of the adverse effects of global warming.

Obviously, serious environmental problems are likely to arise in association with potential impacts of expected climate change in coastal areas of East Africa, and the objectives of the Task Team were as follows:

Long Term Objectives

(a) Assess the potential impact of climate change on the coastal and marine environment as well as on the socio-economic structures and activities; and

(b) Assist Governments in the identification and implementation of suitable policy options and response measures which may mitigate the negative consequences of the impacts.

Short Term Objectives

(a) Analyze the possible impact of expected climate change on the coastal and marine ecological system, as well as on the socio-economic structures and activities; and

(b) Prepare overviews and selected case studies relevant to the Eastern African Region.

This overview is expected to specifically address the following:

(a) Possible effects of the sea-level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);

(b) Possible effects of the temperature elevations on terrestrial and aquatic ecosystems, including the possible effects on economically important species;

(c) Possible effects of climate, physiographic and ecological changes on the socio-economic structures and activities; and

(d) Areas or systems which appear to be most vulnerable to the expected impacts.

The overviews were further expected to be based on:

(a) Best available existing knowledge and insight into the problems relevant to the objectives of the study;

(b) Assumptions accepted at the UNEP/ICSU/WMO International Conference in Villach, 9-15 October 1985, i.e., an increase in temperature of 1.5-4.5°C and a sea-level rise of 20-140 cm before the end of the twenty-first century. For the purpose of this overview and the various studies by members of the Task Team, a temperature elevation of 1.5°C and a sea-level rise of 20 cm by the year 2025 were accepted (with the understanding that these estimates may have to be revised on the basis of new scientific evidence). An IPCC (1990) scenario, for example, estimates the mean global sea-level rise to be between 10-30 cm by the year 2030, and 20-100 cm by the end of the next century; and

(c) Several detailed case studies, which would constitute the substantive annexes of the studies.

This paper reviews the results of a series of papers prepared by members of the Task Team on Implications of Climate Changes in the Eastern African Region, in cooperation with the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of UNEP, these are listed in Annex I of this report.

2. PHYSICAL CHARACTERISTICS OF THE REGION

2.1 CLIMATE

The Eastern African Region straddles latitudes 18°N - 27°S and has large spatial variations in climate, which range from arid and semi-arid to humid tropical. Specifically, rainfall is one climate parameter with the highest spatial and temporal variability in the region. These large variations are due, in part, to the complex topographical features and thermally induced meso-scale circulations. Figure 1 gives some examples of the typical seasonal rainfall characteristics over the region. Most of the areas near the equator have two distinct rainfall seasons centered around March-May and September-November. These seasons are related to the double passage of the Inter Tropical Convergence Zone (ITCZ) which follows the seasonal movement of the sun. Away from the equator, most of the rain is concentrated within the summer seasons as is evident in Figure 1. The peaks in the northern and southern hemisphere are centered around June-August and December-February respectively. It should be noted that the seasonal rainfall patterns are significantly modified in some areas by meso-scale systems. For example, some of the coastal areas receive their rainfall throughout the year as a result of the land/sea breeze effects while those lying on the leeward sides are permanently dry. Apart from the ITCZ, the intensity, location and orientation of the monsoonal wind systems, tropical cyclones, sub-tropical anticyclones, jet streams, extra-tropical weather systems, easterly/westerly waves, global teleconnections, etc., are among the other systems which affect the climate of the area. These, together with the dominant regional features such as the Mozambique channel trough, the dynamic low running across the African Continent in a north-easterly/south-westerly direction and the other thermally induced meso-scale circulations, significantly affect the local climates of some areas. If these features are shifted, changed or modified by the expected greenhouse gas induced climate change, the climate of the region will be changed.

Further away from the equator, temperature becomes a significant variable with a clear distinction between the cold winter and hot summer seasons. Additionally, the highlands have a marked temperature differential, and these differentials determine the local environmental humidity. A description of the climate of the region is provided by Griffith (1972) and Ogallo (1985).

2.2 GEOGRAPHY

The geography of the coastal areas of the Eastern African Region will, in this context, be delimited to latitudes 18°N-27°S to include Comoros, Kenya, Madagascar, Mauritius, Mozambique, Reunion, Seychelles, Somalia and Tanzania. The mainland coastal plain lies less than 100m above sea-level and is narrowest (10km or less) in northern and north-eastern Somalia and from south-eastern Kenya to northern Mozambique. It becomes wider (around 20km) southward and in areas traversed by large rivers such as the Juba, Limpopo, Pangani, Rio Save, Rufiji, Ruvu, Ruvuma, Tana and Zambezi (Figure 2). Immediately inland, the topography is interrupted by a range of mountains and escarpments before rising to inland plateaux (UNEP 1982).

Much of the coast is relatively unindented due in part to the absence of large rivers and to the coastal currents which run parallel to the coastline. A similar situation exists for the east coast of Madagascar where the Madagascar current flows parallel to the coast.

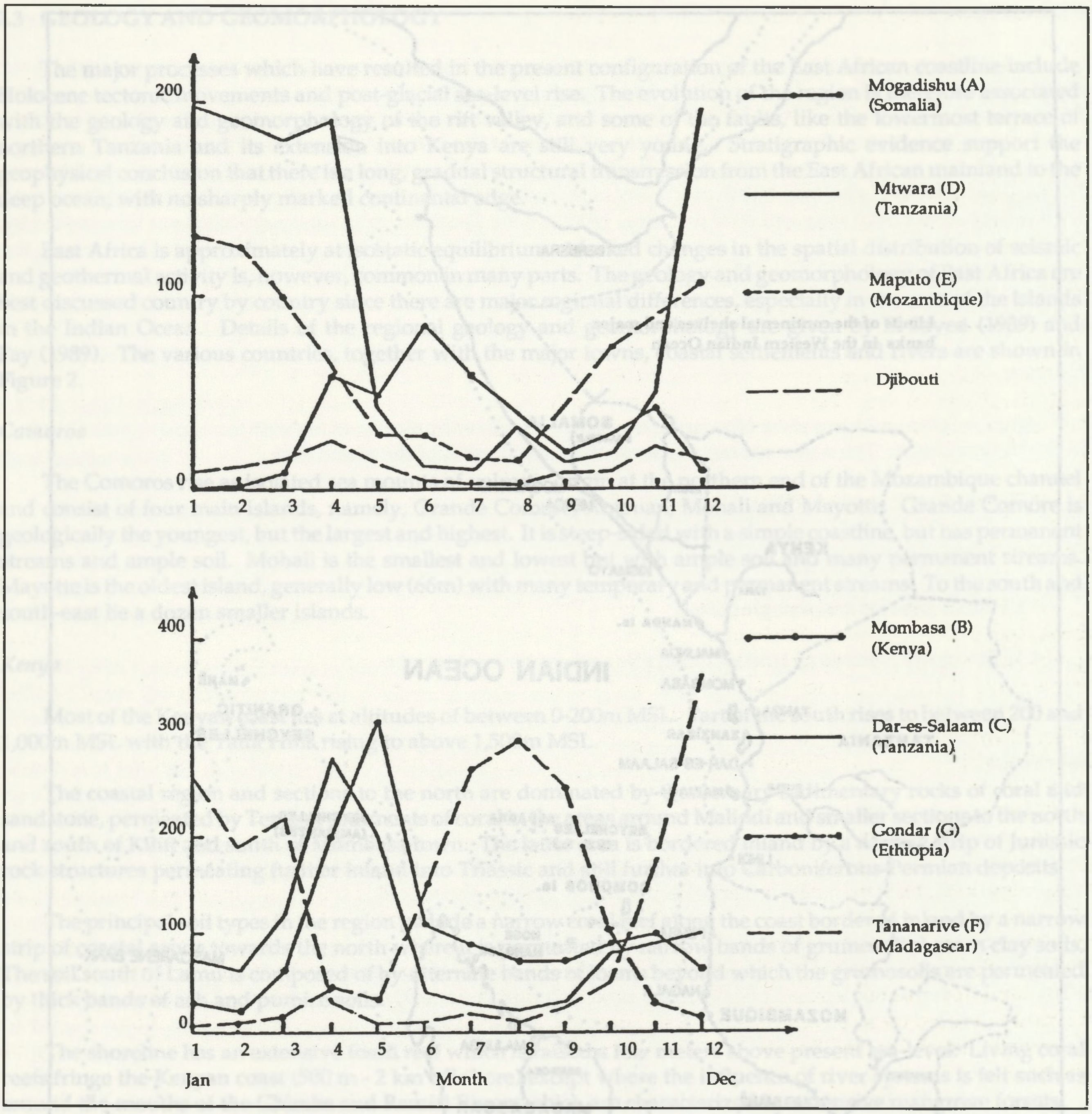

Figure 1: Seasonal distribution of rainfall at various locations in the Eastern African Region

The coastal characteristics of the smaller islands of the western Indian Ocean are quite different from those of the continent and Madagascar. On these islands, the entire land mass can be considered as being included in the coastal zone in the sense that activities nearly anywhere would directly affect the marine environment. The coastal plain is negligible or absent on the granitic islands of the Seychelles, the volcanic islands of Comoros and Mascarenes, and along almost the entire eastern coast of Madagascar. Mauritius which is volcanically older, is less rugged with flat areas along the northern coasts. Western Madagascar's extensive plains are associated with the major rivers and are believed to be the result of deposition of soil from the upland plateau (UNEP 1985).

The coasts of Eastern Africa and the islands are demographically significant. Coastal activities notably fishing, sea ports and tourism have made it attractive for large populations to move to the coast and to occupy some of the islands which would otherwise not be economical to inhabit. The islands especially the small islands, have major constraints on land useful for agriculture, natural resources, and water supplies. There are no significant mineral deposits on any of the small islands under study except for aggregate (sand and gravel) or guano which is found in certain outlying areas. Mangroves and coral reefs are the major coastal ecosystems on these islands.

Figure 2: The Eastern African Region showing major towns, coastal settlements and rivers

Source: Information from *Ambio* 12(6), 1983, IUCN

2.3 GEOLOGY AND GEOMORPHOLOGY

The major processes which have resulted in the present configuration of the East African coastline include Holocene tectonic movements and post-glacial sea-level rise. The evolution of the region is therefore associated with the geology and geomorphology of the rift valley, and some of the faults, like the lowermost terrace of northern Tanzania and its extension into Kenya are still very young. Stratigraphic evidence support the geophysical conclusion that there is a long, gradual structural transmission from the East African mainland to the deep ocean, with no sharply marked continental edge.

East Africa is approximately at isostatic equilibrium. Marked changes in the spatial distribution of seismic and geothermal activity is, however, common in many parts. The geology and geomorphology of East Africa are best discussed country by country since there are major regional differences, especially in the case of the islands in the Indian Ocean. Details of the regional geology and geomorphology are given by El-Sayed (1989) and Fay (1989). The various countries, together with the major towns, coastal settlements and rivers are shown in Figure 2.

