IN THE BARREN DESERT OF WADI RUM CROPS ARE GROWN ON CIRCULAR IRRIGATED PATCHES OF LAND. (PHOTO: CORBIS)

FRESHWATER SHORTAGE

Today, freshwater is used unsustainably in the majority of the regions studied by GIWA. In two-thirds of the regions, water is predicted to become scarcer by 2020 due to demand continuing to grow in parallel with increased agricultural production, and population and economic growth. Global climate change will exacerbate this situation. On a global scale, the most widespread and adverse transboundary consequences result from the modification of stream flow by dams, reservoirs and river diversions, as well as by land-use changes in the catchment area. Downstream ecosystems and riparian communities are severely impacted by changes to the flow regime of international rivers. Inappropriate subsidies encourage inefficient water use, such as the growing of water-intensive crops in water scarce regions.

The growing recognition that entire river basins, estuaries and coastal areas are single planning units has led to a paradigm shift of water management towards more integrated approaches. Demand management was identified as an effective alternative to building new reservoirs and deeper wells. There is a need to move away from focusing exclusively on the direct economic benefits of engineered structures to understanding their actual environmental and socio-economic costs.

Freshwater is a highly valuable resource for a large number of competing demands, including drinking water, irrigation, hydroelectricity, waste disposal, industrial processes, transport and recreation, as well as ecosystem functions and services. Prior to the 20th century, human demand for water was relatively small compared to availability in most parts of the world. Water demand dramatically increased as a consequence of population and income growth, and the expansion of industry and irrigated agriculture, so that demand now exceeds supply in many developed and developing countries. Today, freshwater scarcity affects more than a billion people and the integrity of many of the world's ecosystems. The achievement of many of the UN Millennium Development Goals (MDGs) will depend on the improved management of freshwater resources. One goal focuses specifically on reducing the proportion of people without sustainable access to safe drinking water and basic sanitation by 50%. Managing water in transboundary river basins poses great challenges and requires comprehensive solutions that take into account the needs of both upstream and downstream countries (Box 1).

BOX 1. TRANSBOUNDARY FRESHWATER RESOURCES

- Approximately 60% of global freshwater flows and 50% of the Earth's land surface is located within the 263 international river basins.
- More than 40% of the world's population live within international river basins.
- Many of the world's largest lakes are transboundary, such as the Caspian Sea, Aral Sea, Lake Chad, Dead Sea, Lake Tanganyika, Lake Victoria and the Great Lakes of North America.
- Transboundary groundwater systems of global significance include the Guarani aquifer in South America, Chad Formation and Nubian Sandstone aquifer in North Africa, and Gangetic Plain Quaternary aquifer in Asia.
- More than 400 international treaties or agreements related to shared water resources have been signed since 1820, excluding agreements on navigation, fisheries, or the demarcation of borders. However, 60% of international basins do not have any cooperative management framework.

(SOURCE: UNEP 2002)

The GIWA methodology (see Annex II) provides a framework for evaluating three critical freshwater transboundary issues: (i) modification of stream flow; (ii) pollution of existing supplies; and (iii) changes in the water table. The results of the GIWA assessment for freshwater shortage are summarised in the global matrix in Annex III.

Global situation and trends

- Freshwater shortage was assessed as the priority transboundary concern in more GIWA regions/sub-systems than any other GIWA concern. Many of these regions are arid and either renowned drought-prone basins in Africa or subject to long-term unsustainable water management.
- More than half of the regions/sub-systems considered the overall environmental and socio-economic impacts of freshwater shortages to be moderate or severe (Figure 1).
- Impacts of the modification of stream flow caused by dams or river diversions were more widespread and severe than those caused by the pollution of existing supplies or changes in the water table.
- Water withdrawals by irrigated agriculture were identified by the GIWA regional teams as causing the most severe environmental and socio-economic impacts.
- Overextraction of aquifers is becoming severe in many areas that depend heavily on irrigated agriculture or are densely populated. The extraction of fossil water from deep aquifers is unsustainable as they will not be refilled on human time scales. Knowledge of aquifers is insufficient and further studies are needed in order to comprehensively assess transboundary aquifers.
- Agricultural land is becoming too saline to support important crops, the salinity of aquifers is too high for human use, and saline waters encroach further up rivers during dry seasons.
- Land-use changes, including deforestation and the cultivation of wetlands, affect the water budget, thus causing floods or droughts in many regions.
- The majority of GIWA regional teams predict that environmental problems related to freshwater shortages will increase by 2020.

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

Modification of stream flow

Nineteen GIWA regional teams identified the modification of stream flow as having severe impacts, particularly in Sub-Saharan Africa, North Africa, Northeast Asia, Central America and Europe & Central Asia (Figure 3). Table 2 summarises

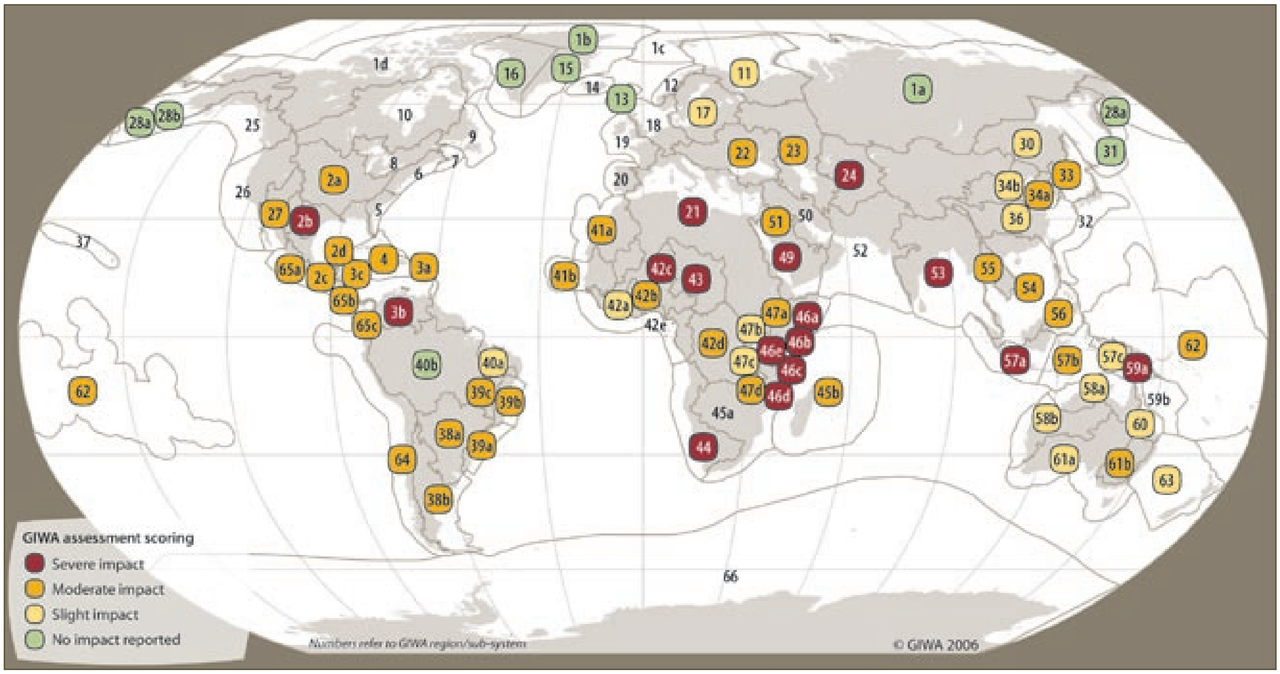


FIGURE 1. OVERALL ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF FRESHWATER SHORTAGE

