



FRESHWATER under THREAT SOUTH ASIA

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Vulnerability Assessment of Freshwater Resources to Environmental Change

South Asia supports a quarter of the world population with one twentieth of the world's annual renewable water resources. Disparities in water availability and use are made worse by widespread poverty: one in three South Asians lives on less than one US Dollar a day. These 500 million people, or half of the world's poor, eke out a living on the region's land and water resources. Region's major river basins are already under considerable pressure from human numbers and economic activities. The big challenge is to manage water resources for maximum benefits - including providing safe drinking water and adequate sanitation, growing food, and producing electricity - while minimizing the risks of floods and water shortages, water logging, water pollution, and ecosystem degradation. As human numbers rise, and the volume of water per person goes down, tensions over water allocation among use sectors and between human and nature would increase. This is especially critical for several key South Asian rivers that cross political borders. Climate change is set to make South Asian water challenges even more complicated. The results can be devastating to the people and nations of South Asia especially the poor already living on the edge of survival.



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# FRESHWATER under THREAT

S O U T H A S I A

Vulnerability Assessment of Freshwater Resources to Environmental Change

Ganges-Brahmaputra-Meghna River Basin  
Helmand River Basin  
Indus River Basin

Mukand S. Babel  
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**AIT**  
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This report also utilizes data and information published by many other organizations. These sources are specified where appropriate in the text, as well as in the Reference.

## Acronyms

ADB	Asian Development Bank
AISDW	Access to improved source of drinking water
AISF	Access to improved sanitation facility
AIT	Asian Institute of Technology
AQUASTAT	FAO Information System on Water and Agriculture
CIA	Central Intelligence Agency
CV	Coefficient of variation
DP	Development pressures
DPSIR	Driver, pressure, state, impact and response
EH	Ecological health
FAO	Food and Agriculture Organization
GBM	Ganges-Brahmaputra-Meghna
GDP	Gross Domestic Product
HDI	Human Development Index
HDR	Human Development Report
IWRM	Integrated water resources management
MC	Management challenges
MDG	Millennium Development Goals
ODA	Official Development Assistance
PPP	Purchasing power parity
RS	Resource stresses
SAARC	South Asian Association for Regional Cooperation
TDS	Total dissolved solids
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VI	Vulnerability Index
WB	World Bank
WR	Water resources
WWDRII	World Water Development Report II

## Abbreviations and Symbols

BCM	Billion cubic metres
ha	Hectare
km <sup>2</sup>	Square kilometres
kWh	Kilowatt hours
MCM	Million cubic metres
mg/L	Milligram. litre <sup>-1</sup>
mm	Millimetres
MW	Megawatts
m <sup>3</sup>	Cubic metres
Sq.km.	Square kilometres

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**1. Mumtaz Bi, 80, cries as she shifts her house in Harsud, expected to be submerged by waters from a dam being built across the Narmada Valley in central India.**

Source: [www.stockvault.net/Prakash Hatvalne](http://www.stockvault.net/Prakash Hatvalne)

**2. Tilicho Lake, Nepal, Annapurna Region**

Source: [commons.wikimedia.org/Kogo](http://commons.wikimedia.org/Kogo)

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Source: [www.stockvault.net/konark ashara](http://www.stockvault.net/konark ashara)

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**5. Poverty in Pakistan**

Source: [www.sxc.hu/Zeeshan Chaudhry](http://www.sxc.hu/Zeeshan Chaudhry)





## FOREWORD

Freshwater resources – essential for life on Earth and the achievement of the Millennium Development Goals (MDGs) – are increasingly vulnerable. A reliable assessment of the current status of major river basins is needed. Major constraints to such an assessment have been a widespread lack of operational frameworks and the availability of accurate and timely data at the basin, and more significantly, sub-basin scale. However, progress in our understanding of vulnerability, and in data gathering and processing techniques offer promising avenues to overcome these constraints.

The United Nations Environment Programme (UNEP) has joined hands with a number of regional partners from Africa and Asia to address the issue of vulnerability of water resources in the major basins on these continents. *Freshwater Resources Under Threat: South Asia Vulnerability Assessment of Freshwater Resources to Environment Change*, produced through collaboration between UNEP and the Asian Institute of Technology, Thailand, is one of a series of reports which has been the outcome of this partnership.

This report focuses on three major river basins in South Asia: the Ganges-Brahmaputra-Meghna, the Indus and the Helmand. A composite Water Vulnerability Index – estimated at basin and sub-basin scales based on analysis of water resource stresses, development pressures, ecological insecurity and management challenges – shows that water resources in both the Indus and Helmand river basins are highly vulnerable. The Indus Basin is the most resource-stressed and, at the same time, the most exploited among the three basins. At a basin scale the Ganges-Brahmaputra-Meghna and Helmand basins are not water stressed. However, uneven endowment and exploitation of water resources within these basins illustrate the need and potential for basin-wide resource development and management. Additionally, inefficient management in all three basins poses considerable challenges. For instance, water productivity – in terms of Gross Domestic Product generated from the use of one cubic metre of water – is less than US \$4 which compares well below the US \$24 generated by the world's top food producers.

Inhabitants' access to sanitation facilities also highlights poor water management in the basins. A total of 454 million people lack access to improved sanitation in these basins. About 50 per cent of the inhabitants of the Indus Basin lack access to improved sanitation, while the corresponding percentages in the Ganges-Brahmaputra-Meghna and Helmand basins are about 60 per cent.

Findings of the study indicate that there is no viable generic solution to these issues, and that a unique mix of policy interventions and preferred route for future development is necessary to reduce water vulnerability in each of the three selected basins. In this context, it is our hope that this first assessment should initiate a long-term process of periodic review and update that will give an authoritative picture of water vulnerability related to environmental change, and climate change in particular, and provide the scientific basis for integrated and sustainable river basin development and management.

**Achim Steiner**

United Nations Under-Secretary General and Executive Director

United Nations Environment Programme

October 2008

### 6. The Deosai National Park, Pakistan - world's highest plateau after Tibet.

Source: [www.sxc.hu/Qavi](http://www.sxc.hu/Qavi)

# Executive Summary



## **Mountains and river in Helmand Province of Afghanistan**

*Source: commons.wikimedia.org/Department of Defense*

The South Asian countries (Afghanistan; Bangladesh; Bhutan; India; Iran; Maldives; Nepal; Pakistan; Sri Lanka) are home to about one-fourth of the world's population, but only contain about 4.5 per cent (1,945 billion m<sup>3</sup>) of the world's annual renewable water resources (43,659 billion m<sup>3</sup>). Except for Bhutan and Nepal, the per capita water availability in the region is less than the world average, with water use in this region being limited mainly to the agriculture sector. Almost 95 per cent of the withdrawn water is consumed by the agriculture sector, a much larger proportion than the average global agricultural water use (70 per cent). In contrast, the region generally exhibits very limited water use in the industrial and domestic sectors. The percentage of the population with sustainable access to improved sanitation facilities in South Asia is 39 per cent (compared to the world average of 59 per cent). The water productivity – in terms of GDP per unit of water use – also is low (US\$ 1.4.m<sup>-3</sup>), compared to the average of US\$ 23.8.m<sup>-3</sup> for the world's top five food producers (Brazil; China; France; Mexico; USA).

Among the South Asian countries, Bangladesh is the downstream and deltaic portion of a huge watershed, thereby being naturally vulnerable due to the quantity and poor quality of water that flows into it from the upstream. All major rivers flowing through Bangladesh originate outside its borders. Thus, any interventions in the upper riparian regions can have significant impacts on Bangladesh. Although Nepal is considered to be water rich, this situation may change with increasing water demands. Bhutan receives a high amount of precipitation overall, but it varies

significantly spatially inside the country. Of the total precipitation Bhutan receives, surface runoff constitutes 76 per cent, snow constitutes 5 per cent, and soil infiltration constitutes the remaining 19 per cent. Maldives has achieved remarkable success in rainwater harvesting. It has been estimated that 25 per cent of its population currently depends on groundwater for drinking, while the rest of the population uses rainwater and desalinated water for this purpose, and groundwater for other purposes. Water has been central to Sri Lanka's evolution as a nation. Apparently water rich, the per capita water availability in Sri Lanka is 2,400 m<sup>3</sup>. However, it is estimated, that this availability will decline to 1,900 m<sup>3</sup> by 2025. The annual distribution of precipitation in Afghanistan suggests an essentially arid country, with more than 50 per cent of its territory receiving less than 300 mm of rainfall per year. Although Afghanistan is located in an arid environment, it is rich in water resources, mainly because of the series of high mountains (Hindukush; Baba) covered by snow. Its internal annual renewable water resources are estimated to be 55 billion m<sup>3</sup>. India is by far the largest country, in terms of population and land area, in South Asia. It is home to one-sixth of the world's population, while only endowed with 1/25th of the world's available water resources. On a basin scale, the annual per capita water availability in India varies considerably between 13,400 m<sup>3</sup> in the Brahmaputra–Barak basin, to about 300 m<sup>3</sup> in the Sabarmati basin. Precipitation in Pakistan is markedly variable in magnitude, timing, and areal distribution. The Indus River is the primary water source.

In view of the uneven endowment and development of water resources in South Asia, the issues and challenges of the water sector are large in scale, diversity and complexity. A number of studies and reports have highlighted the complexity of water issues from natural, political, social and economic perspectives. The diversity of these studies and reports serves as a knowledge base for South Asia, but one can only rarely find a study that provides a holistic view of the water-related vulnerabilities in the river basins of South Asia.

This report is one of the primary outputs of the Vulnerability Assessment of Freshwater Resources to Environmental Change project, and presents a situation analysis with regard to the vulnerability of water resources systems in South Asia. In addition to the more general issues addressed herein, this report considers three South Asian transboundary river basins as case studies: (i) Ganges-Brahmaputra-Meghna (GBM); (ii) Indus; and (iii) Helmand. Collectively, these basins provide South Asia with a variety of water-related challenges that encompass floods in the monsoon season; water shortages in the summer; sedimentation and erosion in the river and associated flood plains; drainage congestion in low-lying areas; and environmental and water quality problems. The population explosion in the basins during the past century has exerted heavy pressures on its water resources, causing noticeable changes to the functioning and uses of water. About 67 per cent of the nearly 34,000 km<sup>2</sup> (12,124 mi<sup>2</sup>) of Himalayan glaciers are reported to be receding. As the ice diminishes over the long term, glacial runoff in the summer and river flows will decrease, leading to severe water shortages in the basins. Nearly 70 per cent of the water in the Ganges River comes from rivers in Nepal, which are fed by glaciers. If the Himalayan glaciers disappear, rivers at lower altitudes also will dry up. To effectively manage the water resources in the basins, and cope with the variety of stresses affecting them, it is essential to better understand the nature and extent of the associated problems.

The vulnerability of the water resources of the selected river basins is assessed from two perspectives: main threats to the development of water resources and its utilization dynamics; and the management challenges in coping with these threats. The main threats are assessed based on three different components: (i) resource stresses; (ii) development pressures; and (iii) ecological insecurity. The challenge of coping capacity is measured via state of



water resources management. Thus, the report methodologically departs from a preconceived notion of “water crisis” being synonymously linked to water vulnerability. Evaluation of the different components is based on the related indicators (parameters), and considers a number of constraints related to data and information, including lack of access to some official data, and to wide seasonal and spatial variations in the hydrology of the case study basins. A composite vulnerability index (VI) is calculated for the three basins on the basis of four components of water vulnerability: (i) resource stresses; (ii) development pressures; (iii) ecological insecurity; and (iv) management challenges.

A number of conclusions have been drawn from the analyses presented in this report. These are discussed below in categories that relate to specific components of the vulnerability assessment adopted in this study.

## Resource Stresses

The water resources of a river basin is under stress when the available freshwater fails to support socioeconomic development and maintain healthy ecosystems. The availability of freshwater is expressed in terms of per capita water resources, and by variation of precipitation in a basin. The first parameter is related to the ‘richness’ of water resources, dictating the degree to which it can meet the demands of the population. The second parameter encapsulates the uncertainty associated with water availability. As a benchmark for defining relative water availability,  $1,700 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$  is taken as the threshold for water-stressed condition (Falkenmark and Widstrand, 1992). To benchmark the variation in precipitation, a coefficient of variation (CV) of 0.3 is taken as the critical level, beyond which a water resources system is considered most

vulnerable. The analyses in this report indicate that the annual per capita water availability are high, in the GBM and Helmand and Indus Basins. About 3,500 and  $2,600 \text{ m}^3$  of water are available per capita annually in the GBM and Helmand Basins. Thus, these two basins are not water stressed *per se*. However, individual sub-basins exhibit large seasonal and spatial variations in water availability. The per capita water availability in the Indus Basin is  $1,330 \text{ m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$ , indicating extremely stressful situation. The per capita availability of water in India, as a whole, has decreased to  $1,869 \text{ m}^3$ , from  $4,000 \text{ m}^3$  in last two decades and farmers increasingly tap the available groundwater. Millions of tubewells have been dug in India, with the groundwater levels plunging in many areas because of excessive pumping. By 2025, the per capita water availability could fall below  $1,000 \text{ m}^3$ .

The variation of water resources, measured in terms of CV of precipitation, suggests a high variability in the water resources in the lower and drier parts of the Indus and Helmand Basins, compared to their upper parts. This observation highlights the spatial variability of the water resources and their inconsistency within these basins. In contrast, the upper parts of the GBM Basin in India exhibit a comparatively larger precipitation variation (CV of 0.27-0.34) from year to year.

## Development Pressures

The rate of development of water resources is used to demonstrate the ability of a river basin to exhibit a healthy renewable process. It is evaluated as: (i) the ratio of water use and water availability; and (ii) the percentage of the population with sustainable access to improved drinking water, which reflects the level of water infrastructure development. Water use in this context refers to consumption in three major sectors (agriculture; domestic; industry).

A comparison of the water resources development rates among the three river

basins reveals that the Indus Basin is by far the most exploited river basin. Water resources development, in terms of population with access to improved drinking water, also is greater in the Indus Basin (87 per cent), compared to the GBM (83 per cent) and Helmand (43 per cent) Basins. Water resources development and use, in contrast to annual per capita water availability, reflects contrasting trends between the Indus and GBM Basins, indicating a worsening situation in the former, compared to the latter. Similarly in the lower Ganges Basin, the population factor contributes to major environmental issues, including: (i) increasing demands of natural resources to support development activities; (ii) the inward intrusion of higher salinity levels; (iii) the spread of waterborne diseases related to the extensive embankment of former waterbodies; (iv) water and soil pollution; (v) declining fisheries due to human interventions; and (vi) biodiversity loss in the Sundarbans forest.

## Ecological Insecurity

Lack of sufficient vegetation coverage - can cause severe problems, in terms of water conservation and maintaining natural flow regime. Thus, the percentage of land without vegetation coverage was used as an indicator of ecosystem insecurity. At the same time, water quality deterioration, as a consequence of water resources development and use, is an important indicator of current ecological health. The volume of wastewater discharged to receiving waters, therefore, is compared to the available water, in order to evaluate the water quality situation in the basins. A comparison of the annual volume of wastewater discharged as a percentage of available water in the three basins revealed a high discharge in the Indus

“The recommendations available for reducing the water vulnerability in river basins must rely on a unique mix of policy interventions and preferred route for future development.”



Children bathing in the river, Omkareshwar, India

Source: [www.sxc.hu/hagit](http://www.sxc.hu/hagit).

Basin, compared to the Helmand and the GBM Basins. This finding corresponds to a greater irrigation water use and indicates greater pollution from agricultural activities in the Indus Basin. Vegetation coverage, as a pre-condition for preserving natural ecosystems, is relatively greater for the Helmand Basin (40 per cent), compared to the Indus (39 per cent) and GBM (20 per cent) Basins.