Comoros

The Comoros rise as isolated sea mounts of volcanic origin at the northern end of the Mozambique channel and consist of four main islands, namely, Grande Comore, Anjouan, Mohali and Mayotte. Grande Comore is geologically the youngest, but the largest and highest. It is steep-sided with a simple coastline, but has permanent streams and ample soil. Mohali is the smallest and lowest but with ample soil and many permanent streams. Mayotte is the oldest island, generally low (66m) with many temporary and permanent streams. To the south and south-east lie a dozen smaller islands.

Kenya

Most of the Kenyan coast lies at altitudes of between 0-200m MSL. Part of the south rises to between 200 and 1,000m MSL with the Taita Hills rising to above 1,500m MSL.

The coastal region and sections to the north are dominated by Quaternary sedimentary rocks of coral and sandstone, permeated by Tertiary sediments of coral in the areas around Malindi and smaller sections to the north and south of Kilifi and south of Mombasa town. The latter area is bordered inland by a narrow strip of Jurassic rock structures permeating further inland into Triassic and still further into Carboniferous-Permian deposits.

The principal soil types in the region include a narrow coral reef along the coast bordered inland by 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 by-alternate bands of loams beyond which the grumosolis are permeated by thick bands of ash and pumice soils.

The shoreline has an extensive fossil reef which is raised a few meters above present sea-level. Living coral reefs fringe the Kenyan coast (500 m - 2 km off shore) except where the influence of river systems is felt such as around the mouths of the Chimba and Ramisi Rivers which are characterized by extensive mangrove forests.

Madagascar

The coastline consists of a series of sandy beaches interrupted by rocky outcrops. There are extensive fringing reefs all along the coast. Sandy beaches are extensive along the western coast, while fluvial deposits cover the eastern coast. The north-west and parts of the west coast contain the most extensive mangrove forests in the entire region. The north-east is a mountainous region with little habitable area near the coast, a rugged indented coastline is characteristic of this region. There is an extensive barrier reef formation, some 24 km in length, off the south-east coast of Toliasa. The east coast also has extensive fringing reefs and coral sand barrier beaches behind which run a chain of lagoons connected to form an inland waterway called the Pangalanes canal.

Mauritius

Mauritius, a member of the Mascarene group of islands has a mountainous topography contained within a coastline of 200 km and a total area of 1,865 km^2. It is almost totally surrounded by a fringing reef of about 150 km in length broken at frequent intervals by surge channels, narrow passages and river mouths. The reef is absent on the south coast for about 15.5 km and on two stretches totalling 15.5 km along the west coast (UNEP 1984).

Mozambique

Mozambique is generally lower lying than most of the other East African countries. The influence of the great river systems is greater in Mozambique than elsewhere on the East African coast. Most of the coast of Mozambique, 2,730 km, faces the Mozambique channel, hence it is mostly protected from the strong forces of wind-driven waves from the open Indian Ocean. Because of the low energy nature of the coast there are large volumes of riverine sediment and deposits. The Bay of Maputo lies at the confluence of four rivers - the Maputo, Matola, Tembir and Umbeluzi. North of the Bay of Maputo to the Zambezi river the coast is sandy and swampy with mangroves, sandy spits and offshore bars. North of the Zambezi delta sandy stretches are interrupted by rocky cliffs and headlands as well as coral islands. In all, some 25 main rivers enter the Indian Ocean along the Mozambique coast (UNEP 1982). Where such rivers have not resulted in the formation of mangrove forests, there are significant areas of coral fringed coast, coastal dunes, and swampy areas protected by barrier beaches and islands.

Reunion

Reunion is the youngest of the Mascarene islands and is still volcanically active with the highest peak (3,069m) in the Indian Ocean. The major characteristics of the coastal areas of the island are:

- 93 km of rocky intruded headlands;
- 13 km of low-lying rocky coasts;
- 59 km of pebbles and shingle coasts;
- 35 km sandy beaches of biodastic, basaltic and coral reef deposits;
- 8 km of alluvial lagoonal coasts.

Seychelles

There are about 100 islands spread over the Indian Ocean between 5° and 10°S and 45° and 56°E. These are divided into the inner granitic islands to the north east and the outer coralline islands to the south and west. The former are characterized by a rugged topography with mountains rising steeply to 905m elevation, with the highest peak on the largest island (Mahé) being nearly 1,000m above MSL.

The second group of islands spreads westward and southward from the granitic group towards the coasts of Africa and Madagascar. The sixty or more coralline islands are characteristically flat and low-lying (between 3-5m MSL). They are composed of calcareous sand and rubble derived from the debris of adjacent coral reefs.

Somalia

Somalia has the longest coastline of the tropical East African countries with 2,000 km facing the Indian Ocean and 1,300 km facing the Gulf of Aden. Most of the coastline consists of a series of sandy beaches and bays interrupted in places by rocky cliffs and headlands. The southern coast of the Gulf of Aden consists of a series of sandy bays interrupted by rocky promontories extending into the sea down to a shallow depth. There are neither fringing reefs nor bars. Between 6°N and 8°N the coast becomes sandy with gradual appearance of coral (UNEP, 1984, 1987).

In general, the land area contiguous to the shoreline of the Somali coast consists of:

- flat, sand and gravel covered coastal plains of varied width usually occurring at the mouths of river systems;
- mountains with precipitous cliffs that form a rocky shoreline; and
- coastal dunes that are active, i.e., have no vegetation cover or are lightly covered with thorn-bush or scrub and acacia woodlands.

Tanzania

Tanzania has a fairly narrow coastline which extends from approximately 5° to 10°S (694 km), and has large sweeping sandy beaches with rocky outcrops, steep limestone cliffs, fringing mangrove forests and areas with elevated fossil reef (UNEP/IUCN 1988).

The Tanzanian coastal area is unique within East Africa in showing an almost complete stratigraphic sequence from the Karroo to recent times, permitting the development of models for the continental margin in terms of sedimentation, local warping and dating of fault movements. In the Karroo, the marine intercalations and lagoon evaporites are limited to the broad coastal zone. Comparison of topography, surface geology and geophysical definition of the deep structures shows that on the large islands, the known fold and fault structures have developed progressively through tertiary times. The coastline is characterized by extensive growth of mangroves near the mouths of large rivers such as the Rufiji and smaller, intermittent rivers, such as the Ruvu. The Mowankulu and the Pangani are the major ones.

2.4 OCEANOGRAPHY

Continental Shelf

The width of the continental shelf off the East African coast varies markedly throughout the region, but is generally very narrow. Table 1 gives a breakdown of estimated shelf area in the Eastern African Region (El-Sayed 1989). The barrier reef is virtually absent from the west Indian Ocean. The continental shelf is however, colonized by corals, hence the fringing reef is a dominant feature along most of the edge of the shelf, usually at 45 m depth and in water temperatures of 18°C.

The principal ocean currents in the west Indian Ocean depictedin Figure 3 show that the waters in the west Indian Ocean are characterized by a warm, surface water layer with small annual temperature variations. However, the hydrography of the Indian Ocean waters is strongly influenced by seasonal variations of the monsoon wind system. Figures 4, 5, 6 and 7 are the current patterns and vector mean currents during January, the winter, and July, the summer monsoons, while Figure 8 gives the vector mean currents for the periods between the monsoons.

In the southern hemisphere, the Southern Equatorial current which flows at around 12°S is the principal current flowing from east to west all year round. Part of the current branches off north-east of Madagascar to form the southward-east Madagascar current, while the main stream splits after the northern tip of Madagascar into a southward current which flows through the Mozambique channel forming the perennial Mozambique Current, and a northward component which forms the East African Coastal current. This latter current is the main surface layer of water bathing the continental shelves of Kenya and Tanzania with nutrient-poor mid-ocean water resulting in low biological productivity along the coast. South of Madagascar, the East Madagascar current and the Mozambique current join at about 26°S to form the Agulhas current, while south of 30°S the West Wind Drift is predominant.

Table 1

Breakdown of estimated shelf area in the Eastern African Region

Country	Land Area km²	Estimated Shelf Area km² (Depth Range 0-200m)	Length of Coastline (km)
Comoros	2,236	900	350
Kenya	582,650	6,500	500
Madagascar	595,790	135,000	4,000
Mauritius	1,865	1,600	200
Mozambique	738,030	120,000	2,500
Seychelles	443	48,000	600
Somalia	637,657	32,500	3,000
Tanzania	939,703	30,000	800

Note: the average width of the shelf is some 15-25 km but it ranges from a few hundred metres wide to nearly 145 km wide. (See Figure 2 for the delineation of the continental shelf.)

Source: El-Sayed, M., 1989. Unpublished manuscript.

The current flow in the northern hemisphere changes direction with the seasonal reversal of the monsoon winds. During the period of the south-west monsoon (April to October) an eastward flowing surface current, the south-west monsoon current prevails. The East African Coastal current, which becomes the Somali current is influenced by the prevailing strong wind with a speed of over 600 km/sec (over 10 knots) causing it to flow north. The fast flowing Somali current transports about 50-65 million m^3/sec. of water penetrating deep into the oceanic water mass and causing an upwelling about its west flank along the north-west Somali coast. This upwelling induces high productivity off the Somali coast as the turbulent activity brings nutrient rich cold sub-surface waters with temperatures below 20°C to the surface. The average temperature of the surface water is 24°C with a salinity of 25‰.

During the north-east monsoon (November-March), the surface flow pattern changes from a clockwise flow pattern in the northern Indian Ocean as the north-east monsoon current dominates, flowing westward with its southern border at 3°S. The Somali current forms the equatorial counter-current and partly flows downwards to join the Mozambique current. With less turbulence due to the weak Somali current, a thermocline develops at about 60-80m depth with the surface waters having uniform temperatures between 28-30°C and a salinity of approximately 34.5‰. The region can therefore be divided into three hydrographic zones, (El Sayed, 1989):

(a) Somali upwelling zone, north-east of Somali coast;

(b) Monsoon current zone: Tanzania, Kenya, Seychelles; and

(c) Agulhas and Mozambique current zone: Comoros, Madagascar, Mauritius and Mozambique. In this zone, current flow patterns are subject to seasonal, cyclonic influence in December-April.