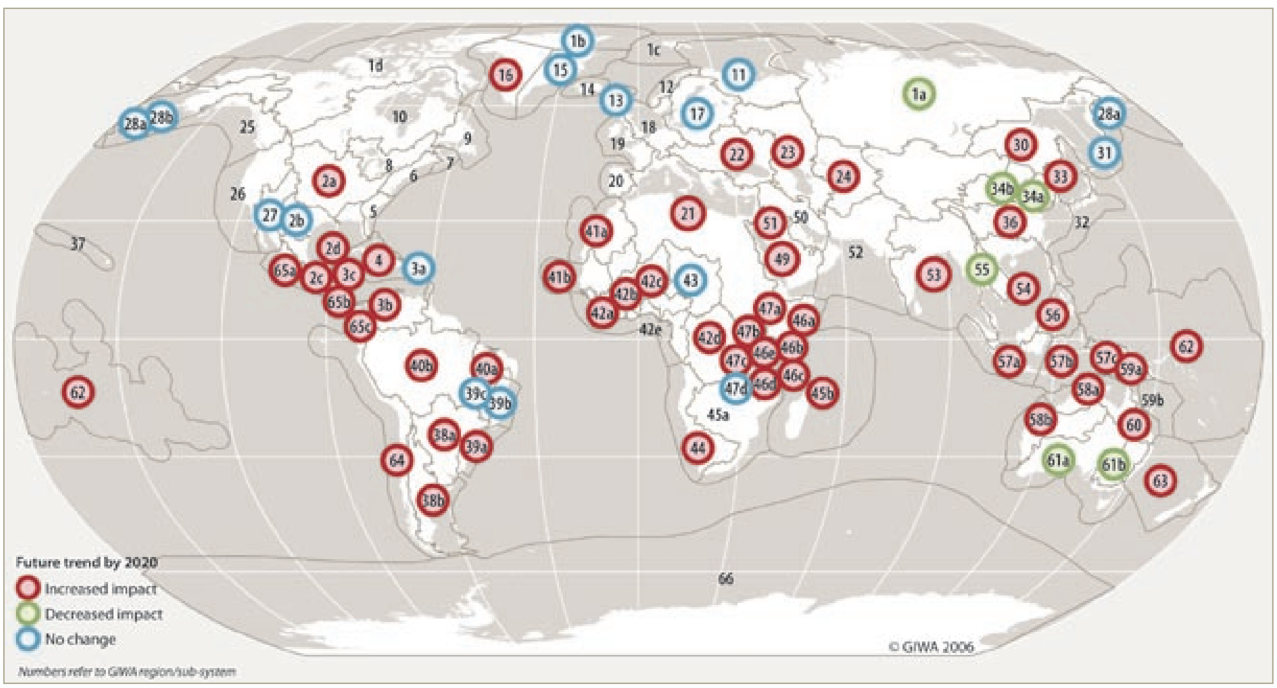


FIGURE 2. FUTURE ENVIRONMENTAL TRENDS OF FRESHWATER SHORTAGE

the environmental and associated socio-economic impacts assessed by GIWA for a selection of transboundary river basins.

Changes in the flow regime were principally attributed to the development of large dams (e.g. the Colorado River, Figure 4). River diversions, inter-basin transfers and other structures designed to supply water and energy also modify stream flow.

Dams change flow patterns by storing water in reservoirs during the wet season and releasing part of it during the dry season. The biodiversity of riparian and aquatic habitats changes in response to the alteration of the flow regime. Dams can also obstruct migration routes and reduce fish spawning habitat. For example, dams on the Volga River (Caspian Sea/23) have reduced the spawning habitat of

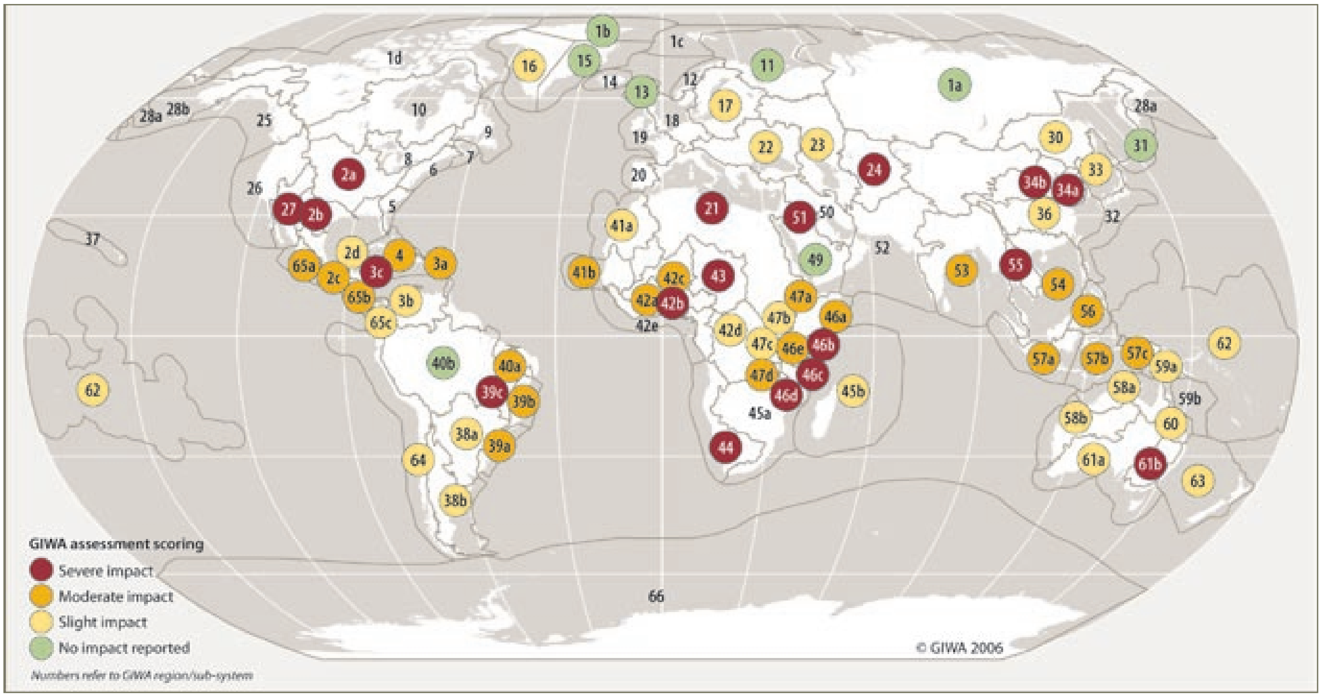


FIGURE 3. IMPACTS OF MODIFICATION OF STREAM FLOW

Caspian sturgeon, and these fish are now predominantly recruited in hatcheries.

Fragmentation of rivers results in the trapping of sediments in reservoirs which can lead to downstream ecological changes and erosion in floodplains, deltas, estuaries and the coastal zone. Land use changes, particularly deforestation, modify sedimentation and flooding regimes. The accumulation of sediments behind dams can affect downstream natural resources and associated livelihoods, and may impede the efficiency of dam infrastructure and reduce the storage capacity of reservoirs. For example, in the Save River in Zimbabwe, soil erosion and sedimentation has significantly reduced

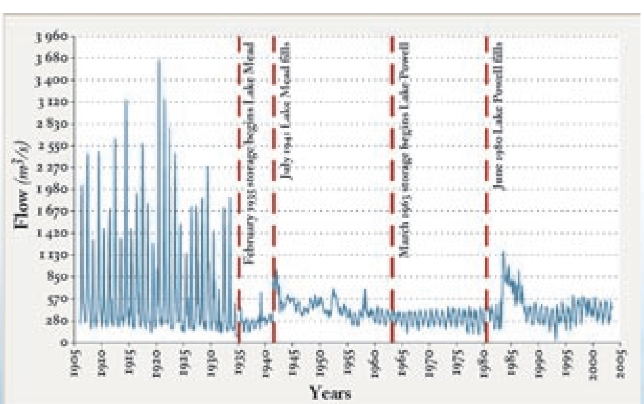


FIGURE 4. FLOW OF THE COLORADO RIVER BELOW THE HOOVER DAM 1905-2003
(SOURCE: USBR 2002)

the storage capacity of reservoirs, thus intensifying competition over water supplies (Agulhas Current/45a). In the Niger River (Guinea Current/42c), sedimentation in upstream reservoirs causes coastal erosion and reduces nearshore productivity as fewer sediments and nutrients reach the coast.

In addition to fragmentation and changed flow regimes, evaporation and water consumption have significant consequences for downstream ecosystems and societies. Globally, irrigated agriculture accounts for around 70% of freshwater withdrawals, followed by industry (21%) and domestic uses (10%). Not all water withdrawals are 'consumed', as return flows re-enter the hydrological system downstream. Irrigated agriculture, however, returns only 30% of its water withdrawals, while industrial and domestic users return 85-90% (FAO 2002). In Namibia's Eastern National Water Carrier canal, more than 70% of the water is lost through evaporation (Benguela Current/44). Freshwater shortage in the Benguela Current region illustrates the problems faced by arid coastal environments worldwide (Box 2).

