CHEMICAL OUTFLOW PIPE, NEW ZEALAND.
(SOURCE: K.ADAM/UNEP/STILL PICTURES)

POLLUTION

Ocean currents and rivers transport various pollutants over large distances with transboundary consequences. Complex synergies between the various contaminants can increase the overall environmental impact. Globally, the severity of the various pollutants varies considerably. Suspended matter, resulting mainly from deforestation and agricultural activity, has degraded aquatic ecosystems the most extensively, particularly in the tropics and subtropics.

While eutrophication is widespread in temperate regions, hotspots of microbial pollution are extensive in Central America, North Africa & Middle East and Europe & Central Asia. Solid wastes are dumped into rivers, lakes, coastal waters and the high seas throughout the world, but are particularly prevalent in Sub-Saharan Africa. Chemical pollution, originating predominantly from agricultural run-off and industrial and domestic effluents, is severe in several regions. At a mega-regional level, oil spills and radio-nuclides were not considered to cause severe transboundary impacts.

The root causes of pollution are again agricultural development, population growth, urbanization and industrialization, as well as market and policy failures. In most regions it is not the lack of regulations but their weak enforcement that hinders progress. Appropriate economic incentives and greater public awareness are therefore required.

The GIWA focuses on eight critical transboundary pollution issues (see Annex II):

(i) suspended solids; (ii) eutrophication; (iii) microbial pollution; (iv) solid wastes; (v) chemical pollution; (vi) oil spills; (vii) radionuclides; and (viii) thermal pollution. This last issue is not discussed further in this report as it was generally not considered to be a transboundary issue.

Pollution is often transboundary as hydrological interlinkages between river basins, marine ecosystems and the atmosphere result in effects far from the source of emissions (Box 8). This global synopsis provides a broad overview of transboundary pollution based on the GIWA regional reports. Many of the reports assess pollution impacts on smaller geographic scales and should be consulted for more detailed information.

BOX 8. TRANSBOUNDARY POLLUTION

All pollutants can be transported through the aquatic environment and atmosphere, and many accumulate in downstream water bodies and their biota. The probability that pollution will cause transboundary impacts depends on the location of its source in relation to national boundaries, as well as the time it takes for a given pollutant to degrade. In general, microbial pollution is primarily a local problem, whereas suspended solids, hydrocarbons and nutrients pose a risk over larger spatial areas. The risk of transboundary impacts tends to be highest for persistent organic pollutants (POPs), particularly substances that readily migrate between water and air (such as DDT and mercury). Although other persistent pollutants, such as PCBs and heavy metals (e.g. cadmium), are less mobile, they also have transboundary aspects. As pollution transcends national boundaries, international cooperation is required to reduce human and environmental health risks.

Global situation and trends

- Transboundary pollution is the top priority concern in a quarter of all GIWA regional reports, and a further third of the regional teams ranked it as the second most serious concern.
- Pollution has a severe overall impact in more regions than any other concern (Figure 8).
- Suspended solids, which have increased mainly as a result of deforestation and agricultural practices, severely affect coral reefs, seagrasses and riverine habitats in one fifth of the GIWA regions/sub-systems, including the Caribbean Sea/3, Brazil Current/39 and East African Rift Valley Lakes/47, and all regions in Southeast Asia.
- Microbial pollution, primarily from untreated or inadequately treated human and livestock sewage, is a severe health issue in many parts of Sub-Saharan Africa, Southeast and Northeast Asia, and Central and South America.

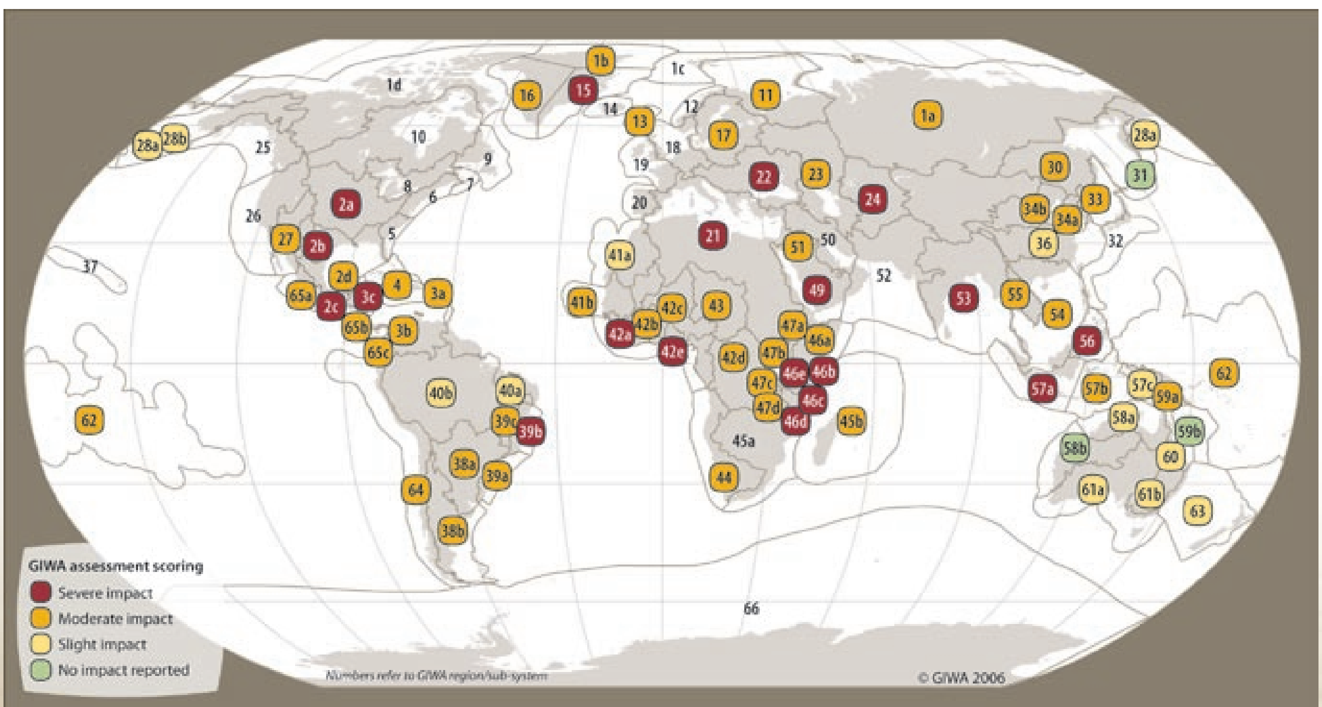


FIGURE 8. OVERALL ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF POLLUTION