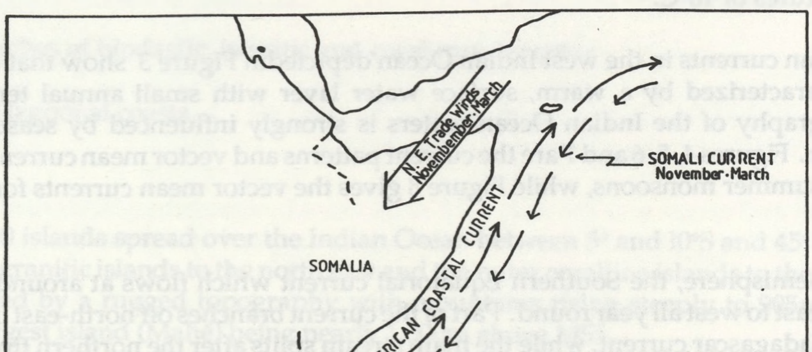

Figure 3: Ocean currents and winds in the Eastern African Region

Source: After IUCN/UNEP, 1982

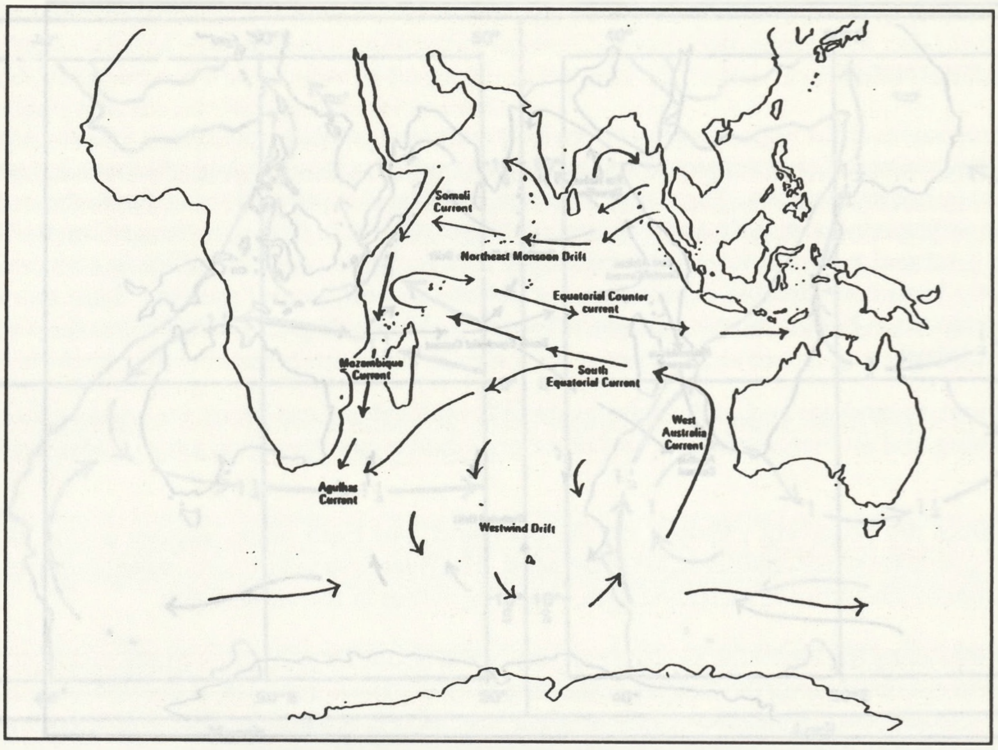

Figure 4: January current pattern

Source: UNEP, RSRS No. 12, 1982.

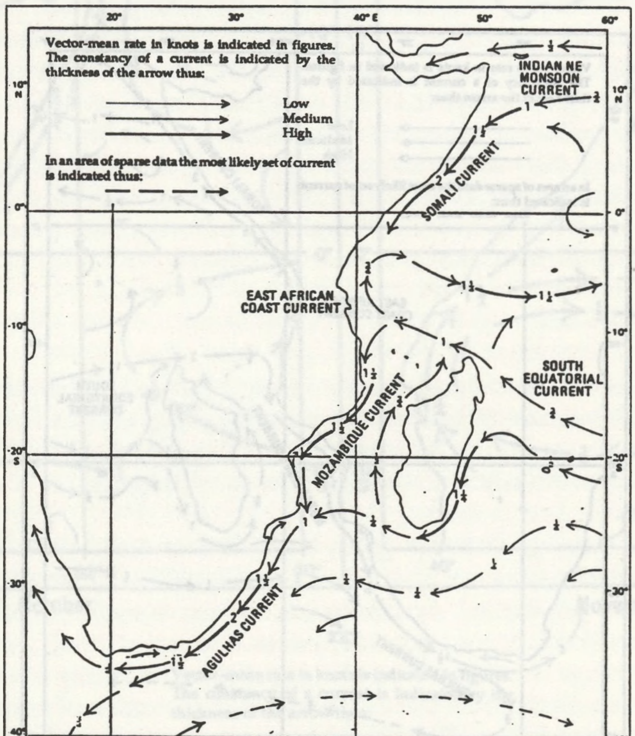

Figure 5: Vector mean currents for January

Source: UNEP, RSRS No. 12, 1982.

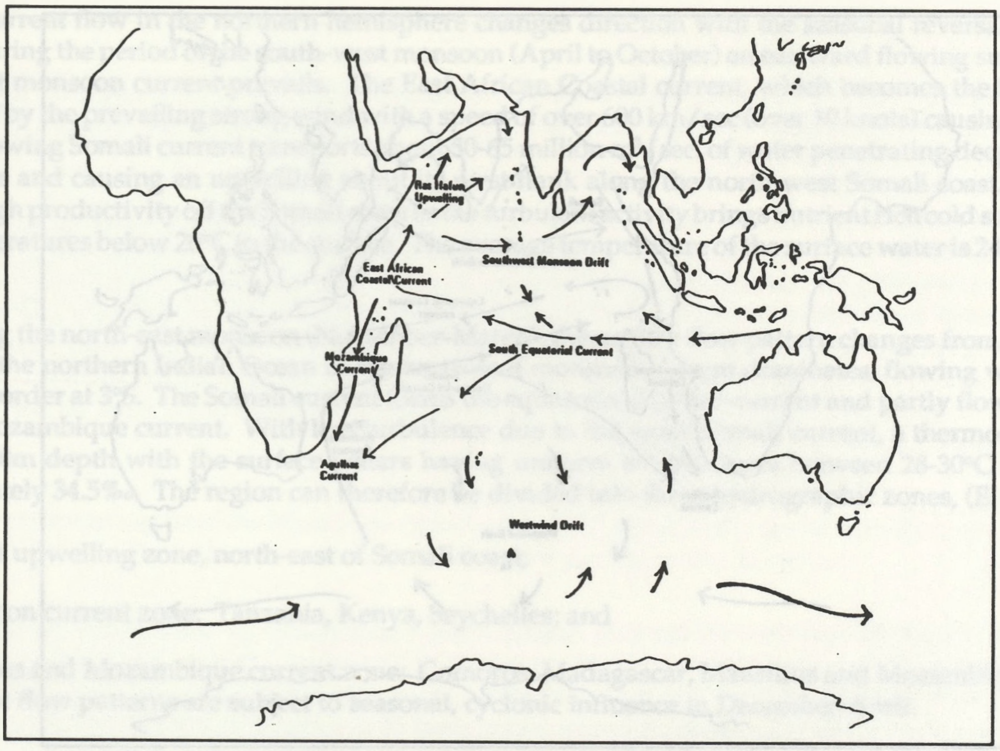

Figure 6: July mean current pattern

Source: UNEP, RSRS No. 12, 1982.

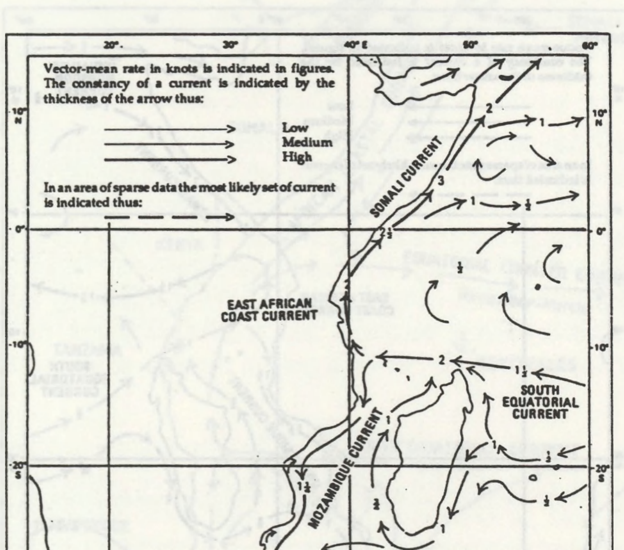

Figure 7: Vector mean currents for July

Source: UNEP, RSRS No. 12, 1982.

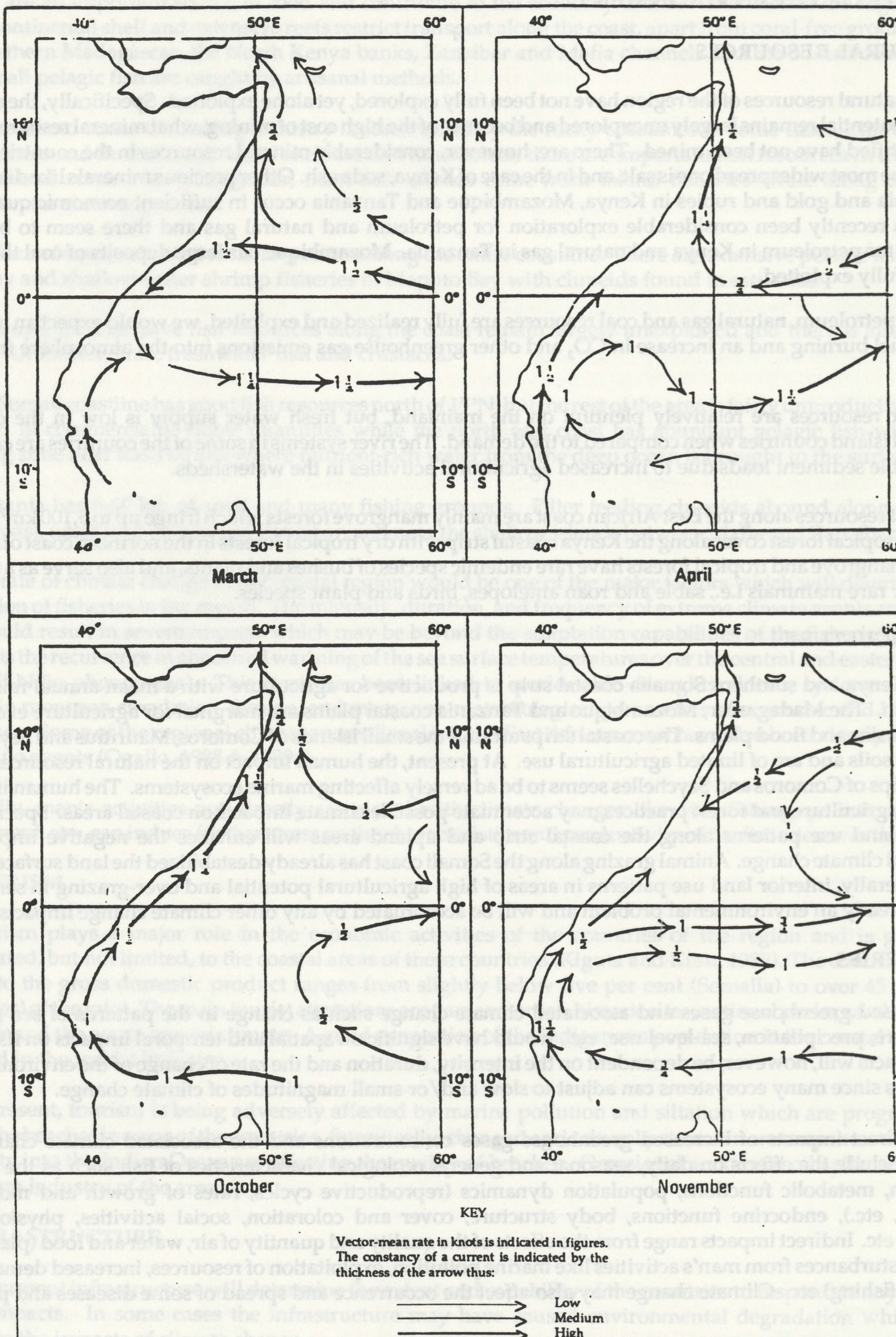

Figure 8: Vector mean currents between monsoons

Source: UNEP, RSRS No. 12, 1982.