Loss of freshwater inflow to enclosed water bodies has resulted in dramatic changes to many ecosystems, notably the shrinking of the Aral Sea/24 and the Dead Sea (Jordan/51) (Box 3). In the inland areas of the Canary Current/41 region, the Volta River Basin (Guinea Current/42b) and the Lake Chad/43 Basin, reduced rainfall over the last few decades

TABLE 2. IMPACTS OF MODIFICATION OF STREAM FLOW IDENTIFIED IN GIWA REGIONS

GIWA region	River basin or hydrological system	Environmental impacts	Social, economic and health impacts
27 Gulf of California	Colorado River	▪ Decreased sediment transport to the coast ▪ Erosion of the Colorado River Delta ▪ Loss of wetlands ▪ Loss of endemic plants	▪ Lack of potable water ▪ Loss of crops ▪ Loss of fisheries ▪ Loss of traditional livelihoods
2b Gulf of Mexico	Rio Grande/Rio Bravo, river and estuary	▪ Increased salinity of estuarine habitats	▪ Impacts on coastal fisheries ▪ Conflicts over water resources
34a Yellow Sea	Yalu River, Huai River, Yongsan River, Taedong River, Imjin River, Han River, Kum River	▪ Reduction in water flow ▪ Pollution degrading nearby habitats and leading to annual mass fish kills ▪ Pollution of water supplies ▪ Salinisation of coastal aquifers	▪ Interruptions in water supply ▪ Increase in infectious diseases
39c Brazil Current	São Francisco, river and estuary	▪ Decreased sediment transport to the coast and coastal erosion ▪ Reduced primary productivity	▪ Displacement of people ▪ Loss of traditional livelihoods ▪ Reduced availability of fish ▪ Navigation impediments
42b Guinea Current	Volta River	▪ Decreased sediment transport to the coast and erosion ▪ Loss of marine biodiversity	▪ Loss of farmland and infrastructure ▪ Reduced agricultural output ▪ Displacement of people ▪ Increased water-related diseases ▪ Loss of traditional sites
43 Lake Chad	Komadugu-Yobe River Basin	▪ Loss of floodplain ecosystems and wetlands	▪ Reduced productivity of farmland ▪ Degradation of grazing lands ▪ Reduced availability of fish ▪ Acute freshwater shortage ▪ Food insecurity in downstream areas ▪ Increased water-related diseases ▪ Upstream/downstream conflicts ▪ Political disputes ▪ Displacement of people ▪ Increased vulnerability to flooding
	Chari-Logone River Basin	▪ Loss of floodplain ecosystems and wetlands	
	Lake Chad	▪ Shrinking of Lake Chad ▪ Loss of plant species ▪ Decreased fish stocks and diversity	
44 Benguela Current	Orange-Vaal River Basin	▪ Changed hydrological regime	▪ Increased water-related diseases ▪ Displacement of people ▪ Disruption of family and community structures
46d Somali Coastal Current	Rufiji/Ruvuma River Basin	▪ Changed flow and flood patterns ▪ Increased salinity in the Rufiji Delta	▪ Displacement of people ▪ Malnutrition during periods of relocation ▪ Social conflicts
24 Aral Sea	Amu Darya River, Syr Darya River, Aral Sea	▪ Shrinking of the Aral Sea ▪ Fish extinctions ▪ Salinisation of soil and water resources	▪ Deteriorating human health ▪ International disputes ▪ Loss of agricultural productivity ▪ Loss of fisheries ▪ Displacement of people
51 Jordan	Jordan River, Dead Sea	▪ Shrinking of the Dead Sea ▪ Salinisation of water resources	▪ Lack of potable water ▪ Increased water-related diseases

NOTE: THE TABLE PRESENTS A SELECTION OF REGIONS WHERE THE GIWA ISSUE MODIFICATION OF STREAM FLOW HAS BEEN ASSESSED AS SEVERE.

BOX 2. DESERTS BEHIND THE SEA: FRESHWATER SHORTAGE IN THE BENGUELA CURRENT REGION

In GIWA region 44, the land areas adjacent to the Benguela Current are arid or semi-arid, with rainfall dropping below 50 mm in coastal Namibia and parts of Angola. Evaporation rates exceed mean annual run-off in most of the region. Standing water is limited, and few permanent rivers enter the Benguela Current. Freshwater systems of transboundary significance include the Cunene and the Orange-Vaal systems.

The GIWA regional team considered the anthropogenic impacts on water resources and associated social and economic processes to be severe. The natural aridity, coupled with highly variable rainfall and the geographic disparity between water availability and the distribution of human settlements and activities, has led to the construction of many dams and inter-basin water transfer schemes. The Orange-Vaal Basin is considered to be the most modified river system in southern Africa, with annual flow data indicating a 50% reduction in flow since 1935. Overabstraction of water for agriculture, industry and urban supply has placed enormous stress on water resources, and severely modified stream flow and subsequently the aquatic ecosystems of the region. Pollution from a variety of sources also threatens the ecological integrity of freshwater systems. Furthermore, there is growing concern regarding the presence of aquatic alien species and the overabstraction of aquifers which have slow replenishment rates.

The region's freshwater resources are unsustainably exploited due to a number of anthropogenic factors, including: population growth, particularly in dry, coastal urban areas; irrigated agriculture, which is inappropriate and wastes large quantities of water; and increased demand from the expanding industrial and mining sectors.

Although there are existing measures to address freshwater shortage in the region, the situation is likely to further deteriorate due to increasing demand for water and decreased supply resulting from predicted changes in rainfall patterns.

(SOURCE: BENGUELA CURRENT/44)

BOX 3. SHRINKING LAKES: CASE OF THE DEAD SEA

In 1933, freshwater inputs to the Dead Sea averaged 1.37 km^3. Since then, the overexploitation of water resources and the construction of dams and canals in the catchment area have reduced the annual flow to less than 0.2 km^3. Discharges by the Jordan River comprise of mostly poor quality irrigation return flows, inter-catchment run-off and discharges from saline springs.

The surface area of the Dead Sea has reduced by over one-third, and its water level has dropped by over 20 m and continues to fall by up to 1 m per year. Groundwater extraction for development activities has lowered the water table in surrounding areas, leading to land subsidence.

(SOURCE: JORDAN/51)

(PHOTO: IMAGE PROCESSING, UNEP/GRID-GENEVA 2002)

BOX 4. IMPACTS OF CLIMATE CHANGE ON FRESHWATER RESOURCES

Predicted climate change, including changes to temperatures, weather systems, and sea level, will alter the global hydrological cycle. Impacts on freshwater resources that can be confidently predicted include:

- In river basins strongly influenced by snow or glacier melting, peak stream flows will occur earlier in the year, winter run-off will increase, summer run-off will decrease, and flooding events will become more intense. These changes are already occurring in several drainage basins in Eastern Europe, Central Asia, Canada and California.

- In arid or semi-arid regions, small changes in precipitation can significantly affect run-off. Even if precipitation rates do not change, higher temperatures would increase evaporation rates, reduce stream flow and cause additional droughts. This has serious implications for areas like the Volta Basin, where a large volume of water is lost through evaporation from reservoirs; in Burkina Faso, almost 85% of the total volume of most reservoirs is lost by evaporation (Guinea Current/42b).

- Lakes are particularly vulnerable to climate change due to their dependence on climatic variables, such as precipitation, evaporation, wind conditions and ice formation. Enclosed river basins with no outflow are most sensitive to climate changes, including the Caspian Sea/23, Aral Sea/24, Lake Chad/43, Lake Balkhash (Aral Sea/24) and Lake Titicaca (Humboldt Current/64).

- Sea level rise will cause greater saline intrusion in coastal aquifers. Low-lying islands are particularly vulnerable, with the mean global sea level predicted to increase by 0.09 to 0.88 m by 2100 compared with 1990. In the Pacific Islands/62, global warming is expected to: increase the salinisation of the limited groundwater supplies; cause human migration due to the inundation of coastal areas; and increase the frequency of storm surges and cyclonic events resulting in property and infrastructure damage.

- The small islands of the Indian Ocean Islands/45b region are preparing for the impacts of climate change. The majority of the population inhabits the coastal plateau which is only about 2 m above mean sea level. As the sea rises, many communities will be displaced and economic activity, which is concentrated on the coast, will be disrupted. The loss of beaches will have a significant impact on regional tourism. Water shortages resulting from saline intrusion in aquifers will require the importation of water or desalination, both expensive alternatives.

- While many water-scarce regions in the sub-tropics will have decreased water availability, other regions will have greater precipitation, including Southeast Asia. In many regions, climate change is predicted to increase the pressure on water resources, particularly for irrigated agriculture. Africa appears to be the most vulnerable to the impacts of climate change on water supplies due to widespread poverty, recurrent droughts and the dependence on rain-fed agriculture.

(SOURCE: IN ADDITION TO THE GIWA REPORTS MENTIONED, THIS BOX INCLUDES INFORMATION FROM ARNELL ET AL. 2001) has magnified the effects of water withdrawals for irrigation and water diversion schemes. Discharges by the Chari-Logone River, which is the major inflow for Lake Chad, have decreased by 55% over the last 40 years. In the future, global warming will increase evaporation rates and pose a considerable threat to the supply of freshwater in many regions (Box 4).

Loss of freshwater inputs to coastal ecosystems has also severe transboundary impacts in many areas. As a consequence of upstream water withdrawals, the Berg River estuary in South Africa experiences intrusions of high salinity waters which affect many species of fish, benthic invertebrates and birds (Benguela Current/44). In the Rio Grande/ Rio Bravo Basin (Gulf of Mexico/2b), irrigation diverts nearly 90% of the Rio Grande's average annual flow which has adversely affected many estuarine species, including commercially important fish and shellfish. This region, which has low precipitation rates, is therefore extremely vulnerable to drought.