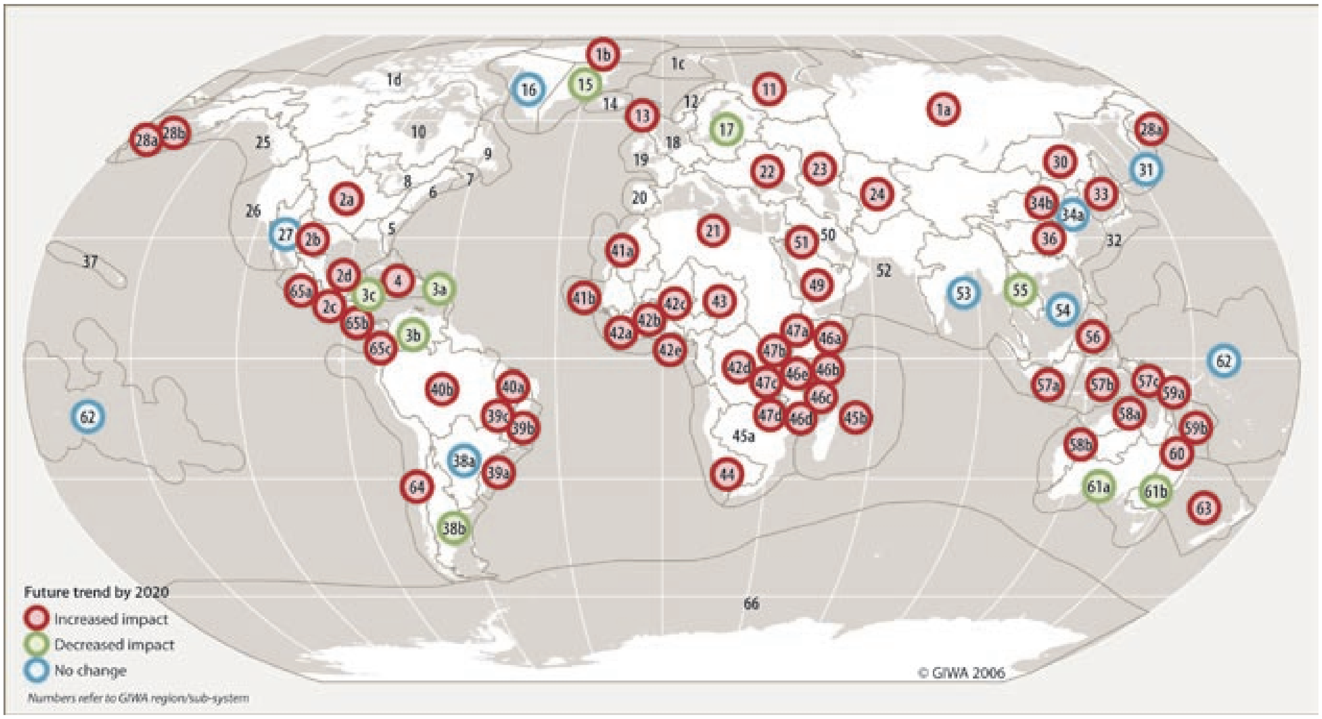


FIGURE 9. FUTURE ENVIRONMENTAL TRENDS FOR POLLUTION

- Eutrophication is prevalent in many of the lakes, rivers and semi-enclosed seas of Europe & Central Asia and Sub-Saharan Africa. Evidence from Northeast Asia and the Gulf of Mexico indicates that eutrophication is an emerging problem in open coastal marine environments.
- The dumping of solid wastes is a priority issue in many rivers and coastal areas of Sub-Saharan Africa, in Small Island Developing States (SIDS), parts of the Indonesian Seas/57 and along stretches of the Rio Grande (Gulf of Mexico/2b).
- Chemical pollution is a transboundary issue at several hotspots in Central America, West Africa, South Asia, and Southeast Asia, as well as the Jordan River/51, Aral Sea/24 and the Arctic Rim.
- The impact of oil spills was assessed as severe in the Caribbean Sea/3, Niger Basin/42c and Benguela Current/44.
- By 2020, the environmental impacts of pollution are predicted to increase in severity in over three-quarters of GIWA regions/sub-systems, making this the most negative future outlook for any of the GIWA concerns (Figure 9).

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

Suspended solids

More than half of the GIWA regional teams identified suspended solids as having severe or moderate impacts, concentrated particularly in tropical regions (Figure 10). Increased erosion and sediment mobilisation, caused by agricultural practices, deforestation and construction, is resulting in higher concentrations of suspended solids. Conversely, river diversion and damming often results in reduced sediment transport. Excessive suspended solids increase turbidity and siltation, while reduced sediment yields may lead to coastal erosion and lower primary productivity as nutrients are often bound to suspended solids. The same water body may experience environmental impacts from both increased and decreased suspended solids, but in different locations.

Sediments can smother coral reefs, seagrass beds and riverine gravel beds that are important spawning habitats for fish. A high concentration of suspended solids also tends to decrease the productivity of an ecosystem by reducing the penetration of sunlight through the water column, particularly affecting benthic ecosystems. Increased sediment trans-

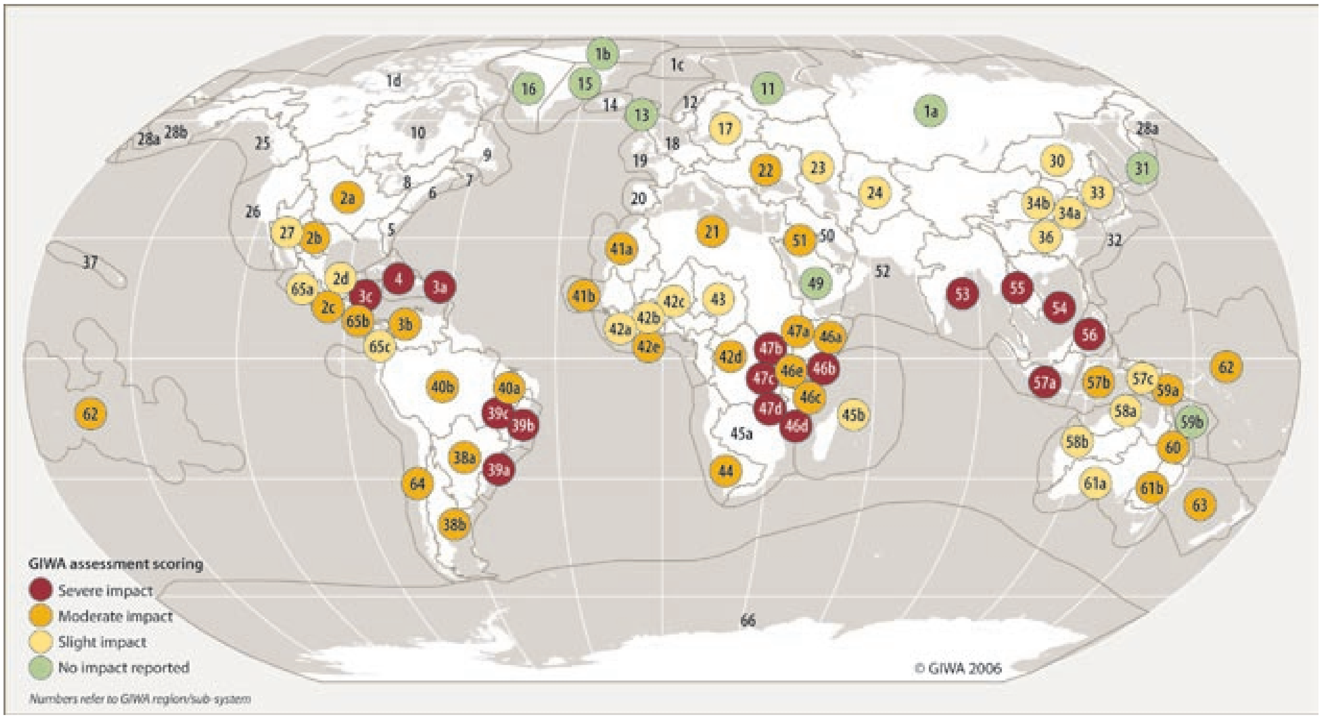


FIGURE 10. IMPACTS OF SUSPENDED SOLIDS

port related to intensive deforestation can change downstream floodplains and river deltas, thus impacting flora and fauna.

The Brazil Current/39 region illustrates both the complexity and the potential severity of the impacts of increased suspended sediments. The deforestation of large areas for agriculture and mining has increased riverbed and coastal zone siltation, which is impeding navigation along the heavily transited São Francisco River. Erosion from land-use changes in Paraná state (Brazil) has increased river turbidity considerably, resulting in higher water treatment costs for over 200 cities. The diversion and damming of waterways has

FIGURE 11. RUN-OFF FROM BAUXITE MINING IN JAMAICA
(PHOTO: CORBIS)

trapped sediments in reservoirs, which has negatively affected the sediment erosion-accretion dynamics of most rivers in the eastern part of the region. Extensive erosion of the coastline resulting from reduced sediment accretion is destroying the fringes of mangrove forests and dunes.

In the Caribbean, deforestation, inappropriate management of agricultural land, mining and urbanisation have increased erosion rates and resulted in greater sediment loads in streams, rivers and coastal waters (Figure 11). Deforestation to clear land for agriculture is considered the most significant cause of erosion, particularly in Jamaica and Haiti. The prevalence of suspended sediments has decreased biodiversity, severely degrading shallow coastal waters. For example, increased sedimentation and turbidity have adversely affected coral reefs by reducing light penetration necessary for photosynthesis, as well as scouring and smothering corals. Greater turbidity in coastal waters and elevated algal cover on reefs is attributed to nutrient enrichment and sedimentation from coastal development, particularly in Puerto Rico and the Bahamas.

