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Addressing Land Based Activities in the Western Indian Ocean

Regional Synthesis Report on the Status of Pollution in the Western Indian Ocean Region

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our future through science

EXECUTIVE SUMMARY

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ACRONYMS AND ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research (South Africa)
DEAT	Department of Environmental Affairs and Tourism (South Africa)
DWAF	Department of Water Affairs and Forestry (South Africa)
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
IMO	International Maritime Organisation
SAP	Strategic Action Plan
TDA	Transboundary Diagnostic Analysis
UNEP	United Nations Environment Programme
WIO	Western Indian Ocean
WIO-LaB	Addressing land-based activities in the Western Indian Ocean

ACKNOWLEDGEMENTS

1. INTRODUCTION

1.1 Background

In an endeavour to address the problems in coastal and marine environments, Governments of the Eastern African region - Somalia, Kenya, Tanzania, Mozambique, Comoros, Madagascar, Mauritius, Seychelles and France (Reunion) - came together under the framework of United Nations Environmental Programme (UNEP) Regional Seas Programme in 1985 and endorsed the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa region (also called the Nairobi Convention) and related Protocols. The Convention is broadly aimed at maintaining essential ecological processes and life support systems, preserving genetic diversity, and ensuring sustainable utilization of harvested natural resources. Today all ten Eastern and Southern African countries have ratified the Convention: Comoros, France (La Reunion), Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa and Tanzania.

The project "Addressing land-based activities in the Western Indian Ocean (WIO-LaB)" is an initiative of the Nairobi Convention, designed to address some of the main environmental problems and issues related to the degradation of the marine and coastal environment due to land-based activities in the Western Indian Ocean (WIO) region. The Project represents a strong partnership amongst its eight participating countries (Kenya, Tanzania, Mozambique, South Africa, Madagascar, Mauritius, Comoros and Seychelles), UNEP and its financiers: the Government of Norway and the Global Environment Facility (GEF).

WIO-LaB is designed as a demonstration project for the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) in the WIO region. In this regard, the objectives of the WIO-LaB Project are to:

- Reduce stress on the ecosystem by improving water and sediment quality
- Strengthen the regional legal basis for preventing land-based sources of pollution, including the implementation of the GPA
- Develop regional capacity and strengthen institutions in the WIO region for sustainable, less polluting development including the implementation of the Nairobi Convention.

One of the key activities of the WIO-LaB Project concerns the execution of a Transboundary Diagnostic Analysis (TDA) focused on land-based activities in the WIO region.

This Regional Synthesis Report on the status of pollution in the WIO region synthesises information presented in the National Status of Pollution Reports which form the basis for the TDA of the WIO region. The TDA is an important part of the overall strategic planning process, providing a basis for formulation of the Strategic Action Plan (SAP) and the harmonised National Action Plans (NAPs) on environmental protection of WIO region.

The focus of this study is on *land-based sources* of marine pollution, i.e. issues typically covered under the GPA and the Nairobi Convention (see www.gpa.unep.org/). This report does not deal with sea-based sources of marine pollution (e.g. maritime transportation or offshore dumping of waste) which are typically dealt with under other international Conventions such as:

- The Convention of the International Maritime Organisation (IMO, see www.imo.org/) (e.g. International Convention for the Prevention of Pollution from Ships 1973/78 [MARPOL])

- The International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004)
- The London Convention for the Prevention of Marine Pollution by Dumping of Wastes and other Matter, 1972 (amended in 1978, 1980 and 1989, see www.londonconvention.org/).

1.2 Approach and methodology

As this regional synthesis is used as input to the TDA/SAP process for the WIO region, a causal chain approach, similar to that recommended for the TDA/SAP process was followed, as documented by the GEF International Waters Programme (GEF, 2005). The approach uses a step-by-step process, including:

Step 1: Information and data 'stock taking' exercise

Step 2: Identification of priority problems and associated environmental impacts and socio-economic consequences

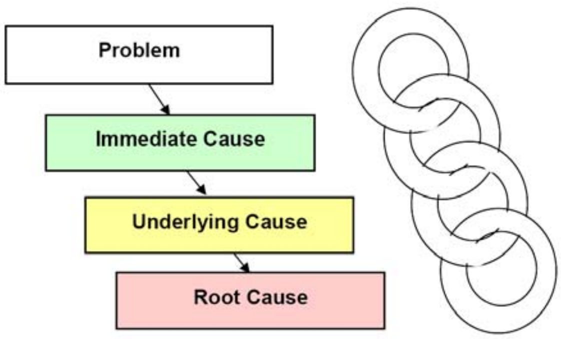
Step 3: Analysis of causal chains - identifying the immediate (or direct) causes and underlying sectors (or 'pressures') and the root causes (or 'drivers') of each priority problems

Step 4: Governance analysis (or response).

Information and data stock taking (Step 1) was achieved using feed-back from the Regional Consultative workshop on the preparation of the TDA for the WIO region in Nairobi, Kenya (17 to 19 April 2007) as well from the following documents:

- Overview of land-based sources and activities affecting marine, coastal and associated freshwater environment in the eastern Africa region (UNEP, 1998)
- GEF MSP - Development and protection of the coastal and marine environment in sub-Saharan Africa: National Report Phase 1: Integrated Problem Analysis for Tanzania, Kenya, Seychelles, Mauritius, Mozambique and South Africa (also referred to as the Africa Process Reports, Francis *et al.*, 2002; Kazungu *et al.*, 2002; Jones *et al.*, 2002; Dulymamode *et al.*, 2002; Hoguane *et a.l*, 2002; Clark *et al.*, 2002)
- National status reports on priority land based activities, sources of pollution, and pollutant levels in water and sediment in the WIO region (Anon Madagascar, 2006, Anon Mozambique, 2006; Anon Mauritius, 2006; Munga *et al*, 2006; Mohammed *et al*, 2006; Abdallah *et al*, 2006; Dubula *et al*, 2006)
- UNEP/GEF - the State of the Environment: Regional Assessments for southern and eastern Africa (Taljaard *et al.*, 2006; Ruwa, 2006)
- Regional overview and assessment of marine litter related activities in the WIO region (Lane, 2007).
- Draft Regional Status Report on Municipal Wastewater Management in the WIO-Lab region (Kayombo, 2009).

At its simplest, a causal chain is one-dimensional like an iron chain, as illustrated below (GEF, 2005). A problem can first be linked to some immediate (or direct) cause or pressure (e.g. disposal of sewage effluent). There can be several direct causes for a particular transboundary problem while on the other



hand the same direct cause can result in different transboundary problems.

Direct causes can usually be aggregated into underlying causes. In turn, underlying causes can be grouped into different sectors, where each sector may have underlying causes of a different nature. Generic sectors are used wherever possible when constructing causal chains, because of their ease of use. It is usually possible to aggregate underlying causes the following generic set of sectors:

- Urbanisation
- Tourism
- Agriculture
- Fisheries
- Industry
- Mining
- Transportation (including harbours)
- Energy production
- Aquaculture.

Finally, root causes for problems can be identified. Root causes (or drivers) are usually cross-cutting to transboundary problems and their direct and underlying causes and can typically be divided into the following categories:

- Population pressure
- Poverty and inequality
- Inappropriate governance
- Inadequate knowledge and awareness
- Inadequate financial resources.

1.3 Report structure

This report is structured as follows:

Following this introductory chapter, Chapter 2 provides an overview of the study area, describing the key features of the coastal marine environment, the socio-economic milieu, major marine pollution hot spots (attributable to land-based activities) and major circulation systems that play an important role in the transport and fate of pollutants.

Chapter 3 deals with major transboundary marine pollution problems (here defined as problems common to the countries of the WIO region) that are a result of land-based activities, as well as their potential impacts. Supporting scientific information on such impacts in the WIO region is also provided, where readily available.

Root cause analysis (or problem trees) for the major transboundary marine pollution problems is discussed in Chapter 4, including an evaluation of the direct causes, underlying sectors and root causes.

Chapter 5 provides an overview on Governance analysis, with specific reference to issues affecting marine pollution. This was largely extracted from the Governance Analysis that was conducted as part of the TDA, as well as information contained in the national status reports (Anon Madagascar, 2006, Anon Mozambique, 2006; Anon Mauritius, 2006; Munga *et al*, 2006; Mohammed *et al*, 2006; Abdallah *et al*, 2006; Dubula *et al*, 2006). (Legislative framework and institutional set-up)

The final chapter (Chapter 6) provides recommendations for consideration in the SAP and NAPs, specifically related to marine pollution matters.

2. OVERVIEW OF STUDY AREA

2.1 Coastal marine environments

An overview of the natural features of the coastal marine environments of the WIO region is provided below insofar as it is relevant to the influence of land-based activities on coastal marine water quality. The WIO region comprises the mainland countries and islands of Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia[1], South Africa and Tanzania with a combined coastline exceeding 15 000 km (including those of the island states).

2.1.1 Important oceanographic features

The oceanographic characteristics of the WIO within the context of this assessment can best described in terms of ocean circulation patterns, the key physico-chemical parameters of salinity, temperature and oxygen, and finally primary productivity (Kanagev et al., 2009).

Ocean surface circulation in the WIO region (Figure 1) is primarily wind driven and is an important feature that strongly influences the distribution of marine organisms, availability of nutrients and the transport and fate of pollutants. The prevailing wind regimes in the WIO region can be divided into two distinct systems; the monsoon regime that dominates the Somali Current Large Marine Ecosystem and the subtropical high-pressure system that dominates the southern region (the Agulhas Current Large Marine Ecosystem) (Beckley 1998, Okemwa 1998). The Northeast Monsoon affects the climate of the Northwest Indian Ocean from November to March and is characterized by north-easterly winds over the tropics and northern subtropics (Ngusaru 1997). The Northeast Monsoon has winds of moderate strength, with dry terrestrially-derived air blowing from Arabia to Madagascar (Weller et al. 1998). In contrast, during the Southwest Monsoon (June to October) wind direction reverses and winds tend to be much stronger, with an intense wind stream developing along the high Eastern African highlands (Ethiopian highlands, Kenya highlands, highlands of northern and southern Tanzania, etc.) (Ngusaru 1997; Slingo et al. 2005).

During the Northeast Monsoon, the North Equatorial Current flows westward, turns south at the coast of Somalia, and returns east as the Equatorial Countercurrent between 2° and 10° S. During the Southwest Monsoon, the North Equatorial Current reverses its flow and becomes the strong east-flowing Monsoon Current. Part of the South Equatorial Current turns north along the coast of Somalia to become the strong Somali Current. A pronounced front, a phenomenon unique to the Indian Ocean at 10° S, marks the limit of the monsoon influence (Kanagev et al., 2009).

[1] Although Somalia is also considered part of the WIO region, no easily accessible data on land-based sources of marine pollution could be obtained for the country. Reunion (France), also located in the WIO region, falls under the legislation and governing structures of the European Union and was therefore also not included here.

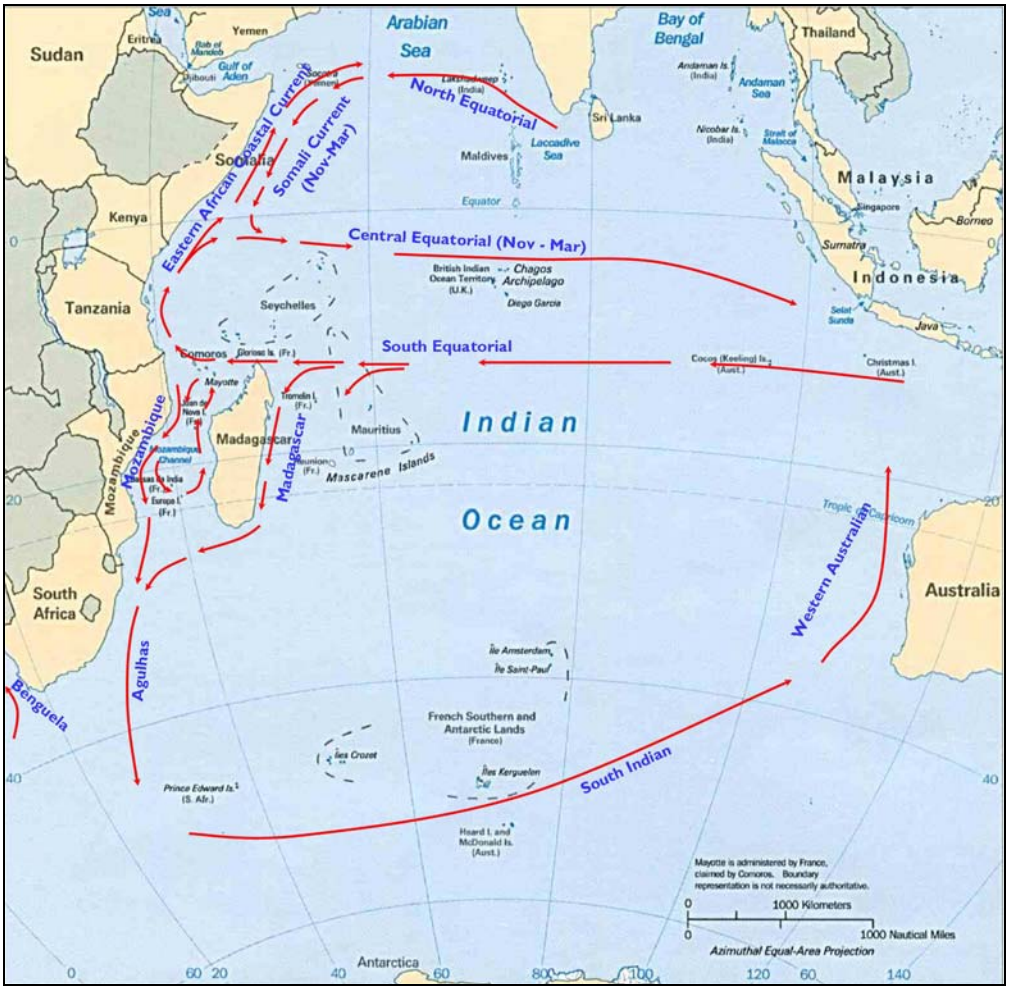


Figure 1: **Schematic illustration of surface ocean currents in the Western Indian Ocean (after UNEP, 1998 and Pidwirny, 2006)**

The Somali Current reverses direction with season (American Meteorological society, 2000) and is the western boundary current of the Northwest Indian Ocean when flowing northwards along the East African coast. During the Northeast Monsoon, the Somali Current flows south, meeting the north-flowing East African Coastal Current which originates from the South Equatorial Current (Okemwa, 1998; Horrill et al., 2000; American Meteorological society, 2000). The East African Coastal Current's geographical extent is seasonally determined and its interaction with the Somali Current shifts southward as the monsoon progresses (Horrill et al., 2000). By the time the Southwest Monsoon peaks in August, the Somali Current is established as a continuous current running from the East African Coastal Current to the East Arabian Current (American meteorological society, 2000).

South of the monsoon region, there is a steady subtropical anti-cyclonic gyre, consisting of the west-flowing South Equatorial Current between 10° and 20° S, which divides as it reaches Madagascar (Kanagev et al., 2009; Lutjeharms, 2006). One branch passes to the north of Madagascar and turns south as a series of slow-moving gyres or eddies that constitute the Mozambique Current between mainland Africa and Madagascar (Lutjeharms, 2006). These drift southward along the shelf edge (Schouten et al., 2002) and can cause minor upwelling. The other branch, the East Madagascar Current, turns south to the east of Madagascar and then curves back to the east as the South Indian Current at about 40° to 45° S (Kanagev et al., 2009; Lutjeharms, 2006). A strong, narrow, western boundary current, the Agulhas Current, is generated by the East Madagascar Current and, to the greatest extent, the Southwest Indian Ocean sub-gyre, with little inflow from the Mozambique Current (Lutjeharms, 2006). The Agulhas Current flows along South Africa before turning east and joining the Antarctic Circumpolar Current south of 45° S. It generates periodic gyres between its western boundary and mainland which are responsible for minor upwelling (Lutjeharms, 2006).

The current system at the eastern boundary of the ocean is not as developed, but the West Australian Current flowing north from the South Indian Current closes the gyre to a certain extent. The Agulhas Current extends down to about 1200 meters and the Somali Current to about 800 meters; the other currents do not penetrate farther than 300 meters.

Below the influence of the surface currents, water movement is sluggish and irregular, and is derived from a number of oceanic sources apart from the Indian Ocean. These cold, dense layers creep slowly northward from their source in the Antarctic Circumpolar region, becoming nearly anoxic (oxygen-deficient) en route.

The WIO region display all three tidal types, namely diurnal, semi-diurnal and mixed, with semi-diurnal (i.e. twice daily) being most widespread. Semi-diurnal tides prevail on the coast of eastern Africa as far north as the Equator (Hamilton and Brakel, 1984). Tides are mixed in the northern region particularly towards the Arabian Sea (Sheppard et al., 2000). Tidal ranges vary considerably, where Mauritius, for example, has a spring tidal range of only 0.5 meter, while, along the eastern Africa coast, the spring tidal range is of the order of 3-4 meters (Alusa and Ogallo, 1992; Hamilton and Brakel, 1984, Kanagev et al., 2009).

The WIO region is a tropical area where the air temperature at sea level rarely falls below 20°C and seawater temperature is usually between 20-30°C. Upwelling is a seasonal phenomenon in some parts of the region. During the Southwest Monsoon, upwelling occurs off the Somali and Arabian coasts (Bakun et al., 1998, Kanagev et al., 2009). It is most intense between 5° and 11° N, with replacement of warmer surface water by water of about 14 °C.

The WIO region is subject to large variations in salinity as a result of high seasonal and annual variability in rainfall. Sea surface salinity is affected by rainfall, as well as by anomalous anticyclonic winds blowing in the Southeast Indian Ocean and preventing the export of saltier water from the WIO region. Overall, the salinity of WIO surface waters varies between 32 and 37 ppt, but with large local differences. High surface salinity (greater than 35 ppt) is also found in the Southern Hemisphere subtropical zone between 25° and 35° S; while a low-salinity zone stretches along the hydrological boundary of 10° S from Indonesia to Madagascar.

The WIO region, particularly the area known as the Agulhas and Somali Currents, is considered to be oligotrophic, characterized by low nutrient concentrations, low phytoplankton biomass with higher values being associated with surface upwelling areas (McClanahan, 1988; Mengesha et al., 1999). Nutrient levels vary seasonally, especially between the monsoons (Mengesha et al., 1999). The flow of the South Equatorial Current, on the other hand, delivers high levels of nutrients to the central and northern Mascarene Plateau regions, which may be responsible for higher levels of productivity in these areas (New et al., 2005). Seasonal upwelling occurring off the Somali and Arabian coasts during the Southwest Monsoon introduces colder nutrient rich waters to these areas. Nutrients and primary productivity in the surface waters of the Somali Current are generally low, although this is seasonal.

2.2.1 Important coastal ecotones (ecological habitats)

Some of the blue text could/should be incorporated in Chapter 3: Problems and Associated Impacts (under the different impacts – specifically euthropication, suspended solids, chemical pollution) – see what you think

The term ecotone is used here to imply an ecologically distinct zone (or ecological habitats) showing some degree of ecological homogeneity. The main ectones of the WIO region are seagrass beds, mangrove forests and coral reefs. Consideration was given to including estuaries as an additional ecotone, but these are complex systems that comprise a numerous habitats and gradients in physico-chemical conditions, and are better considered here as domains (along with nearshore and offshore, for example). Furthermore, consideration of seagrass beds and mangroves allowed the two most sensitive estuarine habitat types to be included in this assessment.

Seagrass beds are a predominant feature throughout the shallow waters of the WIO region, and serve as habitat to a wide diversity of marine organisms ranging from algae and invertebrates through to the vertebrate classes. Larger animals that are threatened species (marine turtles and dugongs) depend on seagrasses as a source of food (Richmond, 2002). Seagrasses are continuously degraded either by direct removal or indirect impacts of land based activities. Key taxa within seagrass ecotones are bacteria, fungi, macro and micro-algae, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (shrimp, prawns, crabs, isopods, and amphipods), fish, marine turtles and dugongs.

Mangroves in the WIO region are species rich habitats that support major fisheries, particularly in the estuaries of Mozambique, Tanzania and Kenya. Ten species of mangroves occur in the WIO region, with the most extensive forests located along the Mozambican coastline (Richmond, 2002, Figure 2). Despite the ecological value of mangroves, these habitats are facing severe degradation from human activities. Key taxa that typically associate with mangroves are bacteria, fungi, macro and micro-algae, invertebrate and vertebrate larvae, post larvae and juveniles, polychaetes, bivalves, gastropods, crustaceans (shrimp, prawns, crabs, isopods, amphipods), fish, marine turtles and dugongs.

Extensive and highly productive coral reefs fringe over 1500 km of the WIO region coastline (Figure 2). Besides the massive bleaching event in 1998 which brought some species to extinction, coral reefs are negatively impacted on by direct and indirect anthropogenic activities. Typical fauna and flora that use coral reefs are macro and micro-algae, tunicates, sponges, polychaetes, bivalves, gastropods, echinoderms (urchins, star fish and sea cucumbers), crustaceans (prawns, crabs, lobsters, isopods, amphipods) and fish.