3. STATE OF THE ENVIRONMENT

3.1 NATURAL RESOURCES

The natural resources of the region have not been fully explored, yet alone exploited. Specifically, the mineral resource potential remains largely unexplored and because of the high cost of mining, what mineral resources have been identified have not been mined. There are, however, considerable mineral resources in the countries of the region. The most widespread one is salt, and in the case of Kenya, soda ash. Other precious minerals like diamonds in Tanzania and gold and rubies in Kenya, Mozambique and Tanzania occur in sufficient economic quantities. There has recently been considerable exploration for petroleum and natural gas and there seem to be good prospects for petroleum in Kenya and natural gas in Tanzania. Mozambique has large deposits of coal that have not been fully exploited.

If the petroleum, natural gas and coal resources are fully realized and exploited, we would expect an increase in fossil fuel burning and an increase in CO_2 and other greenhouse gas emissions into the atmosphere from the region.

Water resources are relatively plentiful on the mainland, but fresh water supply is low in the densely populated island countries when compared to the demand. The river systems in some of the countries are carrying considerable sediment loads due to increased agricultural activities in the watersheds.

Forest resources along the East African coast are mainly mangrove forests which fringe up to 5,100 km^2. There is limited tropical forest cover along the Kenya coastal strip with dry tropical forests in the northern coast of Kenya. Both the mangrove and tropical forests have rare endemic species of bushes and plants, and also serve as a unique habitat for rare mammals i.e., sable and roan antelopes, birds and plant species.

3.2 AGRICULTURE

The Kenya and southern Somalia coastal strip is productive for agriculture with a mean annual rainfall of 400-500mm. The Madagascar, Mozambique and Tanzania coastal plains are marginal for agriculture except for the river basins and flood plains. The coastal strips around the small islands of Comoros, Mauritius and Seychelles have poor soils and are of limited agricultural use. At present, the human impact on the natural resources of the coastal strips of Comoros and Seychelles seems to be adversely affecting marine ecosystems. The human impacts of coastal agriculture and forest practices may accentuate possible climate impacts on coastal areas. Specifically, changing land use patterns along the coastal strip and upland areas will enhance the negative impacts of anticipated climate change. Animal grazing along the Somali coast has already destabilized the land surface in this area. Generally, interior land use patterns in areas of high agricultural potential and over-grazing in semi-arid lands is already an environmental problem and will be accentuated by any other climate change impacts.

3.3 FISHERIES

Increased greenhouse gases and associated climate change such as change in the patterns of sea surface temperature, precipitation, sea-level rise, etc., would have significant spatial and temporal impacts on fisheries. These impacts will, however, be dependent on the intensity, duration and the rate of change of the environmental parameters since many ecosystems can adjust to slow and/or small magnitudes of climate change.

The direct impacts of increased greenhouse gases concentrations and the associated climate change on fisheries include the effects on daily, seasonal and general ecological characteristics of fish such as the rate of respiration, metabolic functions, population dynamics (reproductive cycles, rates of growth and mortality, migration, etc.), endocrine functions, body structure, cover and coloration, social activities, physiological processes, etc. Indirect impacts range from the effects of the quality and quantity of air, water and food (plankton) to other disturbances from man's activities like marine pollution, exploitation of resources, increased demand for fish (over-fishing) etc. Climate change may also affect the occurrence and spread of some diseases and pests in fisheries.

Increased greenhouse gases and the associated climate change will affect the chemistry and physics of the coastal waters and the rest of the oceans through changes in ocean temperatures, salinity, concentration of the gases and solid suspensions in the oceans, upwelling, patterns of the ocean currents, chemical reactions, general cycles of the various gases, effects of UV α, ß, γ and other dangerous solar rays due to ozone depletion, etc.

Fish are an important source of food and contribute to the economy of most countries in the region. The narrow continental shelf and extensive reefs restrict transport along the coast, apart from coral-free grounds such as in Northern Madagascar, the North Kenya banks, Zanzibar and Mafia channels and the Somali coast. Near shore, small pelagic fish are caught by artisanal methods.

In the island states the fishing industry is constrained by the rocky coastlines in some cases, unfavourable coastal waters and limited continental shelf areas. Nonetheless, there are important fish resources in the region off the coastal zones. In Madagascar, most fish catches come from inland fisheries while along the coast exploration for shrimp goes on.

In Mozambique, substantive fishing occurs along the entire coastline. There are extensive pelagic fisheries in Sofala Bay and shallow water shrimp fisheries in Maputo Bay with clupeids found in estuaries.

In Kenya, the extensive fish resources along the coast remain largely unexploited and there is also a large potential for lobster, crab, freshwater fish and crustacea.

The Somali coastline has good fish resources north of 15°N, but the rest of the area is fairly unproductive. Tuna are found in commercially viable quantities while the north east coast has abundant pelagic fish within the upwelling zone near Ras Hafuna where nutrient-rich water from the deep ocean is brought to the surface.

Tanzania has 6-60 km of shelf and many fishing grounds. Filter feeding clupeids abound along the East African coast, notably at Pemba and Zanzibar, and near the shallow islands between Mafia and Zanzibar Islands.

The rate of climate change in the coastal region would be one of the major factors which will determine the distribution of fisheries in the region. The intensity, duration, and frequency of extreme climate events are factors which could result in severe impacts which may be beyond the adaptation capabilities of the fisheries. A good example is the recurrence in abnormal warming of the sea surface temperatures over the central and eastern Pacific Ocean (El-Niño phenomena). This event has been linked to world-wide droughts, floods, cyclone activities, changes in monsoon circulation, famine, and many non-meteorological parameters of economic and biological importance. Some of the regional climate anomalies along the East African coast have also been closely linked to the El-Niño events (Ogallo, 1988 & 1989a).

Finally, man's activities not directly associated with climate changes like over-fishing, pollution, coastal development, etc., can induce further stress on the characteristics and productivity of the fisheries over the region.

3.4 TOURISM

Tourism plays a major role in the economic activities of the countries of the region and is generally concentrated, but not limited, to the coastal areas of these countries (Kiguta and Kihu, 1989). The contribution of tourism to the gross domestic product ranges from slightly below five per cent (Somalia) to over 45 per cent (Seychelles) of the total. The main tourist attractions are game reserves, historic sites, national parks, sand beaches, coral reefs and the warm coastal climate. A good proportion of the indigenous population in the coastal areas are employed in the tourist industry.

At present, tourism is being adversely affected by marine pollution and siltation which are progressively eroding the beaches in some of the countries. Specifically, changed agricultural patterns in areas upstream of rivers that empty into the Indian Ocean are affecting the quality of beaches. Occasional accidental oil spills also affect the tourism industry of the area.

3.5 INFRASTRUCTURE

The present infrastructure will determine the extent and capability of the countries to respond to any climate change impacts. In some cases the infrastructure may have caused environmental degradation which may exacerbate the impacts of climate change.

Transportation

The road network in the coastal areas of East Africa is not very elaborate, but provides adequate access to the interior. Most of the roads are not sealed, hence they become impassable during rainy seasons. In some of the mainland countries, railway lines supplement the road network, but these are not extensive. The present state of the road network leads to the following environmental degradation in the area:

(a) Natural environment adversely affected during construction of new roads;

(b) Noise during construction adversely affects wildlife; and,

(c) Exhaust fumes produced by vehicles using these roads and railway lines cause environmental contamination.

In addition to land transport, the countries rely on maritime transport among themselves and from one part of the coastline to another. Various harbours exist in each country, but their sophistication varies from country to country depending on the level of utilization of the port by the shipping industry. In some cases, the ports are polluted by oil spills which affect marine life.

Different sized airports exist in the coastal areas of East Africa and the island states. Air transport augments the other modes of transport and is mostly associated with international travel in support of the tourism industry. The level of development of air transport varies according to size of the country, the degree of development of the tourism industry and the standard of airports.

Industry

Most of the coastal areas of the countries under study have light industry, except in cases where the capital cities are located on the coast where more and heavier industry tends to concentrate. Being developing countries, however, the level of industrialization is relatively low. The major industries include oil refineries, cement manufacturing, textile industries, sugar factories, breweries and fish processing.

Notwithstanding the low level of industrialization, the manner in which waste is handled is far from satisfactory. Specifically, tanning and textile industries do not handle their effluents in an environmentally sound manner. Consequently, effluents are discharged directly into rivers which ultimately discharge into the oceans and pollute them. At the moment, the problems are not major due to the lightness of the industry. If it should intensify, the degree of pollution could lead to more serious environmental degradation.

3.6 POPULATION AND DEVELOPMENT

The Eastern African Region was estimated to have a total population of about 62.24 million in 1981 with an average annual growth rate of 3 per cent. The population is unevenly distributed over the region. Northern Mozambique and Merca northwards of Somalia are almost inhabited due to extreme climate conditions.

Excluding the islands, about 8.94 million people, or 14.6 per cent of the population, reside in the coastal area. It should also be noted that the bulk of population in the islands is concentrated on the coast. The mean annual growth rate for the coastal areas is about 3.3 per cent which is slightly higher than the mean regional growth rate. Migration and urbanization play an important role in the overall growth of the coastal region. Diversification of socio-economic activities in coastal cities has enhanced employment opportunities in these cities and hence causes the population to drift towards the coast. It is argued that if such a rate of growth continues, the population of cities such as Dar-es-Salaam would double every l0 years. Table 2 gives the breakdown of population by country. The average density in the coastal region is about l24.4 per km^2, but it ranges from 8 per km^2 in Somalia to 509 per km^2 in Mauritius (Kamukala, 1989; Kiguta and Kihu, 1989; Saha, 1989).

Table 2

Population distribution in the Eastern African Region

Country	Population (Millions)	Annual Growth Rate	Coastal Population (Millions)	Density (km)^2
Comoros	0.50	3.08	0.440	1
Kenya	22.40	4.20	1.640	27
Madagascar	11.20	2.90	2.000	14
Mauritius	1.04	1.65	0.772	509
Mozambique	14.72	2.69	3.000	13
Reunion	0.51	-	0.546	205
Seychelles	-	-	0.012	145
Somalia	5.36	2.80	1.600	8
Tanzania	24.19	3.65	3.690	19

Source: World Bank Development Report, 1989.