Large quantities of sediment enter Lake Tanganyika (East African Rift Valley Lakes/47) as a result of increased erosion caused by land-use changes in its catchment. Satellite images revealed that, as early as 1991, 40-60% of the original forest cover in the Lake's central basin and almost 100% in the northern basin had been cleared. Increased erosion resulting from the same pattern of converting forests to farms has also affected Lake Malawi. The loss of soil not only threatens agricultural production for rural communities but negatively impacts water quality. The increasing sediment

FIGURE 12. DEFORESTATION ON JAWA, OCTOBER 2002
ISLANDS OF FOREST APPEAR GREEN AGAINST THE PALER LANDSCAPE. IN NEARLY EVERY PATCH ACTIVE FIRES CAN BE SEEN (RED DOTS).
(PHOTO: NASA)

and nutrient loads have transformed significant stretches of Lake Tanganyika's shoreline from rocky substrates to mixed or sandy substrates.

In the Indonesian Seas/57 region, the limited size of river catchments and high rates of deforestation leads to extensive sediment run-off (Figure 12). In the Java Sea, enormous quantities of sediment are discharged into coastal waters, carrying particle-bound nutrients which stimulate widespread eutrophication. Figure 13 shows reefs at risk due to sedimentation in the region. Sedimentation has been detrimental to tourism, the artisanal fisheries and aquaculture.

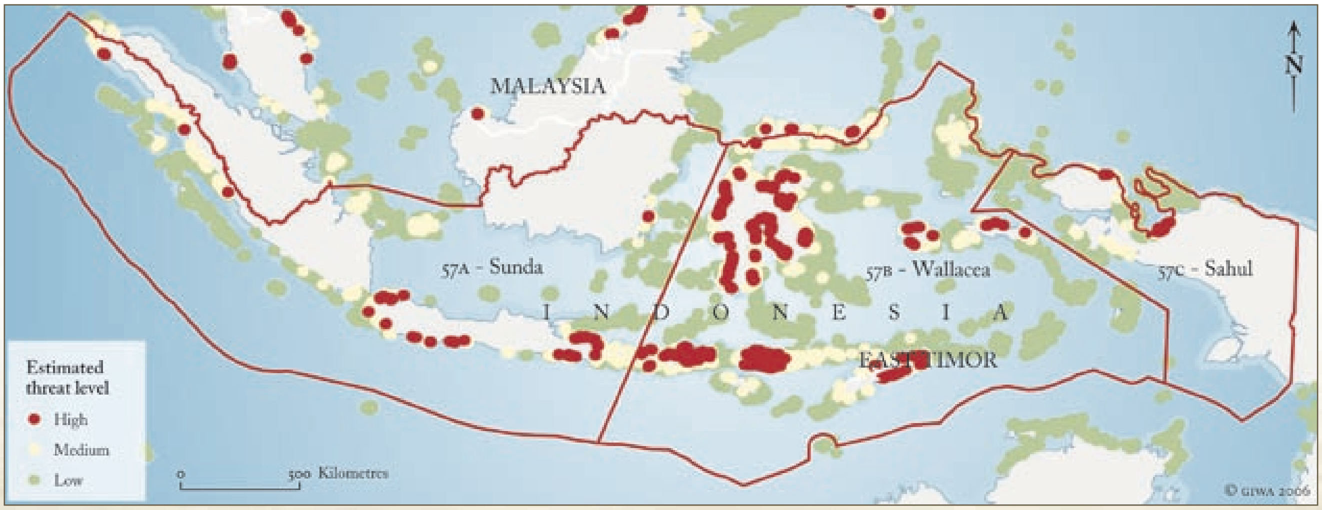


FIGURE 13. CORAL REEFS AT RISK FROM SEDIMENTATION IN THE INDONESIAN SEAS REGION
(SOURCE: BURKE ET AL. 2002)

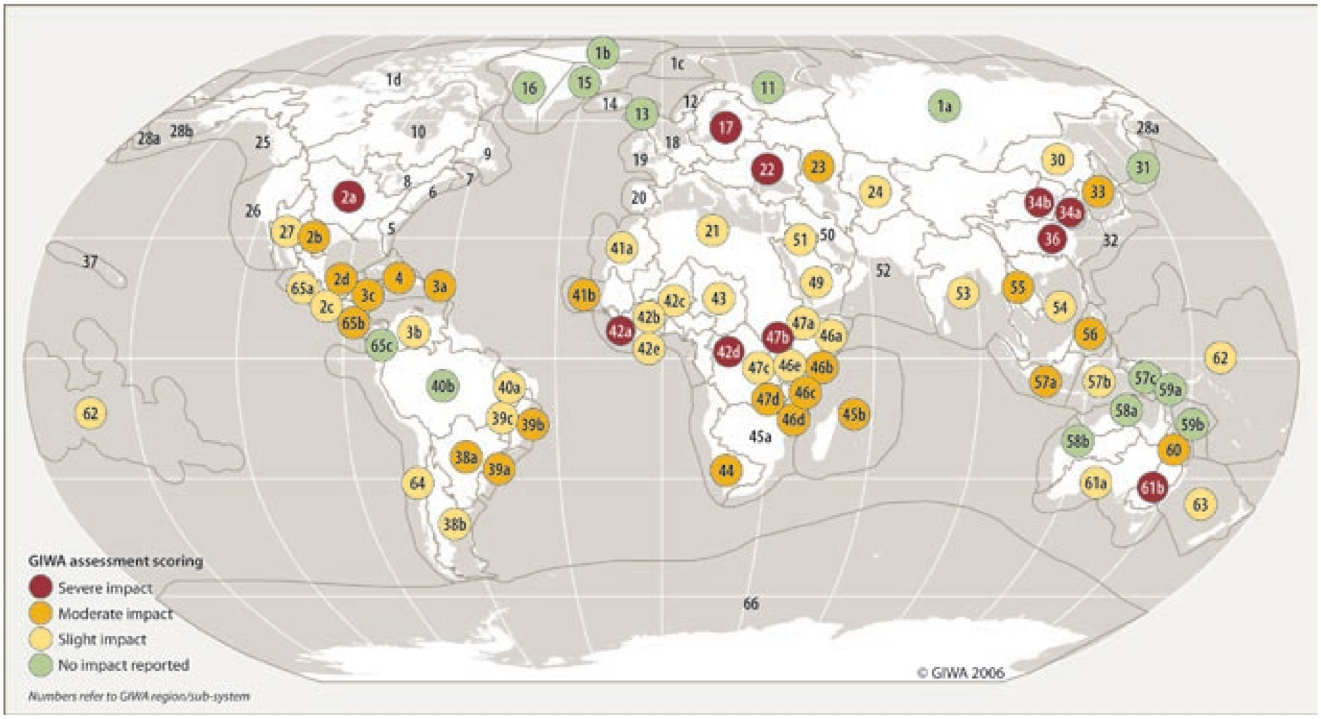


FIGURE 14. IMPACTS OF EUTROPHICATION

Eutrophication

Elevated concentrations of nitrogen and phosphorus in aquatic systems has resulted from the increased application of fertilizers, the discharge of industrial and domestic waste, animal production, the combustion of fossil fuels and nutrient mobilisation due to land clearing. These additional nutrients stimulate algal growth and alter the balance between the production and decomposition of organic matter, leading to eutrophication in many parts of the world (Figure 14).

The proliferation of fast-growing algae increases fish stocks in the short-term but decreases species diversity. Oxygen concentrations are depleted when large volumes of organic matter decompose, causing the widespread degradation of aquatic habitats. Eutrophication can generate large hypoxic zones, a phenomenon which is increasing in frequency and severity on a global scale (Box 9). A number of GIWA regional teams have noted that hypoxic zones and harmful algal blooms (HABs) are the most visible ecosystem reactions to eutrophication (e.g. Black Sea/22, Gulf of Mexico/2, Baltic Sea/17, Brazil Current/39 and Pacific Islands/62). More subtle changes include shifts in the food web, resulting in changes to phytoplankton, zooplankton and benthic communities, as well as fish populations. The initial increase in primary and secondary production often leads to a decline in the mean trophic level of the food web, comparable to the concept of 'fishing down the food web' (see the chapter on overfishing and other threats to living resources).

BOX 9. THREATS FROM HYPOXIC ZONES

Hypoxia occurs when the decomposition of organic matter causes the concentration of dissolved oxygen to fall below 2 ml/l. As a result, aquatic organisms are deprived of oxygen and many die. Several GIWA regional assessments reported dead zones consisting of hundreds or even thousands of square kilometres of hypoxic water. They have become increasingly common in the world's lakes, estuaries and coastal zones, with serious impacts on local fisheries, biodiversity and ecosystem functions. Extensive dead zones have been observed for many years in the Baltic Sea/17, Black Sea/22 and Gulf of Mexico/2.