### Management Challenges

Three indicators are used to assess the management capacity to cope with mismatch between water resources availability and use, including: (i) efficiency of water use (measured as GDP produced from one unit of water use); (ii) human health conditions (measured as access to adequate sanitation facilities); and (iii) conflict management capacity (qualitatively evaluated through the existence and functioning of institutions, agreements and communication mechanisms).

Water use efficiencies in all three case study basins are very low, compared to the world's average GDP production per unit of water use (about US\$ 8.6.m<sup>-3</sup> of water use). A basin-wide analysis revealed that the GDP produced per unit of water use for the GBM basin is US\$ 3.47.m<sup>-3</sup>, while those for the Indus and Helmand Basins are US\$ 3.34.m<sup>-3</sup> and US\$ 1.00.m<sup>-3</sup>, respectively. The access of basin inhabitants to adequate sanitation facilities poses even greater management challenges in all three basins. About 50 per cent of the inhabitants in the Indus Basin have access to improved sanitation facilities while the corresponding values for the GBM and Helmand Basins are about 40 per cent.

All the case study basins in this report are international river basins. The waters of the Indus Basin are shared largely by Pakistan and India, and to a lesser extent by Afghanistan. The GBM Basin waters are shared by five countries (Nepal; India; Bangladesh; Bhutan; China). The Helmand Basin waters are shared by Afghanistan, Iran and Pakistan. Numerous rivers originating in the mountains of Nepal contribute significant flow of the Ganges River, which snakes through neighbouring India and Bangladesh. The Ganges River system remains the main freshwater source for half the population of India and Bangladesh, and nearly the entire population of Nepal. Although some arrangements exist between the respective co-riparian countries in the GBM and Indus Basins, their actual implementation poses considerable challenges, to the extent that these arrangements may prove inadequate as water demands continue to increase. As the population increases, and the per capita water availability declines, conflicts over water allocation are likely to increase.





**Life on the river bank, India**

Source: Narupol Krairiks

## Vulnerability Index

A composite basin water vulnerability index (VI) is calculated, considering equal contributions from resource stresses, development pressures, ecological insecurity, and management challenges, to overall vulnerability. The VI values range from 0 to 1, with 1 representing the highest vulnerability. The findings of vulnerability analysis are summarized as follows:

- Water resource systems in the Helmand and Indus Basins are highly vulnerable. The Helmand basin is the most vulnerable (VI = 0.64) between the two basins. The water resources of the GBM Basin are highly stressed.
- For both the Helmand and Indus Basins, ecological insecurity contributes most to the water resources vulnerability. In contrast, management challenges pose the greatest risk for the GBM Basin. Nevertheless, management challenges in the Helmand Basin are high.
- Key issues leading to vulnerability of water resources in the GBM basin include: (i) seasonal variations of water resources (resulting in floods and water shortages); (ii) climate change implications (increased glacier melt; changes in precipitation; loss of ecosystems); and (iii) water quality degradation and transboundary water management issues.
- Similarly, issues in the Indus Basin include: (i) salinization and sodification of agricultural lands; degradation of the Indus delta ecosystem; (iii) low irrigation water use efficiency; (iv) lack of integrated water resources management in the upper Indus Basin; and (v) declining groundwater levels, due to groundwater mining and other causes.
- For the Helmand River Basin, the key issues leading to vulnerability of freshwater resources include: (i) variability of available water resources; (ii) limited access to water supply and sanitation facilities; (iii) low efficiency of irrigation infrastructure; and (iv)



lack of management capacity and coordination among water-related national agencies, and among riparian countries. Furthermore, lack of a sufficiently dense hydrometeorological network, and lack of an information system poses considerable challenge for hydrological assessment.

## Recommendations

There are no viable generic solutions to the water vulnerability faced by the South Asian countries. Thus, for each selected river basin, the recommendations available for reducing the water resources vulnerability must rely on a unique mix of policy interventions and preferred routes for future water resources development. They can be summarized as follows:

- *Promotion of people-centric and people-oriented water management.* High resource stresses and development pressures in the Indus Basin, and large spatial and temporal water resources variations in the GBM Basin, call for a paradigm shift in the way water resources are managed in these basins. These include (but not limited to): (i) promotion of co-management of domestic and irrigation water supply infrastructure; (ii) encouragement of private sector participation in water development; and (iii) improved public sector spending in the water sector.
  - *Improving water management efficiency.* Agriculture is by far the largest water user in South Asia. Water management efficiency in the agriculture, however, remains much less than desired, implying that the current system of operation, and distribution and use of water resources is inadequate. Moreover, there is a need to adopt policies promoting more efficient use of the existing water resources. As an example, excessive water conveyance losses due to sedimentation and poor maintenance of irrigation networks have been reported in Pakistan. These aged
- old irrigation infrastructures must be rehabilitated and/or remodeled to address these issues as well as changing agronomic conditions.
- *Increased investment in water development and use.* Lack of management capacity, and a low level of water exploitation in parts of the GBM Basin, implies that a scope for further water resources development does exist. However, under-developed socioeconomic conditions on the one hand, and low water exploitation on the other hand, create a vicious cycle. Investments must prioritize the sustainable development of water resources in the GBM Basin.
  - *Full provision for non-consumptive water use.* Findings of poor ecological health in the Indus and Helmand Basins call for provision of desired balance of water allocation between human and nature's needs.
  - *Pursuit of cooperative, basin-level water resources development and management.* All the case study basins are transboundary in nature. Thus, opportunities for cooperation on sustainable water resources development and management exist for all the basins, as evidenced through a number of earlier developments involving the GBM and Indus Basins. The prospects of two or more co-riparian countries working in cooperative, project-based water development activities in the GBM and Indus Basins were also endorsed by South Asian Association for Regional Cooperation (SAARC) summit in 1997 and 1998. Special emphasis should be directed to establishing governing principles for transboundary water sharing and institution building, including regional data collection and monitoring networks, river basin organizations, and tribunals for dispute settlements.

Although the sources of vulnerability of the water resources for the three case study basins are different, it is expected that the comprehensive, and easily-interpretable findings in this report will help decision makers reach sound solutions for reducing the vulnerability of water resources in South Asia.

# 1

## Introduction

### 1.1 Rationale

Asia's underdeveloped condition has increased the sensitivity of its communities to socio-environmental constructs (biophysical, socioeconomic or geopolitical factors). They can affect the ability of water resources systems to effectively and efficiently function, thereby making these water resources vulnerable in terms of quantity (overexploitation, depletion etc.) and quality (pollution, ecological degradation etc.). Understanding the vulnerability of water systems in Asia, therefore, is vital to sustainable water resources management in the region. Therefore, this study is undertaken by United Nations Environment Programme (UNEP) and the Asian Institute of Technology (AIT), Thailand, to address the issue of vulnerability of freshwater resources in Asia. The objectives of the study are closely related to the commitment of the international community to implement integrated water resources management. Thus, the focus in this study is to assess the vulnerability of freshwater at river basin scale. The specific objectives of the assessment are:

- To develop knowledge and understanding necessary for forward-looking cooperation among riparian states with regard to competing water demands;
- To examine water issues and functions in selected river basins;
- To evaluate impacts of environmental change in terms of water resource stresses and management challenges; and
- To complement the efforts and activities of Governments, non-governmental organizations (NGOs), and development agencies engaged in improving the status of water systems, by providing facts, figures and analyses related to water resources vulnerability.

This assessment focuses on four river basins; namely, Ganges-Brahmaputra-Meghna (GBM), Indus and Helmand in South Asia; and Mekong in South East Asia. These four basins mainly comprise developing countries in which the available water resources strongly influence the economic and social development of countries. This report provides a freshwater resource vulnerability assessment of South Asia, based on the analyses of three key river basins: GBM, Indus and Helmand.

### 1.2 The Assessment Process

Following the procedures for river basin vulnerability assessment outlined in the "Methodological Guidelines," developed by UNEP and Peking University (UNEP-PKU, 2008), and with input from the Asian Institute of Technology (AIT), two research teams were formed to conduct an assessment of the above-noted four river basins in South and South East Asia. A desk study is done, involving intensive review of relevant research papers, policy reports, maps, etc., from which a conceptual framework of analysis was formulated and a detailed work plan developed. Continuous consultation and exchange of information

between teams ensured that similar types of information were included in the reports. The state and characteristics of the water resource of the river basins and their management systems were analyzed to identify the key issues influencing the vulnerability of their water resources. This information served as the basis for in-depth DPSIR (Drivers, Pressures, State, Impacts and Responses) analysis for developing a qualitative and quantitative description of the vulnerability of the water resources, and the management, of a river basin. A comprehensive vulnerability assessment was conducted, and an integrated Vulnerability Index (VI) calculated. Synthesis reports of the sub-regions, based on the selected river basins, were prepared.

### Consultation Process

To ensure the correctness of data, and the validity of the assessment, the reports were reviewed by selected experts from the region, comprising representatives from governments, universities, and private sector. A comprehensive peer review workshop was held on 12–14 September, 2007 at the AIT, Thailand, with participation of 20 water experts from Afghanistan, Bangladesh, India, Iran, Nepal and Pakistan from South Asia; Cambodia, Laos, Thailand and Vietnam from South East Asia; and China and Mongolia. The workshop identified the strengths and weaknesses of the report, as well as providing recommendations and additional data for improving and updating relevant information contained in the report. Based on the comments of the experts, the report was appropriately revised to incorporate the updated and additional data provided through the review exercise.

### Summary for Decision Makers (SDM)

The Summary for Decision Makers (SDM), published as a separate report, synthesizes the key findings, gaps and challenges based on the assessment, in the form of main messages. The SDM highlights new

insights into the vulnerability of the freshwater systems in nine major river basins of Northeast, South and South East Asia, and provides critical points of reference to identify policies and recommendations for reducing water resources vulnerability.

## 1.3 Scope and Limitations

For the assessment in South Asia, three river basins (GBM; Indus; Helmand) were considered, based on their hydrologic and physiographic characteristics and socio-environmental functions, as well as their importance in the region. To account for variations in water availability, development, use and management capacity within each of the river basins, a total of 52 sub-basins were considered, including 31 in GBM; 6 in Indus; and 15 in Helmand. Unlike traditional assessments, however, this study relies on to some degree on informed estimates, which were later validated with recourse and views of additional informed experts and published documents including Internet web resources. As such, strict numerical validity was not considered the core issue. Rather, the direction of causality related to vulnerability outcomes was emphasized. Nevertheless, this assessment is not a substitute for a rigorous quantitative analysis, but rather is intended to complement such an analysis. Thus, this assessment should be regarded as the first edition of future comprehensive analyses at river basin or local level.

## 1.4 Structure of the Report

This report is divided into five chapters. The first chapter introduces the study, answering two major questions: Why vulnerability assessment is important? How are we going to assess vulnerability? The second chapter summarizes the specific methodology used in the assessment including calculating the Vulnerability Index (VI). The third chapter describes the important geographic and socioeconomic

conditions of South Asia. It also outlines the status of the region's freshwater attributes. The outline provides the background for the water problems in South Asia, and points to the elements of water vulnerability used in this in-depth analysis of the river basins. The fourth chapter contains the findings of the vulnerability assessment for the selected river basins: GBM, Indus and Helmand. The objective is to examine the significance and magnitude of environmental and socioeconomic factors associated with freshwater resources vulnerability. The fifth chapter provides the conclusions of the assessment, based on the relevant findings presented in the previous chapters. General policy directions aimed at minimizing the vulnerability of freshwater in South Asia are suggested.



# 2

## Methodology

### 2.1 Approach

The method used for this vulnerability assessment, based on the Methodological Guidelines prepared by UNEP and Peking University (UNEP-PKU, 2008), is briefly discussed in this chapter. The vulnerability of freshwater resources was explored by isolating strategically-important issues related to different functions (uses) of freshwater systems in a drainage basin, marking a considerable departure from the preconceived notion of “water crisis” being synonymously linked to vulnerability. Thus, this analysis is based on the premise that the vulnerability assessment of a river basin must have a precise understanding of four components of water resources system, including their states and relationships, as follows:

- **Total water resources:** Analysis of the hydrologic balance, prior to consideration of any water resources development and use; mainly comprising the water resources formulation from a natural hydrologic process, and its relationship with global climate change and local biophysical conditions;
- **Water resources development and use:** Analysis of water resources supply and balance, mainly the water resources development capacity available via an engineering approach and its relation to water resources use and development trends, and with the process of urbanization, as well as water resources support to the economic development;
- **Ecological health:** Analysis of water resources, after development and use for human and economic use, to be utilized for maintaining the basin’s ecological health, and the supply and demand relations, and key issues in the process. At the same time, the analysis needs to be conducted on water quality, as a consequence of water resources development and use (pollution), and its further influences on the freshwater resources budgeting within a river basin;
- **Management:** The above three components focus on the natural processes or natural adaptation of freshwater resources development and use. However, the natural processes are usually heavily influenced by the capacity to manage freshwater resources; that is, the management capacity plays an important role in sustainable development and use of water resources. Thus, the assessment is expanded to include evaluation of the state of institutional arrangements and other factors in freshwater resources management.

This assessment approach recognizes that a sustainable freshwater system can only function within an integrative operational framework that combines both the natural system and the management system. The fundamental components of current vulnerability assessment are able to account for three different aspects related to the natural resource base, and how other factors (climate change, biophysical conditions, policy and management practices etc.) influence the processes that make a natural system vulnerable. Evaluation of the different components is based on the related indicators (Figure 2.1), considering a number of constraints related to data and information, including lack of access to some official data, and wide seasonal and spatial variations in the basin hydrology.



**Figure 2.1 | Freshwater resources vulnerability components and indicators**

The core method builds on a two-step exercise: (1) diagnosis of issues; and (2) in-depth assessment of the identified issues, using a DPSIR framework. A comprehensive vulnerability analysis was subsequently carried out, following a composite Vulnerability Index (VI) calculation based on four components of water vulnerability; (i) resource stresses; (ii) development pressures; (iii) ecological insecurity; and (iv) management challenges.

## 2.2 Diagnosis of Issues

To better understand the water resources vulnerability of river basins, basic data were collected from different sources regarding their current state and development, in terms of the water resources base, and its use and management. The output of this exercise was a detailed description of the water resources functions and key issues.

## 2.3 DPSIR Analysis

The analytical framework, known as Drivers, Pressures, State, Impacts and Responses (DPSIR) framework, used by the UNEP GEO process and others, was employed to put the vulnerability assessment into perspective. It integrates both anthropogenic as well as environmental change (caused by human activities and natural processes) factors, and incorporates social, economic, institutional and ecosystem pressures.

The DPSIR analysis was carried out for each identified issue. The Driving forces (D) represent major social, demographic and economic developments, and corresponding changes in lifestyles, and overall consumption levels and production patterns. Demographic development may be regarded as a primary driving force, whose effects are translated through related land use

changes, urbanization, and industry and agricultural developments. The pressures (P) are subsequently developed as an effect of these driving forces. The pressures represent processes that can affect the resource (water) by producing, for example, substances (effluents) and other physical and biological agents that can consequently cause changes to the state (S) of the water resources. Society will experience either positive or negative consequences, depending on the nature and magnitude of the changes in the state. These consequences are then identified and evaluated to describe the resultant impacts (I), by means of evaluation indices.

## 2.4 Vulnerability Index and Parameterization

The vulnerability of the water resources of a river basin can be assessed from two perspectives: (1) main threats of water resources and its development and utilization dynamics; and (2) the basin's challenges in coping with these threats. Thus, the vulnerability index (VI) for the river basin can be expressed as:

$$VI = f(RS, DP, ES, MC)$$

where:

VI = vulnerability index; RS = resource stresses; DP = development pressures; ES = ecological insecurity; MC = management challenges.