The total population in terms of its present density and distribution may not be particularly critical. What appears critical is the rapid rate of population growth in some of the countries in the region. Kenya for example has an estimated population growth of close to 4 per cent per annum. Such a high growth rate combined with anticipated climate change could have serious socio-economic impacts.

As pointed out above, about 14.6 per cent of the population resides in the coastal areas. The majority of these populations are employed by the light industry located along the coast and others in the tourist industry. Most of the economies rely on agriculture and tourism which together contribute close to 50 per cent of the gross domestic product. Tourism specifically is a main earner of foreign exchange in the coastal parts of most of the countries in the region.

With increasing population, the pressure on social amenities, notably in the coastal cities, has become very high. The infrastructure is unable to keep pace with the population growth rate. As a result, educational facilities are no longer adequate and the resource base to support the required expansion programme is non-existent.

Development trends in the region are markedly varied partly reflecting the differences in political ideology as vehicles for development. There are marked developments in some countries of the region but others lack the basic resource base to get started, while others have charted political and ideological paths that require a gestation time to produce visible results. These differences are manifested in the great disparity in per capita income in the countries of the region.

With regard to human settlement, one can classify the various settlements along the coast, (Kamukala, 1989), as:

(a) Scattered or clustered pattern of settlement;

(b) Nomadic and pastoralist migratory settlements;

(c) Urban settlements; and

(d) Rural centres.

The first type of settlement is associated with a kin-based land tenure system and this has been largely enhanced in some countries such as Madagascar, Mozambique and Tanzania where efforts have been made to plan and develop villages as a deliberate government policy. The second settlement pattern is centred around livestock in semi-arid parts of the region while rural centres are population settlement clusters based on farm-associated economic activities such as commercial retailing, agro-industries, etc. The urban settlements, on the other hand, are primary cities characterized by rapid population growth, deteriorating employment situation, and inadequate social services.

3.7 POLLUTION

In the recent past, urbanization has been fast and remarkable within the Eastern African Region. Although the ratio of urban population to total population is still low, the rate of urbanization remains unprecedented in the history of urban development. This rapid urbanization has led to inadequate water supply, overcrowding, poor system of refuse collection and disposal of garbage, inadequate drainage and sewerage systems and unemployment. These shortcomings lead to domestic sewage being discharged directly into rivers and in some cases the sea. Urban solid waste remains uncollected in cities and physical congestion in urban and rural areas leads to slums. Such is the situation in the bulk of the cities along the coastal areas of East Africa.

Additionally, there is some light industrialization in the coastal areas and such industrial development and expansion has lead to further pressure on the environment. In most countries of the region, there is no legislation with a systematic enforcement mechanism for the punishment of offenders who pollute the environment. Industrial development has mushroomed without proper environmental impact assessments being carried out. Consequently, rivers, creeks and the sea have become dumping sites for industrial wastes.

Industries of major environmental concern in the region include textiles, tanneries, paper and pulp mills, breweries, chemical factories, cement factories, sugar factories, fertilizer factories, and oil refineries. In some countries, slaughter houses near the sea are a serious source of marine pollution.

3.8 COASTAL DEGRADATION

There is a serious trend towards the degradation of the coastal environment, with a decline in the natural vegetative cover and soil fertility, and the death of wildlife - all as result of human activity. Animal husbandry and agriculture have both contributed towards the degradation of the coastal environment. The many competing demands on the limited natural resources have resulted in depletion of forest cover, destruction of mangroves and general degradation of coastal habitats.

Marine resources are threatened by these activities. Mangroves were a common feature in sheltered bays and estuaries providing shelter to many important fish species and prawns. They are now threatened by intensive cropping for poles, firewood and by large-scale clearing for salt production. Corals are now endangered by the frequent blasting by artisanal fishermen. Coral reefs have also been damaged by excessive siltation caused by soil erosion through poor agricultural practices and deforestation along river banks. Harbour development involving dredging and dumping has also damaged the reef. Coral areas are therefore under stress from both natural and human impacts.

The shoreline in most of the region is receding as a result of coastal erosion. In tropical areas such as the areas under study, coral reefs are often an integral part of the low lying barrier islands. Sand supplies are insufficient to keep pace with rising sea-levels, hence barrier islands are being drained (Hekstra, 1989). The shoreline retreat over parts of Tanzania has been estimated at between 3-5 metres per day (Fay, 1989).

3.9 DESERTIFICATION

Long drawn out droughts, over-grazing and poor agricultural practices, deforestation and reclamation of wetlands for agriculture are all combining to bring about desertification in the coastal areas of East Africa. Additionally, and as pointed out earlier, the continued high population growth rate is placing pressure on land beyond its carrying capacity. Ironically, the new development of creating infrastructures in the semi-arid areas where nomadism was the natural system for sustaining population is shifting and concentrating human and animal populations in a few areas and seriously degrading them as the land is not given the recovery period it would naturally experience under nomadic practice. Where the digging of boreholes, etc., has been found beneficial for livestock development, their arrival when not accompanied by proper pasture management has led to high concentrations of livestock beyond the holding capacity of the pastures. Such developments have led to desert conditions around towns where such infrastructures have been built.

Desert encroachment is encouraged as noted above, by deforestation, poor agricultural practices which lead to soil erosion, and prolonged droughts. When these occur in semi-arid areas with shallow soils, desertification becomes irreversible (Sestini *et al* 1989). There is evidence that this problem is present in the semi-arid parts of the region.

3.10 HYDROLOGY AND WATER RESOURCES

The coastal region of East Africa has abundant water resources through rainfall, regional rivers and groundwater. Rainfall is the dominant factor which determines the quantity and quality of water available underground and in the rivers. Water available from rainfall, however, varies highly in space and time. The mean annual rainfall over the coastal region ranges between 800-1,600mm per year, but the coastal zones of Somalia receive less than 400mm per year while coastal Mozambique and the islands (Comoros, Madagascar, Mauritius, Reunion and Seychelles) receive between 800-3,2000mm per year (UNEP 1987). The amount of precipitation generally decreases inland from the coast.

The region is well drained by rivers including the Juba, Limpopo, Rufiji, Ruvu, Ruvuma, Tana, Wami and Zambezi. Some characteristics of these rivers are shown in Table 3. Many projects have been developed along these rivers for flood control, hydropower generation, water supply, irrigation, etc. Increased surface runoff, soil erosion, pollution, changes in water storage, sedimentation, mismanaged water use, and other increases in human activity are some of the major threats facing these rivers.

The region is formed of sedimentary rocks and alluvial deposits which store groundwater resources. Groundwater exploration is under way in the coastal zones of Kenya, Somalia and Tanzania. The groundwater resources along the coastal areas of East Africa are not fully utilized with the exception of parts of Somalia where the water source is groundwater.

The water resources of the region are abundant but unevenly distributed, depending largely on rainfall. Some regions receive abundant rainfall and therefore have adequate water resources for their needs, while others have water shortages. As an example, Somalia has been experiencing considerable water deficit in recent years while other parts of the region have had excess water resources.

Table 3

Some characteristics of the major rivers of the Eastern African Region

River	Drainage Area (1,000 km²)	Highest Recorded Flow (m^3/s)
Tana	132.00	5,400.00
Juba	200.00	-
Rufiji	158.20	5,754.00
Ruvu	15.19	1,177.50
Wami	36.45	348.90
Pangani	36.45	248.90
Zambezi	1,300.00	8,625.00
Limpopo	358.00	-

Source: Matondo, J., 1989. Unpublished manuscript.

4.0 EXPECTED CLIMATE CHANGE AND SEA-LEVEL RISE

The emission of carbon dioxide and other greenhouse gases such as chlorofluorocarbons, methane, nitrous oxides, ozone, has been increasing as a result of human activities such as the burning of fossil fuels, changing agricultural practices and deforestation. The consensus in the scientific community is that if the trend continues it will enhance the greenhouse effects and lead to a general increase in the mean global temperature. Water vapour which is one of the major greenhouse gases will also increase on the average in response to increased evapotranspiration possibly resulting in further warming of the globe.

Carbon dioxide has been responsible for more than half of the enhanced greenhouse effects in the past (IPCC, 1990). Carbon dioxide records derived from Antarctic ice cores given an estimated CO_2 concentration between 270-290 ppmv during the period 1000-1800. The estimated concentration increased by 15 ppmv by the year 1900. Instrumental records give the 1958 and the present CO_2 concentrations as 315 and 354 ppmv respectively, indicating a mean increase rate of 0.6 ppmv per year.

4.1 INCREASE IN TEMPERATURE

There is a general agreement that increased concentration of the greenhouse gases will enhance the greenhouse effect leading to the general warming of the atmosphere. Various models predict temperature increases ranging between 0.5-4.5°C with the doubling of CO_2. The IPCC "business as usual" scenario gives a mean global warming of about 1°C by the year 2030. The large variations in the model outputs of the mean global temperatures are associated with the inability of the climate models to characterize accurately the complex interactions between the land/ocean/atmosphere processes and the temporal variability in climate parameters (Charney, *et al*, 1976; Manabe and Stouffer, 1980; Hansel *et al* 1986).

Most of the climate models have been unable to give accurate information on the regional temperature anomalies which are required in order to assess climate change impacts. However, the models predict increasing temperatures, but one would expect large spatial variability in temperature anomalies over the Eastern African Region which has complex regional features such as topography and the existence of large water masses. It is therefore necessary to note that no specific anomaly can be standardized for the region to include all the islands with varying locations, size and geomorphological characteristics. But it can be safely said that enhanced greenhouse effects over the region will lead to a general increase in the regional temperature.

The change in global temperature and the result and change in regional temperature have been observed by Barnet (1984), Cadet and Deihl (1984), Cadet (1985) and Ogallo (1988, 1989a, 1989b) among others.

Ogallo (1989a) observed significant teleconnections between the temperature anomalies over many parts of the global oceans and East Africa seasonal rainfall anomalies. The most significant relationship was observed along the coastal areas (see examples in Figures 3 and 4 for the extremely wet and dry seasons of 1988 and 1989 respectively). The significance of this relationship is that even if the regional temperature anomalies are relatively small, the temperature changes over other parts of the world would have significant impacts over the region through the changes in the regional circulation patterns.

4.2 CHANGES IN PRECIPITATION PATTERNS

Precipitation is the major source of water for human fresh water use in the region. It also determines the amount of water discharged into the Indian Ocean by the various rivers and affects general coastal hydrology. Any change in the spatial and temporal distribution of precipitation will therefore have significant impacts on the coastal areas of the region and on the regional hydrological cycle.

The predicted effects of global warming on precipitation have varied significantly from one model to another due to poor understanding of the complex feedback processes associated with climate change and the natural responses of the regional sub-systems. Some studies have noted that a global warming leading to an increase in some cloud cover can easily offset or decrease the impacts of the greenhouse gases. Bretherton *et al* (1986) indicated that an increase of about four to seven per cent in the cover of some clouds can offset the warming induced by doubling of CO_2.