Figure 2: Distribution of mangroves and coral reefs within the Western Indian Ocean region (from Richmond, 2002)

Seagrasses

Seagrasses are marine angiosperms that cover large areas called seagrass meadows or beds. These plants are the only true marine vascular plants. Seagrasses occur on soft substrates (sandy or muddy sediments) in intertidal and subtidal areas. They are usually found in estuarine and sheltered marine waters (den Hartog, 1979; Richmond, 2002) and create highly productive ecosystems that serve key functions (Duarte, 2002). They are important habitats and nursery areas for numerous organisms including crustaceans (crabs, shrimp and lobster), echinoderms (sea urchins and sea cucumbers), molluscs (bivalves and gastropods) and fish. Other organisms such as macroalgae, epiphytes, fungi, sea anemones and a few sponge species are often associated with seagrasses. Seagrasses are a vital source of food for invertebrates and fishes, as well as for dugongs and marine turtles (Orth, 1984; Duarte, 2002). Other functions of seagrass ecosystems included:

- Provision of oxygen to waters and sediments
- Sediment stabilization
- Shoreline protection
- Trapping and cycling of nutrients

Seagrasses cover approximately 0.1 - 0.2% of the global ocean (Duarte, 2002). There are at least 45 species that are distributed mainly in tropical and subtropical regions. Eleven species from three different families have been identified in the WIO region: *Cymodocea rotundata*, *C. serrulata*, *Enhalus acoroides*, *Halodule uninervis*, *H. wrightii*, *Halophila ovalis*, *H. stipulacae*, *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Syringgodium isoetifolium* and *Zostera capensis* (Richmond, 2002). Seagrass beds are a common feature in all of the WIO countries (Table 1) with *Thalassia*, *Halodule*, *Syringgodium*, *Halophila* and *Cymodocea* being the most dominant genera (Richmond, 2002).

TABLE 1: Occurrences of seagrass beds in the WIO region (sources: Fagoonee, 1990; Ramessur, 2002; Richmond, 2002; UNEP/GPA and WIOMSA, 2004a, 2004b)

COUNTRY	LOCALITIES OF HIGHEST OCCURRENCES
South Africa	Warm temperate eastern Cape estuaries, Kosi Bay, St Lucia Estuary and Mhlathuze Estuary
Mozambique	Bazaruto Archipelago
Tanzania	Tanzanian bays, particularly on the west side of Pemba, Kilwa, Tanga, Mohoro, Unguja and Mafia
Kenya	Mombasa, Diani, Mida, Gazi, Kilifi, Tudor and Malindi
Seychelles	Platte, Coetivy and Aldabra
Comoros	Shallow lagoons around the island
Madagascar	Shallow coast areas and lagoon throughout the island
Mauritius	Most coastal lagoons around the island

Deterioration in coastal water quality as a result of sewage and domestic wastewater discharges is a major contributor to the decline of seagrass ecosystems. Excessive nutrients derived from sewage and domestic wastewater discharge theoretically promote seagrass productivity as these ecosystems are nutrient limited. However, such increases in nutrients also increase phytoplankton biomass, epiphytes and macroalgae, which results in a decrease of light available for photosynthesis (Lapointe and Clark, 1992; Schaffelke et al., 2005). This together with excessive concentrations of some nutrients such as nitrates and ammonia, which are toxic or limiting to seagrasses at such levels, has had negative impacts on these ecosystems (Duarte, 2002). Seagrass sediments also trap and accumulate organic compounds resulting in organic-rich sediments which promotes microbial activity (Duarte, 2002). Several studies have found that such activities can lead to oxygen depletion and excessive bacterial growth which releases toxic metabolic by-products like sulphide and methane, and also contributes to plant loss (Schaffelke et al, 2005). Human population growth in WIO countries, particularly in coastal regions, has increased the volume of discharged sewage and domestic wastes (Richmond, 2002; UNEP/GPA and WIOMSA, 2004a). In 1990 the coastal waters and ecosystems of Port Louis (Mauritius) suffered from severe eutrophication as a result of nutrient enriched runoff and sewage effluent, as did seagrass beds in Bain des Dames and Point Moyenne (Ramessur, 2002).

Agriculture is a key contributor to the economy of WIO countries and growth in this sector has been achieved through increased area put to agriculture as well as the use of modern agrochemicals. As a result, pollution derived from fertilisers and pesticides is increasingly affecting ecosystem health. Fertilisers have a high nitrogen and phosphorus content and in marine environments can cause eutrophication, habitat smothering and shading of the water column. Pesticides and herbicides from leached agrochemicals and stormwater effluent have negative effects on seagrasses as these substances can inhibit photosynthesis, reproduction and growth (Duarte, 2002).

Heavy metals from industrial discharges have been shown to accumulate in seagrass tissue through foliar uptake. (Schaffelke et al, 2005). Heavy metals, particularly chromium (from dye factories), zinc and lead (from industrial effluent and land runoff) are prevalent in Mauritian coastal waters

(Ramessur, 2002), Various industries on the island such as steel mills, galvanizing, electroplating and battery factories release their wastes directly into rivers (Grand River North West and St. Louis River) which empty into marine systems. Estuarine habitats such as Tombeau Bay and Poudre d'Or estuary have been exposed to such untreated industrial wastes since 1970 (Ramessur, 2002). A consequence of such long-term water quality deterioration is severe degradation and destruction of marine and estuarine ecosystems in these areas.

Common sources of petroleum and oil in coastal waters are runoff from land based activities, stormwater drains, bilge water discharges from ships, port activities and illegal discharges. These substances are toxic to biota and smother seagrass communities. The main consequence of oiling on seagrass habitats is complete smothering of these benthic plants, as well as their associated organisms (Abuodha and Kairo, 2001). To exacerbate the problem, dispersants which are commonly used to clean up oil spills contain toxic solvents which penetrate the protective waxy cuticles of seagrass blades. Studies have shown such actions effect the biological functioning of cellular membranes and chloroplasts, thereby causing plant loss and as well as harmful effects in other benthic biota (Ellison and Farnsworth, 1996; Abuodha and Kairo, 2001).

Mangroves

Mangroves are woody trees that grow along sheltered shores and within estuarine and brackish waters of tropical and subtropical regions (Abuodha and Kairo, 2001). They thrive in sedimentary lagoons, bays, estuaries and tidal creeks, and have adapted unique physiological and morphological characteristics to survive in environments with high salinity, wave action and anaerobic soils. Such adaptations include aerial roots for gaseous exchange, lateral roots for extra anchorage, tidal dispersal of propagules, rapid canopy growth and efficient nutrient uptake (Alongi, 2002). Mangrove forests are extremely productive ecosystems that support complex food webs consisting of both terrestrial and aquatic organisms, and are vital spawning, nursery and feeding grounds for numerous invertebrates, fish, reptiles and birds (Abuodha and Kairo, 2001; de Boer, 2002). As mangrove sediment is continuously submerged and eroded by wave action, the root system of mangroves provides a habitat for epiphytic communities such as macroalgae and bacteria. In addition to these functions, mangrove systems also provide other ecosystem goods and services, including:

- Visual amenity and shoreline aesthetics
- Shoreline protection by mangrove tree and root structure, which reduces severe wave action and erosion
- Sediment trapping which reduces the turbidity of coastal waters
- Nutrient uptake, fixation, trapping and turnover.

Mangrove forests occur on approximately two-thirds of tropical shorelines worldwide (Sumich, 1992) covering over 18 million hectares in 112 different countries. In the WIO region, they occur from the coast of South Africa to southern Somalia (Table 2).

TABLE 2: Area of mangrove forests in the WIO region (Sources: MacNae, 1963; Abuodha and Kairo, 2001; de Boer, 2002; Richmond, 2002; UNEP/GPA and WIOMSA, 2004a, 2004b)

COUNTRY	AREA OF MANGROVE COVERAGE	LOCALITIES OF HIGHEST OCCURRENCES
South Africa	11 km^2	Kosi Bay, St Lucia Estuary, Mhlathuze Estuary and Richards Bay Harbour, Mgeni Estuary and Mngazana Estuary
Mozambique	925 km^2	Central province in Safala and Zambezia, southern Mozambique in Maputo, Cabo Delgade and Nampula
Tanzania	1155 km^2	Rufiji delta, Kilwa and Chwaka Bay
Kenya	530 km^2	Lamu-Kiung area, Vanga-funzi system, Tana River delta, Mida Creek andGazi Bay
Seychelles	29 km^2	West and east coasts of Mahe, Grande Anse, Anse Takamaka and Anse Lazio on Praslin, Curieuse and Silhouette Islands and Aldabra and Cosmoledo atolls
Comoros	26 km^2	Comoros archipelago, La Grande Comore, l'ile d' Anjouan (Bimbini) and l'ile d' Moheli
Madagascar	3403 km^2	Extensive forests on the west coast of the island
Mauritius	< 1 km^2	Riviere, Baie du Cap, Trou D'eau Douce, Poste Lafayette, Bras D'eau and Poudre D'or

Ten species of mangroves are commonly found in the Western Indian Ocean (UNEP/GPA and WIOMSA, 2004b). The most dominant species found throughout the region are *Bruguiera gymnorrhiza*, *Ceriops tagal* and *Rhizophora mucronata* (UNEP/GPA and WIOMSA, 2004b), but others include *Avicennia marina*, *Avicennia officionalis*, *Heritiera littolaris*, *Lumnitzera racemosa*, *Sonneratia alba*, *Xylocarpus granatum* and *Xylocarpus moluccensis*.

For most countries in the WIO region there is an urgent need for adequate sewage and wastewater infrastructure as these wastes impact heavily on the environment. Mangrove swamps are commonly used for sewage and industrial discharge as the trees filter out nutrients and most of the pollutants are absorbed by mangrove soils, algae and microbes (Wong et al., 1997). However, such increases in pollution eventually render mangroves systems' absorptive capacities and processes inefficient.

Parts of Tanzania and Madagascar do not have sewage disposal facilities and wastes are discharged into estuarine and shallow waters (Richmond, 2002). In the major city of Mombasa (Kenya) there is no sewage or domestic wastewater treatment facility, resulting in unquantifiable loads of raw sewage and wastewater being released into estuarine areas (Mmochi and Francis, 2003). In Mozambique, the capital city Maputo is the only city with a sewage infrastructure. The rest of the country uses pit latrines and septic tanks which contaminate groundwater systems that drain into mangrove ecosystems and cause localized eutrophication (Mmochi and Francis, 2003).

The main pollutants derived from sewage and domestic wastewater discharges are nitrogen and phosphorus. Studies have found that although mangroves can efficiently trap phosphorus for processing by bacterial communities, they are not as effective in nitrogen removal (Duarte, 2002). Mangroves display positive growth responses to nutrient concentrations derived from sewage (Schaffelke et al., 2005). However, at the same time, excess nutrients promote the over-growth of algae which smother and destroy the aerial roots of mangroves. This results in a decreased surface area for respiration and nutrient uptake (Duke et al., 2005, Schaffelke et al., 2005). Also, excessive organic loading in mangrove systems has caused disease outbreaks, retardation of growth, mangrove mortality and a decline in mangrove biodiversity (Duke et al., 2005, Schaffelke et al., 2005).

Most of the economies of the WIO countries depend on agriculture and food processing industries such as breweries, distilleries and sugar factories. Other significant industries include textiles, tanning and paint manufacture. These industries dispose large amounts of toxic contaminants into estuaries and shallow coastal regions (Richmond, 2002). Mangroves act as pollution sinks (Wong et al., 1997; Yim and Tam, 1999) and numerous countries utilize these ecosystems as secondary waste treatment facilities. However, unusually high heavy metal loads in these environments can become sources of pollutants to plants and soils (Yim and Tam, 1999). With the increasing disturbance to mangrove ecosystems, mangrove soils reach their maximum absorptive capacity in terms of binding toxic metals and hence become a source of contaminants themselves. As heavy metals are not bio-degradable they are accumulated in plant tissue, affecting mangrove growth.

Evidence shows that excessive concentrations of heavy metals have adverse effects on mangrove leaf numbers, stem basal diameter and biomass production (Yim and Tam, 1999). Heavy metals also alter chlorophyll formation in leaves and hinder the uptake of essential mineral nutrients, as well as inhibiting root production. In addition to this, heavy metals negatively affect the microbial communities present in mangrove soils (Wong et al., 1997; Yim and Tam, 1999) i.e. decomposition rates become impaired thus limiting the nutrient processing capacity.

The expanding brewing industry in Tanzania has caused severe pollution to ecosystems in the Msimbazi River. Various other industries contribute to the untreated waste loads entering estuaries and shallow coastal environments (Mmochi and Francis, 2003). In Seychelles, industries such as canning and brewing also discharge considerable amounts of waste into the estuarine waters of the island (Mmochi and Francis, 2003), causing negative impacts on mangrove ecosystems .The major contributor of industrial waste in Mauritius is the sugar industry which releases industrial waste products directly into rivers and canals that empty into shallow coastal habitats and affect mangrove systems (Mmochi and Francis, 2003).

Agriculture is also major contributor to pollution of coastal environments. Agrochemicals such as herbicides and pesticides from wastewater, leached groundwater and surface water runoff are notorious for causing mangrove defoliation and mangrove dieback (Duke et al., 2005, Schaffelke et al., 2005). Mangroves situated near agricultural areas are therefore particularly vulnerable to agrochemical exposure. Mangrove forests in Mombasa and Lamu (Kenya) provide an example, where approximately 80 tons of pesticides and fertilisers are used annually in the vicinity of these forests (Mmochi and Francis, 2003). Rice production in Tanzania requires intensive use of fertilisers and pesticides. Consequently the Rufiji Delta and Mafia Island complex receive large contaminant loads into their aquatic systems (Mmochi and Francis, 2003). Similarly 90% of Mozambique's agricultural activities are conducted along river systems which results in leached contaminants affecting mangrove systems downstream. Sugar cane farming in Mauritius uses large amounts of fertiliser and pesticides (Mmochi and Francis, 2003) which have also contributed to mangrove decline on the island.

Petroleum hydrocarbons are introduced to shallow coastal waters through urban sources such as land runoff, municipal and industrial wastes, as well as by port activities and bilge water discharges (Clark, 2002). Extensive mangrove forests in Maputo and Mombasa have been destroyed by oil spills (Munga, 1993; Richmond, 2002). Spillage from the British tanker, Cavalier, caused considerable damage and destruction of mangrove forests in Mombasa in 1972. Since then, the same coastline was subjected to five other severe spills. Such spillage has resulted in mangrove dieback, especially in Mida Creek where the effects of oil spills were still evident ten years after the last oil incident (Abuodha and Kairo, 2001). The main effects of oiling on mangrove ecosystems are complete smothering of estuarine vegetation and organisms (Abuodha and Kairo, 2001). As petroleum compounds persist over long-term periods in mangrove soils, toxic derivatives of oil are continuously re-released into the environment, thereby causing sub-lethal effects to mangroves (Duke et al., 1997). Oiling causes massive mangrove defoliation, chlorophyll-deficient mutations as well as seedling and tree mortality. The recovery of mangrove ecosystems from impacts of these hydrocarbons can take several years (Abuodha and Kairo, 2001).

Coral reefs

Coral reefs are shallow subtidal ecosystems found in tropical and subtropical oceans (McClanahan, 2002). They are formed by the calcification activities of coralline algae and scleractinian corals, which create a calcareous skeleton using chemical reactions (Richmond, 2002). These living structures thrive in shallow and nutrient limited waters up to depths of 20 to 30 meters (McClanahan, 2002).

Coral reefs serve dual roles as key producers of biomass in these environments and their skeletons provide structural habitat for a diverse range of algae, soft corals, sponges, invertebrates, fish and turtles. Besides providing a unique habitat for biota, coral reefs protect the shoreline from strong wave action, provide construction materials and support local subsistence and tourism.

The eastern coast of Africa has a string of coral reefs that covers over 1500 km of the WIO region coastline. There are four main types of coral reefs. The most common type found in the WIO is the fringing reef which is generally associated with shallow lagoons. Patch reefs, atolls and barrier reefs also occur (Table 3).

TABLE 3: Area of coral reefs in the WIO region (sources: Richmond, 2002; UNEP/GPA and WIOMSA, 2004a, 2004b; Obura, 2005)

COUNTRY	AREA OF CORAL REEF COVERAGE	LOCALITIES OF HIGHEST OCCURRENCES
South Africa	< 50 km^2	Fringing and patch reefs in Sodwana, St Lucia and Aliwal Shoal and Leadsman Shoal
Mozambique	1860 km^2	Quirimbas, Bazaruto, Inhaca, Inhambane
Tanzania	3580 km^2	Fringing reefs in Tanga, Pemba, Unguja, Mafia and patch reefs in the Zanzibar channel
Kenya	630 km^2	Northern and southern coasts of the country
Seychelles	1690 km^2	Fringing and patch reefs around the island
Comoros	430 km^2	Fringing and patch reefs around the island
Madagascar	2230 km^2	Fringing and patch reefs around the island and the barrier reef, Grande Recife
Mauritius	870 km^2	Mahebourg barrier reef of Mauritius and patch reefs around the island

Corals of the genera *Acropora* were the most abundant and diverse genus found in the WIO region. However since the 1998 bleaching event the geographic range of *Acropora* has become limited to southern Tanzania and northern Mozambique. *Millepora*, a once dominant genus in shallow coral communities throughout the WIO region, has also experienced a decline in these waters and is now represented in some regions by dead skeletons only. Previously dominant genera are now being replaced by those that are less vulnerable to bleaching, such as *Porites* (Obura, 2005). Other genera commonly found throughout the WIO region include *Astreopora*, *Alveopora*, *Cyphastrea*, *Echinopora*, *Favia*, *Favites*, *Galaxea*, *Goniastrea*, *Goniopora*, *Hydnophora*, *Leptoria*, *Montipora*, *Oxypora*, *Pavona*, *Platygyra* and *Pocillopora* (Fagoonee, 1990; Obura, 2005).

The growth of populations in WIO countries has caused cities to become over-crowded and, in many cases, basic infrastructure cannot cope with the increased volume of sewage and domestic wastes

(Richmond, 2002; UNEP/GPA and WIOMSA, 2004). Many countries dispose untreated sewage and wastewater directly in shallow coastal environments. While nutrients are essential for promoting primary coral reef productivity, the excessive presence of sewage derived nutrients drastically increases the productivity and biomass of phytoplankton and opportunistic algae. The resulting conditions are similar to those experienced in seagrass beds in that the increase in algal and phytoplankton biomass increases light attenuation, which severely affects coral growth and survival. Additionally, algae tend to overgrow and smother corals and an increase in such productivity promotes the growth of other opportunist organisms such as sponges and tunicates, which out-compete corals for habitat space (Pastorok and Bilyard, 1985).

High concentrations of certain nutrients such as phosphorus actually inhibit coral calcification processes (Duke et al., 2005, Schaffelke et al., 2005). Eutrophication, algal blooms and smothering of corals found in shallow lagoons in Mauritius are common, particularly in Port Louis where coral mortality is prevalent (Ramessur, 2002). Certain parts of Tanzania do not have sewage treatment systems, leaving such wastes to be directly disposed of in the sea (Mmochi and Francis, 2003). Coral reefs in close proximity to sewage and domestic waste outfalls can suffer from the effects of eutrophication, bleaching or mortality (McClanahan, 2002).

Rapid expansion of coastal developments has caused an increase of industrial waste discharge into shallow coastal waters (Richmond, 2002; UNEP/GPA and WIOMSA, 2004). Maputo has increased its industrial node in recent years, producing unquantified amounts of waste that are mostly discharged in the ocean, causing coral bleaching and mortality (Mmochi and Francis, 2003). The highly productive food processing, metal and textile industry in Kenya directly discharge untreated wastes into the Kilindini Harbour and Port Reitz, negatively affecting the health and productivity of sensitive ecosystems such as coral reefs (Mmochi and Francis, 2003).

Corals contain symbiotic zooxanthellae which are photosynthetic algae. The symbiotic relationship is one in which the coral provides zooxanthellae with a sheltered environment, nutrients (CO_2 and nitrogenous and phosphorus by-products of coral cellular respiration) and in return the algae provides O_2 and photosynthetic by-products to the coral. This unique relationship is maintained by chemical communication between the coral and algae, and this renders certain coral species are extremely sensitive to heavy metal contamination (Peters et al., 1997). Reef invertebrates and fish are vulnerable to metals and accumulate these contaminants within soft body tissues and display distinct physiological and cytological responses to varying levels of pollutant exposure (Rainbow, 1995; Ravera, 2001). In addition, heavy metals derived from industrial effluent are easily absorbed by the tissue of coral skeletons thereby altering various chemically mediated processes such as reproduction and recruitment. Consequently, such pollutant exposure causes severe modifications to reef productivity and mortality rates (Peters et al., 1997).

PCBs and pesticides are also extremely toxic to corals which have been shown to display decreases in photosynthesis of the symbiotic algae, changes in coral metabolism and growth retardation when exposed to such contaminants (Pastorok and Bilyard, 1985). Agrochemicals increase the nutrient loading in shallow waters, resulting in localized eutrophication, which impacts on coral health as outlined above. Numerous studies have reported high occurrences of diseases, blemishes and dead patches of coral reefs situated in close proximity to urban outfalls (McClanahan, 2002).

Petrochemicals are another potential pollution threat to coral reef ecosystems and are most commonly derived from runoff from land, wastewater effluent and ballast water discharges from ships. The increase of port activities and shipping traffic has resulted in an increase of oil spills in shallow coastal waters. In the marine environment, this pollution floats above coral reefs (Peters et al., 1997) and even if petroleum does not come into contact will the reef, the pollutant contains toxic substances that are water soluble and are taken up by corals. Studies have shown that corals exposed to oil undergo a variety of negative impacts that include coral tissue death, bleaching, and impairment of biological processes such as photosynthesis, reproduction and growth (McClanahan, 2002). In addition, dispersants used to clean-up oil leaks contain toxic chemicals that exacerbate the effects of the oil spill and can prolong coral recovery by years (Peters et al., 1997).