High vulnerability is apparently linked with greater resource stresses, development pressures and ecological insecurity, as well as low management capacities. In order to quantify the vulnerability index, the indicators for each component were determined and quantified. The value of vulnerability ranges from 0 to 1.0, with 1.0 indicating the most vulnerable situation.

### Resource Stresses (RS)

The general influence of water resources to vulnerability is related to water resources quantity and variation, and the pressures from them can be expressed as "scarcity" and "variation" of water resources.

**Water scarcity parameter:** The scarcity of water resources can be expressed in terms of annual per capita water resources availability of a region or a basin, in comparison to the generally-agreed minimum level of per capita water resources requirement ( $1,700 \text{ m}^3 \cdot \text{person}^{-1}$ ). That is,

$$\begin{cases} RS_s = \frac{1,700 - R}{1,700} & \text{if } (R \leq 1,700) \\ RS_s = 0 & \text{if } (R > 1,700) \end{cases}$$

where:

$RS_s$  = water scarcity parameter; and R = per capita water resources availability per year ( $\text{m}^3 \cdot \text{person}^{-1} \cdot \text{year}^{-1}$ ).

**Water variation parameter:** The variation of water resources is expressed by the coefficient of variation (CV) of precipitation over the last 50 years. A CV value equal to or greater than 0.30 is taken to indicate the most vulnerable situation and expressed as:

$$\begin{cases} RS_v = CV / 0.30 & \text{if } (CV < 0.30) \\ RS_v = 1 & \text{if } (CV \geq 0.30) \end{cases}$$

where:

$RS_v$  = water variation parameter.

### Development Pressures (DP)

**Water exploitation parameter:** This parameter is based on the water resources development rate (i.e., ratio of water supply and total water resources availability), and is used to demonstrate a river basin's capacity for a healthy renewable process, as follows:

$$DP_e = \frac{WR_s}{WR}$$

where:

$DP_e$  = water exploitation parameter;  $WR_s$  = total water supply (capacity); and  $WR$  = total water resources.

**Safe drinking water inaccessibility parameter:** This parameter encapsulates the state of social use of freshwater (i.e., how freshwater resources development facilities address the fundamental livelihood needs of the population). The contribution of safe drinking water inaccessibility parameter ( $DP_d$ ) can be calculated with the following equation:

$$DP_d = \frac{P_d}{P}$$

where:

$DP_d$  = safe drinking water inaccessibility parameter;  $P_d$  = population without access to improved drinking water sources; and  $P$  = total population.

### Ecological Insecurity (ES)

The ecological health of a river basin was measured with two parameters; namely, the water quality/water pollution parameter and ecosystem deterioration parameter.

**Water pollution parameter:** The contribution of water pollution to water resources vulnerability is represented as the ratio of total untreated wastewater and the total water resources. The ratio equal to or greater than 15 percent of the available water is considered to represent the most vulnerable situation. Thus, the water pollution parameter ( $EH_p$ ) is expressed as:

$$\begin{cases} EH_p = \frac{WW}{0.15 \cdot WR} & \text{if } (WW < 0.15 * WR) \\ EH_p = 1 & \text{if } (WW \geq 0.15 * WR) \end{cases}$$

where:

$EH_p$  = water pollution parameter;  $WW$  = total wastewater volume ( $m^3$ ); and  $WR$  = total water resources ( $m^3$ )

**Ecosystem deterioration parameter:** This parameter is represented by the ratio of the basin area without vegetation cover to the total basin area. The area under forest and wetlands is considered as the vegetation coverage:

$$EH_e = \frac{A_d}{A}$$

where:

$EH_e$  = ecosystem deterioration parameter;  $A_d$  = basin area without vegetation (forest area and wetlands) coverage ( $km^2$ ); and  $A$  = total basin area ( $km^2$ ).

### Management Challenges (MC)

Management challenges are measured with the following three parameters:

**Water use inefficiency parameter:** This parameter is represented by the GDP produced from one cubic metre of water use, and compared with the average GDP generated per cubic metre use by selected countries. For this assessment in South Asia, comparison was made to the top five food producers in the world, including Brazil, China, France, Mexico and USA, with a water use efficiency of US\$ 23.8 per cubic metre of water use, as follows:

$$\begin{cases} MC_e = \frac{WE_{wm} - WE}{WE_{wm}} & \text{if } (WE_{wm} > WE) \\ MC_e = 0 & \text{if } (WE_{wm} \leq WE) \end{cases}$$

where:

$MC_e$  = water use inefficiency parameter;  $WE$  = GDP produced from one cubic metre of water use; and  $WE_{wm}$  = mean WE of selected countries.

**Improved sanitation inaccessibility parameter:** The computation of this parameter is based on proportion of the population in the basin that lacks access to improved sanitation facilities, as follows:

$$MC_s = \frac{P_s}{P}$$

where:

$MC_s$  = improved sanitation inaccessibility parameter;  $P_s$  = population without access to improved sanitation; and  $P$  = total population.

**Conflict management capacity parameter:** The conflict management capacity is assessed, utilizing the matrix shown in Table 2.1. The final score of conflict management capacity parameter ( $MC_c$ ) was determined by expert consultations, based on the scoring criteria.



## Weighting

Based on expert consultation weights are assigned to each component of the vulnerability index to calculate the index using the following equation:

$$VI = \sum_{i=1}^n \left[ \left( \sum_{j=1}^{m_i} x_{ij} \times w_{ij} \right) \times W_i \right]$$

where:

VI = vulnerability index; n = number of vulnerability components;  $m_i$  = number of parameters in  $i^{\text{th}}$  component;  $x_{ij}$  = value of the  $j^{\text{th}}$  parameter in  $i^{\text{th}}$  component;  $w_{ij}$  = weight given to the  $j^{\text{th}}$  parameter in  $i^{\text{th}}$  component; and  $W_i$  = weight given to the  $i^{\text{th}}$  component.

To give the final VI value in a range from 0 to 1.0, the following rules were applied in assigning the weights: (a) the total of weights given to each indicator should equal 1.0; and (b) the total of weights given to all components should equal 1.0. As the process of determining relative weights can be biased, making comparison of the final results difficult, equal weights were assigned among indicator in the same component, as well as among different components.

## Explanation of Results and Policy

### Recommendations

After obtaining the calculation results, further explanations were made to support the policy recommendations. To ensure a better understanding and application of VI estimates, Table 2.2 was prepared as a reference sheet to help in interpreting the VI values. From the overall VI score, general conclusion can be drawn on the state of vulnerability of the river basin, and policy recommendations can be made after further reviewing the results of the parameters in the four components (i.e., resource stresses; development pressures; ecological insecurity; management challenges), and specific policy interventions can then be recommended accordingly.

**Table 2.1** | Conflict management capacity parameter assessment matrix

Category of inability	Description	Score and Criteria		
		0.0	0.125	0.25
Institutional inability	Transboundary institutional arrangement for coordinated water resource management	Strong institutional arrangement	Loose institutional arrangement	No institution existing
Agreement inability	Written/signed policy/agreement for water resource management	Concrete/detailed agreement	General agreement only	No agreement
Communication inability	Routine communication mechanism for water resource management (annual conferences etc.)	Communications at policy and operational levels	Communication only at policy level or operational level	No communication mechanism
Implementation inability	Water resource management cooperation actions	Effective implementation of river basin-wide projects/programs	With joint project/program, but poor management	No joint project/program

**Table 2.2** | Interpretation of Vulnerability Index

Vulnerability Index	Interpretation
Low (0.0 - 0.2)	Indicates a healthy basin in terms of resource richness, development practice, ecological state and management capacity. No serious policy change is needed. However, it is still possible that in the basin, moderate problems exist in one or two aspects of the assessed components, and policy adjustment should be taken into account after examining the VI structure.
Moderate (0.2 - 0.4)	Indicates that the river basin is generally in a good condition toward realization of sustainable water resource management. However, it may still face high challenges in either technical support or management capacity building. Therefore, policy design of the basin should focus on the main challenges identified after examination of the VI structure, and strong policy interventions should be designed to overcome key constraints of the river basin.
High (0.4 - 0.7)	The river basin is under high stress, and great efforts should be made to design policy to provide technical support and policy back-up in order to mitigate the stress. A longer term strategic development plan should be made accordingly with focus on rebuilding up of management capacity to deal with the main threat.
Severe (0.7 - 1.0)	The river basin is highly degraded in water resource system with poor management set up. Management for the restoration of the river basin's water resource will need high commitment from both government and general public. It will be a long process for the restoration, and an integrated plan should be made at basin level with involvement from agencies in the international, national and local level.

# 3

## Overview of Freshwater Resources of South Asia Sub-Region

This chapter is divided into three sections. The first section deals with the geographic and socioeconomic setting of the South Asian sub-region, including brief descriptions of the countries. The second section describes the state of the freshwater resources in the sub-region, from the perspective of: (i) water resources availability; (ii) water withdrawals; (iii) water productivity; (iv) access to improved drinking water sources; and (v) access to improved sanitation facilities. The final section provides fact sheets on the major river basins in the sub-region.

### 3.1 Geography and Socioeconomics

#### Geography

South Asia, also known as Southern Asia, comprises the countries of Afghanistan, India, Pakistan, Bangladesh, Nepal, and Bhutan, as well as the island nations of Sri Lanka and the Maldives. It covers approximately 4.48 million km<sup>2</sup> (1.73 million mi<sup>2</sup>) in area (Figure 3.1).

South Asia is surrounded by (from west to east) Western Asia, Central Asia, Eastern Asia, and Southeast Asia. The existence of the highest mountains and largest mangrove forests in the world, lush jungles, the tenth-largest desert on Earth, deep river valleys and many other landscape features, decorate the countries of South Asia, providing one of the most diverse assortment of geographic features.

Geophysically, the sub-region lies on the Indian Plate, and is bordered on the north by the Eurasian Plate.

Geopolitically, however, South Asia subsumes the Indian subcontinent. It also includes territories external to the Indian Plate, and in proximity to it.

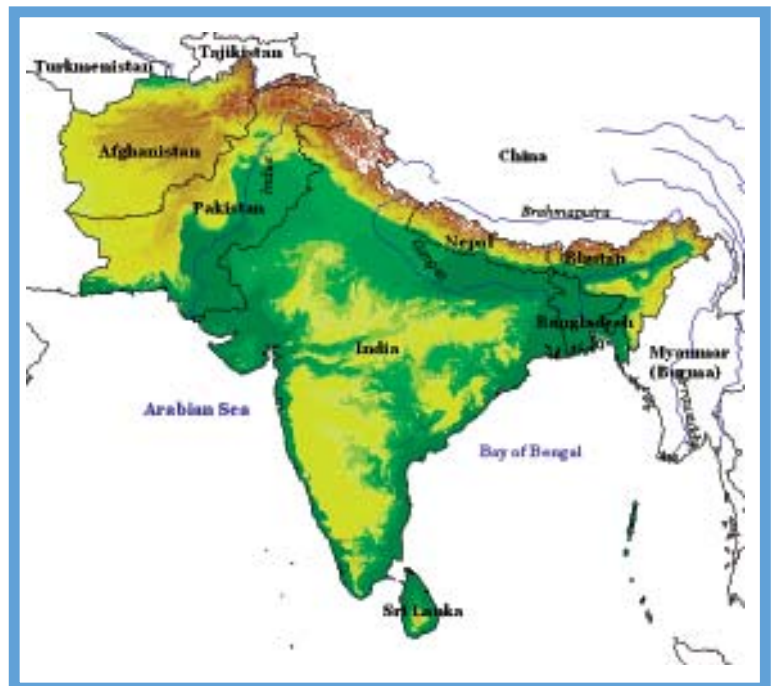


Figure 3.1 | South Asia

Afghanistan, for instance, is sometimes grouped in this region because of its sociopolitical and ethnic (Pashtun) ties to neighboring Pakistan. In contrast, Pakistani regions west of the Indus are sometimes described as being in Central Asia, due to historical connections. A good proportion of the Balochistan land mass is not on the Indian plate, but on the fringes of the Iranian plateau. As in the case of the Hindukush Mountains, everything to the southeast of the Iranian Plateau is considered South Asia.

The Indus River, one of the most important rivers in South Asia, flows from the Himalayas, through the Punjab region of India, and the Sindh Province of Pakistan. The earliest civilizations in South Asia flourished along the banks of the Indus and, in fact, Punjab is still the 'breadbasket' of India and Pakistan. Another river, the Ganges, flows from near the town of Hardwar in the Himalayas, into a broad region called the Gangetic Basin. After centuries of intensive farming, the Gangetic Basin's soil is now poor and exhausted, containing only a trace of the lush jungle that once lined its banks. The Ganges winds its way through India, joining the Yamuna River to form a wide delta in the country of Bangladesh. Every year, massive floods from the Ganges threaten Bangladesh during the monsoon season.

The large Eurasian (Europe and Asia) land mass, and the equally large Indian Ocean, produces differences between the heating capacities of the former and the



**The Indus River in northern Pakistan**

Source: [commons.wikimedia.org/Joonas Lyytinen](https://commons.wikimedia.org/Joonas_Lyytinen)

latter. Because land heats faster and cools down more rapidly than water, a seasonal reversal of winds occurs. This is called the 'monsoon,' from the Arabic word 'Mawsim', the latter describing a seasonal reversal of winds. Southwesterly winds blow toward the shore in South Asia during the Northern Hemisphere summer. In contrast, northeasterly winds blow offshore during the Northern Hemisphere's winter.

During the dry season, the winds from the northeast are dry because they lose their moisture on the Asian land mass. As the winds approach the southern tip of India, specifically the state of Tamil Nadu, they pass over the Bay of Bengal and pick up moisture. Tamil Nadu then receives most of its precipitation during these months. Toward the late spring and early summer, however, the weather is hot and dry over most of the sub-continent.

During the summer, as the land surface temperature increases, air is drawn in from the Indian Ocean and Arabian Sea. The winds pick up large volumes of moisture, with resulting rains falling first along India's western coast. The winds later flow around the southern tip of India, being funneled up the Bay of Bengal into the delta area of the Ganges and Brahmaputra Rivers. The rains later reach the upper Ganges valley, with the Indian capital of New Delhi receiving less moisture than the other areas mentioned above, since the winds arrive there later in June and July. The Deccan Plateau to the east of the Western Ghats (mountains) receives significantly less precipitation than the coastal areas. As the summer (wet) monsoons approach the west coast of India, they rise over the western Ghats, and the air subsequently cools. The cool air is less able to hold moisture, which is then released as



precipitation, a process known as orographic precipitation.

### Socioeconomics

The socioeconomic parameters of South Asian countries, along with Iran (as a riparian of the Helmand basin), are highlighted in Table 3.1. Reports dealing with South Asia have emphasized poverty as the most glaring barrier to human development in this sub-region, with approximately half a billion people living on less than a dollar per day. Agriculture is crucial to South Asia's economy, with 25 per cent of the sub-region's GDP coming from the agriculture sector (compared to the worldwide average of four to five per cent), and with 58 per cent of the workers in the sub-region engaged in agriculture. Nevertheless, the sub-region is a net importer of food. Major constraints of the agriculture sector include low productivity and poor management of scarce water resources. Lack of access to education or poor-quality education for a large sector of South Asian society also inhibits poverty reduction and economic growth. About 58 per cent of the inhabitants in South Asia aged 15 and above cannot, with understanding, read and write a short, simple statement on their everyday lives (World Bank, 2006).

South Asia is not only one of the fastest-growing regions in the world, it is also one of the poorest. This reality puts water and energy at the very heart of the region's development process. According to the report of World's Economic and Social Situation and Prospects (UN, 2006), the region registered a growth rate of 6.7 per cent and 6.5 per cent in the years 2004 and 2005, respectively, with a projection of 6.4 per cent growth in 2006. Despite these developing economies, however, significant progress remains to be made in this sub-region. With a population of 1.4 billion, South Asia is home to half of the world's poor. This huge population number, coupled with expanding economies, has spurred ever-increasing pressures of energy demands for countries in South Asia. The International Energy Agency has projected South Asia to have the highest growth rate of energy consumption in the world by 2010 (Srivastava and Misra, 2007).