Other models have shown an intensification of the rainfall in the currently wet areas of the tropics. Increase in temperature, however, will impose severe water stress in the relatively dry areas. Some models indicate increased mean area rainfall and reduced soil moisture over the Sahel region during the northern summer season.

While it may be difficult to quantify the impacts of global climate change on the regional precipitation patterns, there is evidence from studies that teleconnections exist between the regional rainfall and the global general circulation systems like the sea surface temperature (SST) anomalies, Southern oscillation, El-Niño events, etc., (Nicholson and Entakhabi, 1985; Janourak, 1988; and Ogallo, 1988; 1989a). Further impacts can be estimated from the rain-generating systems like the Inter Tropical Convergence Zone (ITCZ), sub-tropical anticyclones, jetstreams, monsoonal wind systems, extra-tropical weather systems, easterly/westerly waves and tropical cyclones.

It is expected that global warming will affect the onset, cessation, duration, location, intensity and other characteristics of the monsoonal wind systems which are the major sources of water vapour for rainfall formation over the region. Such changes will therefore have adverse effects on the spatial and temporal distribution of rainfall over the region. The space/time characteristics of the ITCZ will also be affected by changes in the monsoonal wind systems and the regional temperature anomalies, inducing further stress on the regional precipitation.

One of the crucial parameters for the formation, intensification, frequency and tracks of tropical cyclones is the sea surface temperature. Changes in the regional temperature may shift the storm characteristics over the region, thereby affecting areas hitherto not hit by tropical storms.

4.3 SEA-LEVEL RISE

It is noted that enhanced greenhouse effects will lead to a general rise in the regional temperature and attendant precipitation increase in the wet areas together with changes in the characteristics of tropical storms.

With a general temperature increase, a melting of the glaciers over the high mountains like Kilimanjaro and Kenya will be experienced. As these glaciers are the sources of the major rivers such as the Galana, Pangani and Tana which drain into the Indian Ocean, it is expected that the melting of the glaciers will contribute towards relative sea-level rise. Further, increased precipitation in the wetter areas is expected to increase the runoff into the rivers and hence the Indian Ocean, further contributing towards the relative rise in sea-level. Higher temperatures will also lead to thermal expansion, melting of polar glaciers and sea-level rise between 10-30cm by the year 2030, and between 20-100cm by the end of the next century. Sea-level rise between 20-140cm was assumed in this review.

The above changes in sea-level presuppose a stable local tectonic platform. If in fact movements and adjustments take place within the region, the sea-level rise estimates will differ greatly from those anticipated as a result of the causes referred to earlier.

Additionally, the expected sea-level rise must take cognizance of a significant lag time and any thermal expansion will be delayed by the large thermal inertia of the oceans.

5. EVALUATION OF THE IMPACTS OF CLIMATE CHANGE ON THE COASTAL ENVIRONMENT

5.1 APPROACH

As discussed above, global warming will lead to changes in precipitation patterns over the region and sea-level rise. The changes in precipitation patterns will be the result of changes in monsoon circulation, and general circulation parameters. These changes will consequently affect:

(a) Surface and groundwater flow and river discharge. They will alter surface and groundwater availability, the incidence of floods, and the amount of sediment transported to the Indian Ocean;

(b) The movement of marine water masses (waves, currents and tides), and the intensity and tracks of tropical cyclones;

(c) Natural ecosystems as a result of increased air temperature and its effects on water and soil qualities; and

(d) Occupation and utilization of the coastal lowland regions due to the sea-level rise and changed parameters of agriculture, fishing, industry, tourism and the quality of life.

The linkage between population growth rate, level of industrial development at the coast, new agricultural practices and future socio-economic needs are central to any development of national management strategies. Additionally, the strategies will be further complicated by the fact that socio-economic forces external to the region will come into play. For example, world-wide commodity prices and trade trends together with the demand for consumer goods in a competitive international market make socio-economic forecasts difficult and hence complicate the development of management strategies.

Impact assessment must also have as its base the present state of degradation of the environment because it is this base against which one can measure the "shock" effect of additional environmental degradation as a result of climate change. It is also necessary to know the extent of changes with a degree of certainty. These are:

(a) Climate change;

(b) Sea-level rise;

(c) Future level of population;

(d) Future level of agricultural and other practice; and

(e) Influence of climate on general planning and development policy.

It is possible to model with a degree of certainty the impacts of changes in rainfall amounts, cyclone intensity and frequency on the physical coastal areas of the region. It is also possible to predict, through modelling, the effect that sea-level rise is likely to have on coastal areas based on an understanding of the geomorphology, hydrodynamics, sediment budgets and plate tectonics of the region. One may also be able to qualitatively estimate the effects of increased air temperatures and changed soil/water parameters on the ecosystems. The real test, however, is in estimating the impact of all these physical and biological changes on the future socio-economic framework of the coastal areas.

The problems posed by climate change and consequent sea-level rise require the development of a coastal zone management strategy. Such a strategy must estimate the "value" of the systems threatened now, and in the future, and determine the cost effectiveness of intervention. The present and expected levels of population based on current and known population growth rates will determine the priority assigned to the available options.

A response to expected impacts can then be evolved. These responses can be preventive or reactive or both. In the following sections we shall discuss the expected impacts of climate changes and sea-level rise on marine parameters, coastal zone, rainfall and water resources, agriculture, fisheries and society.

5.2 IMPACTS ON OCEAN PARAMATERS

To assess the impacts of climate change on the ocean parameters in the East African coastal region, one has to understand how climate change will affect certain forcing functions in climate variables. Parameters like pressure and rainfall will be influenced by climate change. Changes in pressure will come as a consequence of a shift in the position of the ITCZ. This shift will also affect the spatial and perhaps temporal distribution of rainfall in the area. The strength of the monsoons will affect tropical cyclone intensity, distribution in time and space and cyclone tracks.

Increase in rainfall and the melting of the mountain glaciers with increase runoff and will affect salinity. Feedback processes may affect salinity in the opposite way and the relative magnitude of these opposing forces will determine the net salinity of the ocean waters in the area.

Change in surface winds will have a direct bearing on the ocean currents and wave formation and consequently will affect coastline weathering patterns. It is noted that the currents in the Indian Ocean are related most closely to the monsoons. To the extent that climate change will affect these monsoons, ocean currents will alter with significant impacts on regional rainfall as has been observed during the strong El-Niño/Southern oscillation events (Ogallo, 1989).

The temperature increase will affect the dissolved oxygen levels of the ocean waters in shallow areas and perhaps establish stratification which might in turn affect the primary producers of the eutrophic zones. High temperatures may lead to anaerobic conditions in some parts of the ocean waters.

Higher wind velocities will affect evaporation rates and will set up density gradients which will in turn affect ocean circulation.

5.3 IMPACTS ON THE COASTAL ZONE

Climate changes that lead to sea-level rise will affect coastal zones of the region considerably. Specifically, the region's fringing reef is likely to be vulnerable to increased wave action and the deposition of sediment resulting from increased precipitation and flood conditions on the higher grounds where agricultural activities will also have increased.

Rising sea-level will also affect the growth of coral reefs. Whereas coral reefs keep pace with rising sea-level (Marshall and Jacobsen, 1985), the finger-like corals which have this capacity are also extremely fragile and are likely to be destroyed by recurring storms or swells (Saha, 1989). The rise in sea-level may lead to destruction, or submersion, of islands which will lead to a change in the jurisdictional zone of certain island states.

For the island states, continuing sea-level rise will lead to gradually rising beach ridges higher towards the sea, on the lagoonal side of atolls, as land pushes towards the lagoon. This will result in a higher gradient slope from the top of the lagoon beach ridge towards the central depression down which sediment will move forming islands with swampy interiors.

Changes in the space/time characteristics of rainfall (intensity, duration, onset, frequencies of floods, droughts, etc.), cyclone frequency, intensity and tracks coupled with sea-level rise and temperature anomalies is expected to have severe effects on the vegetation and habitats of the coastal zones.

5.4 IMPACTS ON HYDROLOGY AND WATER RESOURCES

Enhanced greenhouse effect and associated climate change will have significant impact on regional hydrology by affecting the various components of the hydrological cycle, including rainfall evapotranspiration, surface runoff, river discharge, mountain glaciers, underground water storage and recharge rates, etc. This will affect the quality and quantity of water available from the three dominant regional sources, i.e. rainfall, rivers and groundwater. Discussions of climate change impacts must therefore include consideration of impacts on regional water resources.

Increase in the regional water resources will greatly enhance flooding in the river catchments and coastal areas. The implications are that there will be serious erosion and consequent sediment transport to coastal areas and the oceans. The high sediment transport will have an effect on dams, management of hydropower and beaches.

The high islands of the south west Indian Ocean are highly dependent on underground freshwater resources although not to the same absolute extent as the coral islands (Saha, 1989). Increase in rainfall will increase the rate of groundwater recharge increasing the potential of the groundwater resources. Increase in temperature and evaporation rates can however, reduce water availability. Additionally, the increased flooding risk, as well as saline intrusion through rising sea-level and recurrence of storm conditions may also lead to a decrease in water quality.

Under dry scenarios when the intensity, duration and frequency of droughts increase, water resources from rainfall will be significantly limited. This will reduce water availability from rivers and groundwater resources. Increased dry conditions, high temperatures and evapotranspiration rates will further increase the demand for water. All these factors may lead to competition for the available water among the various water use activities. Specifically the demand for such uses as hydropower generation, irrigation, and domestic water supply, will place inordinate pressure on scarce water resources. These demands will further deplete groundwater availability in countries where it is the only source of fresh water, either in island states or in some mainland coastal areas. The proportion of energy that can be made available from hydroelectric sources will be reduced at the expense of alternative energies, including fossil fuels.

5.5 IMPACTS ON ECOSYSTEMS

General circulation models of climate change suggest that temperature increases will be greater in the higher latitudes than in the lower latitudes. The "lower" temperature increase at low latitudes may still be severe, exceeding the thermal tolerance limits for species and ecosystems. Because the daily and seasonal temperature ranges are greater at high latitudes, the temperature rise may be within the tolerance limits of ecosystems in these latitudes. Nonetheless, it is expected that temperature changes in the coastal areas of East Africa will lead to latitudinal and altitudinal shifts in plants and animal species - hence disrupting the present ecosystem balance. However, the species could have difficulty in shifting or adapting to rapid rates of climate change which could lead to extinction of certain species and reduction in biological diversity. Increase in aridity, along the dry coastal part, would alter the current ecological balance in the long run. This may disadvantage the survival of dryland ecosystems. The increased CO_2, high temperature and higher rainfall (where relevant) will promote faster forest growth in the coastal areas and the mangrove forest will regenerate faster. Moreover, there will be a remarkable improvement in the sustainable yield of the mangrove forest as well as the habitat quality for fisheries and other wildlife species .