The reduction of water downstream can have substantial socio-economic impacts, including the displacement of people due to a loss of traditional livelihoods, declines in fisheries production, a loss of water supply, health impacts related to schistosomiasis and other water-borne diseases, and the provocation of conflicts over water allocation (Table 2). Many of these issues are exemplified in the Ganges-Brahmaputra River system (Bay of Bengal/53). Bangladesh receives 90% of its stream flow from its upstream neighbours; India, Nepal and Bhutan. More than 30 dams, barrages and river diversions have been constructed upstream, reducing dry season flows in Bangladesh by up to 60%. Additional dams in Bangladesh also contribute to the problem. The consequences are manifold: acute water shortages; loss of inland fisheries; salinisation and reduced productivity of agricultural lands; the encroachment of sea water further upriver in the dry season; and loss of goods and services provided by mangrove forests. The livelihood and nutritional levels of nearly 30 million people in Bangladesh have been adversely affected as a result of stream flow modification. The water-sharing treaties signed in 1996 between India and Nepal, and Bangladesh and India have reduced, to a degree, the severity of the impacts, particularly on the downstream population in Bangladesh. However, the recently proposed 'river linking' project is expected to transfer a significant proportion of the flows from the Ganges-Brahmaputra-Meghna River system to other rivers in India.

FIGURE 5 THE HOOVER DAM ON THE COLORADO RIVER, USA.

Prolonged water shortages can provoke conflict between water users and force the population to adapt, as observed in the Lake Chad/43 region. In the Komadugu-Yobe Basin, disputes were provoked as a result of upstream Nigerian states allocating insufficient water to the downstream riparian states of Borno and Yobe, and Niger. Many fishermen in the basin have tried to compensate for declining fish production caused by the contracting lake by turning to farming the fertile soils left by the receding lake.

In tropical regions, particularly in Africa, reservoir development often leads to a greater prevalence of water-related diseases, including malaria, yellow fever, guinea worm and schistosomiasis. The latter almost always increases dramatically as reservoirs facilitate the transmission of the disease from snails to humans. The construction of the Akosombo Dam on the Volta River in Ghana increased the proportion of schistosomiasis infected children from 5 % to 90% (Guinea Current/42b). Even in temperate regions, water-borne diseases are correlated with the level of access to safe water and sanitation. In the Caspian Sea/23, 30% to 70% of all illnesses in the region are attributable to the quality and availability of drinking water.

Pollution of freshwater supplies

Pollution reduces the availability of water for human use. Chemical pollutants, microbial contamination, increased concentrations of organic matter and elevated nitrates in drinking water can result in health problems, higher water treatment costs and freshwater shortages. Overall, pollution of freshwater supplies was assessed as severe in 12 and as moderate in a further 30 of the transboundary river basins assessed by GIWA (Figure 6). For a holistic assessment of transboundary pollution refer to the chapter on pollution.

In the Aral Sea/24 region, a considerable proportion of available water resources consist of return waters from irrigated cotton plantations that are heavily contaminated with agro-chemicals. Approximately 15% of surface water supplies in the Aral Sea Basin are polluted, severely affecting the human and ecological functions of many reservoirs. In addition to persistent organic pollutants, 60 million tonnes of salt are carried by the rivers annually, causing concentrations in the delta to exceed 2 g/l. This situation has caused severe human health problems. As the Aral Sea recedes, it leaves behind chemical pesticides and natural salts which are blown into noxious dust storms, seriously affecting the health of the local people. Pollution puts further pressure on communities already burdened by water shortages and the loss of large areas of valuable ecosystems, as well as the retreat of the Aral Sea and the collapse of its fisheries (see the chapter on habitat and community modification).

The Vaal River, a tributary of the Orange River in South Africa, is severely polluted by microbes, nutrients, chemicals and acid mine drainage from agricultural, urban and industrial return flows (Benguela Current/44). Average salinity at the Vaal Barrage has more than tripled since the 1930s. As a result, water at several locations has become unsuitable for human use and Rift Valley fever and sheep blindness is prevalent along the Vaal River.

In addition to the economic costs of water-borne illnesses, many GIWA reports note that water pollution incurs significant direct economic costs, from accessing ever-deeper groundwater and improving water treatment facilities, to consumers paying more to buy water from private suppliers.

In the Patagonian Shelf/38 region, contaminated groundwater and a lower water table have increased water treatment costs and required the exploitation of alternative sources of water. The loss of surface and groundwater sources for large cities, such as São Paulo and Buenos Aires, affects millions of people and disrupts crucial industries. Additionally, the exploitation of fluoride and arsenic contaminated groundwater can lead to poisoning. For example, 80 million of the Bangladesh population live in arsenic-contaminated areas (Bay of Bengal/53).

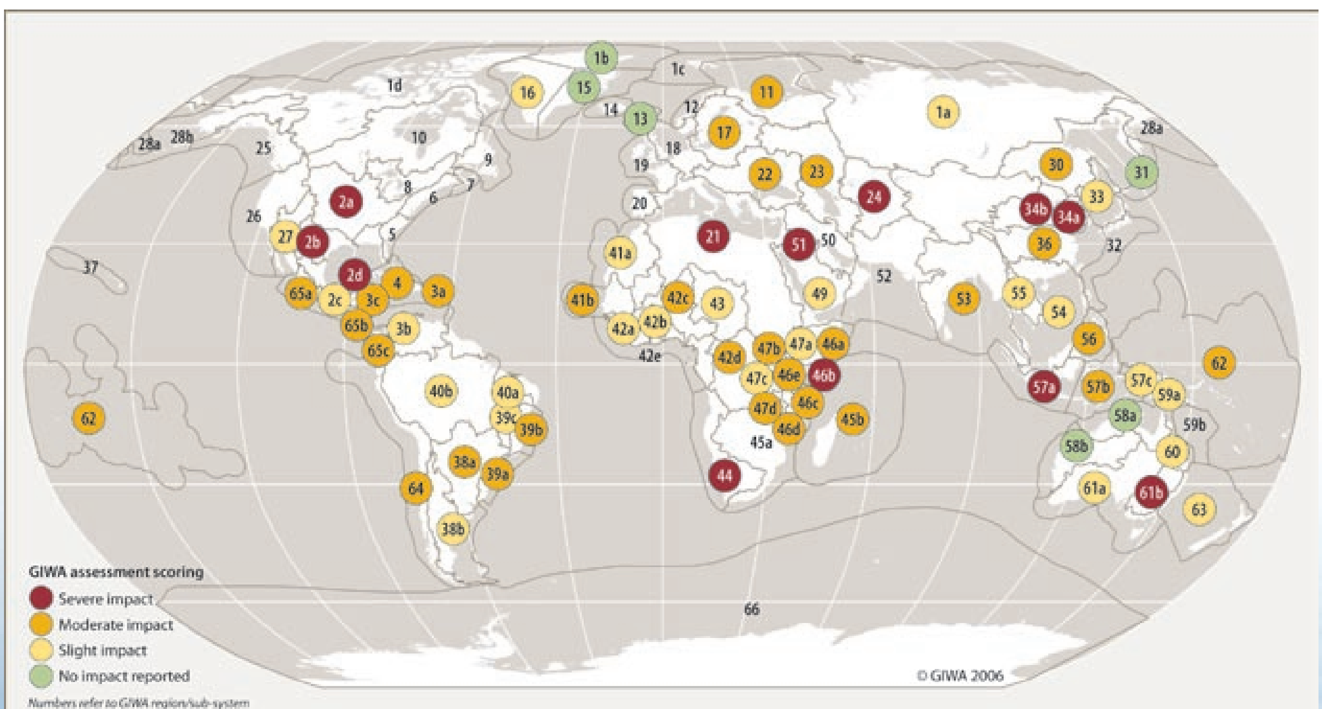


FIGURE 6. IMPACTS OF POLLUTION ON TRANSBOUNDARY FRESHWATER SUPPLIES

In the Colorado River (Gulf of California/27), the economic impacts of freshwater shortages are substantial. Saline waters require expensive purification systems (demineralisation, softening, etc.) that have direct economic impacts on industrial, residential and agricultural water users in both Mexico and California.

Changes in the water table

Most of the world's available freshwater is found in the water-saturated zones of the lithosphere. These groundwater systems supply drinking water to more than 2 billion people and provide irrigation water which is used to generate nearly 40% of global food production (WMO 1997). Despite their global significance, there is a dearth of knowledge regarding aquifers, especially in developing countries.