The majority of South Asia's 1.4 billion population are concentrated in the eastern sub-region formed by four SASEC (South Asia Subregional Economic Cooperation) countries (Bangladesh; Bhutan; India; Nepal). These four countries not only share important socioeconomic characteristics, but also face similar challenges in regard to the provision of water and energy services. The average human development index (HDI) for the region in 2005, based on three measurable dimensions of human development: (i) living a long, healthy life; (ii) being educated; and (iii) having a decent standard of living, was 0.546, compared to the world average of 0.741. Poverty levels in the region, as defined by national poverty lines, ranged from

as high as 49.8 per cent in Bangladesh, to 30.9 per cent in Nepal, 26.1 per cent in India, and 25.3 per cent in Bhutan (ADB, 2006).

### 3.2 State of Freshwater Resources

South Asia is endowed with considerable water resources, and high potential for hydropower development. However, the available water resources are unevenly distributed. Inadequate drinking water and sanitation services are responsible for poor environmental conditions and water-related diseases. The water quality and environment in South Asia are generally much degraded. The major environmental issues in this region, which are associated with population factors include: (i) increasing demands on available water and other natural resources from development activities; (ii) the inward intrusion of higher salinity levels into inland water systems; (iii) the spread of waterborne diseases related to the extensive embankment of former waterbodies; (iv) water and soil pollution; (v) decline in fisheries catch due to human interventions; and (vi) excessive logging. Indeed, the issues and challenges in South Asia regarding the water sector are major in scale, diversity and complexity.

The South Asian countries, including Afghanistan and Iran, comprise about one-fourth of the global population, whereas it has only 4.5 per cent (1,945 billion m<sup>3</sup>) of the world's renewable water resources (43,659 billion m<sup>3</sup>) on an annual basis. Except for Bhutan and Nepal, the inhabitants in all the countries in this region share a smaller per capita water availability than the world average. As an example, the per capita water availability in India has decreased to 1,869 m<sup>3</sup> (6,602 ft<sup>3</sup>) from 4,000 m<sup>3</sup> in last two decades and farmers increasingly tap into groundwater resources. Millions of tubewells have been dug in India, with groundwater levels in many areas having plunged because of excessive pumping. By 2025, the per capita water availability could decrease to less than 1,000 m<sup>3</sup> indicating an extremely stressful situation. The overwhelming majority of the region's water use is limited to the agriculture sector, with almost 95 per cent of the withdrawn water being used for agriculture, compared to the world average of 70 per cent. A very limited portion of the available water resources is used by the industrial and domestic sectors. It is clear that the water productivity of this region is not satisfactory. Except Iran and Sri Lanka, water productivity in terms of GDP produced from the use of one cubic metre of water falls well below the corresponding world average.

An overview of the state of the water resources of South Asian countries is presented in Table 3.2.

Among the South Asian countries, Bangladesh is located in the downstream and deltaic portion of a huge watershed, thereby being naturally vulnerable to the water quality and quantity it receives from the upstream portion of the watershed. Because all major rivers flowing through Bangladesh originate outside its borders, any interventions in the upper riparian regions can have a significant

**Table 3.1 | Socioeconomic state of South Asian countries**

Parameter	Afghanistan	Bangladesh	Bhutan	India	Iran	Maldives	Nepal	Pakistan	Sri Lanka
Population (million) 2004	28.6	139.2	2.1	1,087.1	68.8	0.3	25.20	154.8	20.6
Population density (2003-2007) <sup>a</sup>	39.8	1060	50.9	334	42.9	1127	179	202	295
Annual population growth rate (%), 1975-2004	2.4	2.2	2.1	1.9	2.5	2.9	2.3	2.8	1.3
Total Fertility Rate (birth/woman) 2000-05	7.5	3.32	4.4	3.1	2.1	4.3	4.1	4.3	2.0
Children under five mortality rate per 1,000 live births 2004	257	77	80	85	38	46	87.00	101	14
Maternal mortality rate (per 100,000 live births), adjusted 2000	1900	380	420	540	76	110	740	500	92
Sustainable access to improved water source (% of population), 2004	39	74	62	86	94	83	90	91	79
Sustainable access to improved sanitation (% of population), 2004	34	39	70	33	83 (1990)	59	35	59	91
Adult literacy rate (% ages 15 & above), 2004	28.1	34.2 (1990)	47.0	61.0	77.0	96.3	48.6	49.9	90.7
Female (as % of total labor force) <sup>b</sup> , 2004	28.4 (1990)	35	35	28.3	33.0	42	40.3	26.5	42
Arable land <sup>b</sup> ('000 hectare) 2003 <sup>a</sup>	7910	7976	108	160519	16117	4	2365	19458	916
Per capita energy used: annual (kg of oil equivalent) <sup>c</sup> , 2000	--	145.1	--	504.0	1863.6	--	334.2	463.2	417.5
Per capita electricity consumption (kWh), 2003	25	145	218	594	2,304	490	91	493	407
Population (%) below:									
- national poverty line (1990-2003)	-	49.8	--	28.6	-	--	30.9	32.6	25
- 1 USD per day (1990-2004)	-	36.0	--	34.7	2.0	--	24.1	17.0	5.6
Per capita GDP (USD), 2004	201.62 <sup>b</sup>	406	751	640	2,439	2,345	252	632	1,033
Agriculture, value added (% of GDP) 2005 <sup>c</sup>	36.1	20.1	24.7	18.3	10.4	--	38.2	21.6	16.8
ODA received per capita (net disbursements) (USD), 2004	--	10.1	36.9	0.6	2.8	87.0	16.1	9.2	25.2
HDI rank	--	137	135	126	96	98	138	134	93

Source: UNDP (2006) database unless otherwise specified. <sup>a</sup> AQUASTAT database (FAO, 2007), <sup>b</sup> World Resources Institute (2005), <sup>c</sup> World Bank (WB, 2006)

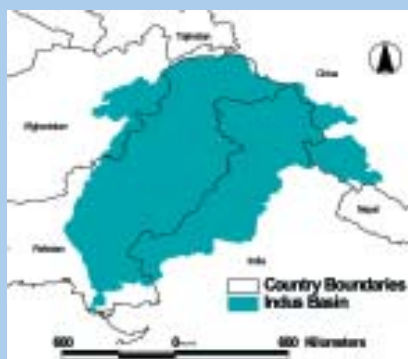
**Table 3.2 | State of water resources of South Asian countries**

Parameter	Afghanistan	Bangladesh	Bhutan	India	Iran	Maldives	Nepal	Pakistan	Sri Lanka	World
Population (million) 2004	28.6	139.2	2.1	1,087.1	68.8	0.3	25.20	154.8	20.6	6,602.224 <sup>d</sup>
Water resources: total renewable (actual) (billion m <sup>3</sup> .yr <sup>-1</sup> ) 2007 <sup>a</sup>	65.0	1211	95.0	1897	138	0.03	210	223	50.0	--
Water resources: total renewable per capita (actual) (m <sup>3</sup> .cap <sup>-1</sup> .yr <sup>-1</sup> ) 2003-2007 <sup>a</sup>	2503	7934	39716	1729	1946	88.8	7996	1382	2582	--
Water resources: total internal renewable (billion m <sup>3</sup> .yr <sup>-1</sup> ) 2007 <sup>a</sup>	55.0	105	95.0	1261	128	0.03	198	52.4	50.0	43659 <sup>c</sup>
Water resources: total internal renewable per capita (m <sup>3</sup> .cap <sup>-1</sup> .yr <sup>-1</sup> ) 2003-2007 <sup>a</sup>	2118	688	39716	1149	1818	88.8	7539	325	2582	6900 (2003) <sup>c</sup>
Total (billion m <sup>3</sup> )	23.3	79.4	--	645.8	72.9	--	10.2	169.4	12.6	3,807
Annual freshwater withdrawal (1987-2002) <sup>b</sup>										
% for agriculture	98	96	--	87	91	--	97	96	95	70
% for industry	0	1	--	6	2	--	1	2	3	20
% domestic	2	3	--	8	7	--	3	2	2	10
Water productivity: GDP/water use (\$ .m <sup>-3</sup> ) (1987-2004) <sup>b</sup>	--	0.6	--	0.8	1.6	--	0.6	0.5	1.3	8.6

<sup>a</sup> AQUASTAT database (FAO, 2007), <sup>b</sup> World development indicators (WB, 2006), <sup>c</sup> AQUASTAT database (FAO, 2006), <sup>d</sup> CIA (2007)

impact on the country. Nepal is considered rich in water resources, containing over 6,000 rivers and rivulets (UNEP-RRCA, 2001). Because its water demands are continuously increasing, there is intense pressure on Nepal's water resources, resulting in alarming levels of groundwater extraction, and fishing intensity to sustain human livelihoods, thereby directly affecting its freshwater ecosystems, including the health of its wetlands and river systems. Although Bhutan receives a large volume of precipitation overall, it varies spatially inside the country. Of Bhutan's total precipitation, surface runoff constitutes 76 per cent, 5 per cent is in the form of snow, and infiltration comprises the remaining 19 per cent. The Maldives has achieved remarkable success in rainwater harvesting. It is estimated that approximately 25 per cent of its population currently depends on groundwater for drinking, with the remainder using rainwater and desalinated water for drinking, and groundwater for other purposes. In regard to

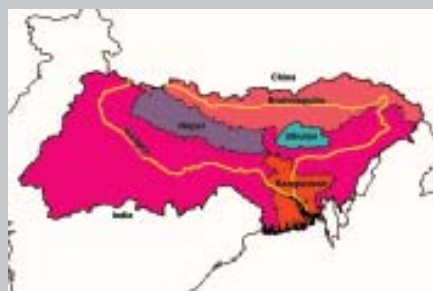
### Box 3.1 | Indus River Basin



Total Basin Area	1,170,838 km <sup>2</sup>
Annual Available Water	224 billion m <sup>3</sup>
<b>Country</b>	<b>Area of Basin (km<sup>2</sup>)</b>
Pakistan	632,954
India	374,887
China	86,432
Afghanistan	76,542
Nepal	23

The Indus River is the longest and most important river in Pakistan, as well as being one of the most important rivers on the Indian sub-continent. Originating in the Tibetan plateau in the vicinity of Lake Mansarovar, the river runs a course through Ladakh, Jammu and Kashmir and Gilgit-Baltistan. Flowing through the North in a southerly direction along the entire length of Pakistan, it merges into the Arabian Sea near Pakistan's port city of Karachi. The total length of the river is 3,200 km (1,988 miles). The river's estimated annual flow is approximately 207 billion m<sup>3</sup>. The river feeds ecosystems of temperate forests, plains and arid countryside. Together with the Chenab, Ravi, Sutlej, Jhelum, Beas Rivers, and the extinct Sarasvati River, the Indus forms the Sapta Sindhu ("Seven Rivers") delta in the Sindh province of Pakistan. It has 20 major tributaries.

### Box 3.2 | Ganges-Brahmaputra-Meghna River Basin



Total Basin Area	1,745,000 km <sup>2</sup>
Annual available Water	2,025 billion m <sup>3</sup>
<b>Country</b>	<b>Area in Basin (km<sup>2</sup>)</b>
Nepal	140,000
India	1,105,000
Bangladesh	129,000
Bhutan	45,000
China	326,000

The Ganges-Brahmaputra-Meghna (GBM) river system, which flows through the northern, eastern and northeastern parts of India, illustrates a major contradiction between water potential and destructive reality. The river basin covers an area of about 1.75 million km<sup>2</sup> stretching across Bangladesh (7.4 per cent), India (62.9 per cent), Nepal (8.0 per cent), Bhutan (2.6 per cent) and China (19.1 per cent). The mean annual precipitation is 1,200 mm and 2,300 mm in the Ganges and Brahmaputra-Meghna river basins, respectively. The system carries a peak flow of 141,000 m<sup>3</sup>.s<sup>-1</sup> at its estuary, emptying about 1,150 billion m<sup>3</sup> of water into the Bay of Bengal. The Brahmaputra and Ganges rivers rank tenth and twelfth in the world, respectively, in terms of discharge they carry. The estimated basin population is approximately 535 million (75.8 per cent in India; 20 per cent in Bangladesh; 3.5 per cent in Nepal; 0.2 per cent in Bhutan; and 0.5 per cent in China). Although the basin has a rich heritage, and tremendous development opportunities, it is home to the largest concentration of poor in the world, with half of its population living in poverty. On the other hand, it is richly endowed with water resources, and has significant power potential of approximating 150,000 megawatt. With fertile alluvial lands in the plains (79.8 million ha) and a favorable climate, the majority of the population (equal to approximately 10 per cent of the global population) subsists on agriculture, the prime component of the economy. Labor resources and the desire for development are plentiful in the basin.



### Box 3.3 | Helmand River Basin



Total Basin Area: 306,493 km<sup>2</sup>

Country	Area in the Basin (km <sup>2</sup> )
Afghanistan	262,341
Iran	33,111
Pakistan	11,041

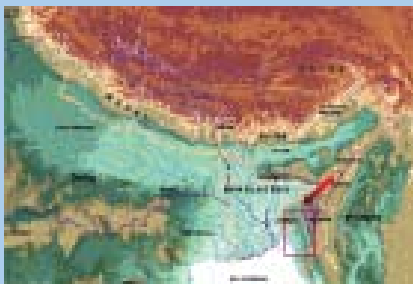
The Helmand River Basin, with a catchment area of 306,493 km<sup>2</sup> (excluding non-drainage areas of 40,914 km<sup>2</sup>), and shared by Afghanistan, Iran and Pakistan, is inhabited by nearly 7.1 million people. The basin is confined by the southern Hindu Kush ranges on the north, East Iranian ranges on the west, and by mountain ranges in the Baluchistan Province of Pakistan on the south and east (Whitney, 2006). The Helmand River is the basin's main river, draining water from the Sia Koh Mountains to the Eastern and Parwan Mountains, and finally to the unique Sistan depression between Iran and Afghanistan (Favre and Kamal, 2004). The Sistan depression is a large complex of wetlands, lakes and lagoons, being an internationally-recognized haven for wetland wildlife and the world's windiest desert. More than 85 per cent of the river basin area is shared by Afghanistan, whereas less than four percentage is occupied by Pakistan. Because only a very small portion of the basin is shared by Pakistan, with no important tributaries flowing in and out of the basin to Pakistan, Afghanistan and Iran are the two key riparian countries, which can develop the basin for the mutual benefit of both countries. Increasing population, improved living standards, and declining forest cover, among other factors, are not the exception for the Helmand Basin as well. These factors, coupled with the variability of available water resources, inefficient management of the available water resources, and lack of coordination among stakeholders, have made water a scarce resource in the Helmand Basin.

Sri Lanka, water has been central to its evolution as a nation. A hydraulic civilization dating from the sixth-century B.C. was based on an advanced system of irrigation. Water was treated with great respect and value, with water usage being regulated by edicts issued by its kings, as well as customary rights and obligations determined by the community. The annual distribution of precipitation in Afghanistan highlights a picture of an essentially arid country, with more than 50 per cent of its territory receiving less than 300 mm of rain annually. Nevertheless, it is still rich in water resources, due mainly to the snow coverage on its series of high mountains (e.g., Hindukush; Baba). Afghanistan's internal renewable water resources are estimated to be approximately 55 billion m<sup>3</sup>.year<sup>-1</sup> (FAO, 2007).

### 3.3 Fact Sheets - Main River Basins

South Asia is home to some of the world's largest river basins, in terms of both catchment areas and water flow volumes. Information on four major international river basins in South Asia is presented in Boxes 3.1 to 3.4.