Extreme climate events such as droughts, floods, cyclones, storms and hurricanes can be particularly destructive to coastal forests. The south coastal region experiences cyclones. An increase in the frequency, intensity and tracks of cyclones will lead to possible extinction of large rare tree species in Madagascar and Mozambique. In Mauritius, for example, endemic ecosystems are already under extreme stress through pressure of population, invasions of exotic species as well as extreme climate events. The prospect of increased cyclone and drought events would further exacerbate the ecological stress in such systems.

High waves associated with storms, hurricanes and cyclones destroy mangrove forests, thus exposing the shore to greater erosion. The mangrove forests reduce the intrusion of saline water into coastal fresh water aquifers, hence their destruction will increase the scarcity of fresh water for domestic, agricultural, industrial and livestock use. With the change in the habitats, animals, although more mobile, will change their distribution in response to habitat change. However, not all animal species, or plants will be able to adapt or shift. This leads to the risk of extinction. Habitat destruction as a result of climate change could set the stage for an even larger wave of extinction than would result from human destruction alone (Peters, 1989).

It should be noted that ecosystems have the capacity to adapt to the impact of climate and weather anomalies, however, a climate change of a fast rate, large magnitude and long duration may exceed their capability to adapt.

5.6 IMPACTS ON AGRICULTURE

A global increase of CO_2 in the atmosphere is likely to have a positive impact on coastal agriculture. The productivity of sugar plantations, cotton fields and banana plantations, would increase. The yield of fodder for livestock would also increase. Since coastal plants such as maize, sorghum and millet are C_4 plants, the higher temperatures will be more important in increasing yields than the so-called CO_2 fertilization which has a greater effect on C_3 plants. The carbon content in the atmosphere is increasing annually by approximately 2.9 billion tons. Increase of CO_2, high temperature and the anticipated higher rainfall in the tropics will promote faster forest growth in coastal areas. The regeneration of the mangrove forests will also be faster (Njoka, 1989).

The impact of temperature increase will be more significant in the northern and southern coasts due to large diurnal and seasonal variations in temperature as one moves polar-wards from the equator. Temperature rise will minimize near-freezing temperatures which are injurious to tropical crops like maize. The warmer temperatures will promote greater productivity in agriculture, but at the same time, the favourable temperature may enhance the spread and persistence of crop and livestock pests and diseases. Additionally, high temperature will enhance humus degradation processes in the soils.

With regard to areas where droughts will be longer and more frequent, there will be higher evapotranspiration rates which will increase demands for irrigation water. Moisture deficits for crops may occur more frequently, thus lowering crop yields.

Changes to the seasonal distribution and total amount of rainfall received will influence the timing of seasonal activities and management of agricultural production.

More rainfall, higher temperatures and higher concentration of CO_2 may aggravate the problem of weeds in cultivated areas and the competition between weeds and crops may reduce the yields.

Possible increase of mean global rainfall of 7 to 11 percent will have positive effects on forests and coastal forested areas will expand. More moisture may aggravate the problem of bush encroachment in coastal areas, and contribute to the spread of tsetse fly into new areas.

The changes in precipitation, temperatures and CO_2 concentration are expected to be accompanied by other climate changes in terms of the frequency and severity of droughts, storms, cyclones and floods which would have adverse impacts on agriculture.

Droughts are frequent in the semi-arid coastal rangelands of Somalia and Western Madagascar. Any climate change that increases the severity and frequency of droughts in East Africa will adversely affect crops and livestock productivity.

The sea is expected to rise by between 20cm and l40cm by the end of the next century. The impacts of sea-level rise on agriculture are particularly serious in the deltas and estuaries of major East African rivers where extensive areas are being reclaimed for rice and sugar cane growing.

Sea-level rise will increase the intrusion of saline water further up river and only crops adapted to saline conditions will do well in the areas. In the Zambezi the saline sea water has already moved about 8 km upstream as a result of dam construction. The fresh water aquifers along the East African coast will also become more saline and thus limit the use of groundwater resources for irrigation and livestock. The sea-level rise and enhanced tidal wave erosion will lead to the loss of coastal wetland areas which are reclaimable for rice and sugar cane growing.

5.7 IMPACTS ON FISHERIES

Climate change is expected to impact the individual fish stocks in the region (Saha, 1989). The year to year variability of stocks could increase which would lead to planning and management problems for the countries in the region. As noted earlier, climate change will affect certain marine parameters which in turn will affect the breeding, migratory patterns and feeding habits of most fish. Tuna, for example, may migrate to colder areas.

Sea-level rise will have the effect of flooding and pushing back the mangrove swamps which are important spawning, nursery, and fishing grounds for oysters, crab, mullet and shrimp, and will have a deleterious effect on production.

Depletion of the ozone layer and subsequent increase in ultra-violet-B radiation may adversely affect crab and shrimp larvae and hence affect individual stocks, although this effect has not been conclusively proved.

Generally, the lack of specific regional climate change scenarios makes it difficult to be specific as to the impacts on fisheries. It is clear, however, that changes will result in different migratory habits, increased inter-annual variation in fish stocks and changes in distribution of fisheries within the region.

5.8 IMPACTS ON SOCIETY

The growth and economic status of any country can be measured in terms of Gross National Product (GNP), GNP growth, Gross Domestic Products (GDP), GDP growth, dept, income distribution, etc. Most of these parameters are severely affected by extreme climate events like droughts and floods, especially in a region like East Africa where rain-dependent agriculture and tourism form the backbone of the economy. The importance of agriculture to the regional economy is indicated in Table 4 which provides an overview of economic indicators for the countries of the region.

Impacts arising from climate change will therefore have far reaching socio-economic impacts on the infrastructure and society in general since many activities are sensitive to rainfall variability. Specifically, it will influence demographic shifts due to expected degradation of the coastal zones and to the frequency and intensity of extreme events such as droughts, floods and tropical cyclones. The expected shift in the monsoonal areas could shift the agroclimate zones which could be expected in the long run to result in a commensurate movement of population.

Sea-level rise, higher rainfall and increased temperature will affect infrastructure such as roads and railways. In particular, the island states will encounter considerable problems in road maintenance and communications in general if the sea-level should rise. Most of the road networks in the region are dirt roads, so any trend towards increase in rainfall is likely to lead to roads becoming impassable most of the time making communication difficult or practically impossible. This will place a strain on economic performance and a changed climate may necessitate transfer of food from productive areas to drought-stricken areas by road.

Higher rainfall may lead to poor landing conditions but is unlikely to seriously affect air transport to any appreciable degree. However, the higher frequency of rainfall, the rise in sea-level and attendant damage to beaches is likely to affect the tourist industry. Siltation along the beaches as a result of flooding and changed agricultural activities inland will affect the quality of beaches and reduce tourism along the coast.

The young, but growing, industrial sector is likely to be adversely affected by climate change and rising sea-level. Ports are most likely to be affected and this will have far-reaching economic implications. Reconstruction of ports, which is a costly exercise, to deal with sea-level rise, will affect maritime trade and the shipping industry. Most of the industry in the region is agro-based or related to fishing. Communication between ports and inland areas (where most of the raw materials for the agro-based industries come from) via road and railway line will be critical for these agro-based industries. To the extent that the road communication network will be affected by climate change, the industries in the coastal areas are also likely to be adversely affected.

These impacts may lead to unemployment in the coastal areas and reduced standards of living. With 13 per cent of the population living in the coastal areas of the region, and with the economic activities of the island states being related to shipping, fishing, and other maritime activities, such an eventuality will affect the entire economy of these countries.

Human settlement is likely to undergo considerable alteration as, through climate change, arid lands get drier and wet areas get wetter. Sea-level rise will displace populations close to the coastline. This will be more pronounced in island states where the nerve centres of activities are coastal. These centres are already sensitive to storm surges and occasional swells and are extremely vulnerable to sea-level rise.

Table 4

Official Development Assistance (ODA) 1984-86, and basic economic indicators for 1986

Country	GNP (Million US$)		% Mean Annual Change		GDP %		% ODA/GDP
	Total	Per Capita	1963-73	1973-86	Agriculture	Industrial	
Comoros	130	280	-	-	37	15	35
Kenya	660	410	8.2	4.3	30	20	7
Madagascar	2,390	230	3.4	-0.3	43	16	9
Mauritius	1,240	1,200	2.4	3.7	15	32	4
Mozambique	3,030	210	-	-	35	12	10
Seychelles	-	-	-	-	-	-	-
Somalia	1,560	280	2.9	2.5	15	9	16
Tanzania	5,371	240	5.6	1.4	59	10	11

Source: World Resources Institute, 1990.

6. CONCLUSIONS

6.1 SUMMARY

It is generally agreed that enhanced greenhouse effects and their associated impacts will result in severe changes to the climate and ecosystems of the region. There is however no definite indication as to the precise magnitude of the temperature and sea-level changes at a regional level. Models have estimated the average rise in mean global temperature and sea-level to be about 1°C and 20cm respectively by the year 2030.

With the assumed temperature changes it is expected that there will be changes in the characteristics of the monsoon winds which would lead to changes in precipitation patterns over parts of the Eastern African Region. However, it is expected that the many differences in topography, and other environmental parameters will lead to extreme variation in the changes of precipitation. Changes in temperature will further lead to changes in the evapotranspiration rates, with deleterious effects on crops in the drier areas where the water resources are generally limited.

The need for a regional climate scenario is critical for an accurate forecast of the impacts of temperature increase and sea-level rise. Such a scenario would take cognizance of the varied topography and the existence of many island states within the region. Until then, the impacts will remain in the realm of educated guesses based on presumed scenarios which are themselves uncertain.

Predicting the effect of temperature increases on agriculture is indeed very difficult. To the extent that if it leads to increased rainfall it can be said to be positive, but in the drier areas where droughts will persist and be more intense the effects will be negative. The demand for irrigation will increase and lead to possible stress on available water resources. Salination of irrigation water will affect the cropping patterns along the coastal areas which may necessitate a change in farming practices.

The effects of sea-level rise appear much easier to forecast but no clear indication of the expected regional sea-level rise scenario has been developed. Assuming a sea-level rise of 20cm (local sea-level rise could be much more than this) the effects could be minimal but there will be impacts such as:

(a) Wave-induced erosion and other impacts on exposed coasts, such as those to be found in island states, and on ports in the entire region.

(b) Flooding of canals and estuaries, lagoons, etc., which have far-reaching implications for agriculture.

The effects could be more serious if subsidence occurs which would mean higher relative sea-level rise. Not enough is known of the geology of the area to estimate these local effects with any accuracy.

An increase in the intensity and frequency of tropical cyclones will have a devastating effect on the island states of the area. If they change their tracks, areas not hitherto used to dealing with tropical cyclones will be prone to extensive damage. None of the suppositions on the frequency or intensity of tropical cyclones however, has been methodically examined and any impacts cannot be specific to any one area at this time.