2.2 Socio-economic overview

The WIO region has a population of approximately 158 million people of which approximately 24% (38 million people) live within 100km of the coast (Table 4). Urbanisation and availability of ports and harbours have attracted high concentrations of people in some coastal areas. In some of the WIO countries, significant percentages of the national population lives on the coast. Annual population growth rates in the region in 2005 ranged from 1.0 in Seychelles, 1.1% in South Africa, 1.8% in Tanzania to 1.9% in Mozambique, 2.1% in Comoros, 2.3% in Kenya and 2.7% in Madagascar (World Bank, 2007).

Table 4: Size, Total population size versus coastal populations in WIO Ocean countries (CIA, 2007; Gossling, 2006; World Bank, 2007)

COUNTRY	SIZE OF LAND AREA (km^2)	POPULATION SIZE ($x 10^3$)	POPULATION LIVING WITHIN 100KM OF COAST ($x 10^3$)
Kenya	582650	33445	3000
Tanzania	945087	37445	8625
Mozambique	801590	19800	6154
South Africa	1219912	46900	11664
Seychelles	455	82	82
Comoros	2170	652	572
Madagascar	587040	17501	5920
Mauritius	2040	1220	1220
La Reunion	2517	766	766

The WIO countries are at various stages of economic growth with considerable differences in the Gross Domestic Product (GDP) and per capita income in each country (Table 5).

TABLE 5: Estimated per capita income for countries of the WIO region, as well as a comparison with other developed and developing countries (Sources:http://www.success-and-culture.net/articles/percapitaincome.shtml; http://www.britannica.com/eb/question-500226/19/GNP-per-capita-Reunion)

COUNTRY	PER CAPITA INCOME (USD) PER YEAR (2003)
Comoros	450
Kenya	390
Madagascar	290
Mauritius	4 090
Mozambique	210
Reunion	14390
Seychelles	7490
South Africa	2 780
Tanzania	290
France	*27460*
Portugal	*17980*

Brazil	*7480*

The socio-economic characteristics of the WIO region are largely dictated by availability and patterns of natural resources utilization. Most coastal communities in the WIO region depend on nearby coastal and marine resources for their livelihood and income generation The main forms of land and sea use are fisheries, tourism, agriculture, industry, forestry, shipping and ports, mining, conservation, urbanisation and infrastructure.

2.3 Marine pollution "hotspots"

Land-based sources of marine pollution in the WIO region are primarily associated with urban areas and discharges from larger catchments into the sea. Hot spots of land-based sources of marine pollution as identified in the African Process Reports and the WIO-LaB Draft Monitoring Framework Report for the Western Indian Ocean are highlighted in Figure 3. Although, at present urban centres in the WIO region are still several hundred kilometres apart, creating distinct hotspots, it is likely that in future rapid urbanisation in the region will result in so-called 'strip development' of coastal areas where smaller coastal towns and suburban areas will eventually join with the main cities, creating larger continuous urban zones along the coastline (Ruwa, 2006).

The transport and fate of land-based pollution is strongly influenced by ocean currents. Unlike enclosed or semi-enclosed marine water bodies such as the Baltic or Mediterranean, the coastal region of the Western Indian Ocean is much more exposed with less chance of land-based sources of marine pollution causing transboundary impacts. However, taking into account the ocean circulation patterns in the area, transboundary impacts cannot be excluded (Figure 1).

For the WIO region transboundary impacts and considered to also include land-based marine pollution issues that are *common* to countries in the WIO region, not necessarily resulting in direct transboundary impacts in the true sense of the word (i.e. pollution originating in one country impacting on coastal areas of another). However, it should be understood that land-based sources of marine pollution can significantly contribute to transboundary issues in an indirect way. For example, land-based activities may affect one or more life stages of a migrating marine organism, thus influencing the distribution and abundance of these organisms in a neighbouring country or region.

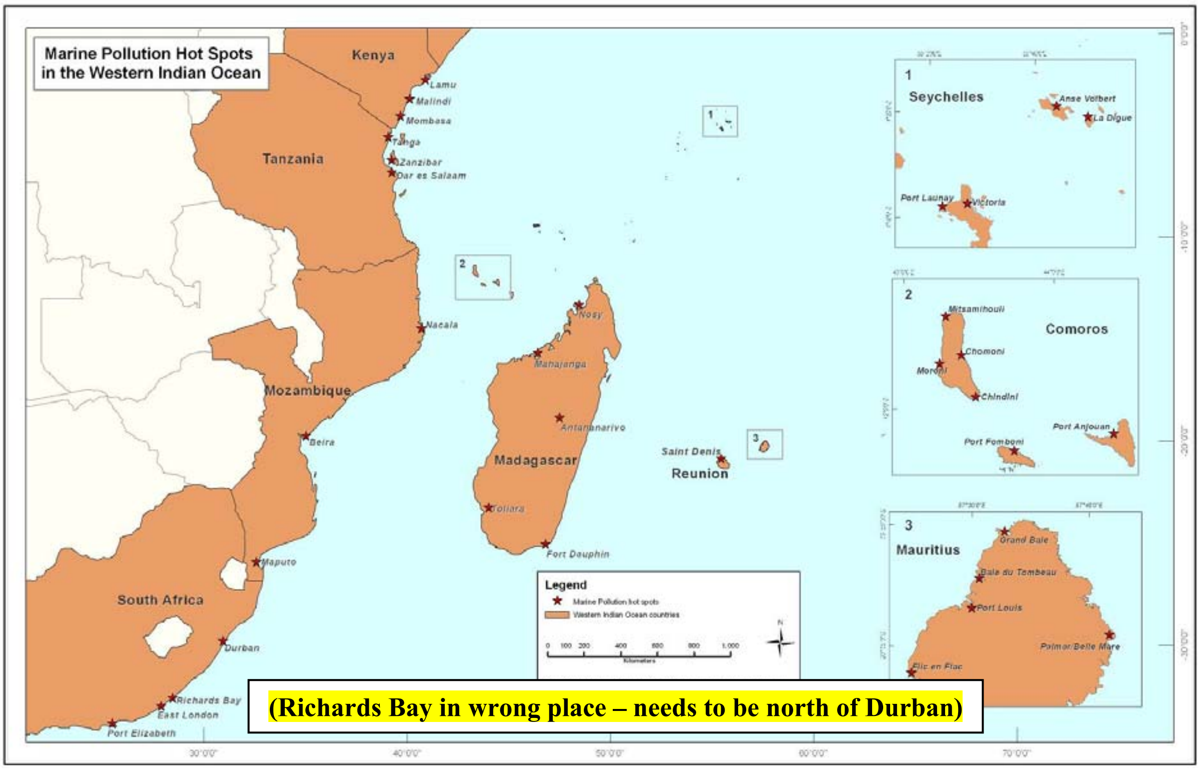


Figure 3: **Large coastal urban centres ('hot spots' for land-based sources of marine pollution) in the WIO region as identified in the African Process Reports and the Draft monitoring framework for the Western Indian Ocean**

3. TRANSBOUNDARY PROBLEMS AND THEIR IMPACTS

The document as it now stands seems largely a duplicate of the TDA, in particular chapter 3 and 4. While the two should obviously be in line, one would expect the synthesis report to go deeper and wider than the TDA in its analysis (the TDA basically summarizing what is in this report) Also, new data has now become available, both through the monitoring programme and through the updated national status reports (some of changed quite a bit).

The Draft National Pollution Status Reports identified five priority (or key) key transboundary problems (here defined as problems that are common to the countries of the WIO region) linked to marine pollution issues (or deterioration of water quality) in the coast as a result of land-based activities (Anon Madagascar, 2006, Anon Mozambique, 2006; Anon Mauritius, 2006; Munga *et al.*, 2006; Mohammed *et al.*, 2006; Abdallah *et al.*, 2006; Dubula *et al.*, 2006), namely:

- Microbial contamination
- High suspended solids
- Chemical pollution
- Marine litter
- Eutrophication (or nutrient over-enrichment).

An overview of identified hotspots, and key associated pollution problems in the WIO region is presented in Table 6.

TABLE 6: Overview of pollution hotspots in the WIO region and associated (perceived) pollution problems (refer to Figure 3 for locations)

COUNTRY	TRANSBOUNDARY PROBLEM				
	Microbial contamination	**Eutrophication**	**Marine litter (solid waste)**	**Suspended solids**	**Chemical pollution**
Comoros	Beach Mitsamihouli Beach Chindini Beach Chomoni		Beach Mitsamihouli Beach Chindini Beach Chomoni		Port Moroni Port Anjouan Port Fomboni
Kenya	Vanga Creek (Wasini) Mombasa inshore waters Lamu inshore waters Malindi/Watamu Marine Park	Mombasa inshore waters	Mombasa inshore waters Lamu inshore waters	Mombasa inshore waters Lamu inshore waters Malindi/Watamu Marine Park Ungwana Bay Malindi Bay	Mombasa inshore waters
Madagascar	Port Mahajanga Port de Nosy-Be Toliara Baie de Fort-Dauphin			Toliara	Port Mahajanga Port de Nosy-Be Toliara Baie de Fort-Dauphin
Mauritius	Baie du Tombeau to Pointe Aux Sables	Pointe Aux Sables Palmar Bain des Dames	Port Louis Harbour	Grand Baie Rodrigues Pointe Aux Sables	Pointe Aux Sables Belle Mare-Palmar
Mozambique			Maputo Bay Nacala Bay		
Seychelles	La Digue Anse Volbert	East coast Mahé Port Launay Marine Park Mahé Wetland	Port Victoria and surrounding areas	East Coast Mahé (including lagoons)	
South Africa					Richards Bay
Tanzania	Dar es Salaam Tanga Zanzibar				Dar es Salaam Zanzibar

Initial prioritisation of transboundary problems was undertaken by regional stakeholders and experts at the Regional Consultative Workshop on the preparation of the TDA in Nairobi, Kenya (April 2007) (Table 7). The primary method applied for this exercise was a multi-criteria analysis undertaken by over 40 experts from various disciplines and representing all the project countries, based on a set of six criteria, which can be divided into two general categories:

- *Scope* of the problem:
  - Transboundary nature of the problem (i.e. geographical scope)
  - Scale of benefits of resolving problem
  - Feasibility of finding solutions to the problem

- *Severity* of the problem:
  - Environmental impact of the problem
  - Socio-economic impact of the problem
  - Macro-economic consequences of the problem

Following detailed analysis of the transboundary problems, the prioritisation of problems was further refined by the Scientific and Technical Review Workshop of the TDA (held in Mombassa August 2008), where the various problems and causes were analysed through a step-wise prioritisation exercise. A detailed overview and description of the methods and criteria used for prioritisation and results is presented in Annex 1.

TABLE 7: Prioritisation of transboundary marine pollution problems for the mainland countries and island states (H = high, M = medium, L = low)

PROBLEMS	SEVERITY	SCOPE	OVERALL RATING
Microbial contamination	H	H	H
High suspended solids	H	H	H
Chemical pollution	M	L	L
Marine litter and debris	L	L	L
Eutrophication	L	L	L

Each of the identified priority transboundary problems, as well as associated environmental impacts and socio-economic consequences are assessed in the following sections.

3.1 Microbial contamination

Microbial contamination refers to the presence of pathogenic organisms (protozoa, bacteria and viruses) of either human or animal origin in the aquatic environment that can pose health risks to humans. In the WIO region, microbial contamination of coastal waters is typically associated with inappropriate disposal of municipal wastewater (including sewage), contaminated surface and sub-surface runoff from urban areas, contaminated runoff from agricultural areas used for livestock rearing and industrial effluents (mainly from food processing industries). The problem tree for microbial contamination in the WIO region, specifically linked to land-based activities, is provided in Figure 4. Stemming from the above, key sectors contributing to microbial contamination are urbanisation and tourism, agriculture, industry and transportation (referring to waste disposal facilities in harbours and ports).

Microbial contamination can have severe socio-economic consequences in coastal waters, such as:

- Human health risks associated with contact recreation or ingestion of contaminated seafood
- Reduced quality of seafood cultured or harvested in a particular area.

These consequences affect stakeholders across society, from local communities to international tourists, and industrial and aquaculture operations, all of which utilise the marine environment for recreation and the collection and culture of seafood.

Loss, or potential loss, of the recreational value of coastal waters, as reflected in unacceptable levels of faecal bacteria (typically used as indicators of microbial contamination), is evident throughout the coastal zone of the WIO region. Areas of concern are usually associated with larger urban centres where poorly treated or untreated waste and wastewater is problematic. In many areas the situation is exacerbated by unacceptable aesthetics and bad odours, also a consequence of inappropriate waste and wastewater management.

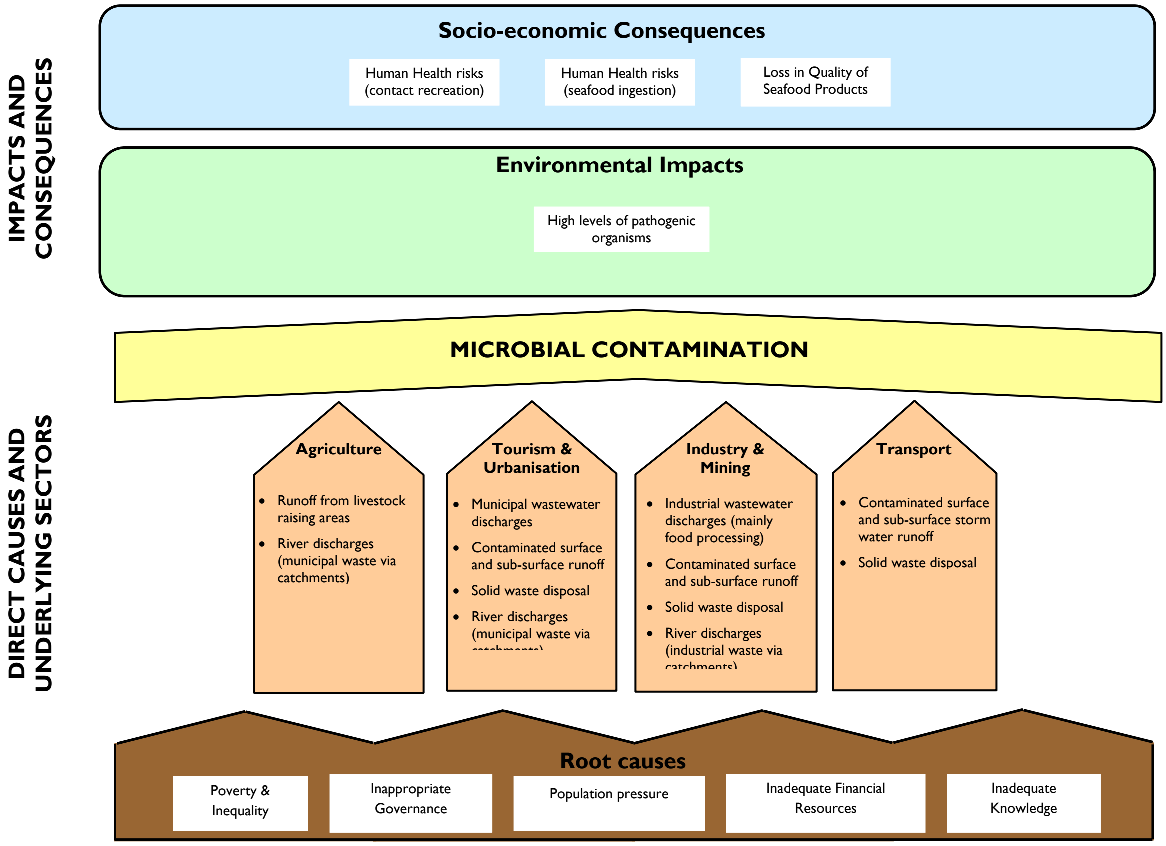


Figure 4: Problem tree: Microbiological Contamination

Studies conducted around Taolagnaro (Madagascar) measured *E. coli* counts as high as 13300 counts/100 ml in coastal waters. The high levels of faecal contamination were attributed to defecation on the beaches as well as inappropriate treatment of municipal wastewater (Anon Madagascar, 2006). Between 1993 and 1998, eighteen cases of human illness caused by ingestion of contaminated seafood were reported (Anon Madagascar, 2006). These included illness resulting from ingestion of marine turtles (seven cases), sharks (eight cases), fish (one case) and molluscs (two cases), though the causal link to microbial contamination was not always clear.

In Maputo Bay (Mozambique), microbial contamination has been recorded in shellfish, the bacteria *Vibrio parahaemolyticus* and *V. mimicus* being found in clams in the Incomati River mouth, in the bay adjacent to the Polana Hotel and near Matola in the Maputo Estuary. *Vibrio* spp. are the main cause of severe gastro-intestinal illnesses (Fernandes, 1996). High faecal coliform counts were also detected at several locations, including the area near the Infulene River mouth where values exceeded 2400 counts/100 ml. Such high contamination results from inappropriate sewage treatment facilities. There is only one sewage treatment plant in Mozambique, located in Maputo City, which treats only about 50% of the city's sewage. Areas near the entrance of the Maputo Estuary (Miramar) are not considered safe for swimming. Faecal contamination has also been recorded in Beira Bay and Nacala Bay, although levels were lower than those recorded for Maputo Bay (Fernandes, 1995).

Along the coast of Mauritius, total and faecal coliforms are monitored on a monthly basis at public beaches at Flic en Flac, Albion, Pointe aux Sables, Trou aux Biches, Mon Choisy, Le Goulet, Grand Baie and Blue Bay. The Ministry of Fisheries reported in 2004 that most of the stations were within recommended water quality guidelines for contact recreation in Mauritius (counts of total coliforms <

1000 per 100 ml and faecal coliforms < 200 per 100 ml) except some areas in Pointe aux Sables near Port Louis (Dulymamode *et al*., 2006).

Studies conducted in Mombasa (Kenya) showed that microbial pollution levels in urban aquatic environments were several orders of magnitude higher than in rural aquatic environments (Table 8) (Mwanguni, 2002).

TABLE 8: Average faecal coliforms and *E. coli* counts measured in urban and rural coastal water in Kenya (Mwanguni, 2002)

AREA		MIROBIOLOGICAL COUNTS/100 ml	
		Faecal coliform	***E. coli***
Urban	Tudor Creek	1703	12.8
	Kilindini Creek	1525	690
	Mtwapa Creek	1400	55
	Bamburi Marine Park	70	19
Rural (Ungwana Bay)	Kipini	19	4
	Sadani	13	4
	Tana	10	3
	Kilifi	12	2
Rural (Ngomeni Bay)	Mambrui	16	3

Risks to human health associated with microbial contamination of coastal water are unclear. In literature consulted for the purposes of this study many sources reported that human diseases in coastal areas were mainly water-borne diseases associated with poor water quality. These include diseases such as dysentery, cholera and diarrhoea. However, the literature seldom distinguishes between the exact sources, i.e. whether these are as a result of ingesting contaminated drinking (fresh) water or associated with contaminated coastal water (e.g. used for contact recreation). The former is probably the most dominant source of these water-borne diseases, although contaminated recreational water certainly contributes to the problem.

Over 50% of all reported diseases in Kenya have been attributed to poor water quality associated with inadequate wastewater management (see note), although no distinction was made between drinking water and coastal recreational–, (Mwanguni, 2002).

In the Seychelles, effluent from wastewater treatment plants discharged directly into the ocean was found to contain total coliform counts between 2000 and 5000 per 100 ml, far above the stipulated standards of 500 per 100 ml (Antoine *et al*., 2007).

Since about 1985, the design of offshore sewage outfalls in South Africa has followed the receiving water quality objectives approach where effluent quantities and composition must be within limits that meet site-specific Environmental Quality Objectives, as recommended in the South African Water Quality Guidelines for Coastal Marine Waters. Generally, long-term environmental monitoring programmes at these outfalls have indicated no detrimental impact on the marine environment or its beneficial uses (in terms of chemical and microbiological contamination). Of greater concern is the rapid increase in discharges to less dynamic and sensitive areas such as surf zones and estuaries, where effluents from malfunctioning or overloaded treatment facilities are adversely affecting the marine environment and other beneficial uses, albeit in a localized manner (RSA DWAF, 2004).

In Cape Town (South Africa) an extensive monitoring programme for microbiological contamination (using *E. coli* as indicator organisms) is conducted by the local municipality. In 2005 approximately 80% of these stations complied with the recommended South African water quality guidelines for contact recreation. Stations that did not comply with recommended guidelines (i.e. *E coli* exceeded 200 counts/100ml in 80% of samples and 2000 counst/100 ml in 95% of samples) were in highly developed, altered and urbanised sections of the coastline with high levels of hardened surfaces (City of Cape Town, 2005).

In Zanzibar (Tanzania), high total and faecal coliform levels have been reported in certain coastal areas (e.g. Stone Town) prompting health concerns and warning of health risks to swimmers. Similarly, some beaches in Dar es Salaam (e.g. Ocean Road and Banda beaches) have also been closed for swimming and other recreational activities due to microbial contamination (Mohammed *et al.*, 2006).

Considering the root causes of microbial contamination into account, particularly *population pressure, poverty and inequality*, it is likely that the problem will intensify in future, posing even greater socio-economic risks to society, unless those responsible intervene in the different sectors that contribute to this problem.

3.2 High suspended solids

High concentrations of suspended solid loads enter WIO coastal waters from land-based sources, mainly in municipal and industrial wastewater discharges, river discharges and surface runoff, particularly during rainy seasons. Dredging activities (usually associated with ports and harbours) can also significantly contribute to this transboundary problem.