### Box 3.4 | Karnaphuli River Basin



Total Basin Area: 12,510 km<sup>2</sup>

Country	Area in Basin (km <sup>2</sup> )
Bangladesh	7,400
India	5,100
Myanmar	10

source: [http://en.wikipedia.org/wiki/Karnaphuli\\_River](http://en.wikipedia.org/wiki/Karnaphuli_River)

The Karnaphuli River is a 667 m (729 yd) wide river in the southeastern part of Bangladesh. Originating in the Lushai Hills in Mizoram, India, it flows 270 km (168 mi) southwest in Bangladesh, through the districts of the Chittagong Hill Tracts and Chittagong, and subsequently into the Bay of Bengal. A large hydroelectric power plant, utilizing the Karnaphuli River, was constructed in the Kaptai region during the 1960s. The sea port of Chittagong, the main port of Bangladesh, lies at the mouth of the river.

# 4

## Vulnerability Assessment

The hydrologic and physiographic characteristics of some of the key South Asian river basins result in a variety of water-related problems, encompassing floods in the monsoon season, water shortage in the dry months, erosion and sedimentation in the river and associated flood plains, drainage congestion in low-lying areas, and environmental and water quality problems associated with human activities in the basin. The population explosion during the past century has put heavy pressures on the available water resources, causing noticeable changes in the functions and uses of the sub-region's water resources. Thus, a fundamental requirement for effectively managing these water resources, and coping with the great variety of stresses on them, is to understand the nature and extent of the water-related problems, and to integrate this knowledge within an holistic management framework.

The comprehensive knowledge base on the sub-region's water resources and associated issues is also needed to formulate an integrated water resources management policy, with an understanding of the vulnerability of water resources being a key requirement for this purpose. An effective vulnerability assessment serves as a guide to water service provision, by providing a prioritized plan for security upgrades, modifications of operational procedures, and/or policy changes to mitigate the risks and vulnerabilities to critical infrastructure.

### 4.1 Selected River Basins

Considering the hydrologic and physiographic characteristics and socio-environmental functions of river basins in South Asia, three key river basins were selected for vulnerability assessment: Ganges-Brahmaputra-Meghna (GBM), Indus and Helmand.

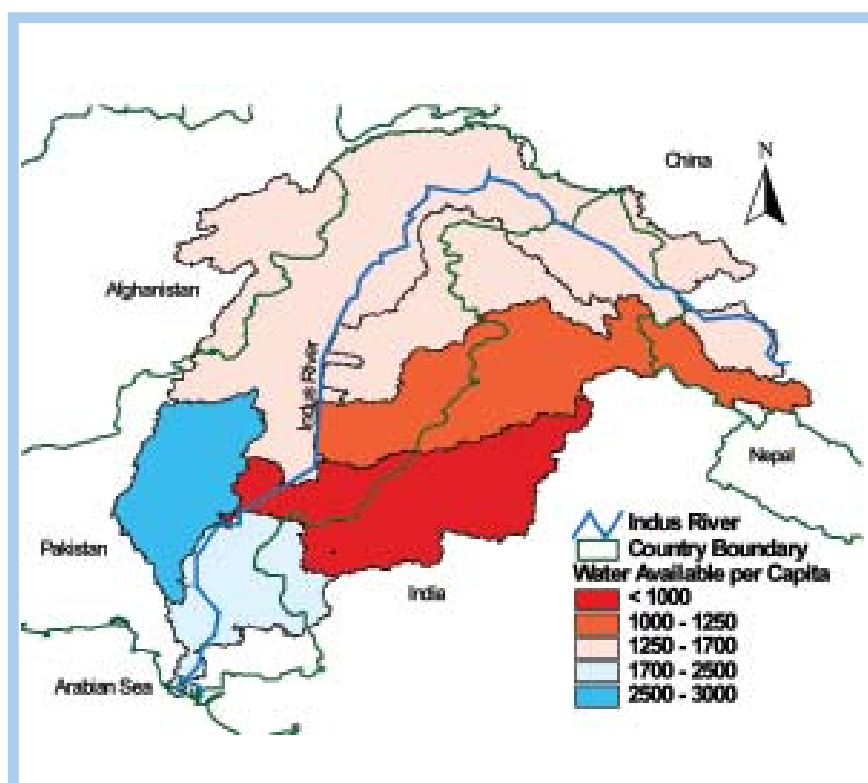


Figure 4.1 | Annual water availability in the Indus Basin (m<sup>3</sup>.capita<sup>-1</sup>)

**Table 4.1 | Water resources stresses of selected river basins in South Asia**

Basin	Indicators		Parameters	
	Available water resources	Coefficient of variation in precipitation	RS <sub>s</sub>	RS <sub>v</sub>
	m <sup>3</sup> .capita <sup>-1</sup>	-	-	-
GBM	3,473	0.11	0.00	0.37
Indus	1,329	0.23	0.22	0.76
Helmand	2,589	0.37	0.00	1.00

RS<sub>s</sub> = Water scarcity parameter; RS<sub>v</sub> = Water variation parameter

## 4.2 Resource Stresses

The general situation of vulnerability of water resources can be expressed as “scarcity” and “variation” of the water resources. Water scarcity refers to the richness of the water resources base to meet the demands of the basin population. It is generally expressed as per capita water availability and compared with the generally-accepted minimum level of per capita water requirement proposed by Falkenmark and Widstrand (1992) (1,700 m<sup>3</sup>.person<sup>-1</sup>.year<sup>-1</sup>). The variation in the water resources is expressed by the coefficient of variation (CV) of precipitation.

Analysis revealed that in the GBM basin annual per capita water availability is slightly more than twice of the minimum requirement of 1,700 m<sup>3</sup>.capita<sup>-1</sup>.year<sup>-1</sup>. It is slightly higher than 1,000 m<sup>3</sup>.person<sup>-1</sup>.year<sup>-1</sup> in the Indus Basin indicating an extremely stressful situation (Table 4.1). The proportions of drainage basin area and their contributions to the overall water resources are not consistent in South Asia. The GBM provides considerably more water resources than the Indus basin. Thus, the water scarcity parameter (RS<sub>s</sub>) in the Indus basin is 0.22. Nevertheless, there is a considerable spatial variation in the water availability in the GBM basin. In fact, it is estimated that about 30 per cent of the GBM basin area, which is home to about 40 per cent of the total GBM basin population, have the poorest water resource (RS<sub>s</sub> > 0.25) in the basin. The annual water variation parameter (RS<sub>v</sub>) is highest in the Helmand Basin compared to the other two basins.

The water resources in the selected South

Asia river basins is described as follows:

**GBM Basin:** The GBM river system constitutes the second largest hydrologic region in the world after the Amazon River basin. Its total drainage basin area of approximately 1.75 million km<sup>2</sup> (0.68 million mi<sup>2</sup>) is shared by five countries: Bangladesh, Bhutan, India, Nepal, and the People’s Republic of China (Tibet). Considering aggregation of population and hydrological variations, more attention is given in this study to Nepal, India and Bangladesh. The annual available water resources in the basin total approximately 2,025 billion m<sup>3</sup>. The water availability, however, is very uneven in both temporal and spatial scales. Both the Brahmaputra and Meghna Rivers are supplied mainly by monsoon rains from June to September. The slopes of the Himalayas in the Brahmaputra source area receive an annual precipitation of 5,000-10,000 mm (197-394 in). The Ganges River also is supplied by monsoon rains and snow, although less intensive than the Brahmaputra. Its annual precipitation is 500-1,000 mm (19.7-39.4 in), with some areas receiving up to 2,000 mm (78.7 in). Combined with the intensive water use in the region, this situation results in flooding of the foothills of Nepal and the lower Gangetic plains of India and Bangladesh, as well as severe water shortages in parts of India and Bangladesh.

**Indus Basin:** The Indus drainage basin area is shared by Afghanistan, Pakistan, India and China. Although the basin has an annual available water resources of 286.93 billion m<sup>3</sup>, the basin’s population of 215.8 million makes the annual per capita water availability of only

1,329 m<sup>3</sup>, which is lowest among the three selected basins (Table 4.1 and Figure 4.1). Despite a general water scarcity on the basin scale, there is sufficient water in the lower portion of the Indus basin (including the delta part), suggesting a spatial variability of water resources. Although the Pakistan portion has the highest volume of water in the basin, compared to the other riparian countries, the large population in the Pakistan portion of the basin has reduced the annual per capita water availability below the threshold of 1,700 m<sup>3</sup>.

The higher value of CV in precipitation suggests a high variability of water resources in the lower part of the basin, compared to the upper parts. The relatively lower CV values in the upper part indicates that the volume of water supplied by the highlands is less variable and, therefore, more reliable in terms of its availability.

**Helmand Basin:** The Helmand River Basin, with a catchment area of 306,493 km<sup>2</sup> (excluding non-drainage areas of 40,914 km<sup>2</sup>), and inhabited by nearly 7.1 million people, is shared by Afghanistan, Iran and Pakistan. More than 85 per cent of the basin area is in Afghanistan, with practically all of the wetlands’ water sources originating there. Snowmelt and spring precipitation in the mountainous upper regions of the Helmand basin are the main runoff sources. Despite being located in a desert-like area, it is rich in water resources, due mainly to the presence of the snow-covered high mountains in the basin, an example being the Koh-i Baba, which feeds the tributaries of the Helmand River.

The destruction of meteorological and hydrological stations in Afghanistan during the decades of civil disorder has resulted in an inadequate assessment of water resources, thereby hindering the planning for water resources development and the prediction of extreme events. Nevertheless, attempts are made to estimate the available water resources, based on the sparse information available

from secondary sources and scientific judgement.

The Helmand River, along with three other important rivers (Farah, Adraskan and Khash) draining to the Sistan lakes (the lowest part of the Helmand basin) provides an estimated total runoff of 15 billion m<sup>3</sup> in the Helmand Basin. Including groundwater resources, the total water availability in the basin is 18.3 billion m<sup>3</sup>. The annual per capita water availability in the entire Helmand Basin is estimated to be 2,589 m<sup>3</sup>, a value close to the per capita water availability in Afghanistan and Iran (together comprising 96 per cent of the basin area). The variation of the available water resources over seasons and years has worsened the state of water resources in the Helmand basin. The annual per capita water availability in the Helmand sub-basins reflects the spatial variability within the basin. Although the north, west and southern parts of the basin are not experiencing water stress on an annual basis, based on the threshold value of 1,700 m<sup>3</sup>.person<sup>-1</sup>. year<sup>-1</sup>, the eastern part experiences extremely stressful situation (annual per capita water resources in the range of 500-1000 m<sup>3</sup>). Droughts and floods are not rare events in the lower Helmand

**Table 4.2 | Water development pressures of selected river basins in South Asia**

Basin	Indicators			Parameters	
	Total water use	Water resources	AISDW	DP <sub>e</sub>	DP <sub>d</sub>
	billion m <sup>3</sup> .year <sup>-1</sup>	billion m <sup>3</sup> .year <sup>-1</sup>	per cent of population	-	-
<b>GBM</b>	304	2,025	83	0.15	0.17
<b>Indus</b>	257	287	87	0.89	0.13
<b>Helmand</b>	9	18	43	0.49	0.57

AISDW: Access to Improved Source of Drinking Water, DP<sub>e</sub> = water exploitation parameter  
DP<sub>d</sub> = Safe drinking water inaccessibility parameter

Basin (Whitney, 2006), highlighting the basin's seasonal variability of water resources, whereby the larger CV of precipitation in the lower, drier part highlights the spatial variability of water resources, and their inconsistency, within the basin. The use of Helmand River water upstream in Afghanistan for irrigation purposes could significantly affect the availability and variability of the water resources in the lower part of the basin.

### 4.3 Development Pressures

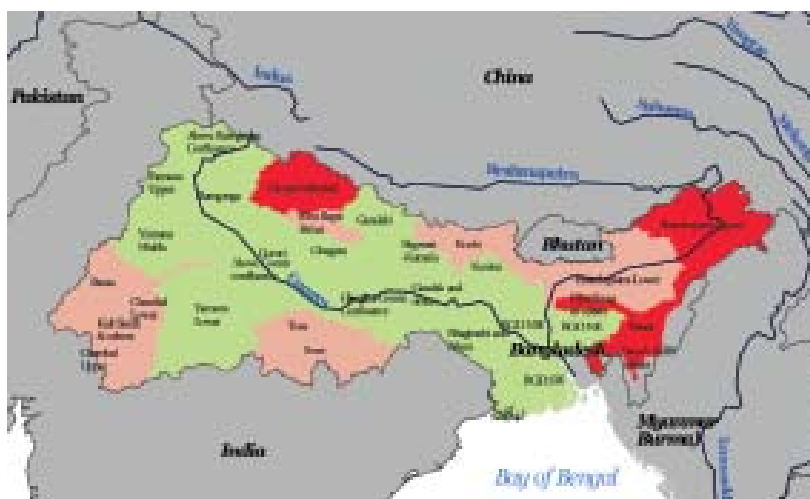
Freshwater is recharged through a natural hydrological process. Over-exploitation of water resources disrupts the normal hydrological process, ultimately causing imbalance in supply and demand. The water resource development rate (i.e., percentage

of available water supply, relative to the total water resources) is used to demonstrate the current level of pressures on the resources, whereas access to improved drinking water sources is used to assess the state of use to meet basic societal demand of freshwater.

The water resources development pressures (DP<sub>e</sub>) is estimated to be 89 per cent for the Indus basin, being considerably greater than that of the GBM basin (15 per cent), and almost double that of the Helmand basin (49 per cent), reflecting the increased development pressures in the Indus basin (Table 4.2). The water use in the Indus is not consistent with the annual per capita water availability, reflecting the worsening situation in the basin.

**GBM Basin:** The development and use of the water resources of this basin have been changing over decades, as more and more people are recognizing the economic, social and cultural importance of water. The pressures on water resources are mounting due to competing demands from different users in the basin. Water from the Ganges River is extensively used and largely exploited, compared to the Brahmaputra and Meghna River systems. The latter two rivers are largely unexploited in the Indian portion of the basin as they flow through the hilly areas in northeastern India.

The irrigation sector comprises a major water user (about 88 per cent) in the GBM basin. The additional population growth in coming years will result in greater pressures on the available water resources, and specially irrigation in the Ganges sub-basins of India. Nepal and Bangladesh are developing



■ Low (<20% pop. lack access) ■ Moderate (20-40% pop. lack access) ■ High (40-70% pop. lack access)

**Figure 4.2 | Development pressures emanating from lack of access to safe drinking water in the GBM Basin**



countries, whose agricultural activities consume about 95 per cent of the total water use. With high population densities, India and Bangladesh withdraw groundwater for irrigation purposes, to meet growing food demands. As a result, the groundwater levels have been sinking at alarming levels in some parts of these countries.

Apart from irrigation water use, new freshwater resource demands are emerging from other sectors (e.g., hydropower; recreation; navigation). Water demands are rapidly increasing, due largely to rapidly-changing lifestyle associated with increased socioeconomic development. In fact, rapid urbanization has become a key issue that will likely to seriously impact water demands and water quality, especially in the Ganges River Basin.

Water stress in all the GBM sub-basins in Nepal and Bangladesh is low, mainly because these countries use a significant fraction of the rain that falls on their territory for agricultural production, the latter not being included in the reported water use statistics. Within Nepal, the West Rapti-Babai and Bagmati-Kamala sub-basins use more than 15 per cent of the available water resources, (see Figure 4.2 for location) while seven GBM sub-basins in India use more than 50 per cent of their available water resources.