The GIWA assessment has compiled information on dead zones in the Southern Hemisphere, including several lagoons in the Brazil Current/39 region, coastal locations in the Humboldt Current/64 region, and in the Yangtze River estuary located in the East China Sea/36 region.

The transboundary inland and semi-enclosed seas of Europe are significantly affected by land-based pollutants, especially nutrients from excessive fertilizer application in their catchments, which tend to accumulate in the waters and sediments due to limited water exchange. In the Baltic and Black Seas, the increased frequency of algal blooms followed by extended hypoxic events has affected the ecosystems of the region (Box 10).

The GIWA assessments highlighted the widespread transboundary effects of eutrophication in freshwater systems. This is evident in lakes, such as Lake Victoria, where eutrophication combined with overfishing and the introduction of alien species has altered the Lake's ecosystem and consequently decreased the variety of endemic cichlid fishes. Wetlands in the Congo River Basin are also suffering from eutrophication, which is attributed to the flat morphology of the coastal plains and the discharge of insufficiently treated wastewater from the many cities in the Basin (Guinea Current/42d).

Although the extent of eutrophication in coastal marine areas is largely restricted to estuaries and inner shelf areas, its expansion into open marine areas, such as the Gulf of Mexico/2, is recognised as a future threat. Higher water

BOX 10. EUTROPHICATION: CASE OF THE BLACK SEA

The Black Sea is one of the world's largest inland seas, with twenty-three countries partially or completely contained within its catchment area. Three of the four largest rivers in Europe flow into the Black Sea, namely, the Danube, Dnipro and Don, and more than 160 million people live in its catchment area.

In the past 30 years, human activity has transformed the Black Sea from a diverse ecosystem supporting varied marine life to a eutrophic plankton-based system. Eutrophication was identified by the GIWA regional team as the most critical environmental issue, primarily caused by excessive nutrient loading from agricultural run-off (80%) and sewage discharges (15%). The application of fertilizers in the Black Sea drainage basin increased rapidly during the second half of the 20th century. Today, nearly 650 000 tonnes of nitrogen and more than 50 000 tonnes of phosphorus enter the Black Sea annually. Communities in the basin discharge 2 500 million m^3 of wastewater every year, much of it untreated.

The high nutrient loads have resulted in extensive eutrophication in the northwest of the Black Sea, the Azov Sea and the lower sections of the Danube and Dnipro rivers. In 2000, a hypoxic area of 14 000 km^2 covered shallow parts of the Black Sea in addition to the permanently hypoxic deep waters of the Black Sea basin. Harmful phytoplankton blooms and toxic red tides have become a regular occurrence in the last 25 years. While native species diversity has been reduced by eutrophication, invasive species, introduced via ship ballasts, have proliferated at the detriment of native species (see Box 26 in the chapter on overfishing).

The degradation of the Black Sea has resulted in substantial economic costs. For example, tourism revenues have declined by an estimated 360 million USD annually, and coastal communities lose 120 million USD every year from reduced fishing yields.

The countries surrounding the Black Sea increasingly recognise the need to cooperate in addressing pollution. National water policies are being adapted to conform to the EU Water Framework Directive. This will create greater harmonisation and integration regarding environmental protection and water management, and ultimately, improve the environmental conditions of the Black Sea.

Despite this progress, eutrophication and harmful algal blooms are expected to increase in prevalence and severity by 2020. Although additional sewage treatment facilities are planned, the region will still lack the capacity to treat increasing quantities of wastewater. Improvements in agricultural practices owing to the adoption of EU environmental policies will reduce nutrient loading in the Danube River Basin. On the other hand, greater fertilizer application in Russia, Belarus and the Ukraine will increase nutrient loads discharged by the Don and Dnipro rivers. This differing outlook for the region's various river basins highlights the need to adopt integrated transnational approaches to rehabilitate the entire Black Sea.

(SOURCE: BLACK SEA/22)

temperatures resulting from climate change may exacerbate eutrophication.

The Humboldt Current/64 region, shared by Chile, Ecuador and Peru, produces more than 20% of the world's total fisheries output. The numerous fish processing plants, which discharge their wastes directly into the ocean, are a major source of nutrient enrichment in coastal waters. This causes eutrophication and hypoxia in semi-enclosed bays, particularly in Peru, which are also susceptible to toxic algal blooms. The growing aquaculture sector is another important source of nutrients for eutrophication. The amount of waste produced by Chilean salmon farms is comparable to that generated by a city of over 2 million inhabitants. For more information on the fisheries and aquaculture industry, see the chapter on overfishing and other threats to living resources.

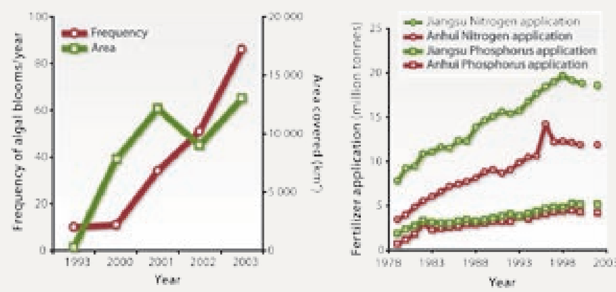
Eutrophication favours the development of HABs, including red tides. Red tide events, originally referring to reddish-coloured algal blooms, is now a term used to characterise the explosive growth of toxin-producing microbes that can cause disease or mortality in fish, wildlife and consumers of contaminated shellfish. In eutrophic freshwater systems, blooms of cyanobacteria and other potentially harmful algae are common. For example, hepatotoxins released by algal blooms in eutrophic reservoirs of Brazil have poisoned hundreds of people. In the Yellow and East China Seas, increases in the frequency, extent and duration of HABs since the 1970s are correlated with increased use of fertilizers (Box II). Even if HABs are confined to relatively restricted areas, they are often transboundary in nature as the nutrient source is from another country and/or the contaminated shellfish are exported. Furthermore, HAB organisms are transported over long distances by shipping traffic.

Eutrophication has been a contributing factor in reducing fisheries production. In the Yellow Sea/34, for example, it has caused drastic declines in catches of penaeid shrimps (*Penaeus* spp.) and scallops (*Pecten* spp.). In many parts of Sub-Saharan Africa, including the Comoe River, Niger Delta and East African Rift Valley Lakes, eutrophication of rivers and lakes has contributed to the "explosion" of aquatic weeds, particularly Water hyacinth (*Eichhornia crassipes*). These weeds have clogged waterways, disrupted navigation routes, reduced hydroelectric power generation and increased water treatment costs. The GEF, UNDP and the World Bank are funding projects to control invasive aquatic weeds in Lake Victoria and the Comoe Basin.

BOX II. HARMFUL ALGAL BLOOMS: CASE OF THE EAST CHINA SEA

Between 1993 and 2003, the number of harmful algal blooms (HABs) in the East China Sea have increased from 10 to 86 events per year and they cover an area of up to 13 000 km². The blooms have caused the mortality of fish and benthic animals, resulting in considerable environmental and socio-economic costs. The blooms mostly occur in the inner shelf of the Yangtze (Changjiang) River. This has been attributed to a 250% increase in fertilizer application in the catchment area, particularly in the upstream and coastal provinces of Anhui and Jiangsu.

(SOURCE: EAST CHINA SEA/36)



The Sea of Japan/33, which is bordered by China, Japan, North and South Korea and Russia, is also experiencing harmful effects from eutrophication, including a decline in the aesthetic value of lakes and reservoirs, reduced drinking water quality and HABs. Although all the countries in the region recognise that inadequate treatment of human waste and agricultural run-off are the major causes of eutrophication, the developing countries cannot afford secondary and teritary treatment that is necessary to reduce the nutrient and organic loads of rivers, lakes and the sea.

Microbial pollution

In many GIWA regions, inadequately treated human sewage is the major source of microbial pathogenic pollution. Improved sanitation is one of the fundamental Millennium Development Goals (MDGs), which is discussed further in the chapter on freshwater shortage. Animal wastes are also an important contributor, especially near large industrial farms such as those located around the Upper Uruguay River in Brazil (Patagonian Shelf/38). The contamination of public water supplies or bathing waters by infectious pathogens creates serious health problems, particularly in low-income areas with inadequate drinking water treatment, sanitation facilities or drainage basin protection. Pathogens can accumulate in filter-feeding molluscs and other seafood, posing health risks to human consumers.