The key sectors contributing to high suspended solid loading in the marine environment are agriculture (linked to soil erosion in river basins/catchments), industry (particularly those discharging effluents containing high suspended solid loads/sediments) and transportation (primarily linked to dredging activities). The urban sector (e.g. local municipalities) also contributes through inappropriate disposal of municipal waste, while aquaculture farms may contribute to the problem through the disposal of waste containing high suspended solids. These factors are depicted in the problem tree shown in Figure 5.

Key environmental impacts linked to high suspended solid loads are:

- Smothering of benthic communities
- Suffocation of marine organisms
- Mortality (acute effects) of marine biota
- Chronic and acute effects on marine biota
- Modification of marine biota species composition
- Discolouration of coastal waters.

Consequences associated with the problem affect stakeholders across society, from local communities to large international tourism concerns. Aquaculture and agro-processing industries are also affected. The social and economic consequences of increased suspension of solids in coastal waters include:

- Loss of aesthetic value
- Loss of commercial and/or artisanal fisheries resources and revenue
- Reduction in quality of seafood.

Impacts associated with sediment loading have been recorded in the WIO region. For example, in Kenya, sediment loading has been found to affect the coral reefs in the Malindi National Marine Park and Reserve (McClanahan and Obura, 1997; Kazungu *et al*., 2002). A decrease in the number of seagrass species has also been reported in Malindi Bay. In 1972, four endemic species were recorded at Mambrui in Malindi Bay, but in 1992 only two species remained (Wakibia, 1995). The decrease occurred in an area experiencing heavy siltation. There is also concern that the loss of seagrass beds, due to sediment loading, may have negative impacts on fisheries, as these are important habitats for numerous fish species (Kazungu *et al*., 2002). Finally, discoloration of coral reef waters impairs their productivity and results in a reduction in their aesthetic value, rendering them less attractive for tourism.

Sediment deposition and beach accretion (e.g. in Malindi Bay) have resulted in the loss of beach frontage from some hotel and resort developments in Kenya with a resulting loss of tourism revenue, further manifested in loss of employment (Kazungu *et al.*, 2002). The Port of Mombassa (Kenya) also requires regular dredging of the navigational channel to maintain the depth required for shipping activities. The associated costs of dredging are another socio-economic consequence of the impacts of suspended solids on the Kenyan coastal waters (Kazungu *et al.*, 2002).

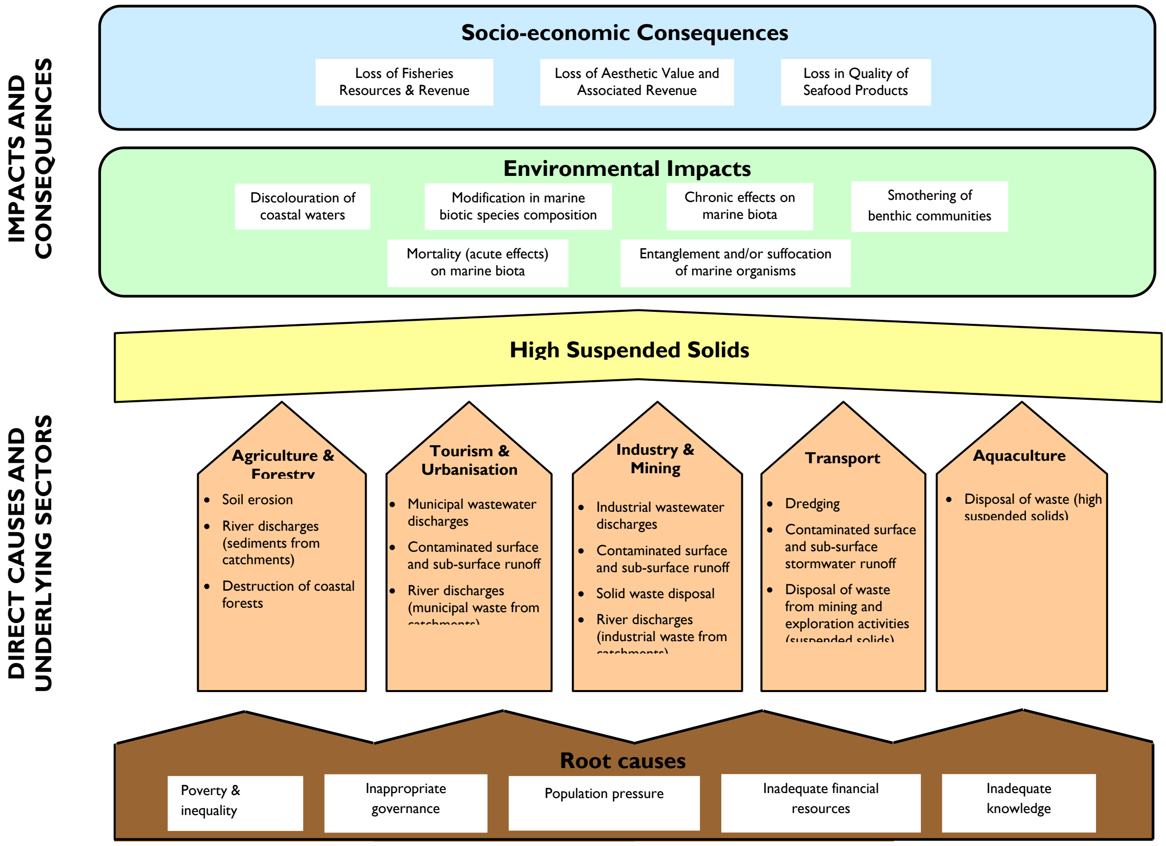


Figure 5: Problem tree: High suspended solids

In Mauritius, increased sedimentation and suspended solids (turbidity) have been reported in the lagoon at Rodrigues and in Grand Baie resulting in the modification of these ecosystems (Resource Analysis-EDC, 1999). In Grand Baie, the increased suspended sediment load was mainly associated with household wastewater discharges, while in Rodriques it results mostly from soil erosion from agricultural pastures in the highlands. Here, some of the bays are completely silted and channels have been constructed to facilitate the movement of boats. Sedimentation has also caused damage to the coral ecosystem (e.g. by smothering), thereby affecting artisanal fishing (Mauritius Pollution Status Report, 2006).

In Mozambique, sedimentation due to poor land-use practices, including deforestation of coastal and hinterland areas are the main contributors to sedimentation in coastal environments. As a result, more frequent dredging of the Maputo and Beira harbours is needed. Surveys from ten years ago showed that between $1.2 \times 10^6\ m^3$ and $2.5 \times 10^6\ m^3$ of sediments need to be dredged annually from the ports of Maputo and Beira respectively (FAO, 1999).

Around the main islands of Mahe, Praslin and La Digue (Seychelles), sediment discharge contributed significantly (~10%) to coral bleaching, together with other factors such as global warming (~70%) (Jones *et al.,* 2002).

In Madagascar, sedimentation has resulted in significant impact on mangrove areas, smothering the root systems of trees and causing die-back of these forests (Anon, Madagascar, 2006).

Increasing agricultural activities in the countries of the WIO region and inappropriate farming practices increase the risk of soil erosion. Together with a projected increase in urbanisation (and associated municipal waste) and industrial activities in the coastal zone, the problem of sedimentation is likely to intensify unless the sectors contributing to this problem implement mitigating measures, through better legislation and regulation, better land-use practices, education and awareness.

3.3 Chemical pollution

Chemical pollution refers to the adverse effects of chemical contaminants released in the coastal environment from land-based human activities. Chemical contaminants are here defined as compounds that are toxic, persistent and/or bio-accumulating. These can be grouped in three broad categories,; heavy metals, hydrocarbons and persistent organic compounds (e.g. pesticides). Sources in the WIO region are typically linked to agrochemical discharges (e.g. persistent organic pollutants), dredging in ports and harbours (thereby releasing sediment-bound heavy metals and hydrocarbons), atmospheric emissions (e.g. heavy metals) and leachates from solid waste dump sites. The key sectors contributing to chemical pollution of coastal marine waters in the WIO region include industry (disposal of toxic substances in wastewaters), agriculture (persistent organic pollutants) and transportation (dredging activities in ports and harbours), and, probably to a lesser extent, the urban sector (through traffic emissions) and energy production (from burning of fossil fuels). Major industries contributing to chemical pollution in the WIO region include manufacturing, textiles, tanneries, paper and pulp mills, breweries, chemical, cement, sugar and fertiliser factories and oil refineries. Inappropriate utilisation, storage and dumping of agrochemicals are also of increasing concern. Furthermore, accidental spills of oil or chemicals in harbour areas or along transport routes near the coast is another potential cause of chemical pollution in coastal areas. These are summarised in the problem tree for chemical pollution provided in Figure 6.

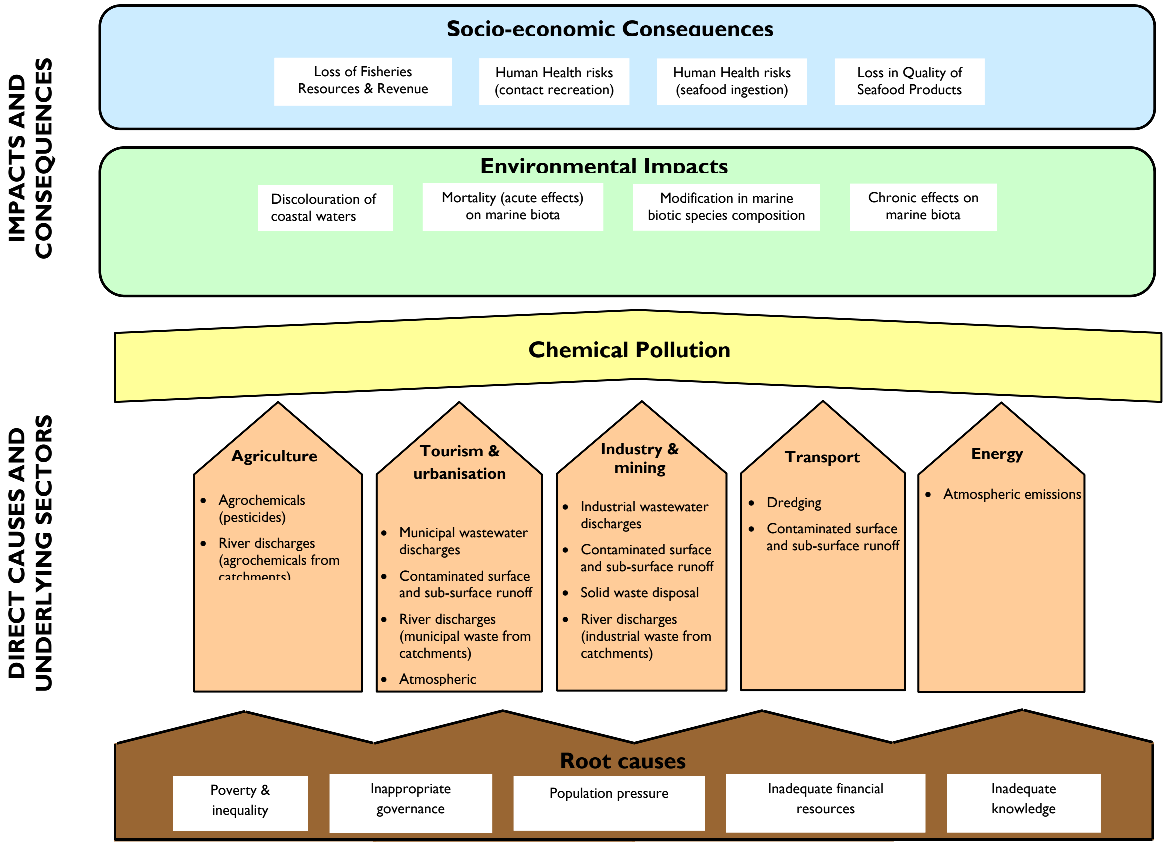


Figure 6: Problem tree: Chemical Pollution

Specific environmental impacts linked to chemical pollution include:

- Discolouration of coastal waters
- Chronic effects (e.g. affecting growth and reproduction) on marine biota
- Mortalities (acute effects) of marine biota
- Modification of marine biotic species composition.

Consequences associated with chemical pollution which pose risks to human health affect stakeholders across society, from local communities to large tourist developments. The fisheries sector, both commercial and artisanal, as well as the aquaculture and seafood production industries, may also be affected. Socio-economic consequences include:

- Loss of artisanal and/or commercial fisheries
- Reduction in quality of seafood products cultured or harvested from a particular area
- Human health risks associated with contact recreation or ingestion of contaminated seafood.

Signs of chemical pollution have been recorded in coastal areas in the WIO region. Studies conducted in the Killindini and Makupa Creeks, Mombasa (Kenya), revealed elevated levels of heavy metals (copper, cadmium, iron and zinc), although these levels were still considered to be substantially lower than those recorded in many perturbed coastal setting (Kamau, 2001). Other studies in Kenya (Makupa and Tudor Creeks) also revealed that overall lead and cadmium concentrations in the water column were low. A few incidents of elevated levels in sediment and some fish species were recorded, but levels of lead and cadmium in most of the fish species analysed were generally within acceptable limits (FAO/WHO, 1986).

Studies conducted in Mozambique have shown the presence of heavy metals, particularly lead, in the Port of Maputo, in the discharges from the Matola and Maputo Rivers and in Nacala Bay (Fernandes, 1995; Anon Mozambique, 2006). Common pesticide residues identified in Mozambique were 2,4,5-TCB, p,p'-DDT, p,p'-DDE, p,p'-DDD, Lindane and HCB. Though DDT is officially banned in Mozambique, it is still used, as it is in neighbouring countries (Massinga and Hatton, 1997).

During the period July 2001 and January 2003, studies were undertaken on six estuaries along the Mauritian west coast to measure heavy metal concentrations. In water samples taken from the river mouths at Grand River North West, Pointe Roches Noires, Grand River South East, Mahebourg, l'Escalier, Baie du Cap, Tamarin and Rivière Lataniers, the heavy metals copper, zinc, lead, cadmium and mercury and the three pesticides, atrazine, diuron and hexazinone were not detected at any of the monitored sites. The study concluded that the levels of chromium, lead and zinc were well below the limits of 600, 2500 and 700 µg/g respectively quoted for contaminated sediments [limits adopted from the draft Netherlands standards (24% clay and 10% organic matter by weight)] during the period January – October 2000 (Mauritius Pollution Status Report, 2006).

In South Africa, municipal and industrial wastewater discharges, including discharges to the marine environment, are regulated and licensed. This appears to have had some positive influence in sustaining acceptable environmental quality (also in terms of controlling chemical pollutants) as reflected in the monitoring and assessment studies conducted in and around the offshore outfalls (CSIR 2004; McClurg *et al.,* 2007). Inputs of persistent organic pollutants into coastal waters from agriculture (e.g. pesticides) have not been quantified in South Africa, though pesticides have been detected in fatty tissues of seals and dolphins along the South African (and Namibian) coast (Vetter *et al*., 1999). In general, the levels were not considered to represent a serious pollution problem.

Studies investigating heavy metal accumulation in Cape Town revealed that the coastal environment is generally in a clean condition, except in localised areas such as the Port of Cape Town (Brown, 2005; CSIR, 2006a, 2006b). The fairly good state of the environment is also reflected in the results of a Mussel Watch Programme conducted along South Africa's west coast. Results for cadmium, lead, zinc and mercury do reflect inter-annual variations but, as yet, no clear long-term (increasing) trends seem to be apparent (Figure 7).

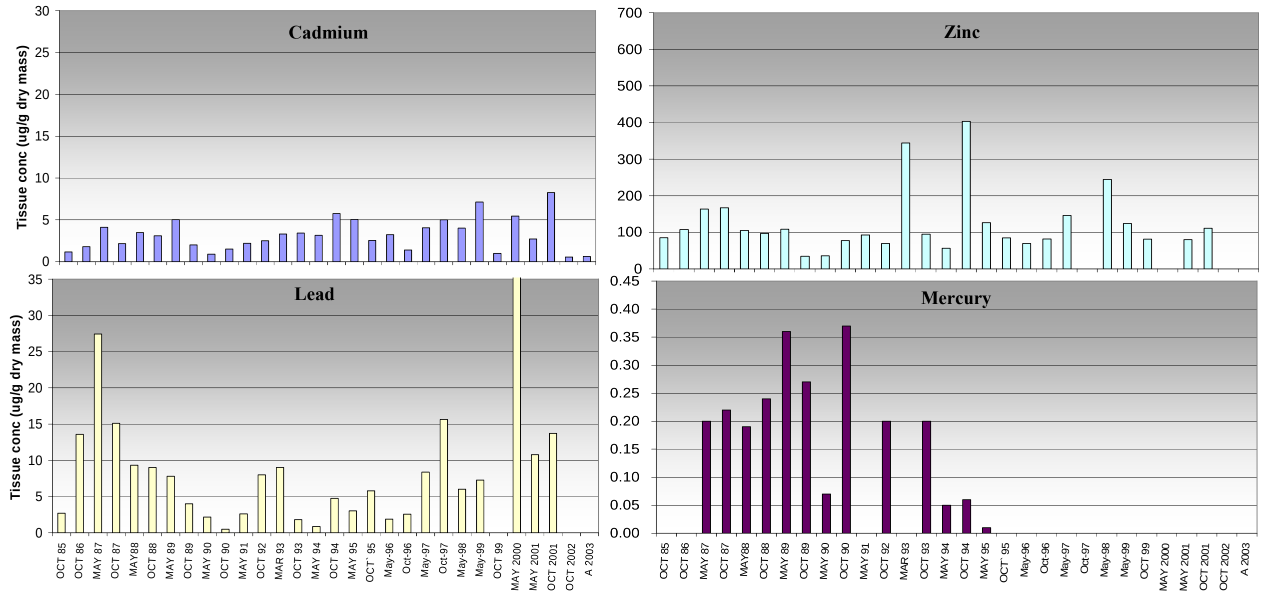


Figure 7: Heavy metal concentrations (µg/g or mg/kg dry weight) measured in mussel tissue along the South African coast (Cape Town) (1985 – 2003) (Source: G Kieviets, Department of Environmental Affairs and Tourism, Marine and Coastal Management, South Africa)

In Dar es Salaam (Tanzania) significant amounts of some heavy metals were found in mangrove sediments and associated biota near the city (Mremi and Machiwa, 2003). Sediment samples from the Msimbazi and Mtoni mangrove areas, which are located within the city, had higher levels of heavy metals (up to three-fold) compared to samples from mangrove forests some distance from the city at Mbweni, clearly inferring anthropogenic input to be a cause (see Table 9).

TABLE 9: Average concentration (mg/kg dry weight) of heavy metals in mangrove sediment and biota in Dar es Salaam area (Mremi and Machiwa, 2003), as well as the recommended environmental targets (EQTs) for sediments in the WIO (Taljaard *et al*., in prep)

HEAVY METAL	RECOMMENDED EQTs (Sediments)	MBWENI		MSIMBAZI		MTONI	
		Sediment	Crab	Sediment	Crab	Sediment	Crab
Copper	18.7	10.7	24.7	31.6	36.2	17.9	39.3
Cromium	52.3	10.1	30.0	31.7	30.0	27.1	30.0
Lead	30.2	27.8	15.0	37.5	14.3	36.8	44.1

Ferletta *et al.* (1996) conducted baseline studies on the accumulation of heavy metals in algae as indicators of pollution in marine water at Dar es Salaam and Zanzibar. A comparison of the results from 1989 and 1994 revealed a significant increase in heavy metal concentrations (Table 10). Zinc and other heavy metal concentrations were highest at stations close to the city centre compared with stations in rural areas. A ten-fold increase in heavy metal content in several algal species was reported over a period of just seven years (Ferletta *et al.*, 1996). Another study showed that macroalgae collected from Chapwani and Changuu Islands off Zanzibar had significant levels of aluminium and cadmium with the suggested source of these contaminants being the various industries in nearby Stone Town (Engdahl *et al.*, 1998).

TABLE 10: Comparison of heavy metal concentrations (µg/g dry weight) measured in the algae in 1989 (Wekwe *et al.*, 1989) and 1994 (Ferletta *et al.*, 1996) in Dar es Salaam (Oyster Bay) and Zanzibar (Mdudya Island)

HEAVY METAL	ALGAE	DAR ES SALAAM (OYSTER BAY)		MDUDYA ISLAND (near Zanzibar)	
		1989	1994	1989	1994
Cadmium	*Padina tetrastromatica*	0.12	2.3	0.14	2.6
Chromium		1.5	6.6	1.5	4.6
Copper		1.0	5.0	1.0	8.4
Iron		1190	613	1189	278
Manganese		58.5	nd	58.6	nd
Nickel		0.38	6.5	0.38	6.5
lead		2.15	6.10	2.17	10.10
Zinc		33.4	104.6	34.0	13.4
Cadmium	*Ulva* sp.	0.3	3.3	0.3	nd
Chromium		0.8	5.5	0.8	nd
Copper		7.0	7.9	7.0	nd
Iron		230	412	230	nd
Manganese		3.5	24	3.6	nd
Nickel		0.9	7.8	0.9	nd
lead		1.6	13.3	1.6	nd
Zinc		28	39.9	27.9	nd

nd - Not detected

An analysis of heavy metals in sediments in the inner area of Dar es Salaam harbour (Machiwa, 2000) also revealed an accumulation of certain heavy metals, notably chromium and copper (see Table 11). The harbour receives large quantities of industrial waste from the city of Dar es Salaam.