When water withdrawals from an aquifer system exceed the long-term rate of replenishment, water tables lower and water resources are said to be 'mined'. This is a common problem in many regions on all continents that have low rainfall and rely on groundwater for irrigated agriculture and domestic uses (Figure 7). In the Jordan/51 region, the majority of aquifers are overexploited and often saline; water tables have fallen as rapidly as 0.6 m/year in the Azraq basin. Inefficient irrigation practices can lead to waterlogging and the salinisation of soils and aquifers. This has already affected approximately 40 million ha of farmland. In Namibia, particularly in the vicinity of the Karstveld aquifer, the water table has dropped several metres (Benguela Current/44).

Over the past 25 years the water table in the Volta River Basin (Guinea Current/42b) has significantly lowered, 60-80% of which is attributed to excessive pumping from aquifers for irrigation, domestic water supply and other urban requirements. The lower water table leads to a scarcity of potable water, forcing inhabitants to use surface water which may be polluted or infected.

Water withdrawals from coastal aquifers can lead to seawater intrusion, causing irreversible salinisation. This is a growing concern in many small island developing states (SIDS) of the South Pacific and Caribbean. In the Pacific Islands/62 region, subterranean lenses of freshwater are the primary sources of drinking water for many small islands, particularly atolls. Burgeoning human populations are placing extreme pressure on this limited resource, often resulting in drinking water shortages. These problems are often exacerbated by dilapidated pipes and storage facilities. Suva, the capital of Fiji, is experiencing increasing disruptions to its municipal water supplies, partly due to the failure of old piping systems, but also because of the rapidly increasing population.

The Caribbean Islands/4 also depend on groundwater as a source of potable water. However, groundwater resources

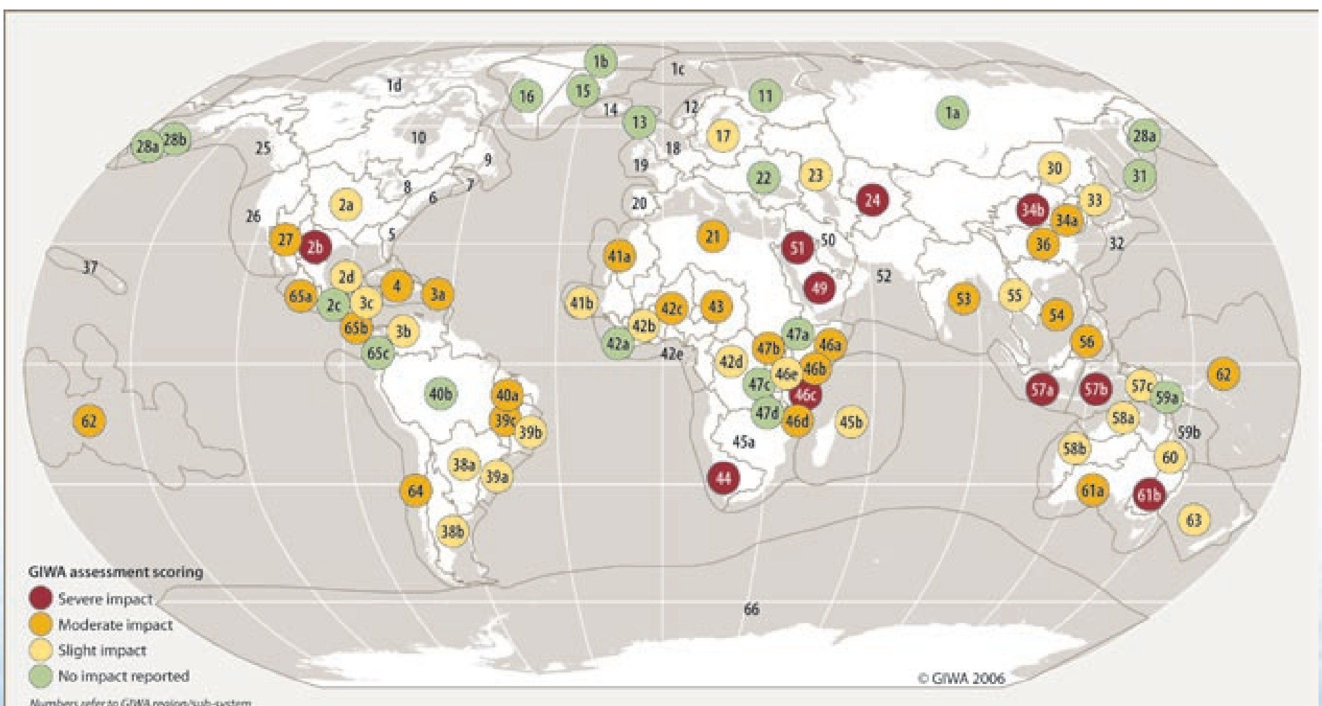


FIGURE 7. IMPACTS FROM CHANGES IN THE WATER TABLE ON TRANSBOUNDARY AQUIFERS

are being eroded by saltwater intrusion resulting from sea level rise and overuse of groundwater reservoirs. In some agricultural regions of Cuba, saltwater intrusions into aquifers extend up to 30 km inland.

Saline intrusion in coastal aquifers is also a serious problem in the East China Sea/36 region and other coastal regions with intense groundwater abstraction for irrigation or the cultivation of marshes and swamps.

The interactions between freshwater shortage and the other GIWA concerns are highlighted in the case of Lake Chad (Box 5).

BOX 5. INTERACTIONS BETWEEN FRESHWATER SHORTAGE AND THE OTHER GIWA CONCERNS: CASE OF LAKE CHAD

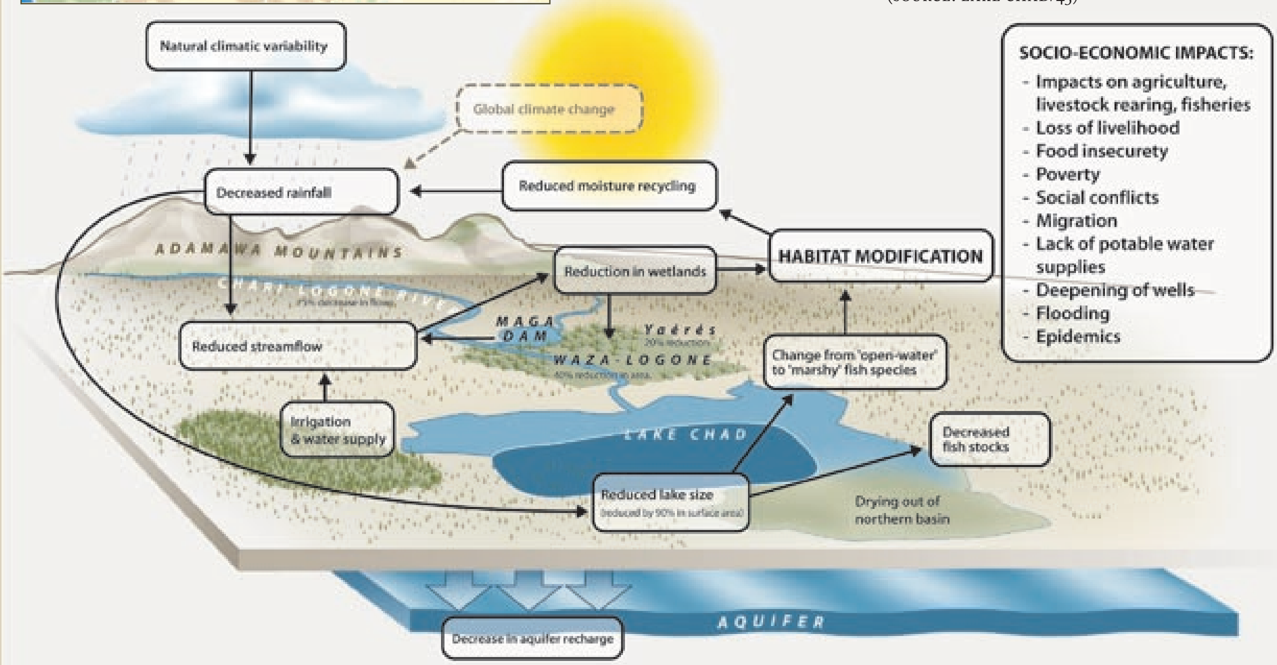
There are strong inter-linkages between freshwater exploitation and the other GIWA concerns, as illustrated in the Lake Chad/43 Basin. The water resources of the Basin are shared primarily by Cameroon, Chad, Niger and Nigeria.

Over the last 30 years, numerous dams and irrigation projects were developed in the Chari-Logone and Komadugu-Yobe river basins, particularly in Nigeria and, to a lesser extent, Cameroon. Over the same time period, the Sahel has experienced a dramatic and sustained decline in rainfall. Lake Chad shrunk by 90% and severe reductions in stream flow from the droughts, as well as the development projects, have severely modified many aquatic habitats, particularly the lake, wetland and floodplain ecosystems.

Previously, high-quality floodplain pastures sustained livestock rearing during the dry season; the third largest source of household income in the basin. Most of the former flooded pastures have lost their perennial grass cover, leaving only degraded grasslands. This has encouraged herders to shift from grazing animals to browsing animals which reduce woody vegetation cover.