Microbial pollution is normally localised, but its root causes and consequences can be transboundary. According to the GIWA regional teams, many international freshwater systems suffer from severe microbial pollution. Marine microbial pollution was assessed as severe in the Gulf of Mexico/2, Caribbean Small Islands/3a, Comoe Basin (Guinea Current/42a), Indonesian Seas/57a and the Eastern Equatorial Pacific/65c. The high bacterial counts recorded in many bays of the Small Islands/3a were attributed to failed septic systems, inadequate or lacking wastewater treatment and discharges from vessels, including cruise liners. In Indonesia, all major rivers in Jawa and Sumatra, as well as coastal areas in the Jawa Sea, have elevated coliform concentrations, and consequently the incidence of bacterial gastro-enteric disorders has recently increased due to the consumption of contaminated fisheries products.

The aquaculture industry in many developing regions, such as the Bay of Bengal/53, Humboldt Current/64 and South China Sea/54, has been adversely affected by transboundary microbial pollution as the contamination of seafood has resulted in reduced exports.

Microbial pollution is extensive in the Humboldt Current/64 region, with high coliform concentrations recorded along the entire Southeast Pacific coastline. Over 80% of wastewater from Peru, Ecuador and Chile is discharged without treatment. Diarrhoea, caused by poor sanitation conditions, is mainly responsible for the high rates of child mortality and morbidity in Ecuador and Peru. Municipal wastewater treatment is also inadequate in the Patagonian Shelf/38 region. The coastal states of Brazil, Argentina and Uruguay only have the capacity to treat 20-30% of their effluent. Intensive poultry and swine breeding facilities in Brazil also contribute large quantities of microbial pollutants to the Uruguay River Basin.

Solid wastes

Solid wastes, such as fishnets, and plastics and rubbish from households and industry, are a major aesthetic nuisance and can harm fish and other wildlife. They are a transboundary problem as rivers and ocean currents transport land-based and ship-borne wastes across vast distances. Improperly disposed solid wastes provide breeding environments for vermin, which may, in turn, become disease vectors. GIWA regional teams determined that solid wastes are a common problem in the majority of GIWA regions, but are particularly severe in many regions of Africa, the Pacific Islands/62 and on Sunda in the Indonesian Seas/57 region.

FIGURE 15. SOLID WASTE ON BEACH, GRAND COMORES (PHOTO: R. PAYET)

Solid waste is the most severe pollution issue for the Indian Ocean Islands/45b. At least 2.8 million tonnes of solid waste is generated annually in the region, of which only 30% is collected routinely. In addition to impacting coastal and marine ecosystems, solid wastes also affect local tourism, damage fishing nets and jeopardise the safety and livelihood of fishers and recreational boaters. Solid wastes, especially containers, provide a habitat for mosquitoes, and have subsequently increased the prevalence of malaria in Madagascar and Comoros.

In the Caribbean Islands/4 region, a large proportion of marine debris originates from shipping traffic. In addition to locally produced solid waste, an estimated 700 000 tonnes of solid waste is generated annually by the 35 million tourists who visit the Caribbean, many on cruise liners. The ports in the region lack waste collection facilities and many ships dump their waste at sea. The large quantity of marine debris deposited on beaches impacts tourism, the cornerstone of the region's economy.

Chemical pollution

In the GIWA methodology (see Annex II), chemical pollution refers primarily to persistent organic pollutants (POPs) (e.g. PCBs, dioxins, furans, DDT and toxaphene) and heavy metals (e.g. mercury and cadmium). These toxic chemicals are ubiquitous as they travel long distances dissolved in water, adhered to sediments, transported by air or transferred in the food chain, but usually only in small concentrations. However, there are chemical pollution hotspots which pose significant health risks to humans and wildlife. Although chemical pollution was considered severe in only nine regions, in a further 35 the impacts were assessed as moderate.

In the Arctic, the presence of persistent pollutants transported by the atmosphere and currents is a major concern. Marine organisms, and consequently food, obtain POPs from the surrounding environment and indirectly through biomagnification in marine food webs, resulting in consumption restrictions for specific species. Exposure to POPs in some Greenland districts is among the highest ever measured. Neurobehavioural effects from POP exposure have been observed in children in some areas of the Arctic.

One of the most heavily polluted river systems in the world is the Ganges-Brahmaputra, where chemical and microbial pollution is prolific. The concentrations of several chemical contaminants, including chromium, cadmium, mercury and lead, exceed health standards by between 10 and 100 times in both India and Bangladesh. The Ganges River is a major recipient of industrial waste from Indian factories. Downstream in Bangladesh, about 6 000 large- and medium-scale industries and another 24 000 small-scale industries also discharge their waste directly into the river.

In Central America, pesticides applied to sugar cane, banana and coffee plantations have caused human mutations, miscarriages and sterility in local populations. Pesticide contamination is also partly responsible for reduced fish stocks in the Nicoya Gulf of Costa Rica. An ongoing GEF/UNEP project addresses these problems by reducing the use of agricultural pesticides in Colombia, Costa Rica and Nicaragua. In the adjacent Small Islands of the Caribbean Sea region, agriculture is also the primary sector causing water pollution, mainly through agro-chemical leaching, direct agro-chemical influx from aerial spraying and improper disposal of solid wastes. This situation is exacerbated by the increasing use of low-lying wetlands for rice cultivation, which requires heavy pesticide use. Fish mortality in the neighbouring Caribbean Islands/4 region is often higher downstream from agricultural areas known to use pesticides. In Jamaica, for example, an increase in fish mortality in coastal areas occurs seasonally when pesticides are applied to coffee plantations.

Oil Spills

Oil tankers, vessel accidents, coastal oil refineries and pipelines are all potential sources of spills which can cause significant, although mostly short-term, impacts on the environment. Lakes and semi-enclosed seas, such as the Black Sea/22, Caspian Sea/23, and Baltic Sea/17, are particularly vulnerable to the impacts of oil spills due to limited or no water exchange.

The impact of oil spills was assessed as severe in most of the transboundary waters of the Caribbean Sea/3, Niger Basin (Guinea Current/42c) and Benguela Current/44. In the future, oils spills are most likely in areas already intensely exploited for oil and around oil fields currently under development.

Nearly 5 000 oil spills in the Niger River delta were reported between 1976 and 1996, releasing nearly 375 000 tonnes of oil in total. This has resulted in groundwater contamination and a loss of biodiversity in the vicinity of oil installations. Oil

BOX 12. POLLUTION SYNERGIES AND INTERACTIONS: CASE OF THE PATOS/MIRIM LAGOON SYSTEM

Pollution is often just one of several human stressors affecting an ecosystem. An example of a transboundary system affected by multiple anthropogenic activities is the Patos/Mirim Lagoon system, located on the border between Brazil and Uruguay. The lagoon system includes extensive estuarine habitats that in the past provided Brazil with over 25% of its fish catches.

Over the last 30 years, rice cultivation has become the principal agricultural activity and now uses 97% of the water withdrawn from the Mirim Lagoon. In addition, large amounts of biocides and fertilizers are applied to the rice paddies. The contaminated run-off pollutes water supplies and increases water treatment costs. The Patos Lagoon is further polluted by the discharge of domestic sewage and industrial effluents.

Deforestation to clear land for agricultural expansion and urban development has resulted in greater sedimentation, increased dredging to maintain navigation routes, reduced tourism and increased water treatment costs. It has also invoked conflict over water quality between Uruguay and Brazil. The increased water turbidity has decreased primary productivity, which combined with overfishing and pollution has reduced fish stocks.

The Patos/Mirim Lagoon system is an all too common example of synergies between multiple stressors where the combined impacts are greater than the sum of the impacts from individual stressors. In this case, as in many others, pollution often drives other environmental changes, such as habitat modification.

(SOURCE: BRAZIL CURRENT/39)

spills frequently occur in the Russian Arctic/1a and the Sea of Okhotsk/30 due to the use of antiquated equipment. Every year, about 300 spills are officially recorded in western Siberia, but the actual figure could be significantly higher. The degradation and dissipation of hydrocarbons tends to be slowed by low temperatures, so Siberia and other cold regions, such as the Barents Sea and the rest of the Russian Arctic, face disproportionately higher impacts from oil spills.