TABLE 11: Average concentration (mg/kg dry weight) of total heavy metals measured in sediments of harbours and estuaries in the WIO region (Sources: Machiwa, 2000; Mauritius Pollution Status Report, 2006), as well as the recommended environmental targets (EQTs) for sediments in the WIO (Taljaard *et al.*, in prep)

STUDY AREA	AVERAGE HEAVY METAL CONCENTRATION (mg/kg)				
	Chromium	Copper	Mercury	Lead	Zinc
Recommended EQTs (sediments)	52.3	18.7	0.13	30.2	124
Dar es Salaam harbour	33	28	0.1	21	68
Mauritius west coast estuaries	225	-	-	27	107

Another study conducted on marine sediments and biota along the coastline of Dar es Salaam (Mwevura *et al.*, 2002b) concluded that organochlorine pesticide levels in sediments (for dieldrin, p,p'-DDT, p,p'-DDE, p,p'-DDD, o,p'-DDT and g-HCH) might cause adverse effects on humans consuming biota directly exposed to the sediments, but that levels measured in biota living in the water column were safe for human consumption, with levels significantly below the FAO/WHO maximum acceptable for fish and seafood (200 mg/kg fresh weight) (see FAO/WHO, 1986).

Although several scientific studies conducted in coastal areas in the WIO region revealed elevated levels of chemical pollutants, most likely attributable to land-based sources, uncertainties remain regarding the geographical spread of chemical contamination as most studies were not designed to reflect the spatial extent of the pollution. Furthermore, scientific data on environmental impacts or socio-economic consequences directly linked to chemical pollution have not been collected in the region.

Industrialization in the WIO region remains slow relative to other parts of the world but is increasing rapidly. Recent history has shown that rapid development often takes place without proper environmental impact assessments or legislative controls, leading to increased pressure on the environment. Commercial agricultural activities are also increasing in the countries of the WIO region, as is the use of agrochemicals. Thus, chemical pollution from these sectors is likely to intensify unless better legislation and regulation is implemented along with best practice guidance awareness raising and education. Despite a lack of data, the risk of chemical pollution of coastal waters from land-based activities should not be ignored. There is a need for a timely intervention by industry managers, farmers and the government authorities responsible for regulating these activities.

3.4 Marine litter

Marine litter pollution refers to the introduction of solid waste material (which either floats or sinks) into water bodies and their surroundings. Inappropriate disposal of solid waste represents a serious problem in most of the urban centres in the WIO region, although quantitative data are limited. Important land-based sources of litter are waste from urban centres (particularly ports, industrial and commercial areas and informal settlements) and that discharged into marine environments via rivers (transporting solid waste from adjacent catchments). The main sectors (or stakeholders) contributing litter in marine environments include the urban and tourisms sectors, industry and transport, mainly linked to inappropriate facilities for the disposal of solid waste, as shown in the problem tree presented in Figure 8.

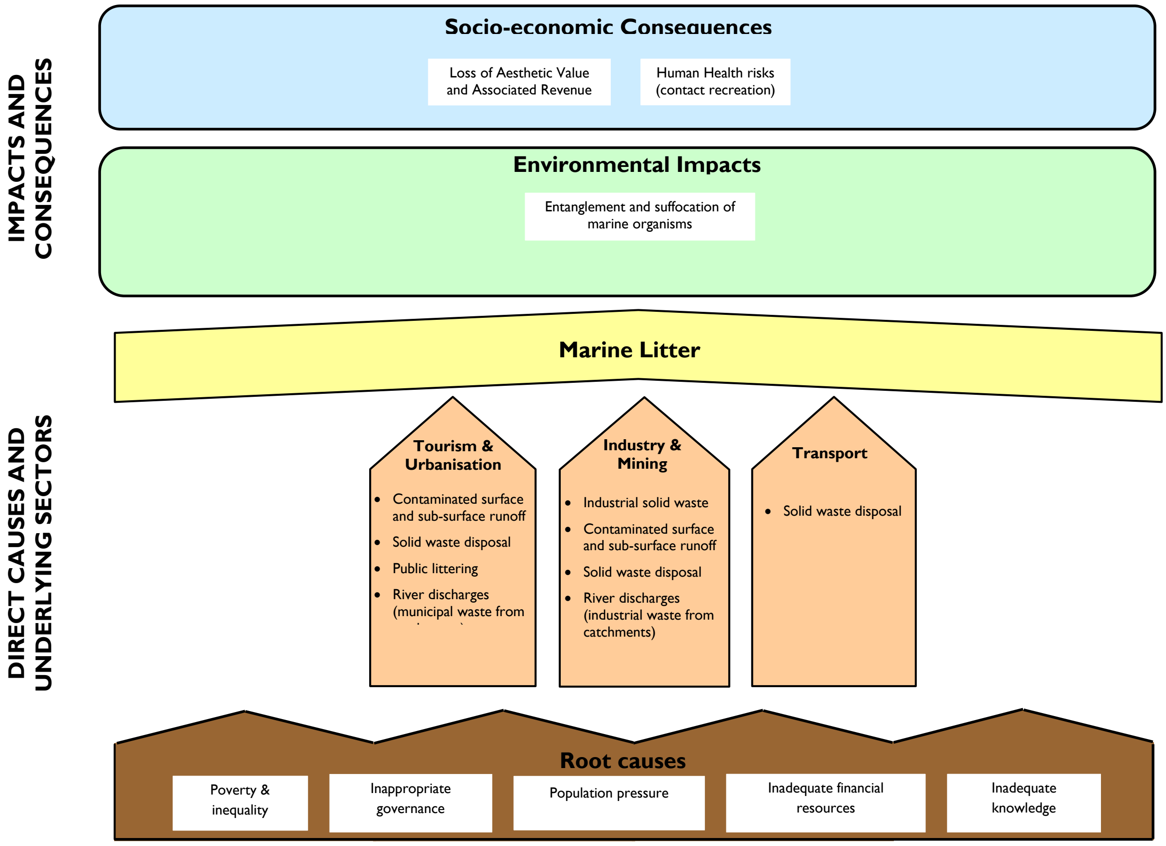


Figure 8: Problem tree: Marine Litter

Major environmental impacts are linked to ingestion by marine organisms, or entanglement resulting in loss of biodiversity (Lane, 2007). Socio-economic consequences include:

- Loss of aesthetic value of coastal areas
- Risks to human heath through contact with contaminated waste products (e.g. medical waste).

The consequences associated with marine litter affect stakeholders across society, from local communities to large tourist developments affecting the aesthetic value of coastal areas and posing risks to human health.

An assessment of marine litter-related issues in the WIO region revealed that environmental impacts and socio-economic consequences of marine litter are largely inferred and not adequately assessed or quantified, other than in South Africa (Lane, 2007). However, the synopsis given in South Africa's national report is applicable to the entire region: It finds that "litter has numerous impacts on marine ecosystems, as well as direct and indirect impacts on humans. The main ecological impacts of floating litter are that it is ingested by, or entangles, marine organisms. Off South Africa, levels of ingestion and, perhaps to a lesser extent, entanglement, are on a par with the highest recorded elsewhere in the world. There are some encouraging developments (e.g. the reduction in virgin [pre-processed] plastic pellets ingested by seabirds), but overall the situation remains unacceptable, with several threatened species affected. It may play a role in rafting invasive organisms to these remote systems, with potentially serious biological and commercial impacts. Litter that sinks to the seabed may impede gas exchange in bottom sediments or become entangled around sessile organisms, increasing their drag and, in shallow depths, their risk of being dislodged or washed off during large storm swells."

National marine litter reports from Kenya, Madagascar and Tanzania have indicate that medical and sewage wastes can impact human health. This urgent matter appears to be being addressed by the governments in partnership with aid agencies. Medical wastes are obviously a priority source of marine litter to eliminate (Lane, 2007).

The impact of marine litter on the aesthetic quality of coastal areas in the WIO region is demonstrable. Quantities of litter are negatively correlated with the popularity of the beaches used for recreation and litter discourages tourism (Lane, 2007). Economic and aesthetic impacts include reduced amenity value (e.g. beach use drops as litter levels increase), ever growing investment in formal beach cleaning programmes, risk of flooding due to blocked drains, disabling or damaging vessels and impacting on commercial fisheries. Most of these impacts have not been quantified in economic terms. Taking some of the root causes of marine litter in the WIO region into account, particularly *population growth pressure*, *poverty and inequality*, it is likely that this problem will intensify in future, posing even greater socio-economic risks to society, unless those responsible in the different polluting sectors intervene. Serious impacts on tourism development will result. As economies develop and expand and infrastructures improve a demand for some waste products has emerged. For example in Dar es Salaam demand for empty plastic mineral water bottles for re-cycling in China has resulted in their removal from local waste dumps, roadsides and beaches (Richmond, M. *pers comm*.). The trend in Seychelles has been to ban take-away boxes, plastic bags, pet bottles and plastic bottle recycling. Grills have been placed on most river outlets and marine litter in port areas and on all of the major beaches is collected.

3.5 Eutrophication

Eutrophication refers to artificially enhanced primary production (e.g. algal and phytoplankton growth) and elevated organic matter loading in coastal waters due to the increased availability or supply of nutrients, usually as a result of inappropriate disposal of municipal wastewater or nutrient-enriched agricultural return flows. Wastewater with a high organic content (e.g. with high biological- or chemical oxygen demand, BOD or COD) or wastewater containing high levels of inorganic nutrients (e.g. nitrogen and phosphate) typically contributes to eutrophication. While eutrophication in the true sense of the word hardly ever occurs in the WIO region, harmful or nuisance algal blooms result from nutrient enrichment are problematic in some areas.

The key sectors (or stakeholders) potentially contributing to eutrophication/algal blooms in coastal waters include the urban sectors (municipalities responsible for waste disposal), industries (generating high BOD and nutrient loads in their wastewater) and agriculture (with inappropriate use and disposal of fertilisers), as shown in the eutrophication problem tree (see Figure 9).

Environmental impacts of eutrophication/algal blooms include:

- Nuisance, opportunistic or harmful algal blooms affecting both aesthetics and biodiversity
- Discolouration of coastal waters, affecting light-dependent benthic species
- Smothering of benthic communities (e.g. during die off of algal blooms)
- Mortalities of marine biota (e.g. caused by anoxic conditions generated on decomposition of organic matter)
- Modification of marine biotic species composition.

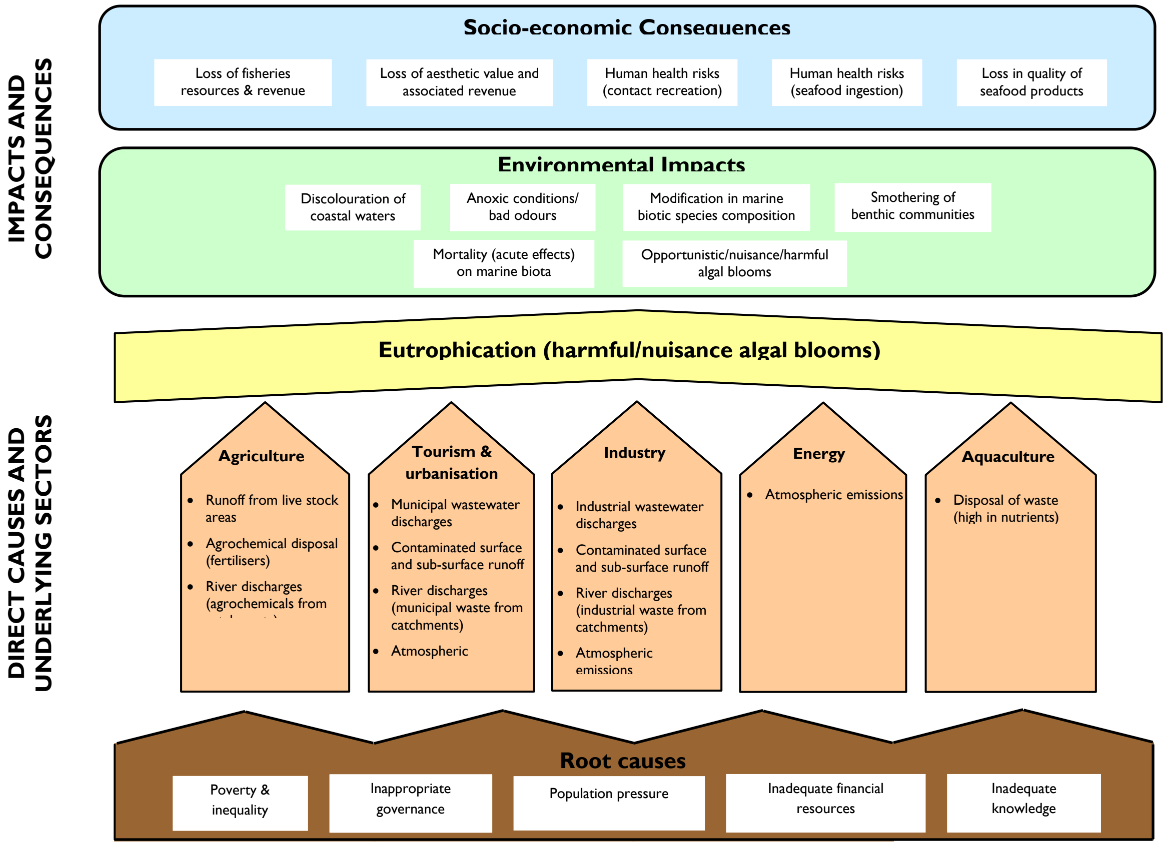


Figure 9: Problem tree: Eutrophication

A broad range of stakeholders are potentially affected by eutrophication/algal blooms, from local communities to larger sectors such as fisheries, aquaculture and tourism, which bear socio-economic consequences which include:

- Loss of aesthetic value
- Risks to human health in terms of contact recreation and ingestion of contaminated seafood

- Loss of artisanal and/or commercial fisheries and aquaculture.

Within the WIO region, there is some evidence of anthropogenic sources of nutrient enrichment that impact on coastal ecosystems through harmful or nuisance algal growth. Along the Kenyan coast, Uku (1995, 2005) and Uku and Björk (2005) demonstrated an abundant growth of epiphytic algae on seagrass and the dominance of the green algae (*Ulva* and *Enteromorpha* sp.) in areas adjacent to dense tourism development, where epiphytic cover reaches up to 69% in the more developed areas. Nuisance algal growth, affecting the recreational (aesthetic) value of coastal resources has also been reported in Mauritius where, for example, high nitrate concentrations introduced into lagoon systems through agricultural return flows have been associated with algal proliferation in the lagoons of Belle Mare/Palmar. As a result, many hotels have had to remove algal deposits from the shoreline on a weekly basis (Dulymamode *et al.,* 2002).

At Flic en Flac, black anoxic sands, smelling of hydrogen sulphide, have been observed at the low water mark and are associated with organic enrichment from wastewater discharges (Prayag *et al.,* 1995). Also in Mauritius, domestic sewage released to coastal waters from urban areas and poorly planned housing developments on reclaimed wetlands is a cause of eutrophication/algal blooms that lead to the smothering of coral reefs. Algal blooms are observed annually at Trou aux Biches and isolated cases have been reported at Bain des Dames near Port Louis. High levels of nitrate and phosphate and associated proliferation of algal growth have been recorded at both Belle Mare and Flic en Flac (Prayag *et al.,* 1995; Botte, 2001). Nutrient enrichment of lagoon waters also results in increased algal growth over coral affecting their biology and the coral reef ecosystem as a whole (Botte, 2001).

Jones *et al*., (2002) identified eutrophication/algal blooms as a major issue in some of the sensitive areas around the coast of the Seychelles, although the report did not include any quantified scientific evidence of this.

Along the South African coast, estuarine systems typically act as nutrient purifying systems where, nutrients from catchments are absorbed, resulting in cleaner water entering the sea. Excessive weed growth or phytoplankton blooms in estuaries provides evidence for this nutrient removal (Snow *et al.*, 2000; Taljaard *et al.,* 2000). This is particularly evident during low flow periods (dry seasons) when river runoff entering the estuaries may have high nutrients levels due to agricultural irrigation return flows. High nutrients levels in estuaries can also result from longer residence times within the estuaries, for example during weak neap tides when tidal exchange is reduced (Taljaard *et al.,* 2006).

In the Tanga area of Tanzania, proliferation of macroalgae has been reported in coastal waters due to nutrient loading from municipal wastewater and industrial discharges, particularly from a fertiliser factory (see Munissi, 1998). Munissi (2000) also demonstrated the association of *Ulva* spp. and *Enteromorpha* spp. with nutrient input from sewage pipes. In Zanzibar, eutrophication/algal blooms, associated with the release of inorganic nutrients from domestic sewage, has been identified as one of the main causes for a decrease in coral-reef-building algae (Bjork *et al.*, 1995). Coralline algae are sensitive to phosphate and are disappearing from phosphate-rich areas (Bjork *et al.*, 1996).

There is therefore, good evidence of impacts associated with nutrient enrichment from land-based activities in the WIO region. The problem is mainly confined to sheltered environments such as estuaries and creeks where weak water circulation generally limits the assimilative capacity for nutrient and biodegradable organic matter. However, with the rapid increase in coastal urbanisation (and associated generation of municipal waste) as well as a projected increase in commercial agricultural and industrial activities in the region, nutrient loads to the marine environment could increase markedly over the next years. This may challenge the assimilative capacity of wider coastal regions in the WIO.

3.5 Summary of transboundary impacts

In summary, Table 12 provides an overview of the key impacts that can be associated with each of the priority transboundary problems discussed in this the chapter.

TABLE 12: Overview of key impacts associated with the major (or transboundary) marine pollution problems identified for the WIO region

TRANSBOUNDARY PROBLEM					ENVIRONMENTAL IMPACTS
Microbial contamination	Eutrophication	Marine litter	Suspended solids	Chemical pollution	
	X		X	X	Modification in marine biotic species composition
	X		X		Smothering of benthic communities
		X	X		Entanglement/suffocation of marine organisms
			X	X	Chronic effects on marine biota
	X		X	X	Mortality (acute effects) on marine biota
	X				Opportunistic/nuisance/harmful/toxic algal blooms
	X		X	X	Discoloration of coastal waters
	X				Anoxic conditions/bad odours
X					High levels of pathogenic organisms
					SOCIO-ECONOMIC CONSEQUENCES
	X	X	X		Loss of aesthetic value
X	X	X		X	Human health risk through contact recreation
X	X			X	Human health risk through ingestion of contaminated seafood
X	X		X	X	Loss in quality of seafood products
	X		X	X	Loss of fisheries resources and revenue

4. CAUSAL CHAIN ANALYSIS

4.1 Direct causes and underlying sectors

In the WIO region, transboundary problems and associated impacts of marine pollution from land-based sources can be attributed to a number of direct causes and underlying sectors. There can be several causes for a particular marine pollution problem and, on the other hand, a single direct cause can result in several different problems. This is illustrated in the summary of the main direct causes (linked to land-based activities) of key marine pollution problems (Table 13). The direct causes (in terms of land-based sources) can roughly be divided into a number of key underlying sectors, namely:

- Urbanisation and tourism
- Agriculture and forestry
- Industry and mining
- Transportation (including harbours)
- Energy production

- Aquaculture.

Activities within each of the most important underlying sectors contributing to transboundary marine pollution problems in the WIO region are further explored in the following sections.

4.1.1 Urbanisation and tourism

Of increasing concern in the countries of the WIO region is rapid and often uncontrolled urbanisation (including tourism developments) occurring in coastal areas. Uncontrolled urbanisation results in increases in municipal wastewater, municipal solid waste and atmospheric emissions (e.g. from fossil fuel burning and vehicular traffic) which are often not properly managed or controlled, thereby contributing to many of the priority transboundary marine pollution problems seen in the region (see Table 13).

TABLE 13: An overview of direct causes and underlying sectors linked to transboundary marine pollution problems related to land-based activities

TRANSBOUNDARY PROBLEM					DIRECT CAUSE	UNDERLYING SECTOR
Microbial contamination	Eutrophication	Marine litter	Suspended solids	Chemical Pollution		
X	X		X		Disposal of un- or under-treated municipal wastewater	Urbanisation, Tourism
X	X		X	X	Industries discharging un- or under-treated wastewater	Industry
			X	X	Dredging activities	Transportation
X	X		X	X	Waste from coastal mining and exploration activities	Mining
X	X	X	X	X	Contaminated surface and sub-surface runoff (e.g. from municipal, industrial and agricultural areas, as well as from accidental spills)	Urbanisation, Tourism, Industry, Mining, Transportation, Agriculture
			X		Destruction of coastal forests contributing to high suspended solid loads	Forestry
X	X	X	X	X	River discharges transporting high suspended solid loads (as a result of soil erosion) and/or transporting municipal/ industrial waste and agrochemicals from catchments	Agriculture. Urbanisation, Industry
	X			X	Leaking and leaching of agrochemical (fertilisers and pesticides) from inadequate storage facilities, dumping or return-flows	Agriculture
X	X				Runoff from livestock rearing areas	Agriculture
	X			X	Atmospheric emissions (e.g. incineration of waste, vehicle and industrial emissions and wood/coal burning)	Industry, Urbanisation, Tourism, Energy production
X		X		X	Inadequate collection, treatment and disposal of solid waste	Urbanisation, Tourism, Industry, Transportation

		X			Public littering on beaches and in areas where litter can be transported into coastal areas	Urbanisation, Tourism
	X		X		Waste products from aquaculture farms that are high in nutrients and suspended solid loads	Aquaculture

i. Municipal wastewater

Untreated sewage from sanitary facilities (septic tanks, pit latrines and malfunctioning wastewater treatment plants) is a major source of marine water quality degradation in many of the countries in the WIO region (Anon Madagascar, 2006; Anon Mozambique, 2006; Munga et al., 2006; Mohammed et al., 2006; Abdallah et al., 2006). Available information on municipal wastewater loads in coastal areas in the WIO region varies from one country to another, with some countries having detailed information on waste loads and others with very limited and often only qualitative information. The level of treatment of municipal (or domestic) wastewater, as well as the type of treatment (or lack thereof) also differs from one country to another (Kayombo, 2007, see Table 14).