Out of a total of 31 sub-basins studied in the GBM, six have about 30 per cent of the respective sub-basin population lacking access to safe drinking water. However, this accounts for approximately 130 million inhabitants (Figure 4.2). On a basin scale, about 24 per cent of the population lacks access to safe drinking water, with the inhabitants in the Kynchiang and other south-flowing rivers sub-basin of India in having the least access. Unfavorable topographical situation and relative socioeconomic backwardness could be the underlying reasons for this situation.

**Indus Basin:** In general, the water resources in the Indus basin are under considerable stress, especially in the eastern parts of the basin shared by Pakistan and India, the latter being due to extensive water use to support agricultural production. A

country-wide assessment of the annual water use of different sectors in the Indus basin reveals that Pakistan is the largest water user, accounting for about 60 per cent of the total water use, followed by India at 38 per cent. The water use for the domestic and industrial sectors is relatively small, being only 3.4 per cent of the total use. The remaining water resources are being utilized in the agriculture sector. These values highlight the extent of agricultural activities in the basin, and the importance of this sector in countries' economy. The total water use of 257 billion m<sup>3</sup> indicates that about 90 per cent of the basin's available water resources are being utilized. Nearly 87 per cent of the Indus basin population has access to improved drinking water sources. Although this proportion may appear satisfactory, a closer look may not be so reassuring, noting that the remaining 13 per cent means that approximately 28 million people in the basin do not have access to improved drinking water sources. Considering the country level, the population living in the Pakistan portion of the Indus Basin has the greatest access (93 per cent), while those in Afghanistan have the least, with not even half of the population of the latter within the basin having access to improved water sources.

**Helmand Basin:** A country-level assessment of water use in the Helmand Basin indicates the annual per capita water withdrawal is

about 1,280 m<sup>3</sup>. A sector-wise assessment indicates that at least 97 per cent of the water being withdrawn is used in the agriculture sector. Another major concern in the Helmand Basin is the lack of water infrastructure to provide safe drinking water to the population, and to address waste discharges. Sustainable access to safe drinking water in Afghanistan is among the lowest in Asia. More than half of all Afghans in urban centers have no access to water from improved water sources, while it is estimated that four-fifths of the Afghan population in rural areas may be drinking contaminated water (MDG, 2005). Moreover, Afghanistan, which has 86 per cent of the Helmand Basin, has been reported to have the highest rate of urbanization in South Asia, being approximately 6 per cent per year (MDG, 2005), highlighting future water development pressures in the basin.

#### 4.4 Ecological Insecurity

In addition to their impacts on the hydrological process, water development and use can produce waste and pollute water resources. Similarly, population expansion and associated pressures (e.g., urbanization and other socioeconomic developmental activities) have a bearing on vegetation cover. Removing vegetation



**Nomadic Afgan Kids, Afghanistan**

Source: [www.sxc.hu/Nigel\\_Clarke](http://www.sxc.hu/Nigel_Clarke)

**Table 4.3 | Ecological health of selected river basins in South Asia**

Basin	Indicators			Parameters	
	Wastewater volume	Water resources	Vegetation cover	EH <sub>p</sub>	EH <sub>e</sub>
	billion m <sup>3</sup> .year <sup>-1</sup>	billion m <sup>3</sup> .year <sup>-1</sup>	per cent of basin area	-	-
GBM	92.0	2,025.0	20.0	0.30	0.80
Indus	54.7	287.0	39.1	1.00	0.61
Helmand	2.8	18.3	40.0	1.00	0.60

EH<sub>p</sub> = water pollution parameter; EH<sub>e</sub> = ecosystem deterioration parameter

from the landscapes can change the hydrological processes on the land surface, as well as have severe impacts on the functioning of ecosystems, thereby contributing to the vulnerability of water resources. Thus, the volume of wastewater discharged to rivers (representing the water pollution status) and vegetation cover (presenting the vulnerability of the natural landscape) are used for the purpose of assessing the ecological health of river basins. As a benchmark, it is assumed that when the volume of wastewater discharged exceeds 15 per cent of the total water resources, the wastewater discharges merit concern

because they make the water system vulnerable. Industries and large urban centers that discharge untreated wastes are responsible for much of water pollution, which reduces the availability of freshwater for other purposes without treatment. The poor quality of surface water can lead to increasing groundwater extraction for agricultural and domestic consumption. The annual volume of wastewater discharged into the Indus and Helmand River systems account for 19 and 16 per cent of their annual available water resources respectively, whereas 4.5 per cent in the GBM Basin (Table 4.3). Thus, the water resources of the Indus and Helmand

basins are facing greater pollution pressures. On the other hand, forest cover increases the capacity of a river basin to preserve natural ecosystems, being greater in the Indus and Helmand basins (39 and 40 per cent, respectively), compared to the GBM (20 per cent). This observation suggests that ecosystem deterioration is greater in the GBM Basin than in the Indus and Helmand basins.

**GBM Basin:** This basin supports nearly 40 per cent of the total population of South Asia, thereby imposing great pressures on ecologically-sensitive areas, in terms of both encroachment and unsustainable use. The Ganges supports a rich fauna and flora, including the endangered Ganga River dolphin (*Platanista gangetica*), and at least nine other species of aquatic mammals. The Ganges River also possesses the richest freshwater fish fauna of 141 species, as well as supporting many plant species of both ecological and economic importance. Threats to the continued functioning of the Ganges River as a living system have reached a critical level, due ultimately to the exponential expansion of the basin's human population and their economic activities. River erosion, which occurs extensively in Bangladesh, has major social, economic and environmental consequences. On average, more than 10,000 people are displaced each year. Salinity intrusion in southwest Bangladesh has increased because of low freshwater flows in the river system during the dry season.

The GBM Basin countries are increasing their industrial activities at rapid rate. According to the UN World Water Development Report (UNESCO–WWAP, 2006), approximately 300-500 million tons (272-454 billion kg) of heavy metals, solvents, toxic sludge, and other wastes are discharged each year from industrial activities, most of which enter the freshwater sources. In the GBM Basin, 70 per cent of the industrial wastes are dumped untreated into surface waters. Of the thirty-one sub-basins analyzed in this study, the wastewater volume exceeds 15 per cent of the available water resources in seven of them. The higher percentage of wastewater discharges in

#### Box 4.1 | Damage caused by floods in Bangladesh



**Flooded houses, Bangladesh**

Source: World Food Programme

Situated at the head of the Bay of Bengal, most of Bangladesh is a delta formed by the convergence of three great rivers – the Ganges, the Brahmaputra and the Meghna. Eighty per cent of Bangladesh is less than 1.5 metres above sea level and every year during the monsoon season the rivers flood half the country to a depth of 30 cm. The floods, which last for several months, have the environmental benefit of bringing fertile silt, but cause great disruption. Yet these annual floods are insignificant compared to the really disastrous floods caused by tropical cyclones.

In 1970 a tropical cyclone and tidal surge killed more than 450,000 people. A repeat of this disaster occurred in 1991 when 125,000 people were killed. And recently in November, 2007, the cyclone which struck Bangladesh affected about 8.5 million people with nearly 564,000 homes destroyed. Death toll reached at 3,268 (VOA, 2007). The cyclone had also dealt a severe blow to the Sundarbans, destroying 1,528 km<sup>2</sup> of the forest out of around 6,000 km<sup>2</sup>, according to forest officials' primary assessment. Of the devastated areas totaling about one-fourth of the forest, 1,200 km<sup>2</sup> are land and the rest water bodies (*Daily Star, November 30, 2007*).

these sub-basins corresponds to a higher agricultural water use.

Floods during the monsoon season and tropical cyclones are a major cause of freshwater contamination. The same reasoning, along with a relatively flat terrain, applies to the West Rapti-Babai sub-basin in Nepal. In the GBM sub-basins located in Bangladesh, the wastewater volume is still relatively low, compared to the available water resources. In addition to the pollution of drinking water supplies, and saltwater contamination of farmlands, floods also cause loss of human life, crops and livestock, as well as destroying roads, bridges, electricity pylons. Bangladesh is the most flood affected country in the GBM Basin (Box 4.1).

In terms of ecosystem deterioration, forest cover in the Brahmaputra-Barak system exceeds 30 per cent of the respective sub-basin areas. This is in contrast to the Ganges and Yamuna sub-basins in India, with less than 10 per cent of the land area under forest. Esty et al. (2005) reported an alarming rate of deforestation in Nepal and Bangladesh, which could change the regional precipitation patterns and rates.

**Indus Basin:** The water quality of Indus River and its tributaries is generally well suited for various activities. The concentration of total dissolved solids (TDS) ranges from 60 mg.L<sup>-1</sup> in the upper reaches, to 375 mg.L<sup>-1</sup> in the lower reaches of the Indus. These concentrations are reasonable levels for irrigated agriculture, and also as raw water for domestic use. The total volume of wastewater discharged into the Indus River system is about 19 per cent of the available water resources, with 90 per cent of the wastewater originating from agricultural areas.

In terms of land cover, about 39 per cent of the basin area is under forests and wetlands. However, more than 65 per cent of the lower Indus Basin is without vegetation. The portions of the basin with relatively high vegetation cover are those covering the highlands of the Indus Basin, and the northeastern portion of Pakistan's Baluchistan Province. These parts of the basin, particularly the Indus highlands, must maintain good vegetation coverage, since further forest degradation could have major impacts on the downstream areas.

**Helmand Basin:** The forest cover in the Helmand Basin has been reduced, due to

#### Box 4.2 | Ecological impacts of over-exploitation of water resources in Helmand Basin



**Dust storm over Afghanistan and Pakistan**

Source: [http://visibleearth.nasa.gov/view\\_rec.php?id=18878](http://visibleearth.nasa.gov/view_rec.php?id=18878)

This Terra MODIS image shows a huge dust storm over southern Afghanistan and Pakistan on Sept. 23, 2003.

Sandstorms that scoured southwestern Afghanistan in early June-Sep 2003 were called the worst in living memory by residents of the area. The dust and sand buried villages, filled waterways, destroyed crops and killed livestock. The storms persisted longer than expected, creating a huge environmental problem for the residents of this region. Most of the windblown dust originated in the Sistan Basin, which is home to the Hamuns (wetlands) straddling the border between Iran and Afghanistan. Persistent drought conditions there, coupled with increased irrigation off the Helmand River, have quickly turned these wetlands into arid salt pans.

continuous demands for fuel wood and illegal logging. In the Sistan region, a continuous decline in the wetland vegetation cover has been observed since 1985. The water quality is generally good in the upper basins of all the rivers in Afghanistan throughout the year (including the Helmand Basin). It also is relatively good in the lower portions of the basin, in spite of the large irrigated areas in there.

The Sistan depression is a large complex of shallow wetlands, lakes and lagoons. The Sistan region also is an internationally-important haven for wetland wildlife. A large part of the Hamuns (wetlands) in Iran, approximately 60,000 ha (232 mi<sup>2</sup>), has been designated as a protected site under the Ramsar Convention. A properly-functioning wetland is important for maintaining acceptable living conditions in the area, and any water withdrawals for irrigation will be at the expense of the Hamuns (wetlands) and their ecosystems (van Beek and Meijer, 2006).

There is a direct relation between the use of water for irrigated agriculture, and the observed environmental conditions in the area. A further increase in the volume of water used for irrigation will decrease the average water cover in the Hamuns (wetlands), with corresponding negative impacts on the ecology and human health (Box 4.2). The poor ecological conditions that currently describe the Hamuns (wetlands) on the Iranian side appear to be the result of mismanagement, rather than the years of drought that occurred in the area (van Beek and Meijer, 2006).

Water quality is generally good in the Sistan area, although salinity can sometimes be a concern. Domestic and industrial pollution is low, with their

**Table 4.4 | Management capacity of the selected river basins in South Asia**

Basin	Indicators				Parameters		
	GDP (PPP)	Water use	Population	AISF	MC <sub>e</sub>	MC <sub>s</sub>	MC <sub>c</sub>
	US\$. capita <sup>-1</sup>	billion m <sup>3</sup>	million people	per cent of population	-	-	-
<b>GBM</b>	1,807	304	582.9	40.0	0.91	0.60	0.50
<b>Indus</b>	4,002	257	215.8	51.8	0.86	0.48	0.375
<b>Helmand</b>	1,272	9.04	7.1	39	0.96	0.61	0.675

AISF: Access to Improved Sanitation Facility; MC<sub>e</sub> = Water use inefficiency parameter; MC<sub>s</sub> = Improved sanitation inaccessibility parameter; MC<sub>c</sub> = Conflict management capacity parameter

effects being limited to local areas. The status of industrial activities in the riparian countries suggest that wastewater from industries is not presently a major concern in the Helmand Basin. Nevertheless, wastewater collection and drainage problems are particularly serious in urban areas, where sewage is often discharged directly into the streets.

The variability of the precipitation is a major factor in the desiccation of wetlands in the Helmand Basin. Rivers often fail to provide sufficient quantities of this life-sustaining resource, thereby this remains a main environmental challenge for the Sistan region. Ecosystem restoration will necessitate reduction in use of water in agriculture sector, through changes in agricultural practices (e.g., improved irrigation efficiency; switch to less water-intensive crops).

#### 4.5 Management Challenges

In addition to the availability (and uncertainty) of water resources, management efficiency (or inefficiency) also contributes to the vulnerability of the sub region's freshwater resources. The current management capacity to cope with (mis)match between water demand and supply is evaluated through: (1) efficiency of water use (measured as the GDP produced per unit of water use); and (2) human health conditions (measured by level of access to sanitation facility).

Although the per capita GDP in the Indus Basin is more than double that of the

GBM and Helmand basins (Table 4.4), water use efficiencies in all three basins are very low, compared to the global average of about US\$ 8.6.m<sup>-3</sup>, and average of the five top food producers in the world (Brazil; China; France; Mexico; USA) at US\$ 23.8.m<sup>-3</sup>. A basin-scale analysis revealed that the GDP produced per unit of water use in the GBM basin is US\$ 3.47.m<sup>-3</sup> while those in the Indus and Helmand Basins are US\$ 3.34 and US\$ 1.00, respectively. The inhabitants' access to adequate sanitation facilities suggests even poorer management efficiency in all three basins. About 50 per cent of the people of the Indus basin have access to improved sanitation facilities, while the corresponding figure in both the GBM and Helmand Basins is about 40 per cent.

Considering transboundary institutional arrangements for coordinated water resources development and management, and policies/ agreement, communication mechanisms, and cooperation for water resources management, both the GBM and Indus River basins can be considered moderately vulnerable (MC<sub>c</sub>).

**GBM Basin:** This basin represents a paradox in that, although it contains a large quantity of water, it is poorly utilized and managed. Governments of the GBM Basin countries seek to control the great rivers of the GBM because it offers partial, but tangible, solutions to the most fundamental problems of rural poverty, industrial constraints, and urban stresses that these governments intend to address. The means by which control presently is being sought – through national visions, covert appropriations, and bilateral bargaining – constrain what might otherwise be achieved (Crow and Singh, 2000). This is reflected in a low GDP production per unit of water use in the basin, and its resulting water

use inefficiency parameter (MC<sub>e</sub>). The value of this parameter, however, ranges between 0.29-0.98 in the 31 sub-basins comprising the GBM Basin. There is least inefficiency in Northeast Bangladesh (BGD-NE sub-basin), since its agriculture is mostly rainfed, with per capita water use being low. The percentage of population without access to improved sanitation facilities also varies between sub-basins (19-81 per cent). The Gantak and others, and the Sone sub-basin, have the lowest access to improved sanitation facilities in the GBM.