Emergency response and clean-up operations for large oil spills are extremely costly. In the Caribbean Islands/4, the spill off San Juan, Puerto Rico in 1994 (Figure 16) required more than 1 000 workers and more than 87 million USD for clean-up operations. Surveys carried out in Cuba, Puerto Rico and the Dominican Republic showed that tourism revenues have been reduced due to the pollution of beaches by marine debris and tar balls.

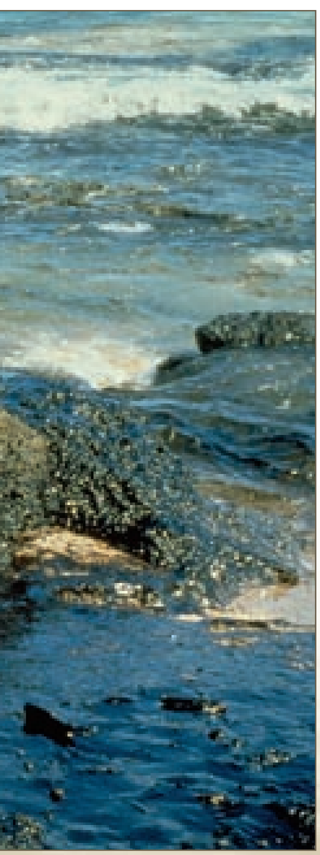


FIGURE 16. OIL SPILL CAUSED BY THE BARGE MORRIS J. BERMAN OFF SAN JUAN, PUERTO RICO 1994
(PHOTO: NOAA)

Radionuclides

The transboundary impact of radionuclides was assessed as severe in only two GIWA regions: the Pacific Islands/62 and the Benguela Current/44. In the Pacific Islands/62, there is concern over recent nuclear weapons testing by France on Muroroa and past tests by the United States on the Marshall Islands. In the Benguela Current/44 region, uranium mining may have contaminated freshwater ecosystems in East Rand, South Africa. The large amount of radioactive waste and the numerous nuclear submarine bases in areas of Russia bordering the Barents Sea and the Arctic Seas also require careful management.

The interactions between the various pollutants and the other GIWA concerns are highlighted in the case of Patos/Mirim Lagoon system (Box 12).

ROOT CAUSES

A causal chain analysis for pollution was conducted for 22 GIWA regions (Tables 5 and 6). Eutrophication, chemical pollution and suspended solids were the issues most frequently targeted for analysis.

TABLE 5. IMMEDIATE CAUSES OF THE GIWA CONCERN POLLUTION

	Targeted issues															
	Suspended solids		Eutrophication					Microbiological pollution			Chemical pollution					Oil spills
	Immediate causes															
GIWA region	Deforestation	Agricultural land use	Agricultural run-off	Transport and energy sector atmospheric inputs	Aquaculture effluent	Industrial and domestic discharge	Deforestation	Agricultural run-off	Industrial and domestic discharges	Discards from beach users and cruise ships	Long-range atmospheric transport	Industry and mining discharges	Waste discharges	Agricultural run-off	Leaking landfills	Oil extraction, refining and transport
1a Russian Arctic											✓	✓				
2a Mississippi River (Gulf of Mexico)			✓									✓		✓		
4 Caribbean Islands			✓			✓			✓	✓						✓
11 Barents Sea																✓
13 Faroe Islands											✓					
15 East Greenland Sea											✓	✓	✓			
17 Baltic Sea			✓	✓		✓										
22 Black Sea			✓			✓										
30 Sea of Okhotsk																✓
33 Sea of Japan			✓		✓											
36 East China Sea			✓		✓	✓										
39a Mirim Lagoon (Brazil Current)	✓	✓	✓											✓		
39b Doce River Basin (Brazil Current)	✓	✓				✓			✓				✓		✓	
42a Comoe Basin (Guinea Current)			✓			✓	✓									
42e Guinea Current LME (Guinea Current)												✓			✓	
47b Lake Victoria (East African Rift Valley Lakes)		✓	✓			✓		✓	✓		✓	✓		✓		
64 Humboldt Current			✓			✓			✓			✓		✓		
65a Southwest Mexico (Eastern Equatorial Pacific)								✓	✓							

NOTE: THE TABLE PRESENTS A SELECTION OF GIWA REGIONS WHERE THE REGIONAL TEAM HAS CONDUCTED A CAUSAL CHAIN ANALYSIS ON THE FIVE MOST FREQUENTLY ANALYSED ISSUES OF THE GIWA CONCERN POLLUTION.

This section groups the root causes of pollution into three broad and interlinked categories: (i) demographic and economic trends; (ii) market failures; and (iii) policy failures.

Demographic and economic trends

Water consumption and wastewater generation increases in parallel with population growth and urbanisation. Many GIWA regional assessments found that urban wastewater treatment coverage has failed to increase at the same rate as urban growth in developing regions (Figure 17). Untreated urban wastewater was identified as a major source of microbial pollution and nutrients in Lake Victoria. Other regional teams that highlighted discharges from urban areas as an important source of pollutants include the Humboldt Current/64, Eastern Equatorial Pacific/65, Indian Ocean Islands/45b, Guinea Current/42, East China Sea/36 and Black Sea/22.

In the Humboldt Current/64 region, the urban population has increased rapidly and now accounts for 74% of the total population of 41 million. Migration to urban areas was

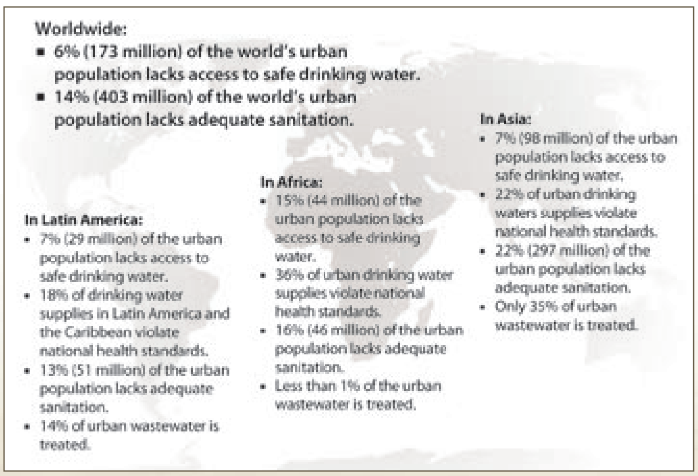


FIGURE 17. PROPORTION OF TREATED URBAN WASTEWATER IN DIFFERENT CONTINENTS OF THE WORLD
(SOURCE: WHO/UNICEF 2000)