TABLE 14: Indication of level of treatment of municipal (or domestic) wastewater in different countries of the WIO region (Kayombo, 2007 unless otherwise indicated)

COUNTRY	ESTIMATED COASTAL POPULATION	PERCENTAGE OF POPULATION (numbers in brackets)			
		Central sewer systems	Septic tanks & soak-aways	Pit latrines	No system
Comoros (WHO and UNICEF, 2000; WHO, 2003)	838399	0.3 (30702)	5.3 (44346)	94 (790980)	-
Kenya (major coastal towns)	844412	12 (96987)	17 (146050)	71 (601375)	-
Madagascar (Mong, 2007; UNEP, 2007)	3940894	-	11 (429309)	70 (2759165)	19 (752420)
Mauritius	1260400	25 (315100)	73 (920092)	2.0 (25208)	
Mozambique (Mozambique Demographic and Health Survey, 2003)	2035324	-	3.1 (64988)	36 (732717)	48.7 (991447)
Seychelles (Montano, 2007)	89575	7.5 (6712)	87.6 (78489)	3.6 (3195)	1.3 (1179)
South Africa[a] (25 coastal municipalities) (derived from Statistics South Africa, 2008)	8994000	47 (4255000)	4 (353000)	18 (1652000)	15 (1330000)
Tanzania (large coastal towns - Tanzania mainland and Zanzibar)	24603587	2.8 (677205)	9.8 (2423160)	81.5 (20046107)	5.9 (2243011)

a *Western Indian Ocean region, i.e. Provinces of Eastern Cape and KwaZulu-Natal (population of 25 coastal municipalities). Note that 16% of the population (1414000) uses other systems e.g. dry and chemical toilets (14.5%) and bucket systems (1.5%)*

Available data on estimated volumes and loads of selected pollutants associated with municipal wastewater in coastal areas of the WIO region are provided in Table 15 and Table 16, respectively.

TABLE 15: Estimated volumes of municipal wastewater generated in coastal areas of the WIO region (i.e. potentially entering the coastal zone)

COUNTRY	ESTIMATED VOLUME (m^3/day)
Comoros	168[a]
Kenya (Mwaguni, 2007, Kayombo, 2007)	145500
Madagascar (Kayombo, 2007)	No data readily available
Mauritius (Radhay, 2007)	100000
Mozambique	29149[c]
Seychelles	4922 (10372[b])
South Africa[d]	255000 (offshore, preliminary treatment) 46300 (surf zone, secondary treatment) 31500 (estuaries, secondary treatment)
Tanzania (Tanzania mainland and Islands)	37912

a. *Assuming 0.8% of population is sewered with an estimated 20 kl/capita/yr given by UNEP, 1982*
b. *Volume of wastewater to be collected and treated after planned extension of systems*
c. *Assuming 15% of population is sewered with an estimated 20 kl/capita/yr given by UNEP, 1982*
d. *Western Indian Ocean region, i.e. Provinces of Eastern Cape and KwaZulu-Natal (RSA DWAF, 2004)*

TABLE 16: Estimated loads of organic material (BOD), suspended solids and nutrients generated from municipal wastewater in coastal areas of the WIO region (Kayombo, 2007)

COUNTRY	ESTIMATED LOADS (tonnes/year)[a]			
	BOD	SUSPENDED SOLIDS	NITROGEN	PHOSPHOROUS
Comoros	489	1,063	212	26
Kenya	2744	3889	802	97
Madagascar	2962	6869	1417	172
Mauritius	598	1388	286	35
Mozambique	1137	1203	108	26
Seychelles	541	1254	259	31
South Africa[b]	39502	30478	4518	2259
Tanzania	21741	50413	10398	1260

a. *Loads from septic tanks calculated as per WHO (1982) unless otherwise stated*
b. *Western Indian Ocean region, i.e. Provinces of Eastern Cape and KwaZulu-Natal (using volumes from Table 5 and estimated concentrations for raw sewage provided in WRC (1990) with secondary treatment concentrations derived from percentage removal estimated in WHO (1982)*

To varying levels, municipal wastewater enters marine environments through seepage or rivers in all of the countries of the WIO region. Microbial contaminants, nutrients and suspended solids are the main pollutants in untreated municipal wastewater. Highest concentrations of these pollutants are found close to the major cities in the region, although in many rural coastal areas low-level sewage contamination from defecation on beaches or in coastal bush is common.

From the above analysis, it may be concluded that the highest pollutant loads entering the WIO originate from the mainland states (mainly South Africa and Tanzania) and Madagascar. This is not surprising considering the size of the coastal cities in these countries. However, in the case of South Africa, about 74% of the municipal wastewater is discharged to the offshore marine environment through properly designed marine outfalls where the quantity and composition of the effluent must be within limits that meet site-specific environmental quality objectives (RSA DWAF, 2004). In terms of wastewater volumes, countries having a high level of water-borne sewerage reticulation system obviously discharge relatively more wastewater than those whose pollution is mainly served by offline systems (pit latrines, septic tanks and soak-away pits). The example in this case is Mauritius, which generates equal or more wastewater than most (much larger) mainland states, although the pollution (BOD, nitrate, phosphate and suspended solid) loads are much lower.

ii. Solid waste disposal

Information and data on the quantities of solid waste disposed in coastal areas of the WIO region varies considerably from country to country (Lane, 2007). Marine litter has been researched in South Africa for over two decades and there is information on the abundance, distribution and trends of different types of litter found around the coast. The sources of the litter are inferred rather than demonstrated, but it is obvious that most of it originates from littering and inappropriate waste disposal on land. Seychelles has a good waste management system in place and has established that it contributes almost no marine litter. Mauritius also shows the ability to contain solid wastes. Mozambique, despite its poverty and inadequate governance, knows that it similarly contributes very little to the marine litter load. This is because it has a very poor transport infrastructure and the vast majority (about 70%) of the population lives in rural poverty with limited access to products with plastic packaging. Additionally, informal recycling of most salvageable products is commonplace. These factors have kept solid waste loads that may contribute to marine litter under control thus far, but this situation may change (Lane, 2007).

In Tanzania, Madagascar and Kenya there is relatively little information on the quantities, types and characteristics of solid waste that contribute to marine litter. It is, however, known that large quantities of litter from urban areas do reach the sea. The main reason for the littering is that none of these countries has an adequate solid waste management system (Lane, 2007).

A feature common to all countries is that most land-based sources of solid waste are associated with urban centres, particularly informal settlements and industrial and commercial areas, and that wastewater runoff is the main distributor via rivers, streams and stormwater drains. According to Lane (2007), the major land-based sources of marine litter are:

- Solid waste dump sites (legal and illegal) located on the coast or on rivers banks
- Surface water runoff (from stormwater drains, untreated municipal wastewater)
- River discharge and flood waters
- Industrial wastewater discharges
- Public litter on beaches and other coastal areas.

The major sources of solid waste contributing to marine litter in each of the countries of the WIO region as summarised by Lane (2007) are presented in Table 17.

TABLE 17: Summary of major sources of marine litter in the countries of the WIO region (Source: Lane, 2007, unless otherwise referenced)

COUNTRY	MAJOR SOURCES
Comoros	Of particular concern is waste from hospitals, including compresses, syringes, braiding, packaging, plastic, glass and human waste discharged in open dumpsites, usually in the vicinity of the hospitals (Abdallah *et al*., 2006).
Kenya	The major sources of marine litter are reported to be beach recreation (66%), shipping (14%), dumping and surface runoff from urban areas.
Madagascar	The major sources are dumping on the beach and surface runoff from urban/industrial areas (including medical and household wastes) and other areas with crude land dumping practices. There are also reported to be numerous shipwrecks that contribute substantially to marine litter, occurring particularly during the annual cyclone period.
Mauritius	Marine litter arises chiefly from beach recreation, surface runoff from urban areas and from rivers. The volume of ship-generated garbage is far smaller than land-generated volumes.
Mozambique	Beach users, garbage from shipping, fishing gear, road users and urban stormwater runoff are the major sources of litter.
Seychelles	Most litter is from water runoff from rivers and storm drains, despite daily cleaning, from

COUNTRY	MAJOR SOURCES
	port wastes and particularly from public eating spots or picnic areas. Data are not available for litter generated by the fishing industry.
South Africa	The major source of marine litter is surface runoff from urban areas (via rivers and storm drains), confirmed by (a) litter deposition being greatest in the rainy season (winter in the Cape) and higher levels close to urban areas; and (b) the high proportion of South African-made articles (96%) in stranded litter. Commercial, industrial and low income residential areas produce most litter. Ship-generated waste in South Africa is trivial compared to land-based litter sources. Some litter comes across the South Atlantic in the West Wind Drift from Argentina, Uruguay and Brazil. Marine litter on uninhabited oceanic islands derives from local and foreign fisheries, and distant continents.
Tanzania	The major source of marine litter arises from uncontrolled disposal of solid wastes in unplanned settlements where, for example, about 70% of Dar es Salaam's population live. Most litter is from surface runoff, illegal dumping into river valleys and drainage from crude, open dump sites located near the beach and rivers. Marine litter also arises from fishing and shipping, as the important economic city of Dar es Salaam has a moderate-sized port and fishing is a major activity amongst the coastal communities. The latter are presumed to contribute a significant quantity of gear, boats, traps, and plastic bottles to marine litter.

iii. Atmospheric emissions

Activities linked to urbanisation, tourism and subsistence agriculture that contribute to marine pollution through atmospheric emissions include:

- Fossil fuel fires: a large majority of coastal communities in the WIO region use fossil fuel for their domestic energy needs (therefore also linked to the energy production sector)
- Traffic emissions: motor vehicles emissions can contribute significantly to atmospheric pollution
- Forest burning for land clearing: urban development adds pressure on land for growth.

Atmospheric pollutants can also originate from solid waste dump sites and burning of waste. Rotting processes cause odour problems and methane gas emissions, while burning of wastes generates smoke which is aesthetically unpleasant and also contains other pollutants, such as particulate matter and gases from burning plastics.

Data on atmospheric emissions (e.g. suspended solids, nitrogen, trace metals and hydrocarbons), particularly those which contribute to marine pollution, are lacking for the entire WIO region. In Mauritius, South Africa and Tanzania, atmospheric emissions are being monitored in some of the coastal centres (see Dubula *et al.*, 2007; Mohammed *et al.*, 2006; Anon Mauritius, 2006), but this fails to provide insights into the actual loads being deposited in the marine environment.

Based on the rapid increase in urbanisation and tourism development, particularly within the main urban centres of the WIO region, it can be expected that pollutant loads from atmospheric emissions (e.g. nitrogen, trace metals and hydrocarbons) have increased markedly over the past years and this requires further quantification and assessment.

4.1.2 Agriculture and forestry

Agriculture is the backbone of the economy in most countries in the WIO region and is central to the alleviation of poverty and revenue generation. Agricultural activities contribute mainly to marine pollution in that they produce elevated levels of four types of pollutant; suspended solids (the result of erosion due to inappropriate land use practices), inorganic nutrients (excessive use of fertilisers), pesticides (persistent organic pollutants) and microbial contaminants (typically associated with runoff from livestock rearing areas). Slash and burn clearing for subsistence agriculture adds to the atmospheric pollution in some countries. Pollutants from agricultural activities usually enter the marine environment through river discharges, although agricultural activities adjacent to coastal areas can directly contaminate coastal waters through surface or sub-surface runoff.

Agro-chemical pollutant loads in river discharges to the sea (i.e. the main route through which pollutants enters the marine environment) have not been determined for the majority of the countries in the WIO region. The sale or application of agricultural fertilisers and pesticides have often used as a proxy for the extent of pollutant inputs from agricultural activities. However, such information can be misleading, particularly for the mainland states, as data are either quoted for the entire countries (therefore overestimating the coastal pollution loads) or only for certain catchments or coastal districts (possibly underestimating coastal pollutant loads) (UNEP, 1998). The physical effects of soil erosion in river basins and the subsequent impacts related to suspended solid loading and siltation in coastal systems are currently of greater concern than agrochemical pollution in most countries throughout the region. Impacts from soil erosion are most notable along the coasts of Kenya and Madagascar (UNEP, 1998).

Agricultural activities in the countries of the WIO region are increasing and are becoming more industrialised. This increases the risk of soil erosion and the use of agro-chemicals. Even without substantial scientific evidence of existing impacts, it can be expected that marine pollution associated with agricultural activities may well increase in coming years, unless appropriate environmentally-sustainable agricultural practices are promoted within the large river basins discharging into the WIO region.

In the Comoros agricultural production occupies approximately 67% of land and accounts for 98% of export revenue. The main export crops include vanilla, ylang-ylang and cloves. Cereals, rice, potatoes, fruits and legumes are also grown for local consumption. As a general rule, the use of pesticides and fertilisers for market gardening is limited. The total quantity of pesticides used between 1991 and 1993 was approximately 70000 kg. Steep slopes and continuous cultivation without the provision of fallow fields have led to the impoverishment of the soil and incidents of serious soil erosion, and subsequent siltation of the coral reefs. Agricultural runoff is also considered to have led to the pollution of groundwater, although there are no data on which an assessment of the problem can be made. Almost all the organic waste coming from the agricultural practices is reintroduced into the soil to improve fertility (Abdallah *et al.,* 2006).

Although Kenya's coastal region is important for the production of vegetables and tropical fruit and some livestock rearing these activities only makes up a small proportion of the land use. Thus, apart from the two large commercial sisal farms (which also rear livestock) located 30-60 km north of Mombasa, agricultural activities are mostly subsistence. Agricultural chemicals and fertilisers are being used by some of the larger farms in Mombasa, Kilifi, and Lamu. Potential sources of persistent organic pollutants that are being used, although still on small scale, include organochlorine insecticides, organophosphorous, carbamates and pyrethroids (for food crops) and herbicides such as 2, 4-Diamineand 2,4,5- Triamine are also used. However, the use of agrochemicals (e.g. pesticides and fertilisers) is increasingly replacing traditional farming methods, even on the smaller farms (UNEP/GPA, 2002).

Livestock rearing is considered to be the major source of pollution from agricultural activities in Kenya. The combined BOD load from livestock wastes in the districts of Mombasa, Kwale, Kilifi and Lamu districts has been estimated to be 1855 tonnes. In the Kilifi district agricultural activities contribute significantly to marine pollution, with large livestock farms such as Vipingo Estate Ltd, Kilifi Plantations Ltd and the Agricultural Development Corporation farm in Malindi, situated along the coast. For example, the combined nitrogen and phosphorous loading to the coastal environment from the Kilifi Plantations Ltd and Vipingo Estate Ltd farms was estimated at 92.5 and 5.3 tons/year, respectively. These farms manage low-density pasture units, where livestock waste is used as manure. Some of the busiest slaughterhouses in the area are also located on the farms, further contributing to marine pollution (e.g. through microbiological contamination and nutrient enrichment). In Kwale district mainly dairy cattle are kept along the coastline (UNEP/GPA, 2002).

River discharges are the main route through which suspended solids and agrochemicals reach coastal areas, particularly during the rainy season. The Tana and Athi Rivers drain hinterland agricultural areas, carrying significant quantities of nutrients into their estuaries. Wandiga (2001) reported estimated loads reaching the coast from the Sabaki and Ramisi Rivers in Kenya (Table 18). Poor agricultural practices along the major river basins and on steep slopes enhance soil erosion resulting in the transportation of high loads of suspended sediments through river discharges into the sea causing siltation in estuaries, adjacent beaches and mangroves. Shadowing and/or smothering of coral reefs and seagrass beds occurs (Munga *et al.,* 2006).

TABLE 18: Estimated loads for pesticides from rivers into coastal regions of Kenya (Wandiga, 2001)

PESTICIDE	ESTIMATED ANNUAL LOAD (kg/year)	
	Sabaki River	Ramisi River
Lindane	400	-
Aldrin	60	1.0
Dieldrin	400	0.009
Alpha-Endosulfan	400	1.0
p,p'DDT	360	1.0
p,p'DDD	600	0.3
p,p'DDE	400	0.4

Solute and sediment transport modeling studies to assess the fate of pesticide residues and nutrients from agricultural activities have been conducted for the Mombasa coastal region (Munga *et al.,* 2006) while nutrient loads from the Sabaki River was reported in Ohowa (1996) (Table 19).

TABLE 19: Estimated nutrients load introduced to coastal areas in Kenya (EU-GROFLO, 1998; KWS Netherlands Wetland Project, 1998; Ohowa, 1996)

COASTAL REGION/RIVER	GROUNWATER DISCHARGE (tonnes/year)	
	Nitrogen	Phosphate
Nyali (south coast)	1.8	-
Diani (south coast)	0.4	-
Mida Creek	780	1.6
Sabaki River	415	840

In Madagascar, cattle-rearing and rice production are the main agricultural activities, although small areas of intensive production of sugar cane and cotton are located in the southwest and northwest of the country, where the greatest quantities of fertilisers and pesticides are applied. The application of fertilisers in intensive agricultural areas was reported to be as high as 163 kg/ha in 1990, and has been linked to localised algal blooms and reduced fish catches in lagoons and particularly around the reef at Toliara (Anon Madagascar, 2006). However, no research has been reported to date to prove cause and effect (UNEP/GEF, 2002).

The clearing of forests for agricultural purposes in Madagascar is of concern as it causes serious erosion. Rivers transport high sediment loads to the coast which smother sensitive coastal habitats (siltation), including coral-reefs, particularly on the west coast. The major causes include bush-fires, harvesting of forests for production of charcoal and clear-felling for agriculture purposes. Little is being done in the way of reafforestation to reduce soil erosion. Although algal blooms have been observed in coastal waters of the region, it is not clear if this is as a result of agricultural activities. To date, algal blooms around coastal urban centres have generally been associated with inorganic nutrients derived from domestic-sewage pollution (UNEP/GEF, 2002).

Atmospheric pollution (e.g. particulate matter) associated with the burning of sugar cane field prior to harvesting is also of concern in Madagascar, particularly in Nosy Be, Ambilobe, Namakia, Brickaville (Anon Madagascar, 2006).

Until the late seventies, agriculture was the main foreign exchange earner in Mauritius. It was also the largest sector in terms of output and employment. The area under cultivation in Mauritius (90100 ha) represents about 48% of the island. Sugarcane cultivation occupies about 77000 ha, covering about 90% of the arable land. The rest of the agricultural land is used for tea, tobacco and food crops. The main food crops cultivated are onion, tomato, chilli and eggplants (UNEP/GEF, 2002; Anon Mauritius, 2006). Despite the decrease in agricultural activities, the island has a long history of pesticides use and using the import figures of agrochemicals as a proxy for potential impacts on the coastal environment, this appears to be significant. Approximately 1153 tons of pesticides are imported annually, out of which 59% are herbicides, 31 % insecticides and 8% fungicides. The vast majority of the country's 35000 small scale farmers use hand sprayers, resulting in wastage and spillage of the pesticides. In addition, plant growth regulators and fruit and cane ripeners are being increasingly used. Some agrochemical importers are also still selling banned pesticides on the island. However, over the past decade there has been a systematic conversion of agricultural lands to land for industrial and urban development with agricultural land decreasing by approximately 5500 ha. Associated with this is also a reduction in the utilisation of agro-chemicals. For example 61266 tonnes of fertiliser was used in Mauritius in 2004. This decreased by about 3.5% in 2003 (63507 tonnes) (Anon Mauritius, 2006).

Most of the agriculture activity takes place along, or close to, the main river basins in Mozambique. River discharges are the main pathways through which suspended solids and agrochemicals enter coastal environments. Rivers with intensive agricultural activity include the Monapo (in Nampula Province), the Zambezi (with agricultural activity of Zimbabwe and Zambia, among others), the Pungoé (with tobacco plantations in Zimbabwe), the Limpopo and the Incomati (used in intensive farming in South Africa) and the Umbeluzi (used for sugar cane plantation in Swaziland) (Massinga and Hatton, 1997).

Presently the contribution of Mozambique farming to the pollution of coastal waters is considered to be negligible, considering that mechanized farming in the country occupies only 8% of the total cropland. However, increased foreign investment after the war is resulting in an increase in agriculture activity. Although DDT is officially banned in Mozambique, it is unfortunately still being used in thye country and neighbouring regions. The common pesticide residues identified are 2,4,5 TCB, pp DDD, pp DDT, pp DDE, Lindane and HCB (Massinga and Hatton, 1997).

Pollution from agricultural activities has not been properly assessed in the Seychelles. However, agriculture does not represent a significant proportion of land use on the island (4% of the total area) or of the GDP. Agriculture only takes place on a local scale, often for own use only (UNEP/GEF, 2002).

No data on pollutant loads entering the marine environment from agricultural activities were easily obtainable for South Africa. River discharges, draining intensive agricultural areas are, however, considered the main transport mechanism by which agricultural pollutants enters marine environments. For example, the Gamtoos River, associated with intensive agriculture and discharging on the South African south coast, introduces high nutrient loads to its estuary causing eutrophication (Snow *et al.,* 2000).

Water quality is monitored in many of South Africa's rivers as part of a national monitoring programme (RSA DWAF, May 2007), but monitoring points are typically located far upstream in the catchments and are generally not representative of the loads that ultimately enter the estuaries or marine environments. Estimated nutrients loads (nitrogen plus phosphorous) entering the estuaries of a number of rivers along the South African are provided in Table 20. These nutrients are mainly derived from agricultural activities in the catchments (Taljaard *et al.,* 2006).