In terms of the conflict management capacity parameter, little regional cooperation has previously been observed among the co-riparian countries. However, the South Asian Association for Regional Cooperation (SAARC), established in the 1980s, provides a forum for discussion. The transboundary management issues in the GBM Basin can be divided into three broad categories: (i) sharing of river waters; (ii) cooperative development of water resources, and (iii) sharing of data and information on common rivers to facilitate flood forecasting and water quality control. Analyses of the visions of the riparian countries regarding water resources management reveal that Nepal wants to exploit the basin's huge hydropower potential, whereas Bangladesh wants to minimize flooding during the monsoon season and the water shortages during dry months. India would prefer to divert water from the North Eastern Brahmaputra basin to augment the dry season water flow in the Ganges River Basin and reduce flood events during the monsoon season. Bangladesh wants to share water multilaterally over time by involving Nepal, whereas India wants to bilaterally share water with Bangladesh over space. Thus, there is an unresolved dilemma between the proposals of Bangladesh and India, regarding whether or not to share water over time or space (Rahman, 2005). These conflicting



interests hinder the integrated management of transboundary water resources for the maximum benefit for all basin stakeholders.

**Indus Basin:** The water use efficiency in the Indus Basin is much less, compared to the average of the world's five top food producers (Brazil; China; France; Mexico; USA). The provision of appropriate policies, and implementation of concrete actions, is needed to increase the value of water-intensive goods and services.

About 52 per cent of the total Indus Basin population has access to improved sanitation facilities. Although the Pakistan portion of the basin has relatively good access to such facilities, the needs of the large population in India and Afghanistan for improved sanitation also should be addressed. The national status of access to improved sanitation facilities also is reflected via the sub-basin scale analysis of the Indus River basin. Pakistan has the smallest proportion of people (41 per cent) without access to improved sanitation facilities, whereas India has the highest proportion (67 per cent). The above figures may indicate that the threats to the quality of the water resources of the Indus Basin from domestic sector is relatively less, considering that the portion of the population with the least access to improved sanitation facilities is located in the lower part of the basin. Efforts are still needed, however, to significantly improve the situation, in order to ensure the sustainability of the quality and use of the available water resources, particularly in the downstream and delta areas, which is home to tens of millions of basin inhabitants.

The Indus Waters Treaty is regarded one of the few successful settlements of transboundary water basin conflicts. Although there was significant dialogue regarding the historical right usage of water versus the inappropriateness of

using historical use to set future water allocations, a compromise was reached by Pakistan and India after approximately nine years of negotiations, through mediation by the International Bank for Reconstruction and Development. However, the Indus Waters Treaty does not address the issue of transboundary pollution of the water resources, which is a significant contributor to the vulnerability of the basin's freshwater resources.

On the other hand, although Pakistan has a clear agreement with India on the use of the water resources of the Indus River, there is no agreement between Pakistan and Afghanistan concerning the water resources of Kabul River, which is a sizeable tributary of the Indus (Favre and Kamal, 2004). The riparian issues in the Indus Basin also are convoluted with the border dispute between Afghanistan and Pakistan. The government of Afghanistan is planning to reinforce irrigation, fishing and hydropower generation along the Kabul River. Unless an agreement is reached, however, further developments could trigger tensions between the two countries. Thus, the rating of the Indus Basin for agreement capacity was determined to be 0.075 (on a scale of 0-0.25, with 0.25 representing the absence of concrete and detailed agreements), basically still reflecting a good rating for the agreement category.

Other categories of institutional, communication and implementation capacities are influenced by established (or absent) concrete agreements. Regarding institutional capacity, the Permanent Indus Commission is tasked with the implementation and monitoring of activities of the Indus Waters Treaty. However, this institution is weak in performing the various research studies needed to prepare scientifically-sound responses to water resources development on both sides of the border (IUCN Pakistan, 2007). The Pakistan Commissioner of Indus Treaty maintains a minimum of two meetings with his Indian counterpart – one meeting each in Pakistan and India. Moreover, several



**A man pulling a kerosene tank in the flooded water in India**

Source: [www.sxc.hu/laxman](http://www.sxc.hu/laxman)

infrastructure projects have been planned and implemented in the water sector during the post-treaty period. Reservoirs (see Box 4.3), and a network of inter-river link canals, were constructed in the Indus Basin under the Indus Basin Settlement plan (Khan et al., 2000). Because of the above-mentioned factors, the rating for institutional, communication and implementation capacities was determined to be 0.10, which is a category above moderate.

**Helmand Basin:** Water resources management in the Helmand Basin focuses primarily on management of irrigation water, since about 97 per cent of the total water use in the basin is in this sector. The Integrated Water Resources Management (IWRM) policy framework for Afghanistan was developed with external support. The prepared draft water resources management policy, and the draft irrigation policy, identify important sector concerns, and provide general policy direction on the basis of international best practices (ADB, 2005). However, these practices are yet to be implemented. Afghanistan still has a weak water resources institutional infrastructure (Alim, 2006), very few skilled professionals to undertake development programmes (Qureshi, 2002), and lack of

coordination among relevant ministries. The combined effect of these factors has resulted in management stresses in the Helmand Basin and its riparian countries.

The GDP produced per unit of water use in the riparian countries is much lower than the world average of US\$ 8.6/m<sup>3</sup> of water use. The low water use efficiency in the irrigation sector, being 25 per cent in Afghanistan (Alim, 2006) and 32 per cent in Iran (Chavoshian et al., 2005), and the fact that more than 90 per cent of the water resources are used in irrigated agriculture, could be reasons for this situation.

In terms of access to improved sanitation, only one-third Afghans in urban areas has access, whereas only one-tenth in rural areas (MDG, 2005). Moreover, Afghanistan has been reported to have the highest rate of urbanization in Asia at 6 per cent per year (MDG, 2005). Poor waste management practices and the lack of modern sanitation and sewage systems in the urban centers further exacerbate the human health problems in the coming years.

### Box 4.3 | Water resources management challenges in the Indus Basin



**Tarbela Dam in Upper Indus Basin**  
Source: [visibleearth.nasa.gov](http://visibleearth.nasa.gov)

The Tarbela Dam, one of the largest earth and rockfill dams in the world, stores the water resources of the upper basin of Indus River, for the purpose of regulating the flows of the river for the benefit of irrigation, hydropower generation, and provision of flood control. In 1971, the Tarbela Watershed Management Project was launched to promote improved methods of land use, and to implement watershed management practices in the catchment area above the Tarbela dam, in order to protect the reservoir. Although management activities have been conducted, they have been done in areas where interventions are possible, since other parts of the Upper Indus are covered with ice and glacier. As a result, large amount of sediment is collected in the dam, especially during extreme events (Ali and De Boer, 2007), resulting in the loss of 20 per cent of its original capacity.

With the pace of sedimentation of Tarbela and other dams, there is a need for more efficient, and integrated, management of the upper Indus Basin. This calls for involvement of other riparian countries, most importantly India and China, as well as Afghanistan for the other parts of upper Indus. In the face of a rapidly-growing population and associated food requirements, the benefits from managing the upper Indus Basin as a single system would be substantial. Moreover, unless the problem is properly addressed, the downstream areas will be badly affected, since continuing sedimentation of the reservoir will cause irrigation water shortages in the future, especially during the Rabi season and the early part of Kharif.



Low (VI < 0.2) Moderate (VI = 0.2-0.4) High (VI > 0.4)

**Figure 4.3 | Water Vulnerability Index**

## 4.6 Vulnerability Index

The vulnerability index is calculated giving equal weight to four components of vulnerability index: (i) resource stresses (RS); (ii) development pressures (DP); (iii) ecological insecurity (ES); and (iv) management challenges (MC) (Table 4.5).

The vulnerability indices suggest that water resource systems in the Helmand and Indus Basins are highly vulnerable. Of the two, the Helmand basin is more vulnerable (VI = 0.64). The water resources in the GBM Basin are also highly stressed, with considerable variation within the basin (Figure 4.3).

For both the Helmand and Indus basins, ecological insecurity contributes most to the water resources vulnerability, while management challenges pose the greatest risk in the GBM Basin. Nevertheless, management challenges in the Helmand Basin are also high (Figure 4.4).

Key issues leading to vulnerability of water resources in the GBM Basin are: (i) seasonal variations in water resources (flooding and shortages); (ii) climate change implications (increased glacier melt, changes in precipitation, loss of ecosystem); and (iii)

**Table 4.5** Summary of vulnerability parameters for selected river basins in South Asia

Basin	RS	DP	ES	MC	VI
GBM	0.39	0.17	0.57	0.65	0.45
Indus	0.49	0.51	0.80	0.57	0.59
Helmand	0.50	0.53	0.80	0.74	0.64

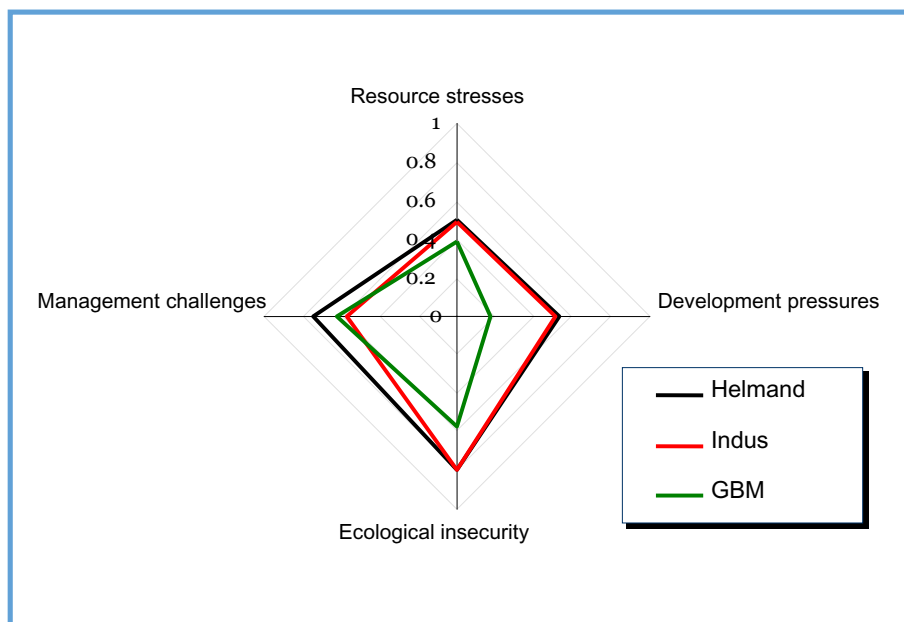
RS = Resource stresses; DP = Development pressures; ES = Ecological insecurity; MC = Management challenges; VI = Vulnerability index

water quality degradation and transboundary water management issues. Similarly, issues in the Indus Basin are: (i) salinization and sodification of agricultural lands; (ii) degradation of the Indus delta ecosystem; (iii) low irrigation water use efficiency; (iv) lack of integrated water resources management in the upper Indus Basin; (v) declining groundwater levels (groundwater mining, etc.). The key issues for the Helmand Basin are: (i) lack of a sufficiently dense hydrometeorological network; (ii) lack of an information system; (iii) variability of available water resources; (iv) limited access to water supply and sanitation facilities; (v) low efficiency of irrigation infrastructure; and (vi) lack of management capacity and coordination among water-related national agencies, and among riparian countries, all of which lead to increased vulnerability of freshwater resources.



High (VI=0.4-0.7) Severe (VI>0.7)

(VI) in the GBM Basin



**Figure 4.4** | Sources of vulnerability in South Asian river basins

# 5

## Conclusions and Recommendations

The South Asian countries, including Afghanistan and Iran, are home to about one-fourth of the world's population, but only has about 4.5 per cent (1,945 billion m<sup>3</sup>) of the world's annual renewable water resources (43,659 billion m<sup>3</sup>). Generally speaking, the underdeveloped conditions characterizing the region means that the water productivity – in terms of GDP per cubic metre of water use – is low (US\$ 1-4), compared to the world average of US\$ 8.6. Because of the poor, and often uneven, endowment and development of water resources in South Asia, the issues and challenges in the water sector are large in scale, diversity and complexity. This report presented a situation analysis, with regard to the vulnerability of water resources systems in South Asia. In addition to the more general relevant issues addressed herein, this report considers three South Asian transboundary river basins as case studies: Ganges-Brahmaputra-Meghna (GBM), Indus, and Helmand. Collectively, these basins provide South Asia with a variety of water-related challenges encompassing floods in the monsoon season, water shortages in the dry months, sedimentation and erosion in the rivers and associated flood plains, drainage congestion in low-lying areas, and environmental and water quality problems associated with human activities in the region. The population explosion in this region over the past century has created serious pressures on water resources, bringing about noticeable changes to the functioning of ecosystem and uses of the region's water resources. To effectively manage these resources, and to cope with the variety of stresses upon them, there is a need to better understand the nature and extent of water problems, and develop holistic sustainable solutions.

The vulnerability of the water resources of the selected river basins considered in this report is assessed from two perspectives: (i) the main threats to the basin's water resources and its development and utilization dynamics; and (ii) the basin's challenges in coping with these threats. Related indicators (parameters) are evaluated, considering a number of constraints related to data and information, including lack of access to some official data, and wide seasonal and spatial variations in the hydrology of the selected basins. A composite vulnerability index (VI) is calculated considering resource stresses development pressures, ecological insecurity and management challenges in the basins.

The analyses reveal that the annual per capita water availability is about 3,500 m<sup>3</sup> and 2,600 m<sup>3</sup> in the GBM and Helmand Basins respectively. Thus, these two basins are not water stressed *per se*. However, the water availability within individual basins exhibits large seasonal and spatial variations. It is estimated that about 30 per cent of the GBM Basin area, home to about 40 per cent of the region's population, has an annual per capita water availability of less than 1,300 m<sup>3</sup>. For the Indus Basin, the per capita water availability is 1,330 m<sup>3</sup>.person<sup>-1</sup>.year<sup>-1</sup>, indicating an extremely stressful situation.

The water resource development rate of 89 per cent in the Indus Basin is high, compared to 49 per cent in the Helmand Basin, and 15 per cent in the GBM Basin, reflecting a greater level of development of the Indus Basin water resources. The annual wastewater volume discharged into the Indus and Helmand River systems account for approximately 19 and 16 per cent of their annual available water resources respectively, whereas this figure is 4.5 per cent in the GBM Basin. This indicates that the freshwater resources of the Indus and Helmand basins are facing more pollution pressures than in the GBM Basin. In contrast, vegetation cover (as a reflection of the preservation of natural ecosystems in a river basin) is higher in the Indus and Helmand basins (39.1 and 40 per cent,



respectively), compared to the GBM Basin (20.0 per cent). As an example, the Sunderbans Reserve Forests in the Lower Ganges Basin encompass 580,000 ha (2,239 mi<sup>2</sup>) of land, with 410,000 ha (1,583 mi<sup>2</sup>) being mangrove forests and 170,000 ha (656 mi<sup>2</sup>) being open water areas in rivers, channels, and creeks. The Sunderbans comprise approximately 45 per cent of the natural productive forest, providing livelihoods for at least 500,000 people. The Sunderbans is also under considerable environmental threat, attributed to the reduction in the freshwater flushing action caused by factors such as the freshwater extraction in the upstream, increasing shrimp cultivation, over-exploitation of forest resources, increased use of water in irrigation, and increased silt deposits. The study results suggest that ecosystem deterioration is greater in the GBM Basin than in the Indus and Helmand basins.

Although the per capita GDP in the Indus Basin is more than double that of the GBM and Helmand basins, the water use efficiencies in all three basins are very low, compared to the world average of about US\$ 8.6 per cubic metre of water use and average of the five top food producers in the world (Brazil; China; France; Mexico; USA at US\$ 23.8 per cubic metre). At the basin scale, analyses revealed that the GDP produced per unit of water use in the GBM Basin is US\$ 3.47 per cubic metre, while those in the Indus and Helmand basins are US\$ 3.34 and US\$ 1.00 per cubic metre, respectively. The inadequate access of the basin inhabitants to sanitation facility depicts a poor management capacity for all the three basins. About 50 per cent of the inhabitants of the Indus Basin have access to improved sanitation facilities, while the corresponding proportion for both the GBM and Helmand basins is about 40 per cent.