The dramatic shrinking of Lake Chad has changed the fish community structure from open water species to wetland species, and reduced fisheries productivity. In the Waza-Logone floodplains, fish yields have declined by 90%. The reduction in fisheries production and the decline in the fertility of agricultural land have contributed to regional poverty and food insecurity. Many households have been forced to migrate to other regions or to urban slums. Freshwater shortages in the Lake Chad Basin have resulted in severe ecosystem degradation and compromised human well-being and economic development.

(SOURCE: LAKE CHAD/43)



ROOT CAUSES

GIWA regional teams conducted 17 causal chain and policy option analyses related to freshwater shortage. The modification of stream flow caused the most severe environmental and socio-economic impacts of the three freshwater issues, and was predominantly chosen as the target for the causal chain analysis (Table 3 and 4). Agriculture, especially irrigation, was the sector most responsible for all three freshwater issues.

This section examines four intertwining categories of root causes of freshwater shortage: (i) demographic and economic development trends; (ii) market failures; (iii) policy failures; and (iv) knowledge gaps and lack of public engagement.

Demographic and economic trends

The most important trends affecting the level of freshwater usage are (i) population growth and urbanisation; (ii) agricultural demand; (iii) hydropower demand; and (iv) industrial demand and trade.

Population growth and urbanisation

Population growth is one of the main drivers of freshwater demand. Most projections estimate that the world population will stabilise at between 8 and 9.5 billion people by around 2050 and that most of this growth will take place in the developing world (UNDP 2004). Population growth not only triggers direct domestic water consumption but also the consumption of agricultural, industrial and other products, and energy use. The population of the world has tripled in the last century, but global water use has increased six-fold (WWC 2000).

TABLE 3. IMMEDIATE CAUSES OF FRESHWATER SHORTAGE

	Targeted issues *																						
	Modification of stream flow													Pollution of existing supplies				Changes in the water table					
	Immediate causes							Main sectors involved						Immediate causes		Main sectors involved		Immediate causes				Main sectors involved	
GIWA region	Increased diversion	Reduced rainfall	Deforestation	Changed return flows	Changed peak flows	Increased sediment load	Changes in land use	Agriculture (irrigated)	Hydropower production	Industry	Domestic supply	Infrastructure (flood protection)	Forestry	Point and non-point effluents	Poor wastewater treatment, agricultural run-off	Agriculture	Industry and/or domestic	Changed return flow or rainfall patterns	Excessive extraction	Reduced recharge	Stream flow modification	Agriculture (irrigated)	Domestic supply
2b Rio Grande/Rio Bravo (Gulf of Mexico)	✓							✓						✓		✓	✓						
24 Aral Sea	✓			✓				✓	✓					✓				✓					
27 Colorado River (Gulf of California)	✓			✓	✓			✓	✓														
34 Yellow Sea	✓							✓		✓		✓		✓		✓	✓						
41a Souss Aquifer (Canary Current North)																		✓	✓	✓	✓	✓	
41b Senegal River basin (Canary Current South)	✓	✓	✓					✓															
42b Volta Basin (Guinea Current)	✓	✓						✓	✓	✓	✓												
43 Lake Chad	✓	✓						✓															
44 Orange-Vaal River Basin (Benguela Current)	✓							✓															
46b Tana/Ahti/Sabaki (Somali Coastal Current)	✓						✓	✓	✓														
46d Rufiji/Ruvuma(Somali Coastal Current)	✓			✓	✓			✓	✓														
51 Jordan	✓							✓						✓		✓	✓		✓			✓	
59a South PNG and Papua (Coral Sea Basin)														✓		✓	✓						
62 Pacific Islands	✓					✓		✓			✓		✓					✓	✓			✓	✓
65b Central Equatorial Pacific (Eastern Equatorial Pacific)			✓	✓		✓		✓	✓					✓	✓	✓	✓						

NOTE: THE TABLE PRESENTS A SELECTION OF GIWA REGIONS WHERE THE REGIONAL TEAM HAS CONDUCTED A CAUSAL CHAIN ANALYSIS ON THE GIWA CONCERN FRESHWATER SHORTAGE. * WHEN ONLY ONE SECTOR IS LISTED, IT IS RESPONSIBLE FOR MORE THAN 50% OF THE IMPACT ON THE TARGETED ISSUE.

Higher incomes stimulate greater consumption of goods and services, the production of which requires water. Income levels are rising in many countries, particularly in China and India, in parallel with economic growth. Decoupling income growth from water consumption is one of the greatest challenges to water management.

Urbanisation is another demographic trend resulting in greater water use. The proportion of the world's population residing in cities was only 14% in the early 1900s and still only 29% in the 1950s. Since then, the urban population has grown rapidly, and more than 60% of people are expected to live in cities by 2030 (UNDP 2004). Urbanisation has had two critical impacts on transboundary freshwater use. Firstly, many cities divert enormous volumes of surface water or overexploit aquifers. Secondly, untreated or inadequately treated sewage from these cities is a major source of pollution.

Along the Rio Grande/Rio Bravo border between Mexico and the United States, population growth and the expansion of industrial and agricultural activities has led to unsustainable water use (Rio Grande/Rio Bravo (Gulf of Mexico/2b)). A major study in 2002 predicted that the total population of the Las Cruces/El Paso/Juarez region could leap from 2 million to 6 million by 2025. Such growth would put great stress on the region's water resources. Even today, the major cities rely on deep wells to abstract water from aquifers. The discharge of inadequately treated wastewater in Mexico and non-point pollution sources on both sides of the border further degrades the region's limited water resources.

Agricultural demand and trade

A growing population consumes more food which, in turn, requires larger volumes of water. Irrigation-based agriculture has contributed 80% of the increases in food production since the 1960s. In most areas, the diversion of rivers and increased water storage capacity has facilitated irrigation development. In a few areas, including parts of South Asia, groundwater extraction makes irrigation possible. In the drought-prone Canary Current region/41, irrigated agriculture consumes close to 80% of water withdrawals (Box 6).

Irrigation water is often used extremely inefficiently. For example, in the arid Senegal River Basin, less than 50% of the water is used productively, particularly in rice and market gardening crop fields. Many farmers do not recognise the economic cost of wasting water or lack the capital to install appropriate irrigation systems.

BOX 6. EXPORTING GROUNDWATER: CASE OF THE SOUSS-MASSA RIVER BASIN

The Souss-Massa River Basin in Morocco covers an area of 27 000 km^2. Although the basin lies within only one country, much of its water is used to produce high value export crops, and such consumption patterns illustrate the concept of virtual water discussed in Box 7. Intensive irrigation development to supply the vegetable and citrus fruit export industry, in combination with urban, tourism and industrial growth, led to chronic water scarcity in this arid to semi-arid region.

The Souss and Massa rivers are the primary sources of surface water in the Basin. Available surface water normally ranges from 341 to 635 million m^3 annually, but can be as low as 35 million m^3 in dry years. Groundwater is obtained from two major aquifers:

- The Souss aquifer, which covers 4 150 km^2 and has an estimated capacity of 30 billion m^3.
- The Chtoukas aquifer, which covers 940 km^2 and has an estimated capacity of 1 billion m^3.

The causal chain analysis undertaken by the regional team identified that the following root causes resulted in the lowering of the water table in the Souss-Massa Basin:

- Inefficient irrigation systems and inappropriate well-digging techniques: flood irrigation still supports nearly 50% of irrigated land.
- Population growth and increasing personal consumption levels: the population of the basin is expected to almost double by 2020 compared with 1994; and domestic water use per capita is expected to increase from 75 to over 120 litres per day by 2020.
- Socio-cultural constraints: water was traditionally considered a public and free resource, which has led to water being heavily subsidised and used wastefully.
- Poor governance and enforcement of water regulations: top-down decision-making and weak institutional capacity have hampered local participation in the decision-making process and constrained regulatory enforcement.

However, there is hope for the future, as Morocco has radically changed its water policies. The 1995 water law is based on the principles of Integrated Water Resources Management (IWRM), and emphasises basin-wide water management. The government is also encouraging the use of micro-irrigation and other efficient irrigation methods. Advanced irrigation systems are now commonly used in greenhouses for export crops. Other improved practices, such as integrated pest management, are also becoming more common. The water law needs to be fully implemented, so that traditional and modern water harvesting systems are considered in future plans for drainage basin and water resources development.

(source: canary current/41)

BOX 7. THE CONCEPT OF VIRTUAL WATER

Producing goods and services requires water: virtual water is a term recently developed to describe the water used to produce agricultural or industrial products. It is an important concept for calculating the total water consumption of a country, or its water footprint, which is equal to total domestic use, plus virtual water imports, minus virtual water exports.