TABLE 6. POTENTIAL POLICY INSTRUMENTS RELATED TO THE GIWA CONCERN POLLUTION

Contributing sector	Underlying root causes	Potential policy instruments: Short-term	Potential policy instruments: Long-term
Eutrophication			
Agriculture	▪ Subsidies for chemical fertilizers ▪ Lack of awareness and training of farmers on the use of fertilizers	▪ Redesign agricultural subsidies to foster efficient use of inputs ▪ Information campaigns ▪ Promote the adoption of effective bio-substitutes	▪ Encourage alternative fertilizing techniques ▪ Encourage R&D for bio-fertilizers ▪ Establish riparian buffer zones ▪ Eco-payments for natural filtering habitats
Urban sewage	▪ Limited funding for treatment infrastructure ▪ Lack of incentives to operate existing infrastructure	▪ Provide additional infrastructure and complementary technology to treat wastewater	▪ Integrate sewage infrastructure in future development
Industry	▪ Lack of appropriate technology for treatment of industrial waste ▪ Lack of regulation, compliance and enforcement	▪ Introduce effluent charges ▪ Provide additional infrastructure and cost-effective technologies.	▪ Introduce clean industrial technologies
Chemical pollution			
Industry and mining	▪ Lack of regulations and enforcement regarding industrial leaks and discharges ▪ Absence or lack of treatment infrastructure	▪ Regulate and enforce ▪ Introduce effluent charges ▪ Provide necessary infrastructure ▪ Introduce assurance bonds ▪ Introduce financial incentives for clean operating industries	▪ Integrate the cleaning of industrial effluents into sector planning ▪ Initiate participatory measures ▪ Introduce cost-effective clean technologies
Agriculture	▪ Limited awareness of how to use chemicals appropriately ▪ Lack of resources for supervision and control of chemical inputs	▪ Information campaigns ▪ Promote the adoption of effective bio-substitutes ▪ Redesign agricultural subsidies to foster efficient use of inputs	▪ Encourage R&D for bio-fertilizers ▪ Promote alternative agricultural practices
Suspended solids			
Forestry, coastal development, mining	▪ Lack of land use planning and governance	▪ Improve watershed planning and management ▪ Improve regulations and enforcement ▪ Provide cost-effective filtering infrastructure ▪ Establish eco-payments to improve land use ▪ Mobilise resources to enforce existing regulations	▪ Coordinate stakeholders in participatory process ▪ Upgrade governance. ▪ Establish eco-labelling
Solid waste			
General public	▪ Lack of collection and disposal infrastructure ▪ Low awareness of impacts ▪ Low compliance with regulations	▪ Revise regulations ▪ Apply fines ▪ Participatory measures ▪ "Deposit-refund" measures for selected items	▪ Awareness campaigns
Industries, municipalities, transportation	▪ Lack of regulations ▪ Low compliance and enforcement ▪ Limited capital and technology	▪ Review regulations ▪ Provide designed disposal areas and infrastructure ▪ Enforce via fines	▪ Provide waste treatment and recycling infrastructure ▪ Information campaigns
Oil spills			
Oil exploitation, transportation, infrastructure	▪ Lack of compliance with IMO rules ▪ Lack of cleaning and waste infrastructure ▪ Lack of contingency planning at regional level ▪ Lack of enforcement capabilities at national level	▪ Build reception facilities ▪ Strengthen compliance and enforcement with IMO rules ▪ Foster regional dialogue and spill preparation ▪ Improve surveillance and traffic monitoring	▪ Regulate and enforce standards for refineries ▪ Improve accident response and clean-up
Microbiological pollution			
Urban sewage	▪ Limited resources for treatment ▪ Lack of incentives to operate existing infrastructure ▪ Lack of local regulations and compliance	▪ Provide and sustain infrastructure, technology and manpower ▪ Include treatment costs in price of water	▪ Integrate sewage infrastructure in future urban development ▪ Promote use of treated water

NOTE: THE TABLE PRESENTS ROOT CAUSES AND POTENTIAL POLICY INSTRUMENTS IDENTIFIED BY GIWA REGIONAL TEAMS.

triggered by low agricultural productivity and profitability, violence in the countryside and open access to urban lands. These new and, in most cases, informal settlements create a tremendous demand for sanitation, health care and other services, which governments find hard to meet. The discharge of untreated wastewater from these settlements has deteriorated the coastal waters.

Agriculture was identified as the major cause of nutrient enrichment in nearly all GIWA regions that conducted a causal chain analysis related to eutrophication (Table 6). The use of fertilizers has dramatically increased global food production, but it is the main source of nitrate pollution, with up to 80% of the nitrogen fertilizer resulting in environmental contamination rather than improving yields. The quantity of fertilizer nutrients entering the environment is closely connected to the extent appropriate technologies have been employed in agricultural production. Agriculture is also a source of phosphate pollution and persistent organic pollutants, such as pesticides.

Industrial effluents, particularly in developing countries, are usually discharged directly into water bodies and can pollute large volumes of water and infiltrate aquifers. In western South America, like in many developing regions worldwide, effluent treatment is frequently inadequate in the mining, petrochemical, fishmeal and cannery industries. Industrial pollution can be transported in the atmosphere for thousands of kilometres before being deposited. Emissions from Europe, Asia and North America are the major sources of chemical contamination in the Arctic. Reducing these sources requires significant international effort to control emissions and to enforce existing agreements.

Market failures

Transboundary pollution is rarely caused deliberately by individuals or organisations, but is usually the result of negligence or actions taken to protect private interests, such as avoiding financial costs for waste treatment. The social and environmental costs of pollution caused by production processes are not included in the price of products.

In the Caribbean Islands/4 region, waste treatment is costly for cruise line operators and there is an absence of economic incentives to discourage them from dumping wastes at sea. The countries of the region are reluctant to penalise these polluters due to their dependence on foreign exchange from tourism.

In the Baltic Sea/17 region, consumer prices for water and water treatment vary considerably between the riparian countries. Ideally, prices should include indirect costs to ensure sufficient investment in wastewater treatment and to minimise pollution. However, in the Baltic region, even the direct costs related to water services are only fully recovered in Finland and Sweden. In Denmark and Germany, the degree of cost recovery is high, whereas in Estonia, Latvia, Lithuania, Russia and Poland, it remains low. It is anticipated that new legislation in these countries will gradually lead to the full recovery of costs for water services.

Policy failures

The GIWA regional teams stressed the importance of policy-driven root causes of transboundary pollution. Policy failures commonly result from the inability of institutions to perform three key functions:
(i) identify the indicators of a problem and agree on its nature; (ii) reach agreements that balance the interests of stakeholders both within and across countries; and (iii) implement and enforce these agreements.

A scientifically reliable understanding of an environmental problem is insufficient to trigger mitigatory actions. For example, despite acknowledging the negative affects of deforestation on aquatic ecosystems and subsequently human well-being, governments rarely take action to control forestry.

When formulating policies, governments commonly disregard environmental and stakeholder concerns. In the Aral Sea/24 Basin, the centralised planning policies of the former Soviet Union subsidised agricultural inputs in order to increase cotton production, which led to excessive fertilizer application. The governments also failed to deter cotton farmers from withdrawing excessive quantities of water. Consequently, the Aral Sea shrank to a fraction of its former size and the coastal zones of Kazakhstan and Uzbekistan are heavily polluted.

Agreed goals and actions that address transboundary issues are often inadequately implemented and/or enforced. Sea-borne pollution is still extensive in the Caribbean Islands/4 region despite the adoption of the International Convention for the Prevention of Marine Pollution from Ships (MARPOL). Enforcement of MARPOL is the responsibility of national governments, but they lack the capacity and the political will to fulfil their obligations. Ships can therefore avoid compliance with the regulations.

Chile, Ecuador and Peru are faced with an urban waste crisis because waste treatment is already subsidised to such an extent that they cannot afford to extend or upgrade the treatment infrastructure. There is an absence of an incentive framework, which could include clean technology subsidies and regulatory enforcement. In Chile, industries have stepped forward to partially address this policy failure through industry self-regulation.

The implementation of a bilateral integrated management plan for the Mirim Lagoon Basin failed due, partly, to a lack of harmonisation between the legal instruments of Brazil and Uruguay. With both countries finding it difficult to obtain national agreement on pollution management, it is not surprising that the bilateral agreement was difficult to implement. Furthermore, State agencies charged with pollution management lack autonomy and the capacity to control pollution in the lagoon.

In the former Soviet states, governments and international agencies pursued decentralisation before establish-

BOX 13. POLLUTION AND POLICY FAILURE: CASE OF THE AMUR RIVER BASIN

The Amur River is one of the largest rivers in Asia, with a catchment area of 2 million km². The basin has a population of 75 million; over 90 % live in China. Three other countries also share the river basin; Russia, Mongolia and North Korea.

The quality of surface water in the Amur River Basin ranges from pure in the upstream mountainous regions to highly contaminated in the downstream urban areas. Agricultural run-off and sewage from urban areas contribute excessive quantities of nutrients and organic matter to the rivers. Consequently, a considerable portion of the population is forced to consume polluted surface water, which has resulted in a high prevalence of water-borne illnesses.

The GIWA regional team identified the main root causes of eutrophication to be inadequate water management policies and a lack of long-term and inter-sectoral planning. In addition, they noted that short-term economic interests have taken priority over sustainable development. More specifically, insufficient revenues are generated from water due to low taxation and underpricing which prevents the adequate financing of water monitoring and water treatment facilities. National water laws are also absent or inadequate, and institutional capacity is weak and undermined by corruption, resulting in ineffective enforcement. With such weak national frameworks, it is not surprising that there are no basin-wide intergovernmental agreements for the management and protection of the Amur River.

To address these policy failures, the GIWA regional team recommended adopting Integrated Water Resources Management (IWRM) principles. Their recommendations include:

- Creation of an intergovernmental agreement on the use and protection of the Amur River Basin's water resources;
- Establishment of a basin commission to oversee the agreement and to report and monitor progress;
- Revision of national water laws based on IWRM principles;
- Implementation of appropriate water pricing.