TABLE 20: Estimated nutrient loads entering the marine environment from selected rivers n South Africa (mainly nitrogen and phosphorous associated with agricultural activities in the catchments, Taljaard *et al.*, 2006)

RIVER	ESTIMATED NUTRIENT LOAD (tonnes/yr)
Orange (west coast)	150
Breede (south coast)	250
Thukela (east coast)	860

Agriculture employs about 80% of Tanzania's population and accounts for about half the GDP. Most agriculture in Tanzania occurs in river valleys and flood-plains. However, the extent of agricultural pollution has not yet been evaluated. To control pests, diseases and improve farm yields, the agricultural industry in Tanzania uses a range of agrochemicals, many of them imported. The pesticides commonly used in Tanzania include aldrin, dieldrin, lindane, endosulfan and heptachlor. Poor storage and transportation of such chemicals may result in accidental spills into freshwater and marine systems (UNEP/GEF, 2002).

In Zanzibar, agricultural activities are still artisanal in nature, dominated by the cultivation of food crops rather than cash crops. These food crops include banana, cassava, yams, sweet potatoes, rice, millet and maize. Sugarcane is cultivated in the northern district. The use of fertilisers and pesticides has remained relatively low. Fertilisers are used mainly in rice and sugarcane cultivation. However, given that supply of the chemicals is often erratic, their use has been severely curtailed. For example, use of fertiliser dropped from 2800 tonnes in 1988 to 406 tonnes in 1996 (Ministry of Agriculture, Zanzibar). According to the Zanzibar livestock census of 1993, there are about 73000 domestic animals on the island. Most of these animals are taken to communal dips, to protect them against diseases. Poor management of these dips results in an estimated 300000 litres of waste disposed annually (Mohammed *et al.,* 2006). Given that the majority of smallholdings do their own dipping/spraying, the amount of waste produced through livestock rearing can be much greater (UNEP/GEF, 2002).

The destruction of coastal forests also contributes to high suspend solid loading in coastal areas, although no quantitative data are currently available for the WIO region.

4.1.3 Industry and mining

Major industries and mining activities situated within coastal areas of the WIO region include:

- Textile industries
- Tanneries
- Paper and pulp mills
- Breweries
- Chemical factories including production of agrochemicals and pharmaceuticals
- Cement factories
- Sugar refineries
- Food processing industries (e.g. fish factories and slaughter houses)
- Fertiliser factories
- Oil refineries
- Oil and gas exploration (an emerging activity).

These industries and mining activities contribute, or potentially contribute to transboundary marine pollution problems through inappropriate disposal of liquid wastewater, solid waste or atmospheric emissions. An overview of the industries and mining activities and their potential contribution to transboundary marine pollution problems is presented in Table 21.

In the Comoros, processing industries associated with agricultural and livestock production (including food processing) account for 85% (14.41 tonnes per annum) and 92% of the BOD and suspended solid load, respectively (Abdullah *et al.*, 2006). However, the loads of BOD, suspended solids and solid waste produced by such industries are considered to be small in comparison to domestic waste loads.

In the coastal areas of Kenya, most industrial activity is situated in and around the Mombasa, Kilifi and Lamu districts. Very few industries treat their wastewater which is discharged either to municipal sewers or stormwater drains. Due to the proximity of industrial areas to the natural drainage systems, most of the pollution generated on Mombasa Island and the surrounding mainland shores ends up in the creeks around Mombasa. The solid wastes from industries are of unknown composition and quantity, but are likely to include hazardous components (Mwaguni and Munga, 1997). The petroleum refinery at Changamwe produces considerable hazardous sludge (containing toxic substances such as hydrocarbons and heavy metals) which is dispersed on agricultural land within the refinery grounds. Large quantities of solid waste are produced by cashew nut and sisal processing factories, producing about 15330 and 8400 tonnes/year respectively. The sisal processing industry also discharges considerable quantities of liquid waste directly into the sea, thereby introducing a significant BOD load.

TABLE 21: Overview of key industries and their potential contribution to transboundary marine pollution problems in the WIO region

INDUSTRY TYPE	TRANSBOUNDARY PROBLEM				
	Microbial contaminants	Eutrophication (nutrients)	Marine Litter (solid waste)	Suspended solids	Chemical pollution
Manufacturing			X		X
Textile factories		X		X	X
Sisal processing		X	X	X	
Tanneries		X	X	X	X
Paper and pulp		X	X	X	

INDUSTRY TYPE	TRANSBOUNDARY PROBLEM				
	Microbial contaminants	Eutrophication (nutrients)	Marine Litter (solid waste)	Suspended solids	Chemical pollution
Breweries		X	X	X	
Chemical factories		X		X	X
Cement factories			X	X	
Sugar production		X	X	X	X
Food processing (including fish)	X	X	X	X	
Fertiliser factories		X		X	X
Oil refinery				X	X
Oil and gas exploration				X	X

Most industrial activities in Madagascar are situated in coastal urban centres, mainly near the ports of Antsiranana, Ambilbe, Mahajanga, Tolagnaro and Toamasina. The exception is the textile industry, which is primarily located inland at Antananarivo. Coastal industrial activities are focused on seafood processing, sugar extraction, oil and soap production, breweries, tanneries and sisal production (Anon Madagascar, 2006). The majority of these industries do not treat their waste. However, where there is some treatment, it is limited to coagulation and decanting, or to decanting only prior to discharge into a treatment system or directly into the sea (Anon Madagascar, 2006; Kayombo, 2007). By comparison with municipal waste, the pollution load from industry is considered to be relatively small.

In Mauritius, about 10 million cubic metres of industrial wastewater is produced annually. Most is discharged to treatment plants (Anon Mauritius, 2006) from industries that include sugar production (the largest contributor), textiles (e.g. dye houses), breweries and food processing plants. Plaine Lauzun, Vacoas-Phoenix and Coromandel are the main industrial zones in Mauritius. The Coromandel industrial zone, comprising mostly of dye houses and soap and food processing industries, directs wastewater to Mt Jaquot Wastewater Treatment Plant prior to discharge through a 600 m long marine outfall into Pointe aux Sables lagoon. Industries in Plaine Lauzun and Vacoas-Phoenix discharge wastewater directly to the St Martin wastewater treatment plant. Other major wastewater treatment plants are located at Grand Baie and Baie du Tombeau. The estimated pollution load from the 31 major industries located in Mauritius introduces 1117 tonnes of BOD, 17 tonnes of nitrogen, 81 tonnes of total phosphorous and 2306 tonnes of suspended solids to the marine environment annually (source: Wastewater Management Authority, 2007).

Most industrial facilities in Mozambique are located in the coastal urban centres of Maputo, Matola and Beira and include textile, paper and tyre factories as well as a brewery. Most of these industries discharge untreated wastewater into the Infulene River that drains into Maputo Bay (Anon Mozambique, 2006). The total number of industrial units listed for Maputo has increased from eleven in 1982, to 29 in 1992 and 137 in 1996. These industries produced a total of 79388 tonnes of BOD in 1996, including an unknown quantity of waste containing heavy metals such as mercury, lead, chromium, manganese, nickel and zinc (Anon Mozambique, 2006).

Major industries in the Seychelles known to be sources of marine pollution are the food processing and chemical industries. Estimates of BOD loads introduced to the coastal water environment by industrial activities indicate that the food processing industries dealing with agriculture and livestock products account for 71.6% and 88.7% of the BOD and suspended solid loads, respectively (Radegonde, 1997). Other major contributions are from the fish processing and canning industries (also food processing industries) which account for 17.7% and 6.7% of the BOD and suspended solid loads respectively. The brewing industry is reported to contribute 18% to the total BOD load. In Seychelles, industrial waste accounts for only 17.5% of the total BOD load discharged into the environment, with 72% derived from stormwater runoff and municipal wastewater. Fifty six percent of the suspended solid load was reported to be derived from industrial waste, with the remainder being derived from municipal sources.

In South Africa, industrial wastewater disposed to the WIO region occurs mainly in the larger urban centres along the east coast (e.g. Port Elizabeth, East London, Durban and Richards Bay) where an estimated 308100 m^3/day of industrial wastewater is discharged to the sea. Most of this effluent is discharged to the offshore environment through properly designed marine outfalls that are subject to regular environmental monitoring and assessment studies (RSA DWAF, 2004; Taljaard *et al.*, 2006) (Table 22).

TABLE 22: Estimated volume for industrial wastewater (point sources) discharged directly into the marine environment of South Africa (RSA DWAF, 2004)

URBAN CENTRE	ESTIMATED VOLUME (m^3/day)					
	Food (fish) processing	Oil refinery	Chemical	Paper & pulp	Fertiliser	Textile
Port Elizabeth	-	-	-	-	-	-
East London	-	-	-	-	-	1800
Durban	-	-	9700	87000	-	3600
Richards Bay	-	-	120000 (combined) 86000 (gypsum)			-

* During production periods, not throughout year

Although the level of industrialisation in Tanzania is considered to be relatively low, disposal of untreated industrial waste causes localised pollution. About 80% of the industries in Tanzania, including food processing industries (agro-industries), chemical factories, breweries, soap and steel manufacturing plants, are located in the coastal city of Dar es Salaam where most of the industries discharge their wastewater into the Msimbazi and Mzinga Creeks (Mgana and Mahongo, 1997, 2002). Industrial wastewater discharge contributes an estimated 2715 tonnes/year of BOD and 15454 tonnes/year suspended solids to the marine environment. This is equivalent to 19% of the total BOD and 55% suspended total solid loads for the city, respectively. Breweries account for most of the BOD and suspended solids, while nutrient loads (nitrogen and phosphorus) originate mainly from slaughter houses (Table 23).

TABLE 23: Estimated pollutant loads from industrial activities into the Msimbazi Creek (Dar es Salaam)

INDUSTRY TYPE	ESTIMATED LOAD (kg/year)				
	BOD	Suspended solids	Oil	Nitrogen	Phosphorous
Food processing (Breweries)	1117.3	433.8	-	-	-
Food processing (Slaughter houses)	53.6	59.9	18.8	6.3	0.5
Textile	50.4	20.7	-	-	-

About 43% of the major industries considered in Dar es Salaam emit atmospheric pollution. Among these, the cement industry (at Wazo Hill) is the principal atmospheric polluter, emitting approximately 2831 tonnes of air-borne particulate material per year. If Wazo Hill is representative, the same levels of pollution may be expected from the cement factories located elsewhere in the region, e.g. Maputo, Bamburi (Mombasa) and Kaloleni (Kilifi).

In Zanzibar industrial activities are mainly concentrated in the Saateni, Maruhubi and Mtoni areas and include mainly food processing (slaughter houses, dairy products and beverages) and chemical (soap production) industries, generating between 15 tonnes of BOD and 16 tonnes of suspended solid loads per year (Table 24).

TABLE 24: Estimated pollutant loads from industrial activities on Zanzibar

INDUSTRY TYPE	ESTIMATED LOAD (kg/year)				
	BOD	Suspended solids	Oil	Nitrogen	Phosphorous
Food processing (slaughter houses)	13512	12611.2	4729.2	1576.4	112.6
Food processing (dairy)	7885.4	2505.6	-	461.0	101.1
Food processing (soft drinks)	303	101	-	-	-
Food processing (coconut oil)	44.3	43.8	50.0	-	-
Chemical (soap production)	3256	814	18.5	-	-

Coastal mining activities in the WIO largely comprise the extraction and baking of coral rock and mineral mining and refining. These activities contribute to the deterioration in water and sediment quality through the disposal of solid waste, suspended solids and chemical pollution. No quantitative information on the contribution of these activities to marine pollution is available for the region.

4.1.4 Transportation

Almost all of the large urban centres within the WIO region support large commercial ports and harbours. Activities within harbours may contribute significantly to transboundary marine pollution. Activities include ship maintenance and repair at dry docks, the disposal of garbage and dredging. Furthermore, industrial zones are often located in close proximity to the major ports and harbours. Issues that have been listed for ports and harbours in different countries are highlighted in Table 25.

In the Comoros the harbour at Mutsamudu is located near a river and as a result of continued sedimentation is becoming shallower, reducing its capacity to accommodate larger ships and vessels (Abdullah *et al*, 2006).

Kilindini Harbour in Mombasa is the major Kenyan port, managed by the Kenya Ports Authority. It is a natural harbour and is strategically positioned to serve a number of east and central African countries including Rwanda, Uganda, Burundi, Tanzania, Zaire and Sudan. The location of the port has attracted many industries to Mombasa. The port area is, however, subjected to environmental perturbation due to shipping and other marine and land-based activities. Periodic dredging in the port and approach channels for maintenance and expansion puts into suspension considerable quantities of particulate material and associated chemicals (e.g. nutrients, heavy metals, persistent organic contaminants etc.) (Munga *et al*, 2006).

Madagascar has numerous harbour facilities along its coast, as maritime transportation is a very important transport mechanisms for the island. In general, the sources of marine pollution linked to harbours are as a result of (Anon, Madagascar):

- Spillage of pollutants (e.g. chemical products and oil) during cargo handling
- Lack of facilities to handle garbage, oil residues and wastewater from vessels
- Lack of facilities and infrastructure to remove wrecks.

TABLE 25: Major ports in the countries of the WIO region and reported marine pollution issues

COUNTRY	PORT/HARBOUR	MAJOR ISSUES

COUNTRY	PORT/HARBOUR	MAJOR ISSUES
Comoros	Mutsamudu	Located near a river and is becoming shallower as a result of continued sedimentation, reducing its capacity to accommodate larger ships and vessels (Abdullah et al., 2006).
Kenya	Kilindini (Mombasa)	The port area is subjected to environmental perturbation due to shipping and other marine and land-based activities. Periodic dredging in the port and approach channels for maintenance and expansion of facilities re-suspends considerable quantities of particulate material and associated pollutants (e.g. nutrients, heavy metals, persistent organic pollutants, etc.) (Munga et al., 2006).
Madagascar	Numerous ports, e.g. Antisranana, Mahajanga, Toamasina and Toliar	According to Anon Madagascar (2006), marine pollution linked to harbours is derived from: • Spillage of pollutants (e.g. chemical products and oil) during loading and offloading • Lack of facilities to handle garbage, oil residues and wastewater from vessels • Lack of facilities and infrastructure to remove wrecks.
Mauritius	Port Louis	Dredging is undertaken on an ad hoc basis for maintenance of existing channels as well as for port development (Anon Mauritius, 2006).
Mozambique	Maputo, Beira and Nacala and several small ports e.g. Inhambane, Quelimane, Pebane, Angoche and Pemba	No specific issues have been listed, but major issues are most likely associated with dredging and spills. Waste management in Maputo harbour is a major issue (solid waste enters the port through streams/surface runoff during rainy seasons) (Anon Mozambique, 2006).
Seychelles	Port Victoria	Dredging, land-reclamation, waste from rivers and fishing vessels, food processing plants (cannery) (Antoine et al., 2007).
South Africa	Port Elizabeth, Ngqura, Richards Bay, Durban and East London	Contribute to marine pollution through poor operational practices and dredging activities (Clark et al., 2002).
Tanzania	Dar es Salaam, Tanga, Mtwara and Zanzibar	Heavy metals and organophosphates levels in sediments are of concern, while other issues are mostly associated with dredging operations and chemical spills. There are also waste management problems (Mohammed et al., 2006).

Port Louis is the only port in Mauritius and it has undergone substantial development to cater for the increasing maritime activities accompanying economic development of the country. Dredging is undertaken on an ad-hoc basis in existing channels for maintenance purposes as well as for strategic port development (Anon Mauritius, 2006).

There are three large ports in Mozambique (Maputo, Beira and Nacala) and several smaller ones (Inhambane, Quelimane, Pebane, Angoche and Pemba). These handle cargos to and from Swaziland, South Africa, Zimbabwe, Zambia, Malawi and Congo.

There are four commercial ports along the Western Indian Ocean coast of South Africa controlled by Transnet National Ports Authority. These are situated at Port Elizabeth, East London, Durban and Richards Bay. These ports are not only conduits for trade between South Africa and its partners in Africa, but also function as hubs for traffic emanating from, and destined for, Europe, Asia, the Americas and the east and west coasts of Africa. In 2008, South African ports handled close to 13000 vessels, over 185 million tons of cargo and 3.9 million containers (TNPA 2008). A new deep water port, the Port of Ngqura has been developed withy an adjacent Industrial Development Zone 20km east of Port Elizabeth. This is South Africa's primary location for major new industrial investments in the coastal zone. The new deepwater port is intended to provide development impetus in the Eastern Cape Province and is anticipated to make South Africa the hub of north-south and south-south sea traffic. Furthermore, major upgrades currently under way at several of the other major national ports to increase handling capacity and absorb the rapid increase in commercial traffic. Although these ports and harbours have triggered extensive industrial and urban development in South Africa (and continue to do so) they have also contribute to land-based sources of marine pollution through bad operational practices and dredging activities.

Dar es Salaam, Tanga, Mtwara and Zanzibar are major ports along the Tanzanian coast with smaller ports situated at Kilwa, Lindi and Mafia. The port at Dar es Salaam is the largest and also serve the neighbouring countries of Rwanda, Burundi, Democratic Republic of the Congo, Malawi, Zambia, Zimbabwe, and Uganda.

4.1.5 Energy production

The energy production sector influences marine water quality mainly through thermal discharges of cooling water and atmospheric emissions from combustion of oil, gas, or coal from power generation installations and through atmospheric emissions associated with burning of fossil fuels (e.g. wood, charcoal and paraffin) for domestic cooking. Pollutant loads from these activities have not been properly quantified for the WIO region and further investigation is needed before conclusive statements can be made in terms of their contribution to marine pollution.

4.1.6 Aquaculture

The WIO has much potential for aquaculture but these activities are currently largely limited to the farming of crustaceans (e.g. shrimp, prawns and crabs) and seaweed in the Seychelles, Madagascar, Mozambique (crustaceans) and Tanzania (seaweed) (WIOMSA, 2007). Although aquaculture is still poorly developed in the region, it is an emerging sector that could have deleterious effects on coastal water quality, in terms of organic/nutrient pollution from uneaten feed or waste products (e.g. faeces), cleaning fluids and antibiotics in the feeds, and suspended solids from cleaning of ponds.

4.1.7 Summary of direct causes and underlying sectors

From the above overview, it may be concluded that the main sectors contributing to the transboundary pollution problems in the WIO region are urbanisation, agriculture and industry. All have cross-cutting impacts. Aquaculture, tourism, mining, transportation and energy generation and consumption are associated with specific types of pollution.

4.2 Important root causes

Finally, root causes for problems can be identified. Root causes (or drivers) are usually cross-cutting to transboundary problems and their direct and underlying causes and can typically be divided into the following categories:

- Population pressure
- Poverty and inequality
- Inappropriate governance
- Inadequate knowledge and awareness
- Inadequate financial resources.

These root causes are largely cross-cutting to all key marine pollution transboundary problems identified in Chapter 2, as can be seen from the causal chain analyses.

4.2.1 Population pressure

Population growth is a fundamental root causes posing a threat to marine resources in coastal areas of the WIO region because of the increase in demand for goods and services and resources needed to sustain livelihoods. The associated rapid urbanisation with changes in lifestyles characterised by high consumption rates has resulted in increased generation of waste. All of the countries in the WIO region have experienced rapid population growth and urbanisation in coastal areas, particularly within the larger coastal centres.

The Comoros are characterised by a relatively high population size of 0.5 million (1996) compared to their land area of 1861 km^2. Population growth rate is 2.7% (Abdullah *et al.*, 2006).

In Kenya the Coastal Province supports about 9% (2.5 million) of the country's population according to a 1999 census. The population in the Coastal Province increased from 1.34 million people in 1979 to 1.83 million in 1989 and to 2.5 million in 1999 (a 37 % increase). While precise data are unavailable, the urban centres on the coast have seen greater in population in recent years. For example, the population for Mombasa has more than doubled in the last 15 years. Trends in population growth indicate that the tourist destinations of Diani, Mombasa, Malindi and Watamu are experiencing rapid growth due to opportunities for employment in the tourism sector. This growth in population has severely stretched the capacity of local authorities in the providing infrastructure and essential services, such as housing, adequate water and sanitation (Munga *et al*, 2006).

The population of Madagascar is estimated at 19.4 million with a growth rate of about 3% (2007, https://www.cia.gov/library/publications/the-world-factbook/geos/ma.html).

From 1995 to 2004, the population in Mauritius increased by 10.9% from 1.1 million to 1.2 million. In 2001 the population annual growth rate was about 1.0%.

In Mozambique around 42% of the population (8 million of 19.1 million) lives in coastal districts and according to the last census in 2000. The population is still growing at 2.3 % a year (Hoguane *et al*, 200; Anon Mozambique 2006). Apart from keeping pace with food demands of a fast growing population, the country also faces the challenge of providing sufficient, adequate and safe water and sanitation.

The Seychelles has experienced very rapid social and economic development over the past 20 to 30 years. In 2001 the population was estimated at 0.08 million on an island of about 455 km^2. Population growth rate was about 0.5%. Tourist numbers have also grown markedly from about 0.5 million in 1971 to 1.3 million in 2000. The increase in population and demographic change has been a significant factor in the increased demand for flat land suitable for housing and associated infrastructure development (e.g. sanitation and waste management). Rapidly changing lifestyles, including increasing and changing consumption patterns and rising expectations, are a major root cause of the pressure on ecosystems (Jones *et al*, 2002).