Trade in virtual water has increased steadily over the last 40 years: about 15% of water used worldwide for export is virtual water. The global virtual water trade is estimated to be more than 1 000 km^3 annually, 67% of which is from crops, 23% from livestock and 10% from industrial products.

Virtual water trade not only generates water savings for importing countries, but also global real water savings from differentials in water productivity, which may amount to 385 billion m^3 for food trade alone.

SOURCES: (DE FRAITURE ET AL. 2004, ZIMMER & RENAULT 2004)

The Aral Sea/24 region needs to modernise its irrigation systems and practices, which were inherited from the Soviet era. The GIWA regional team identified critical obstacles to improving water management, including:

- Absence of inter-state agreements, which are necessary given the transboundary nature of the major drainage basins;
- Continuation of centralised planning and regulation of water resources;
- Poor condition of irrigation systems;
- Smallholder farms cannot introduce modern large-scale water saving technologies.

Environmental problems from irrigation are not limited to developing countries. In the Australian Bight & Muray Darling Basin (Great Australian Bight/61), more than a century of agricultural development has required the construction of more than 4 000 dams and weirs. Up to 80% of water flow has been diverted, primarily for agriculture, resulting in the extensive alteration of riverine ecology. Irrigation has also changed the water table and caused the widespread salinisation of groundwater, which has degraded cropland, damaged infrastructure and caused widespread loss of wetlands and biodiversity.

Trade poses both risks and opportunities for transboundary water resources. It can promote more efficient use of water by encouraging water abundant regions to produce water-intensive goods. On the other hand, the increased price of export crops following trade liberalisation can lead to the expansion of water-demanding agricultural activities. In Morocco, for example, water abstraction to irrigate export crops has increased foreign exchange but at the cost of lowering the water table of the Souss Aquifer (Canary Current/41). A similar problem is reported in the Rufiji-Ruvuma sub-system in East Africa.

The concept of virtual water is proving useful in understanding the volume of water implicitly traded via goods or services (Box 7).

Hydropower demand

Hydropower accounts for almost 20% of worldwide electricity production, and there is potential for further growth, especially in developing countries.

Although hydropower has been at the centre of successful regional and national development projects, many of these projects have resulted in unnecessarily high environmental, social and economic costs. Downstream countries and their ecosystems are the most impacted by the associated water flow changes. Of all the GIWA regions that conducted a causal chain analysis related to the modification of stream flow, Aral Sea/24, Gulf of California/27, North Canary Current/41a, Guinea Current/42 and Somali Coastal Current/46 identified hydropower and irrigation as main sectors responsible for increased diversion of freshwater resources. In the Somali Coastal Current/46 region, less than 50% of the potential hydropower is harnessed, yet the downstream impacts of hydropower developments on freshwater availability are already apparent.

The potential for hydropower development has only just begun to be utilised in many developing regions. In the Mekong River/55 Basin, only 11 hydropower facilities have been constructed, representing 5% of potential development. An additional 250 000 GWh per year could be exploited, mainly in the Yunnan Province of China, Lao PDR and Cambodia, to meet surging electricity demand in Southeast Asia and China. Many of the probable environmental and social costs from future hydropower projects could be avoided if improved practices and designs were adopted, taking into account the recommendations by the World Commission on Dams.

Market failures

Market mechanisms do not automatically lead to the sustainable use of water resources. Two market failures are particularly notable for transboundary issues. Firstly, preventing users from accessing water resources through institutional and physical means is difficult, resulting in overuse and under-investment. Secondly, water consumption by upstream users reduces the quantity and sometimes the quality of water for downstream users.

In the Lake Chad/43 region, there is little evidence that the large irrigation and water development projects in Nigeria provide any net economic benefits. In fact, it is likely that the projects have generated negative returns because of the large capital costs and the extensive loss of environmental goods and services previously provided by downstream wetlands. It is estimated that the decline in the wetlands represent an economic cost to the downstream communities of approximately 9 million USD (discussed in Box 5).

The prices consumers from industrialised countries pay for crops imported from the southern hemisphere do not include the actual costs of excessive water use.

Policy failures

Policy interventions frequently create or aggravate environmental problems, such as establishing inappropriate subsidies that encourage the overexploitation of water. The subsidies and trade distortions of the United States and EU severely impact agriculture and the water economy of developing countries. The failure of governments to take action can also affect international waters. For example, in the Yellow Sea/34 region investment in pollution prevention and wastewater treatment, and stronger enforcement of regulations may have averted some of the social and economic costs caused by pollution.

Policies implemented by governments in the Aral Sea/24 Basin failed to reduce water withdrawals for cotton farms, causing the Aral Sea to shrink to a fraction of its former size. The policy failures include: (i) inadequate use of scientific information in the decision-making process; (ii) the lack of a clearly formulated legal framework; (iii) water prices that do not reflect the full costs of water use; and (iv) the absence of a regional water strategy.

Inappropriate economic incentives

Prices, subsidies and taxes often inadvertently discourage efficient water use. Governments in developing countries give out 75% of the world's water subsidies, amounting to 45 billion USD annually (Pearce 2002). Irrigation farmers are the main recipients and in many GIWA regions in the southern hemisphere they are not charged for this water. Subsidised irrigation water is a problem in the majority of the GIWA causal chain analyses of freshwater shortage, including the Aral Sea/24, Gulf of California/27, Canary Current/41, Lake Chad/43 and Benguela Current/44.

Water subsidies allow farmers to grow water-intensive crops, like alfalfa, citrus or rice, in water scarce regions, and gives them no incentive to invest in water saving devices and new technologies. Furthermore, irrigation subsidies also tend to favour wealthier rather than poorer farmers and consumers.

Water is greatly underpriced in the Yellow Sea/34 region. In China, industrial water use is 5 to 10 times less efficient than in industrialised countries, and only 25-30% of irrigation water is effectively utilised, resulting in an annual loss of 2.5 million tonnes of grain. The GIWA regional team noted that market-based pricing of water would help increase efficiency and encourage the use of new technologies.

Irrigation water charges in the Souss-Massa Basin (Canary Current/41) are averaging only one-tenth of urban water charges and generating revenues less than 10% of the actual cost of the water. This policy encourages farmers to waste water and generates insufficient funds to upgrade irrigation systems. The government's recent pricing reforms aim to gradually increase water irrigation prices, but at a rate too slow to achieve any short-term results.

Efforts to privatise water supply and wastewater treatment in developing countries has proved challenging as local users often strongly resist price increases (which reduce subsidies).

Additional agricultural subsidies, especially for energy, fertilizers and pesticides, also have considerable impacts on water use. These subsidies are especially high in developed countries, averaging 335 billion USD annually in the late 1990s, compared with 65 billion USD in non-OECD countries (Pearce 2002). Energy subsidies for extracting water from aquifers have resulted in lower water tables in several regions, such as the Bay of Bengal/53, Gulf of Mexico/2 and Gulf of California/27.

Knowledge gaps and lack of public engagement

Knowledge gaps regarding freshwater resources have been identified by many GIWA regional teams. A strong knowledge base is essential for understanding the nature of water resources and human needs and for identifying priorities for policy makers to address. Unfortunately, a lack of technical and financial resources, and fragmented organisations are considerable obstacles to building a knowledge base, especially in developing countries.

Information on transboundary aquifers is particularly deficient. In reflection of this substantial knowledge gap, GIWA regional teams often assessed changes in the water table only by using indirect indicators, such as the construction of deeper wells and the degradation of subsurface water quality. Many hydrogeologists and international organisations have acknowledged that the lack of information on transboundary aquifers is a major impediment to water resources management. It has led to the establishment of the International Shared Aquifer Resource Management (ISARM) project in 2000, with the support of UNESCO, IAH, FAO and UNECE.

Information needs to be communicated to stakeholders, including local communities. The Pacific Island/62 regional experts recognised the need to increase public awareness of water use issues and of the impact of poor land management. Similarly, Senegalese communities downstream of sugar processors are poorly informed of the dangers posed by the contamination of their water supply (Canary Current/41).

Those excluded from participating in the decision-making process are often the most affected by unsustainable water management, e.g. the Senegalese communities discussed above. Stakeholder participation is not only a matter of equity; it also has implications for policy efficiency, implementation effectiveness and the longevity of an initiative. The major irrigation projects in the Lake Chad/43 Basin, in both Cameroon and Nigeria, are classic examples of failed stakeholder engagement. In both countries, consultation was limited to government officials with project proponents ignoring floodplain communities, which ultimately were the most affected by the projects (the impacts are described in Box 5).

POLICY RELEVANT CONCLUSIONS

The GIWA regional teams predicted that freshwater shortage will increase in severity in over two-thirds of the GIWA freshwater systems by 2020. In the arid and semi-arid GIWA regions, the accumulative impact of increased water consumption, greater pollution and global climate change may cause extreme water scarcity. In many parts of the world, a shortage of clean water is predicted to be the most serious threat to future socio-economic development.