The case study river basins are international. Although some arrangements exist between respective co-riparian countries in the GBM and Indus transboundary basins, the implementation of these arrangements poses considerable challenges, and they may prove to be inadequate with increasing water demands.

Overall, the water resources systems in both the Helmand and Indus basins are highly vulnerable. Comparatively, the Helmand Basin

is the most vulnerable (VI = 0.64) of the two basins. The water resources in the GBM Basin are highly stressed. For both the Helmand and Indus basins, ecological insecurity contributes most to the water resources vulnerability, while management challenges pose the greatest threat for the GBM Basin. Nevertheless, management challenges in the Helmand Basin also remain high.

## Recommendations

There are no viable generic solutions to the water vulnerability faced by the South Asian countries. Thus, for each selected river basin, the recommendations available for reducing the water resources vulnerability must rely on a unique mix of policy interventions and preferred routes for future water resources development. They can be summarized as follows:

- *Promotion of people-centric and people-oriented water management.* High resource stresses and development pressures in the Indus Basin, and large spatial and temporal water resources variations in the GBM Basin, call for a paradigm shift in the way water resources are managed in these basins. These include (but not limited to): (i) promotion of co-management of domestic and irrigation water supply infrastructure; (ii) encouragement of private sector participation in water development; and (iii) improved public sector spending in the water sector.
- *Improving water management efficiency.* Agriculture is by far the largest water user in South Asia. Water management efficiency in the agriculture, however, remains much less than desired, implying that the current system of operation, and distribution and use of water resources is inadequate. Moreover, there is a need to adopt policies promoting more efficient use of the existing water resources. As an example, excessive water conveyance losses due to sedimentation and poor maintenance of irrigation networks have been reported in Pakistan. These age-old irrigation infrastructures must be rehabilitated and/or remodeled to address these issues as well as changing agronomic conditions.

- *Increased investment in water development and use.* Lack of management capacity, and a low level of water exploitation in parts of the GBM Basin, implies that a scope for further water resources development does exist. However, under-developed socioeconomic conditions on the one hand, and low water exploitation on the other hand, create a vicious cycle. Investments must prioritize the sustainable development of water resources in the GBM Basin.

- *Full provision for non-consumptive water use.* Findings of poor ecological health in the Indus and Helmand Basins call for provision of desired balance of water allocation between human and nature's needs.

- *Pursuit of cooperative, basin-level water resources development and management.* All the case study basins are transboundary in nature. Thus, opportunities for cooperation on sustainable water resources development and management exist for all the basins, as evidenced through a number of earlier developments involving the GBM and Indus Basins. The prospects of two or more co-riparian countries working in cooperative, project-based water development activities in the GBM and Indus Basins were also endorsed by South Asian Association for Regional Cooperation (SAARC) summit in 1997 and 1998. Special emphasis should be directed to establishing governing principles for transboundary water sharing and institution building, including regional data collection and monitoring networks, river basin organizations, and tribunals for dispute settlements.

Although the sources of vulnerability of the water resources for the three case study basins are different, it is expected that the comprehensive, and easily-interpretable findings in this report will help decision makers reach sound solutions for reducing the vulnerability of water resources in South Asia.

# References

- ADB (2005). *Technical Assistance to Islamic Republic of Afghanistan: Capacity Development for Irrigation and Water Resources Management*. Technical Assistance Report, Asian Development Bank.
- ADB (2006). *ADB Basic Statistics 2006*. Accessed online from <http://www.adb.org/Statistics/pdf/Basic-Statistics-2006-Web.pdf>.
- Ali, K. and De Boer, D. (2007). Spatial patterns and variation of suspended sediment yield in the upper Indus River basin, northern Pakistan. *Journal of Hydrology* 334, 368-387.
- Alim, A. K. (2006). *Sustainability of Water Resources in Afghanistan, country paper in TASAE*.
- Chavoshian, S.A., Takeuchi, K. and Funada, S. (2005). *An overview of transboundary and shared water resources management in Iran: Technical challenges and solutions*. In: Proceedings, International Symposium on Role of Water Sciences in Transboundary River Basin Management, held at Ubon Ratchathani, Thailand, 10-12 March 2005. United Nations University, Asian Institute of Technology, and Thammasat University.
- CIA (2007). *The World's Fact Book 2007*. United States Central Intelligence Agency. Accessed online from: <https://www.cia.gov/library/publications/the-world-factbook/>
- Crow, B. and Singh, N. (2000). Impediments and Innovation in International Rivers: The Waters of South Asia. *World Development*, 28 (11). 1907-1925.
- Esty, D. C., Levy, M., Srebotnjak, T. and de Sherbinin, A. (2005). *Environmental Sustainability Index: Benchmarking National Environmental Stewardship*. Yale Center for Environmental Law and Policy, New Haven, Connecticut, USA
- Falkenmark, M. and Widstrand, C. (1992). Population and water resources: A delicate balance. *Population Bulletin*, 47 (3). Population Reference Bureau, Washington D.C
- FAO (2007). *FAO's Information System on Water and Agriculture (AQUASTAT)*. Accessed online from <http://www.fao.org/AG/AGL/aglw/aquastat/main/index.stm>.
- Favre, R. and Kamal, G. (2004). *Watershed Atlas of Afghanistan: First edition-working document for planners*. Kabul, Afghanistan.
- IUCN Pakistan (2007). *Pakistan Water Situational Analysis*. Accessed online from [www.waterinfo.net.pk/pwsa.htm](http://www.waterinfo.net.pk/pwsa.htm)
- Khan, A., Ullah, M. and Muhammad, S. (2000). Water availability and some macro level issues related to water resources planning and management in the Indus basin irrigation system in Pakistan. Accessed online from <http://www.inbo-news.org/ag2000/pakistan.htm>.
- MDG (2005). *Millennium Development Goals Islamic Republic of Afghanistan Country Report 2005: Vision 2020*. Accessed online from <http://www.ands.gov.af/mdgsgroups.asp>

- Qureshi, A. (2002). *Water Resources Management in Afghanistan: The issues and options*. IWMI Working Paper 49, Pakistan Country Series No. 14, International Water Management Institute, Battaramulla, Sri Lanka.
- Rahman, M.M. (2005). *Integrated Water Resources Management in the Ganges Basin: Constraints and opportunities*. Department of Civil and Environment Engineering, Laboratory of Water Resources, Helsinki University of Technology, Finland.
- Srivastava, L. and Misra, N. (2007). Promoting regional energy co-operation in South Asia. *Energy Policy* 35, 3360-3368.
- UN (2006). *World Economic and Social Survey 2006: Diverging growth and development*. United Nations, New York.
- UNDP (2006). *Human Development Report 2006*. United Nations Development Programme, New York.
- UNEP-RRC.AP (2001). *Nepal: The State of Environment 2001*. Regional Resource Center for Asia and the Pacific, United Nations Environment Programme. Accessed online from: [http://www.rrcap.unep.org/reports/soe/nepal/soe.nepal.cfm](http://www.rrcap.unep.org/reports/soe/nepal/soe.nepal/soe.nepal.cfm)
- UNEP-PKU (2008). *Methodological Guidelines for Vulnerability Assessment of Freshwater Resources to Environmental Change*. Bangkok, UNEP and PKU. (In Press).
- van Beek, E. and Meijer, K. (2006). *Integrated Water Resources Management for the Sistan Closed Inland Delta, Iran. Main Report*. Version 1.3. Delft Hydraulics and Water Research Institute, Iran, April 2006.
- VOA (2007). "Damage from Bangladesh Cyclone Much Worse Than First Thought," VOA News, November 4, 2007.
- Whitney, J.W. (2006). *Geology, Water and Wind in the Lower Helmand Basin, Southern Afghanistan: Scientific Investigations Report 2006-5182*, US Geological Survey, Reston, Virginia, USA.
- World Bank (2006). *World Development Indicators 2006*. World Bank. Retrieved in January 2007 from <http://devdata.worldbank.org/wdi2006/contents/cover.htm>.
- World Resources Institute (WRI), in collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank (2005). *World Resources 2005: The Wealth of the Poor—Managing Ecosystems to Fight Poverty*. Water Resources Institute, Washington, D.C.
- UNESCO–WWAP (2006). *The United Nations World Water Development 2: Water a shared responsibility*. UNESCO Publishing, Barcelona.

# Glossary

## A-G

**Access:** Access refers to the rights or entitlements of an individual or a group to obtain or make use of water resources or the services that water provide for different uses.

**Actual renewable water resources:** The maximum theoretical amount of water actually available for use in a basin or country, including both internal renewable resources and external renewable resources. This takes into consideration the quantity of water reserved for upstream and downstream basins or countries through formal or informal agreements or treaties, and possible reduction of external water due to upstream water withdrawals.

**Adaptation:** A process of societies and ecosystems dealing with water stresses, and referring to the capacity of societies and ecosystems to handle their water resources vulnerability issues.

**Conflict management capacity parameter:** A parameter demonstrating the capacity of river basin management system to deal with transboundary conflicts. A good management system can be assessed by its effectiveness in institutional arrangements, policy formulations, communication mechanisms, and implementation efficiency.

**Domestic uses of water:** Drinking water plus water withdrawn for homes, municipalities, commercial establishments, and public services (e.g. hospitals).

**Ecological health:** The ecosystem health of a river basin. Low wastewater discharges and high vegetation cover on the land surface generally reflect a good ecological health of a river basin.

**Ecological water use:** All ecosystems require water to maintain their ecological processes and associated communities of plants and animals. Environmental water requirements describe water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk.

**Ecosystem deterioration parameter:** The land ratio without vegetation coverage (forest area and wetlands) used to present the contribution of an ecosystem's deterioration to the vulnerability of its water resources.

**Freshwater:** The portion of water resources suitable for use by humans and most terrestrial vegetation and wildlife. It is renewable from rainfall, in the form of runoff to surface water, groundwater and water retention by soil. In this report 'water' and 'freshwater' are used synonymously.

**Groundwater recharge:** The total volume of water entering aquifers within a basin or country's borders from endogenous precipitation and surface water flows.



## I-P

**Improved sanitation:** Facilities that hygienically separate human excreta from human, animal and insect contact, and include sewers and septic tanks, pour-flush latrine and simple pits, etc.

**Improved sanitation accessibility parameter:** A parameter typically used to measure the capacity of a management system capacity to deal with the livelihood needs of inhabitants, and refers to the percentage of population with sustainable access to improved sanitation facilities.

**Improved water supply/source:** These sources include piped water, public taps, boreholes or pumps, protected wells, or protected springs or rainwater.

**Indicator:** A parameter, or value derived from parameters, which points to, or provides information about, the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value.

**Industrial uses of water:** Includes cooling machinery and equipment, production of energy, cleaning and washing goods produced as ingredients in manufactured items and as a solvent.

**Internal renewable water resources:** The average annual flow of rivers, and the recharge of groundwater (aquifers), generated from precipitation occurring within a basin or country's borders.

**Irrigation water use:** The primary water use in the agricultural sector.

**Management capacity:** The capacity of a management system to cope with mismatches between water resources demands and water supply, by improving water use efficiency (measured as GDP produced per unit of water use) and human health conditions (measured by access to adequate sanitation facilities).

**Policy:** A plan of action to guide decisions and actions. The term may apply to governments, private sector organizations and groups, and individuals. The policy process includes identification of different alternatives (e.g., programs; spending priorities), and choosing among them on the basis of their potential impacts. Overall, policies can be understood as political, management, financial, and administrative mechanisms arranged to reach explicit goals. Policy alignment is the process by which consistency is achieved across a number of policies that have the potential of interfering with each other.

## S-V

**Safe drinking water accessibility parameter:** Designed to present the state of social adaptation of freshwater use (i.e., how freshwater resources development facilities address the fundamental livelihood needs of the population). This is an integrated parameter reflecting a comprehensive impact of the coping capacity of all stakeholders.

**Sectoral water withdrawals:** The proportion of water resources used for one of three major purposes: agriculture, industry, and domestic uses. All water withdrawals are allocated to one of these three categories.

**State:** The state or status of a water system, as described by adequate structural (e.g., river morphology), physical (e.g., temperature), chemical (e.g., concentration of phosphorus and nitrogen), and biological (e.g., abundance of phytoplankton or fish) indicators.

**Surface water:** Water on the Earth's surface, such as in streams, rivers, lakes, or reservoirs. It includes the average annual flow of rivers generated from endogenous precipitation (precipitation occurring within a basin or country's borders). Surface water resources are usually computed by measuring or assessing the total river flow occurring in a country or a river basin on an annual basis.

**Total water resources:** The total freshwater available in a river basin to maintain healthy ecosystems and socioeconomic development.

**Transboundary management:** The framework for managing water resources across a basin and beyond political borders, including management for resolving water use conflicts.

**Vulnerability:** The characteristics of a water resource system's weaknesses and flaws that make the system difficult to function in the face of socioeconomic and environmental changes.

**Vulnerability assessment:** An investigation and analytical process to evaluate a system's sensibility to potential threats, and to identify key challenges to the system in reducing or mitigating the risks of negative consequences from adversarial actions.

## W

**Water resources management:** Planned development, distribution and use of water resources, in accordance with predetermined objectives, and with respect to both the quantity and quality of these resources

**Water pollution parameter:** A parameter for measuring the ecological health of the river basin, defined as the ratio between the untreated wastewater discharges and the total water resources in a river basin.

**Water quality:** A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

**Water scarcity:** A relative concept, describing the relationship between water demands and water availability. The demand may vary considerably between different countries, and different regions, within a given country or basin, depending on sectoral water uses. Thus, a country or basin with high industrial water demand, or which depend on large-scale irrigation, will be more likely to exhibit more water scarcity than a country or a basin with similar climatic conditions, but which lack of such demands.

**Water scarcity parameter:** The richness of the water resources in a given basin will dictate the degree to which the water demands of the population can be met. Thus, the scarcity of water resources can be expressed as the per capita water resources of a region (country or basin), compared to the generally accepted minimum level of annual per capita water resource requirement ( $1,700 \text{ m}^3 \cdot \text{person}^{-1}$ ).

**Water stress parameter:** Water stress causes deterioration of freshwater resources, in terms of quantity (over-exploitation of aquifers; dry rivers; etc.) and quality (eutrophication; organic matter pollution; saline intrusion; etc.). The water stress parameter refers to the ratio of total water withdrawals to the total water resources available in a river basin.

**Water use:** The total quantity of water distributed to all different water users (including losses during its transportation to its point of usage). Based on the intended purposes, water use can be divided into productive (agricultural or industrial) water consumption; domestic water consumption; and ecological or environmental water consumption. Water use refers to human interactions with, and influence on, the natural hydrologic cycle, and includes elements such as water withdrawals from surface and groundwater sources; water delivery to homes and businesses; consumptive water uses; water released from wastewater treatment plants; water returned to the environment; and in-stream water uses (e.g., water for producing hydroelectric power).

**Water use efficiency:** The GDP produced from the use of one cubic meter of water.

**Water use inefficiency parameter:** A parameter representing the inefficiency of a water resources management system, as demonstrated by the gap between a basin or country's water use efficiency and the average water use of selected countries as a standard of comparison. In this report, the water use inefficiency parameter is presented as the gap between the GDP value from one cubic metre of water use in a basin, compared to the average GDP value produced from one cubic metre of water use in the world's five top food producers (Brazil; China; France; Mexico; USA).

**Water variation parameter:** The variation of the water resource, expressed as the coefficient of variation (CV) of annual precipitation over the last 50 years.

**Water withdrawals:** The gross quantity of water extracted from any source, either permanently or temporarily, for a given use. It can be either diverted to a distribution network or used directly. The term includes consumptive water uses, conveyance losses, and return flows. The total water withdrawal is the sum of the estimated water uses by the agricultural, domestic and industrial sectors.