There are likely to be impacts on industry in the coastal areas which will have socio-economic significance. Sea-level rise will affect the shipping industry and fishing while any increase or decrease in precipitation will influence the productivity of agro-based industry in the region. The expected negative impact of increased rainfall on road transport will further affect the movement of raw materials from up-country to the coastal areas hence influencing industrial productivity that may lead to unemployment and other socio-economic problems.

Temperature increase and an increase in CO_2 may have a positive impact on forest growth although in the drier areas the potential for forest fires will be greater. With increased precipitation, it is expected that there will be an increase in weeds and the warmer temperature will favour an increased risk of agricultural pests especially in swamps. As temperatures increase, ecosystems will migrate or adapt gradually, but it is likely that biodiversity will be reduced, especially on islands, due to the limited supply of fresh water. Gradual adaptation of ecosystems will however, depend on the rate, intensity and duration of the climate change.

6.2 VULNERABLE AREAS/SYSTEMS AND FUTURE STRATEGIES

It is important that strategies be evolved now to respond to expected climate change. To be able to do this, however, it is important that global climate change scenarios be refined, and having been refined, that regional models are developed for the Eastern African Region.

The Intergovernmental Panel on Climate Change (IPCC) Working Group I is presently evolving climate change scenarios on the basis of which impacts can be assessed, and global response strategies evolved (IPCC 1990).

There are also considerable gaps in knowledge of the region and such gaps need to be filled in order to quantify impacts and facilitate the development of response strategies and policy options.

Response strategies must be based on climate change scenarios, expected impacts and future plans for the coastal areas of the region. Plans such as land use, human settlement, port development, tourism development (hotels and resort areas), are all necessary in this respect.

Sestini *et al* (1989) speak of two types of response strategies - preventive and reactive. Preventive strategies address the protection of present investment while reactive strategies seek to adjust, react and adapt to changes as they arise. Preventive strategies use prior knowledge of the economic worth of present investment and its relative significance vis-à-vis the cost of erecting preventive structures or creating new ones if damaged. Reactive strategies respond to events as need the arises and are basically "adaptive". Resettlement of populations is a reactive strategy and need not be done before the event. However, reactive strategies need to be based on predictable developments so that planning can be made to deal with future developments.

To the extent that climate change and sea-level rise scenarios at a regional level are unlikely to be available in the next 10-20 years, reactive strategies might be the most applicable in the Eastern African Region. This is all the more significant in view of the level of economic development in the region which can ill-afford an investment in protective structures that, in time, may prove not to have been necessary.

Notwithstanding the above, cost-effective management strategies should be put in place towards the sustainable exploitation of the natural resources. Land use practices should be geared towards sustainable development with climate change taken into account. Likewise, planning the settlement of large populations along river banks, coastlines and large water masses should first consider the risk of flooding due to increased rainfall, sea-level rise, and changes in storm surge frequency.

Research programmes to monitor water resources, and living resources should be carried out in order to evolve adjustment activities to climate change. Such research programmes should include identification of suitable crop varieties, and tree provenances.

It is important to mount educational programmes to sensitize coastal communities to the risks posed by expected climate change and sea-level rise. This will lead to the development of a state of preparedness in coastal settlements for reactive strategies in the event the expected impacts occur.

Plans to mitigate the effects of droughts and floods should be prepared in terms of food storage and distribution systems and infrastructure. Water resource projects should take into account expected climate change impacts, including high evaporation rates, low inflows (droughts) and silting (floods).

There is a need to enhance regional efforts towards afforestation/reforestation in order to address the basic issue of an increase in CO_2 in the atmosphere. In this respect, public education on environmental issues would go a long way in increasing "on-farm" afforestation.

There is an urgent need for in-depth research into the likely implications of climate change and sea-level rise on the south west Indian Ocean island states which are seen as being particularly vulnerable.

Governments should be encouraged to review all proposed major investment decisions, especially on coastlines or on coral islands under their control, such decisions being confirmed only after a review of sea-level rise impact. Governments should also screen private sector projects along the littoral and on coral islands and establish local criteria that would ensure greater longevity of structures as well as effluent disposal systems relating thereto.

Finally, it is evident from this review that the coastal areas are vulnerable to the expected climate change. The impacts at the individual coastal locations will however, depend on the height of the location above the sea-level, geology of the area, time/space patterns of the climate change, the degree of adaptability of the local ecosystems and human population to the expected climate change and many other related factors. A multi-disciplinary project for the region will need to address the various issues which have been raised in the text, and assess the vulnerability of coastal areas and systems under various regional climate change scenarios.

REFERENCES

Allela, S.O. 1989. An overview of the West Indian Ocean fish resources in relation to expected climate change. *Task Team Report (Eastern African Region).*

Alusa, A.L. and L.J. Ogallo. 1989. Expected climate change in the East African Coastal Region as a result of Global Warming and Sea-level Rise. *Task Team Report (Eastern African Region).*

Barnet, T.P. 1984. Interactions of the Monsoon and Pacific trade with system and inter annual time scales, Part III, Partial Anatomy of the Southern Oscillation. *Mon. Wea. Rev.* 112:2389-2400.

Bliss-Guest, P. 1983. Environmental Stress in the East African Region. *Ambio.* 12:290-295.

Bolin, B., B. R. Doos., J. Jager and R. A. Warrick. Eds. 1986. The greenhouse effect, Climate Change and Ecosystems. *SCOPE.* 29. John Wiley & Sons, New York.

Bretherton, F., J. Coakley and D. Baldwin. 1986. CO_2 Doubling and its effect on Cloud Cover. *NCAR, Newsletter.* 1986-8.

Cadet, D.L. and B. Deihl. 1984. Inter annual variability of the surface field over the Indian Ocean during the recent decades. *Mon. Wea. Rev.* 112:21-25.

Charney, J., R. Peagle, H. Riehl, V.R. Lally and D.Q. Wark. 1976. Feasibility of a global observation and analysis experiment. *Bull. of Amer. Met. Soc.* 47:200-220.

El-Sayed, M.Kh. 1989. Physical characteristics of the Eastern African Region, Geomorphology, Continental Shelf and Oceanography. *Task Team Report (Eastern African Region).*

Fay, M. 1989. Maziwi Island off Pangani (North Tanzania): History of its destruction and possible causes. *Task Team Report (Eastern African Region).*

Griffith, J.F. 1972. *Climates of Africa.* Elsevier Publishing Co.

Hansel, J., A. Licas, R. Rind, G. Russel, I. Fungi, P. Ashcraft, S. Levedef., R. Ruedy and P. Stone. 1986. The greenhouse effect, Projections of Global Climate Change. *EPA, UNEP.* 1:199-218.

Hekstra, G.P. 1989. Global warming and rising sea-levels: The policy implications.

IPCC. 1990. Climate Change. *WMO/UNEP Intergovernmental Panel on Climate Change.*

Janourak, J.E. 1988. An investigation of inter annual rainfall. *Journ. of Climate.* 1:240-255.

Kamukala, G.L. 1989a. Implications of Climate Change on Marine Environment. *Task Team Report (Eastern African Region).*

Kamukala, G.L. 1989b. Implications of Climate Change on Coastal Settlements in the Eastern African Region. *Task Team Report (Eastern African Region).*

Kiguta, P. and M. Kihu. 1989. Report on the current state and implications of climate change and rise in sea-level on infrastructure, industry, and tourism in the East African Region. *Task Team Report (Eastern African Region).*

Manabe, S. and R. J. Stouffer. 1980. Sensitivity of a global climate model to an increased CO_2 concentration in the atmosphere *J. Geophysical Res.* 85:5529-5554.

Matondo, J. 1989. Implications of climate change on hydrology and water resources in Eastern African Region. *Task Team Report (Eastern African Region).*

Nicholson, S.E. and E. Entakhabi. 1985. The quasi periodic behaviour of rainfall variability in Africa and its relationship with the Southern Oscillation. *Arch. Met. Geophys. Biocl.* A-34:311-345.

Njoka, T.J. 1989. Possible impact of climate change on agriculture and forest - with special emphasis to East African Coastal Areas. *Task Team Report (Eastern African Region).*

Ogallo, L.J. 1985. Rainfall Climatology in East Africa. WMO.TMP. 16:96-102.

Ogallo, L.J. 1988. Relationship between seasonal rainfall in East Africa and the Southern Oscillation. *J. Climatology.* 8:31-43.

Ogallo, L.J. 1989a. Teleconnections between seasonal rainfall over East Africa and Global sea temperature anomalies. *J. Met. Soc. Japan.* 66:6:807-822.

Ogallo, L.J. 1989b. The Spatial and temporal patterns of the East African rainfall derived from PCA. *Inter. J. Climatology.* 9:145-167.

Saha, V.L. 1989. The impact of sea-level rise and climate change on the small islands of the South West Indian Ocean. *Task Team Report (Eastern African Region).*

Sestini, G., L. Jeftic and J. D. Milliman. 1989. Implications of expected climate changes in the Mediterranean region: an overview. *UNEP Regional Seas Reports and Studies No. 103.*

UNEP. 1982. Environmental problems of the Eastern African Region. *UNEP Regional Seas Reports and Studies No. 12.*

UNEP. 1984. Socio-economic activities that may have an impact on the marine and coastal environment of the Eastern African Region. *UNEP Regional Seas Reports and Studies No. 51.*

UNEP. 1985. Management and Conservation of renewable marine resources in the Eastern African Region. *UNEP Regional Seas Reports and Studies No. 66.*

UNEP. 1987. Coastal and marine environmental problems of Somalia. *UNEP Regional Seas Reports and Studies No. 84.*

UNEP/IUCN. 1988. Coral reefs of the World Vol. 2. Indian Ocean, Red Sea and Gulf. *UNEP Regional Seas Directories and Bibliographies.* IUCN, Gland, Switzerland and Cambridge, England / UNEP, Nairobi, Kenya. 389 pp.

ANNEX I

LIST OF PAPERS AND CONTRIBUTIONS BY TASK TEAM MEMBERS USED IN PREPARATION OF THE OVERVIEW

Allela, S.O. 1989. An overview of the West Indian Ocean Fish Resources in relation to expected climate change.

Alusa, A.L. and L.J. Ogallo. 1989. Expected climate change in the Eastern African Coastal region as a Result of Global Warming and Seal Level Rise.

El-Sayed, M.Kh. 1989. Physical characteristics of the Eastern African Region - Geomorphology, Continental Shelf and Oceanography.

Kamukala, G.L. 1989. Implications of climate change on coastal settlement in the Eastern African Region.

Kamukala, G.L. 1989. Implications of climate change on marine environment.

Kiguta, P. and M. Kihu. 1989. Report on the current state and implications of climate change and rise in sea-level on Infrastructure, Industry and tourism in the Eastern African Region.

Matondo, J. 1989. Implications of climate change on hydrology and water resources in Eastern African Region.

Njoka, T.J. 1989. Possible impacts of climate change on Agriculture and Forest, with special reference to East African Coastal Areas.

Saha, V.L. 1989. The impact of sea-level rise and climate change on the small islands of South West Indian Ocean.

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