The apparent difficulties in managing freshwater resources have led to the development of a framework: Integrated Water Resources Management (IWRM). According to the Global Water Partnership (GWP 2000), IWRM is "a process that promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". Sustainable development is impossible without better environmental management, particularly of freshwater resources. There are widespread demands for the decoupling of environmental pressure from economic growth. This is crucial considering the likelihood of rapid economic growth in developing countries with large populations. More efficient infrastructure should be developed to facilitate the sustainable use of water resources. Solutions must improve environmental quality whilst maintaining human welfare and economic development.

The paradigm shift of water management towards integrated approaches is closely linked with the recognition that entire river basins and their estuaries and adjacent coastal areas are single planning units. There is also a greater appreciation for demand-side management, rather than increasing supply by building new infrastructure. It complements the move away from focusing exclusively on the direct economic benefits of engineered structures to understanding their full environmental, economic and social effects. Inappropriate subsidies which benefit a minority of water users are also slowly giving way to water prices that reflect the actual costs.

Demand management

Demand management aims to change the way people and institutions use water in order to improve efficiency and reduce the need for expensive infrastructure development. The GIWA regional teams identified demand management as an alternative or complement to the conventional approach of increasing supply by expanding infrastructure.

The GIWA experts who prepared the Guinea Current/42 regional report stressed the importance of demand management. Specific actions recommended for the urban water sector included: (i) minimising distribution losses; (ii) encouraging industries to introduce water saving technologies and practices; and (iii) optimising reservoir management. Their counterparts in the Central Equatorial Pacific (Eastern Equatorial Pacific/65b) recommended implementing water reuse practices and providing users with guidance for optimising their water use. In the Benguela Current/4, the three national governments have historically impounded water as a means to control the highly variable supply, but only recently have they begun to manage water demand.

The provision of appropriate economic incentives, mainly through the reformulation of subsidies, is a fundamental component of any effective demand management programme. Although subsidy reforms are plausible, they are difficult to implement politically. Whilst many regional reports discuss the need to reduce water subsidies, concrete examples remain rare. Hungary successfully rolled back domestic water subsidies in the 1990s, which reduced household water consumption by around 50% (Black Sea/22). Demand management in agriculture means the replacement of water-intensive crops, like citrus fruits and bananas, by less water demanding crops or grassland, despite reduced revenues. National campaigns for "turning the desert green" by irrigation have largely proved unsustainable.

GIWA regional experts also suggested subsidies that encourage the adoption of environmentally friendly practices. The Gulf of Mexico/2 regional team recommended introducing eco-payments, in which wetland owners are paid for the wastewater treatment services provided by their wetlands. Subsidies to implement water conservation measures were recommended for farmers in locations as diverse as northern Nigeria and Southwest United States (Lake Chad/43 and Gulf of California/27).

International cooperation

Upstream and downstream countries may have different, but legitimate, interests regarding water use and management which can potentially lead to conflict. The international community has devised principles for the use of water in order to avoid such conflicts. These principles are proclaimed in the UN Convention on the Law of the Non-Navigational Uses of International Watercourses (1977) and the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992). However, the practicality of

TABLE 4. POTENTIAL POLICY INSTRUMENTS RELATED TO FRESHWATER SHORTAGE

Contributing sector	Underlying root causes	Potential policy instruments: Short-term	Potential policy instruments: Long-term
Modification of stream flow			
Agriculture	▪ Inadequate integration of environmental considerations ▪ Lack of clear water strategy ▪ Unclear legal framework ▪ Inadequate planning of water usage ▪ Inadequate incentives ▪ Insufficient land use management	▪ Development of normative concepts and legislation ▪ Implementation of appropriate water-economising technologies ▪ Campaigns to raise public awareness	▪ Inter-state cooperation ▪ Adoption of modern water saving technologies ▪ Grant subsidies for implementing water conservation measures ▪ Institutionalise water market ▪ Encourage public participation in the planning and implementation of development activities ▪ Improved land use and management practices
Energy production	▪ Common pool resources ▪ Inadequate implementation of improved technology ▪ Ineffective promotion of compliance	▪ Monitoring and treatment facilities for rehabilitation of water quality ▪ Improved efficiency of dams and stream flow	▪ International legal agreements ▪ Enhancement of enforcement mechanisms ▪ Convert electricity subsidies ▪ Promote energy-saving technology
Domestic water supply	▪ Rapid population growth ▪ Migration ▪ Lack of land use planning	▪ Initiate shared management of water resources ▪ Set up viable networks for information collection	▪ Regional international cooperation agreements ▪ Integrated management ▪ Strengthen family planning programmes ▪ Development of land use plans
Pollution of existing supplies			
Industry	▪ Inadequate laws and enforcement for mining activities and industrial waste management ▪ Insufficient investment in wastewater treatment	▪ Encourage the use of green production technology	▪ Enhancement of laws and enforcement mechanisms
Agriculture	▪ Lack of public awareness ▪ Lack of regulation for exploitation of aquifers	▪ Adoption of regulations and enforcement mechanisms	▪ Public awareness campaign programmes ▪ Legal framework to control use of pesticides and fertilisers
Changes in the water table			
Agriculture	▪ Insufficient management of groundwater use	▪ Salinity targets	▪ Integrated catchment and coastal management ▪ Increased cooperation between government and non-governmental organisations

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

these conventions has been limited by their vague and sometimes contradictory language and the lack of proper enforcement mechanisms. Consequently, the impact they have made on international water management has not met expectations. The Atlas of International Freshwater Agreements (UNEP 2002) notes that "the presence or absence of institutions [such as treaties] has proven to be one of the most important factors influencing co-riparian water relations, exceeding such traditionally cited variables as climate, water availability, population density, political orientation, and levels of economic development."

Despite the complexity of transboundary river basin management and the potential conflicts of interest, countries that share international waters are generally keen to cooperate and often maintain productive relationships. This is demonstrated in many GIWA regions, including the Black Sea/22, Gulf of California/27, Amazon/40b, Canary Current/41 and Benguela Current/44.

At the international level, there is a need for a harmonised strategy for the implementation of conventions and declarations related to water. The GIWA regional assessments confirm the need for greater cooperation between riparian countries. A cooperative management framework is absent in 60% of international basins, and in many GIWA regions water allocation agreements do not exist or have not been implemented. In the Lake Chad/43 Basin the regional experts recommended the creation of a water allocation agreement, which would provide a legal framework for the equitable sharing of the Basin's water resources. Over 80% of international agreements involve only two countries, even though other countries may also share the river basin (UNEP 2002).

Successful agreements not only allocate water but address a wide range of other issues, such as hydropower, tourism and regional development. A fair distribution of benefits is more likely to result in a win-win agreement, whereas focusing solely on water volume can stall negotiations because the water received by one country equals the water loss of its neighbour. The Pacific Islands/62 experts explicitly note that all stakeholder groups, in addition to the environment, must benefit from new water resources strategies in order for them to succeed.

The mechanisms to promote participation, compliance, enforcement and conflict resolution are especially important. In addition to crucial monitoring and enforcement efforts, GIWA regions, such as the Central Equatorial Pacific (Eastern Equatorial Pacific/65b) and the Pacific Islands/62, recognised the need for education to change the behaviour of producers, particularly farmers, and domestic water consumers. Finally, agreements must consider the specific and evolving cultural, political, economic and hydrological conditions of riparian states.

International conflicts over water are becoming more common. Disputes over access to rivers and inland seas are occurring in Africa, Central and South Asia, and the Middle East. For example, conflict has been provoked by development projects reducing the flow of the Jordan/51 River by 90%.

Freshwater policy and global climate change

Farsighted international and national freshwater policies need to account for global climate change in addition to the direct human root causes of freshwater related problems. Global climate change will have varying impacts in different parts of the world, effecting vegetation and agriculture by temperature increases and shifts in the distribution and severity of droughts, precipitation and natural disasters, e.g. flooding. Global warming will also cause sea levels to rise. Changes in freshwater availability will be one of the most serious consequences of global climate change (see Box 4), which is predicted to gain momentum unless drastic measures are taken to reduce greenhouse gas emissions. The Kyoto Protocol is a step in the right direction.

Water management must adapt to the effects of climate change by adopting a holistic approach to managing ecosystems on a regional basis. Several GIWA teams advocated an integrated approach to regional freshwater management.

Capacity building for sustainable freshwater management

A new generation of scientists and managers is needed to address freshwater shortages and the other water problems. To develop and implement integrated concepts, natural and social scientists, and policy makers, need to cooperate locally and regionally. Existing expertise has to be enhanced and coordinated. However, in most parts of the world there are insufficient human resources. According to the GIWA assessments, scientific and technical capacity regarding water research and management needs strengthening. Training programmes should instil an understanding and appreciation of the complex interactions between freshwater shortage, climate change, pollution, overfishing, and habitat modification.