The single greatest root cause for environmental change posing a threat to the coast of South Africa is population growth (RSA DEAT, 1999). In 2006 the South African population was estimated at 47.4 million. The coastal province of KwaZulu-Natal has the largest share of the population (20.5%) The other two large coastal provinces - the Eastern Cape and Western Cape – support 14.9% and 10% of the population, respectively (Statistics South Africa, 2006). It is estimated that about 30% of South Africa's population lives within 60 km from the coast (Griffiths *et al*, 1999). Populations along the coast are however not evenly distributed, but are mostly associated with the seven large urban coastal centres at Saldanha Bay, Cape Town, Mossel Bay, Port Elizabeth, East London, Durban and Richards Bay, each with its own commercial port. Specific issues of population growth that pose potential risks to the natural environment (including the marine environment) are, amongst others, sanitation and solid waste facilities, which if not provided for adequately can have severe impacts in terms of pollution.

The Tanzanian coastal area (mainland and Zanzibar) encompasses about 16% of the county's total land area. The area supports a total population of about 7.9 million people, more than 25% of the country's population. The population is mostly concentrated in the urban centres of Dar es Salaam, Tanga, Mtwara and in Zanzibar. Dar es Salaam has the highest population growth rate (4.3%) followed by Unguja (3%) and Coast (2.4%). There is a significantly rural-to-urban migration particularly to the cities such as Zanzibar and especially Dar es Salaam, spurred on by search of livelihood opportunities (Mvungi, 2003). Lack of opportunities in the rural areas has led to many young people especially, migrating to coastal cities and towns in search of better living conditions (Mohammed *et al*, 2006).

4.2.2 Poverty and inequality

The WIO region is characterised by some of the highest levels of poverty in the world, as seen from the estimated per capita income in the different countries (Table 5). Consequently, lack of adequate resources is one of the main reasons for insufficient or unsuitable sanitation and solid waste disposal facilities in many of the countries in the region.

Alleviating poverty in the WIO region will be a major challenge, requiring transparency, progressive development, management of land and water resources, education on effective technologies for both commercial and subsistence farming, and policies for food security, Furthermore, education, healthcare and empowerment of the people are essential elements for poverty alleviation.

4.2.3 Governance

Governance concerns the values, policies, laws and institutions by which issues are addressed and it defines the fundamental goals, the institutional processes and the structures that are the basis for planning and decision-making. Management, on the other hand, is the process by which human and material resources are harnessed to achieve a known goal within a known institutional structure. Thus, governance sets the stage within which management occurs (UNEP, 2006).

Based on the assessment of governance of marine pollution in the WIO region (Chapter 5), it is clear the level of inefficiency varies from one country to another, and that in many of the countries some of the important building blocks for effective governance are not in place.

4.2.4 Knowledge and awareness

Empowerment of people in society is considered a key factor in the alleviation of poverty allowing them to play an active role in effective governance and management of natural resources (including marine resources). Knowledge is a key pillar for empowerment of people, however, within the countries of the WIO region many people do not have access to appropriate knowledge on matter such as:

- Environmental impacts and socio-economic consequences of human activities that, in many instances, are affecting people's quality of life
- Technologies to prevent or minimize the impact on environment and the goods and services that are provided. For example appropriate agricultural activities, technologies for municipal wastewater treatment, solid waste treatment and disposal
- Existing policies and institutional structures that provide (often legally) enforceable ways of preventing or mitigating impacts on the environment and socio-economic well-being of people.

4.2.5 Financial resources

Lack of financial resources to implement and enforce appropriate technologies and practices to prevent or minimise environmental impacts and/or socio-economic consequences of human activities in the marine environment is a concern in many countries in the WIO region. Furthermore, the lack of commitment by politicians, in many instances, to address issues of environmental concern (including marine pollution) is reflected in the low priority given to such issues in the policies and budget allocations of countries in the region. The socio-economic consequences of such impacts are also not properly communicated to politicians. This is knowledge that could change such behaviour.

5. LEGISLATIVE FRAMEWORK AND INSTITUTIONAL SET-UP

Based on the national status report, this chapter mainly refers to the Response sections dealing with legislative framework and institutional set-up. I therefore suggest that we change the chapter title to reflect that (governance analysis is much broader and was not addressed in the national pollution status reports) Here we need to provide a synthesis on the state legislation and institutional set-up, as presented in national status reports insofar as it pertains to marine pollution management from land-based activities. This we need to update from the final National Status Report.

Comoros…

Kenya…

Madagascar…

Mauritius…

Mozambique…

Seychelles…

As a signatory to UNEP's Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) South Africa adopted its National Programme of Action (NPA) in October 2008 (RSA DEAT, 2008). The NPA aims to coordinate relevant national, provincial and local initiatives playing a role in the control of land-based activities detrimentally impacting on the coastal marine environment. It further seeks to strengthen cooperative governance, to identify shortfalls in current efforts and to facilitate appropriate future initiatives. South Africa's greatest effort, particularly over the past 10 years, in combating marine pollution has been in the development of sound environmental policies and legislation. Currently, the disposal of land-derived wastewater is primarily governed under the National Water Act (NWA) (1998) where municipal wastewater and industrial wastewater discharges (i.e. point discharges) are required to be authorised by licenses issued by Department of Water and Environmental Affairs (DWEA). The development of the Operational Policy for the Disposal of Land-derived Water Containing Waste to the Marine Environment of South Africa in 2004 was largely an attempt to improve matters with regard to the management and control of land-based wastewater sources. Diffuse wastewater discharges (e.g. stormwater runoff, agricultural return flows, etc) still remains a challenging aspect, but a number of best practice guides have been developed by national government to assist with the management and control of such diffuse sources (e.g. stormwater). Solid waste disposal by landfill is required to be authorised by a license issued by the DWEA. To combat littering in the coastal environment, public involvement and awareness have been stimulated through clean-up initiatives, under the banner of Coastcare, a national programme that was established to assist with education and the exchange of information about coastal issues. Atmospheric pollution in South Africa is governed under the National Environmental Management: Air Quality Act of 2004, also administered by DWEA. The quantity and quality of catchment (river) runoff is also governed by DWEA under the NWA (1998) requiring water resources to be classified and resource quality objectives be specified in order to protect aquatic ecosystems. In 2006, South Africa also promulgated new Environmental Impact Assessment Regulation under the National Environmental Management Act (NEMA) (1998). Waste disposal activities are also scheduled activities under these regulations that require an Environmental Impact Assessment.

While national government is largely responsible for establishing a sound legal framework, protocols and best practice guides, the control and management of land-based sources of marine pollution have largely been delegated to the regional (provincial) and local (municipality and local industries) levels. Reflecting on existing institutional structures for coastal management in South Africa, these are still largely sectoral, where various government departments, to a greater or lesser degree, established in-house systems pertaining to specific sectors. However, despite good environmental legislation (as discussed above), effective implementation remains a challenge due to shortage of skilled resources. This matter requires serious intervention on all levels to follow on the significant achievements made over the past 10 years. To this end, the new National Environmental Management: Integrated Coastal Management Act (2008) offer great opportunity in that the establishment of cross-sectoral national, provincial and municipal coastal management committees, to facilitate cooperative governance of the coastal marine environment, will soon become a mandatory requirement in South Africa.

Tanzania…

6. RECOMMENDATIONS FOR STRATEGIC ACTION PLAN (SAP)

The coastal marine environment of the WIO region are currently being threatened by numerous anthropogenic (human) activities, causing marine pollution (the focus if this assessment), physical destruction and modification of habitats and modification of freshwater inflows. However, land-based activities are not the only threats to the coastal marine environment. Others, for example, are exploitation of living resources (fisheries), maritime transportation, dumping of waste at sea and climate change (Figure 10).

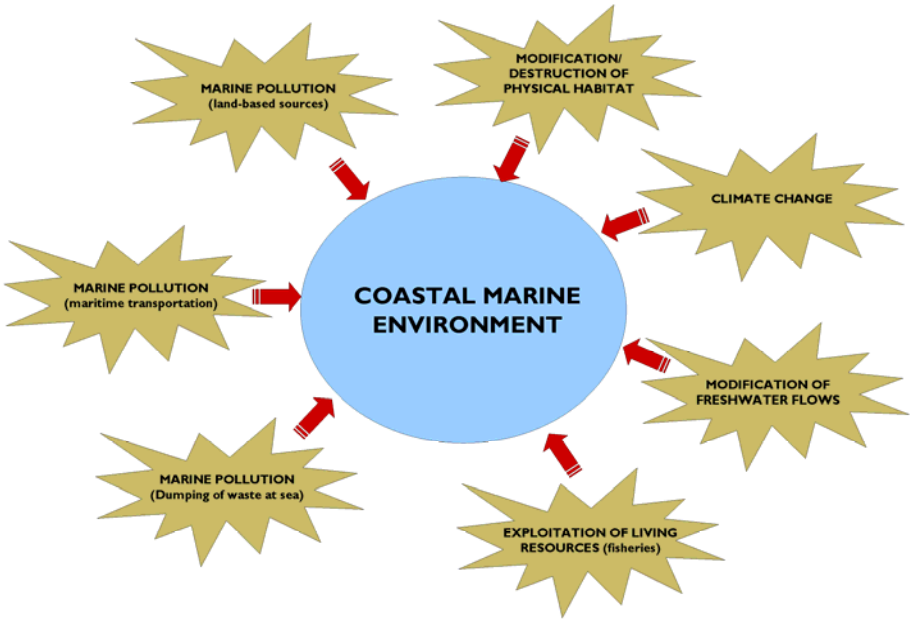


Figure 10: Schematic illustration of different activities threatening the coastal marine environment in the WIO region

Therefore, although the focus of this regional assessment is on *marine pollution from land-based activities*, other threats have to be considered in the integrated management of the coastal marine environment so as to consider possible cumulative or synergistic impacts. The need for such integration should also be acknowledge in the SAP and NAPs developed for the region.

Focusing on *marine pollution from land-based activities*, based on the outcome of this regional assessment, recommendations for consideration in the SAP and NAPs are provided in Table 26. These are specifically related to the root causes: *Inappropriate governance, inadequate knowledge and awareness* and *inadequate financial resources* (the root causes of population pressure and poverty and inequality require much broader interventions than the scope of this regional assessment on marine pollution).

TABLE 26: Recommendations for consideration in the SAP and NAPs in the WIO region, addressing specific root causes

ROOT CAUSE	RECOMMENDATIONS
Inappropriate governance	Develop specific management tools (e.g. regional best practice guidelines) and demonstrate best practice technologies and management approaches for: • Municipal and industrial wastewater and solid waste (including governance aspects such as holding products manufacturers responsible for the treatment and recycling of their packaging, applying the 'polluter pays' and 'cradle to grave' principles and introducing economic incentives for low-waste packaging) • Ports and harbours (including issues related to on- and offloading, disposal of waste from vessels, disposal of used oil and oil related products, and contingency planning in instances of accidental spills) • Agricultural activities (including issues related to soil erosion, agrochemical application and livestock raising).
	Develop regional guidelines for setting effluent limit values (ELV) / standards for different industry types based on a Technology-based Approach or Environmental Quality Objective (EQO)-based approach
	Develop targeted investment plans and proposals for the establishment of appropriate wastewater

ROOT CAUSE	RECOMMENDATIONS
	and solid waste management infrastructure in priority hot spots of pollution, e.g. based on the above-mentioned guidelines and lessons learnt from the demonstration projects.
	Establish sector-specific effluent limit values (ELV) / standards for different industry types based on a Technology-based Approach and/or Environmental Quality Objective (EQO)-based approach and develop mechanisms to convert such scientifically set standards into legally enforceable mechanisms.
	Mainstream the above-mentioned guidelines and investment plans into national policies, strategies, legislation and budgets.
	Enforce legislation/regulation for industries to conduct EIA studies and regular audits to assess and evaluate potential impacts on the coastal marine environment - in alignment with the overarching EQOs and sector-specific ELVs – and ensure that local level ('on the ground') mechanisms are in place to audit and enforce compliance (e.g. monitoring programmes, incentive systems and penalty systems).
	Develop a register of municipal wastewater and solid waste management facilities for each of the countries (working towards a permitting system particularly for central wastewater treatment facilities and landfills).
	Develop a register of manufacturing industries working towards a permitting system for such facilities.
	Develop a register of agro-chemicals use (e.g. fertilisers, pesticides, herbicides, etc), specifying allowable products and dosages (working towards legally enforcing such specifications)
Inadequate knowledge and awareness	Develop and implement monitoring and assessment programmes to fill gaps (e.g. identified in the national pollution status reports) in knowledge of priority pollutants, including major sources of pollution and the driving forces, with special emphasis on the identified coastal hot spots of pollution.
	Develop and enroll regional training programmes to build capacity in wastewater and solid waste management (in many instances focusing on local municipalities and harbour authorities)
	Develop and enroll regional education and awareness programmes to inform all sectors of society (e.g. general public, politicians and managers) on their roles and responsibilities in the generation, collection, treatment and disposal of wastewater and solid waste, as well as the consequences on the environment and socio-economic wellbeing.
	Develop and maintain a web-based regional information management system that includes information on best practice technologies, registers (listed above) as well as tools and guidelines for the selection of appropriate technology, institutional and policy frameworks and financial mechanisms.
Inadequate financial resources	Identify and establish sustainable financial mechanisms for investments in the field of wastewater and solid waste management, and cleaner production technology (including through the development of public-private partnerships).

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ANNEX 1
CRITERIA FOR THE PRIORITISATION OF TRANSBOUNDARY PROBLEMS

LEVEL 1: PRIORITISATION OF TRANSBOUNDARY PROBLEMS

Simple Rating Form:

	Severity	Scope	Overall rating
Problem 1			
Problem 2			
Problem 3			
Problem 4			
Problem 5			

Rating Criteria for Transboundary Problems

Severity - The level of damage to the WIO coastal and marine ecosystem that can reasonably be expected within 10 years under current circumstances (i.e., given the continuation of the existing situation).

- **Very High:** Likely to destroy or eliminate part of the ecosystem.
- **High:** Likely to seriously degrade part of the ecosystem.
- **Medium:** Likely to moderately degrade part of the ecosystem.
- **Limited:** Likely to only slightly impair part of the ecosystem.

Scope - Most commonly defined spatially as the geographic scope of impact on the ecosystem integrity that can reasonably be expected within 10 years under current circumstances (i.e., given the continuation of the existing situation).

- **Very High:** Likely to be widespread or pervasive in its scope and affect the ecosystem throughout the WIO region.
- **High:** Likely to be widespread in its scope and affect the ecosystem in many parts of the WIO region.
- **Medium:** The threat is likely to be localized in its scope and affect the ecosystem in some parts of the WIO region.
- **Limited:** Likely to be very localized in its scope and affect the ecosystem in limited parts of the WIO region.

LEVEL 2: PRIORITISATION OF DIRECT CAUSES

Simple Rating Form

For each transboundary problem, list and rank the immediate causes, using the criteria below.

Problem 1

	Contribution	Irreversibility	Overall rating
Direct Cause 1:	**VH, H, M, or L**	**VH, H, M, or L**	**VH, H, M, or L**
Direct Cause 2			
Direct Cause 3			

Rating Criteria for Direct Causes:

Contribution - The expected contribution of the cause, acting alone, to the full expression of a threat (as determined in the threat assessment) under current circumstances (i.e. given the continuation of the existing management situation).

- **Very High**: The cause is a very large contributor of the particular problem.
- **High**: The cause is a large contributor of the particular problem.
- **Medium**: The cause is a moderate contributor of the particular problem.
- **Limited**: The cause is a limited contributor of the particular problem.

Irreversibility - The degree to which the effects of a cause of problem can be restored.

- **Very High**: The cause produces a problem that is not reversible (e.g., destruction of coral reefs due to unsustainable fishing practices).
- **High**: The cause produces a problem that is reversible, but not practically affordable (e.g. changed river flow regime due to damming).
- **Medium**: The cause produces a problem that is reversible with a reasonable commitment of resources (e.g. conversion of mangrove wetland into fish pond).
- **Limited**: The cause produces a problem that is easily reversible at relatively low cost (e.g. degenerated water quality due to wastewater discharge).

LEVEL 3: COMBINING RATINGS

Combining problems (level 1) and causes (level 2) ratings results in a combined rating and it done using the threat matrix below.

		Cause			
		Very High	High	Medium	Limited
Problem	Very High	**Very High**	**Very High**	**High**	**Medium**
	High	**High**	**High**	**Medium**	**Limited**
	Medium	**Medium**	**Medium**	**Limited**	**Limited**
	Limited	**Limited**	**Limited**	**Limited**	**Limited**

APPLICATION: DEGRADATION OF WATER AND SEDIMENT QUALITY

Level 1: Prioritisation of transboundary problems

Problems	Severity	Scope	Overall rating
Microbial contamination	H	H	H
High suspended solids	H	H	H
Chemical pollution	M	L	L
Marine litter and debris	L	L	L
Eutrophication	L	L	L

Level 2: Prioritisation of direct causes

Microbial contamination

Direct Cause	Contribution	Reversibility	Overall rating
Disposal of un- or under-treated municipal wastewater	VH	H	VH
Industries discharging un- or under-treated industrial effluents	L	H	L
Waste from coastal mining and minerals (oil, gas, etc) exploration activities	L	H	L
Contaminated surface and sub-surface runoff (from municipal, industrial and agricultural areas, as well as from accidental spills)	H	H	M
River discharges transporting high suspended sediment loads (as a result of basin soil erosion) and/or transporting municipal/ industrial wastes and agrochemicals from catchment areas	M	H	M
Runoff from livestock rearing areas	L	H	L
Inadequate collection, treatment and disposal of solid waste in urban areas	L	H	L

High suspended solids

Direct Cause	Contribution	Reversibility	Overall rating
Disposal of un- or under-treated municipal wastewater	M	H	H
Industries discharging un- or under-treated industrial effluents	H	H	H
Dredging activities in ports and harbours	L	H	L
Waste from coastal mining and exploration activities	M	H	M
Contaminated surface and sub-surface runoff (from municipal, industrial and agricultural areas, as well as from accidental spills)	VH	H	VH
Destruction of coastal forests contributing to high suspended solid loads	M	H	M
River discharges transporting high suspended sediment loads (due to soil erosion) and/or transporting municipal/ industrial waste and agrochemicals from catchment areas	VH	H	VH
Waste products from aquaculture farms - high in nutrients and suspended solid loads	L	H	L

Marine litter

Direct Cause	Contribution	Reversibility	Overall rating
Contaminated surface and sub-surface runoff from municipal, industrial and agricultural areas, as well as from accidental spills)	M	M	M
River discharges transporting high suspended sediment loads (due to soil erosion) and/or transporting municipal/ industrial waste and agrochemicals from catchments	M	H	M
Inadequate collection, treatment and disposal of solid waste	H	H	H
Public littering on beaches and in areas where marine litter can be transported into coastal areas	H	H	H

Chemical pollution

Direct Cause	Contribution	Reversibility	Overall rating
Industries[a] discharging un- or under-treated industrial effluents	VH	H	VH
Dredging activities in ports and harbours	L	L	L
Waste from coastal mining and mineral (oil, gas, etc) exploration activities	L	L	L
Contaminated surface and sub-surface runoff (from municipal, industrial and agricultural areas, as well as from accidental spills)	H	H	H
River discharges transporting high suspended sediment loads (due to soil erosion) and/or transporting municipal/industrial waste and agrochemicals from catchment areas	H	L	M
Leaking of agrochemical (fertiliser and pesticide residues) from inadequate storage facilities, dumping or return-flows	L	L	L
Inadequate collection, treatment and disposal of solid waste in urban areas	L	L	L

Eutrophication

Direct Cause	Contribution	Reversibility	Overall rating
Disposal of un- or under-treated municipal wastewater	H	H	H
Industries[a] discharging un- or under-treated industrial effluents	L	H	L
Waste from coastal mining and exploration activities	L	H	L
Contaminated surface and sub-surface runoff (e.g. from municipal, industrial and agricultural areas, as well as from accidental spills)	M	H	M
River discharges transporting high suspended sediment loads (due to soil erosion) and/or transporting municipal/ industrial waste and agrochemicals from catchment areas	M	H	M
Leaking of agrochemical (fertiliser and pesticide residues) from storage facilities, dumping or return-flows	L	H	L
Runoff from livestock rearing areas	L	H	L

Level 3: Overall ranking

TRANSBOUNDARY PROBLEM					DIRECT CAUSE
Microbial contamination	Eutrophi-cation	Marine litter and debris	Suspended solids	Chemical Pollution	
H	L		H		Disposal of un- or under-treated municipal wastewater
L	L		H	L	Industries discharging un- or under-treated industrial wastewater
			L	L	Dredging activities in ports and harbours
L	L		M	L	Waste from coastal mining and mineral (oil, gas, etc) exploration activities
M	L	L	H	L	Contaminated surface and sub-surface runoff (e.g. from municipal, industrial and agricultural areas, as well as from accidental spills)
			M		Destruction of coastal forests contributing to high suspended solid loads
M	L	L	H	L	River discharges transporting high suspended sediment loads (as a result of soil erosion) and/or transporting municipal/ industrial waste and agrochemicals from catchment areas
	L			L	Leaking of agrochemical (fertiliser and pesticide residues) from inadequate storage facilities, dumping or return-flows
L	L				Runoff from livestock rearing areas
L		L		L	Inadequate collection, treatment and disposal of solid waste
		L			Public littering on beaches and in areas where litter can be transported into coastal areas
			L		Waste products from aquaculture farms that are high in nutrients and suspended solid loads

Key: L: Limited M: Medium H: High VH: Very High

Check tons/tonnes