(SOURCE: SEA OF OKHOTSK/30)

ing legal frameworks for environmental management and building institutional capacity. In the Black Sea, the repeated amendment of water laws and regulations has made long-term planning difficult and discouraged investment in infrastructure. Under decentralisation, new water and sewage facility ownership structures have made services more unreliable and impaired water resources management. Box 13 outlines the policy failures behind pollution in the Amur River Basin.

POLICY RELEVANT CONCLUSIONS

Population growth, urbanisation, industrialisation and agricultural development will increase pollution loads in the international waters of more than three-quarters of the GIWA regions by 2020. Nevertheless, interventions by governments, communities, industries and NGOs can reduce or control pollution, depending on political will, available financial resources and technological developments.

Eutrophication is likely to intensify in many regions, primarily in response to the increased application of fertilizers, especially in Asia and Africa. It will also increase in prevalence due to the growth in the aquaculture industry, increasing quantities of human sewage, the generation of nitrogen from fossil fuel combustion, and, potentially, as a result of global warming. However, many technical and political options are available to reduce fertilizer use, decrease nutrient run-off, encourage sustainable aquaculture and enhance sewage treatment.

Similarly, suspended solids will continue to be a widespread problem. The implementation of afforestation schemes and the adoption of sustainable agricultural and land use policies can reduce erosion in the catchment area.

Microbial pollution related to sewage is also projected to increase due to population growth and urbanisation, particularly in Asia, Africa and Latin America. This trend may be averted by investing in sewage treatment facilities, industries adopting cleaner technologies and by strengthening the institutions responsible for waste management.

Pollution in international waters can be reduced, as demonstrated by the substantial reduction in hazardous substances and microbial pollution in the Baltic Sea/17. According to UNEP's Global Environmental Monitoring System (GEMS), other successful examples include reductions in organic loading in Europe and Australia, lower phosphate levels in North America and Europe, and reduced nitrate levels in the Danube Basin. The GIWA regional teams emphasised that to address transboundary pollution, governments must recognise the need for action, increase stakeholder participation, provide appropriate incentives, improve regulations,

BOX 14. LACK OF INTERNATIONAL ENFORCEMENT: CASE OF THE CASPIAN SEA

Agricultural run-off is one of the main sources of pollution in the Caspian Sea, with pesticides causing the most severe impacts. Chemical pollution hotspots are located in the dense agricultural areas of Iran's river deltas. Agricultural activities and associated pollution are also prominent in the Ural, Volga and Kura river basins, with the Volga thought to contribute the majority of the total pollution load into the Caspian Sea.

While DDT was prohibited in 1970 in the Soviet states, the GIWA regional team reported that supplies are still readily available. Small-scale farmers have become dependent on pesticides, including DDT, to maintain production on infertile arable land. They have little understanding of the ecological consequences of pesticide use. Clearly, enforcement of the 30-year-old DDT ban must be strengthened, which requires building capacity in the institutions responsible for enforcement. One approach is to improve regional control functions and to give local officials adequate authority and resources to prohibit and seize local supplies and sales. The enforcement of the ban is expected to be highly feasible and effective as DDT is easily identified and confiscated.

(SOURCE: CASPIAN SEA/23)

and cooperate with other nations sharing an international water. In many regions, capacity building is required to better monitor and enforce regulations related to transboundary aquatic pollution.

Table 6 summarises the root causes behind pollution and potential policy instruments identified by the GIWA regional teams. It also lists other instruments that have been successfully used by international and national programmes.

Regulations

Regulations are the most common instruments used to address water pollution due to their simplicity and ability to satisfy the interests of both the authorities and the private sector. Conditions that favour the use of regulations include:

- Unacceptably high economic and/or environmental costs resulting from even minor contamination;
- A small number of polluters;
- The existence of a more environmentally friendly and economically viable technology.

The GIWA regional reports note that regulators are often unwilling or do not have the resources to enforce regulations. As discussed in Box 14, DDT is widely used in the Caspian Sea/23 region despite being prohibited by governmental regulations.

In the Humboldt Current/64 region, many pollution related laws are obsolete, whilst others are inappropriate or have weak sanctions that do not motivate violators to improve their practices. The various national and local institutions often have overlapping responsibilities concerning environmental management. This has often impeded the enforcement of regulations. Global quality systems and certification (e.g. ISO, clean production, organic production) can complement regulations, but generally receive inadequate governmental support.

Economic incentives and public engagement

Economic incentives can be highly effective in changing behavioural patterns. The Benguela Current LME project uses economic incentives to promote environmentally friendly technologies and practices, phase-out subsidies and introduce user fees. Table 7 illustrates the main economic policy instruments for addressing water pollution, with examples from GIWA regions.

TABLE 7. ECONOMIC INCENTIVES AND DISINCENTIVES FOR ADDRESSING WATER POLLUTION WITH EXAMPLES FROM GIWA REGIONS

Instrument	Examples
Reduced subsidies or surcharges (taxes)	Reduced subsidies for fertilizers and pesticides Reduced taxes on waste separation and treatment technologies (Indian Ocean Islands/45b)
Targeted subsidies	Subsidies to promote natural buffer zones to capture nutrients from agricultural run-off Tax reductions on less harmful pesticides (Caspian Sea/23) Subsidies provided to the municipality to commence a waste collection service, and to the private sector to facilitate investment in waste minimisation/treatment (Indian Ocean Islands/45b) Tax incentives to encourage the use of recycled products (Indian Ocean Islands/45b)
User charges	Levy water effluent charges based on the amount of pollutants Tax the disposal of industrial solid wastes (Indian Ocean Islands/45b) Taxes and fines on oil pollution (Caspian Sea/23) Establish market-based fees and charges (Volta Basin (Guinea Current/42b))
Deposit refund systems	Consumers pay a refundable deposit for plastic bottles, batteries, etc. (Indian Ocean Islands/45b)
Performance bonds	Users of hazardous pollutants post a refundable bond to cover potential environmental damage
Insurance markets	The price for insuring potentially damaging activities depends on the expected loss. Insurance companies may also ask their clients to use certain technologies or follow certain procedures

TABLE 8. DIRECT GOVERNMENT INSTRUMENTS FOR ADDRESSING WATER POLLUTION WITH EXAMPLES FROM GIWA REGIONS

Instrument	Examples
Understanding pollution problems and developing solutions	Strengthening institutions responsible for enforcement of maritime regulations (Caribbean Islands/4) Information system on water resources in the Madeira River Basin (Amazon Basin/40b) Training and environmental education programmes (Amazon Basin/40b) Develop national/regional HAB contingency plans (Comoe Basin (Guinea Current/42a)) Develop coordinated river and coastal management (Guinea Current LME (Guinea Current/42e) Establish a water quality and aquatic environment institutional network (Guinea Current LME (Guinea Current/42e)
Infrastructure	Municipal water treatment plants Improve design and maintenance of purification systems (Guinea Current LME (Guinea Current/42e)) Provide sufficient waste receiving and treatment infrastructure at ports (Amazon Basin/40b, Caribbean Islands/4) Allocate funding for solid waste management (Indian Ocean Islands/45b)
Protection	Develop protected areas that serve as buffer zones Reach agreement among governments for the creation of special protection areas (Small Islands (Carribean Sea/3a)) Strengthen national policies, regulations and law enforcement for protection of water resources (Jordan/51)
Transboundary agreements	Reach agreement on common environmental standards (Small Islands (Caribbean Sea/3a), Sea of Japan/33, and Humboldt Current/64) Integrate sector policies with environmental policy proposed by the various international conventions (Baltic Sea/17) Develop comprehensive water policies and institutions for transboundary river basins and coastal zones (widespread, including Small Islands (Caribbean Sea/3a), Baltic Sea/17, Uruguay River Basin (Patagonian Shelf/38), Brazil Current/39, Amazon Basin/40b, Volta Basin (Guinea Current/42b), Guinea Current LME (Guinea Current/42e) and Jordan/51)

Many GIWA regional teams emphasise the importance of stakeholder engagement for addressing complex transboundary issues.

Direct government investment

Government investment can be effective in reducing pollution. For example, the construction of wastewater treatment plants in the Baltic Sea/17 region has improved coastal water quality. As a result, nearly all of the beaches along the southeastern coast of the Baltic Sea that were closed in the late 1980s were re-opened in the mid-1990s. Initiatives often involve the construction of infrastructure and the creation of protected areas. Governments, however, often cannot afford to make the investments or are unable to charge users for the services. The main governmental instruments for addressing transboundary water pollution are presented in Table 8.