WORLD WATER RESOURCES AND REGIONAL VULNERABILITY: IMPACT OF FUTURE CHANGES

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Foreword

For the past decade much attention has been placed on assessing the impacts of climate change on the world's water resources. These assessments have focused on the hydrologic impacts or the supply side. IIASA's Water Resources Project has played a role in these international activities. This study takes a broader look: it analyzes the combined impact of population growth, economic development, and climate change on regional water resources vulnerability. Vulnerability is assessed by examining a region's demand–supply balance. The work does not perform a static analysis, but forecasts water supply and demand on the basis of various scenarios for the time horizon to 2025 when most of the global changes involved may have a significant impact.

This report is the first presentation of results from the Water Resources Project's current focus on climate change, water resources, and socioeconomic impacts. Not only is the global assessment valuable in itself, but the regional analysis has identified areas of acute vulnerability which require further in-depth study. Future efforts should focus on reducing the spatial (river basins) and temporal (crucial periods within the hydrologic year) scales of the analyses, as well as on addressing water-quality issues and socioeconomic/water resource feedback mechanisms.

This study should be of value to water resources analysts and economic development policy makers as well as scholars and researchers in the field. It clearly shows that water vulnerability will be one of the most urgent problems of the coming decades and must be explicitly considered in any analysis of global change or sustainable development.

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Acknowledgments

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Any remaining errors of omission or of commission are the responsibility of the author.

Chapter 1

Introduction

1.1 Background

Among all the natural resources available to mankind, water holds a prominent place, particularly because of its importance for human sustenance. An essential element for the sustenance of life on earth, it is equally important for social and economic activities so necessary for the preservation of modern society. Its importance to society can be described as follows:

- Water is essential for human life.
- It is an important input for the production of crops, and for the supply of timber as a source of energy, as well as meeting other economic needs.
- It is used to extract other natural resources (such as crude oil); it is a key ingredient in the manufacturing process of some products, besides being used as a coolant in other industrial processes.
- It is used for the disposal of human waste, as well as industrial waste in most countries.
- Water contained in water bodies, such as lakes or rivers, leads to an improvement in the aesthetic beauty of a region, which becomes a major attraction in terms of leisure activities, particularly for those people living in large metropolitan areas.
- Numerous species live in water, some of which become a major source of food for human beings.
- Water is essential for the ecosystem. In fact, according to Brouwer and Falkenmark (1989, p. 75), "the hydrological cycle of evaporation, precipitation and runoff plays a central role in the biogeochemical cycles of, among others, carbon, nitrogen and phosphorus. Disturbances of water chemistry and/or water flows caused by pollutants or by intervention

Table 1.1. World annual water withdrawal and consumption, by continents and type of use, for selected years.

	Total withdrawal (km^3)			Change	Total consumption (km^3)		
	1900	1950	1980	1900–1980	1900	1950	1980
Continent							
Africa	41.8	56.2	168.0	126.2	34.0	44.6	128.0
Asia	414.0	859.0	1,910.0	1,496.0	323.0	654.0	1,380.0
Australia & Oceania	1.6	10.4	29.4	27.8	0.6	5.1	14.6
Europe	37.5	93.8	435.0	397.5	17.6	38.4	127.0
North America	69.4	286.0	663.0	593.6	29.3	107.0	224.0
South America	15.1	59.4	111.0	95.9	11.3	44.7	71.0
Total World[a]	579.4	1,360.0	3,320.0	2,740.6	415.8	894.0	1,950.0
Type of use							
Agriculture	525.0	1,130.0	2,290.0	1,765.0	409.0	859.0	1,730.0
Industry	27.2	178.0	710.0	672.8	3.5	14.5	61.9
Municipal	16.1	52.0	200.0	183.9	4.0	14.0	41.1
Reservoir	0.3	6.5	120.0	119.7	0.3	6.5	120.0
Total selected uses[a]	578.6	1,370.0	3,320.0	2,741.4	416.8	894.0	1,950.0

[a]Figures do not always add up to the total world.
Source: Shiklomanov (1990a and 1990b).

with soil and vegetation, therefore, tend to produce many secondary effects on flora, fauna, and human health."

Water availability, as well as the amount of water used, is a significant factor for social (and economic) activities. According to Stanhill (1982, p. 459),

> The variation in the amount of water supplied to each person is enormous, the value depending partly on objective factors such as climate, water sources and level of technology and partly on subjective factors such as lifestyle and societal attitude.

The lower limit to this usage is set by human metabolic requirements.

With a changing global environment, the water supply–demand balance would come under constant pressure. Some of these trends are already under way. In *Table 1.1*, the world's water use (both withdrawal and consumption) is shown from 1900 to 1980, both by continent and by type of use. Water withdrawal and consumption during the 20th century (1900 to 1980) have increased by more than fourfold. Although larger absolute increases in use were noted for Asian and the North American countries, larger relative increases in water use were observed for Australia (including Oceania), Europe, and North America (*Figure 1.1*). Consistently, growth in water use

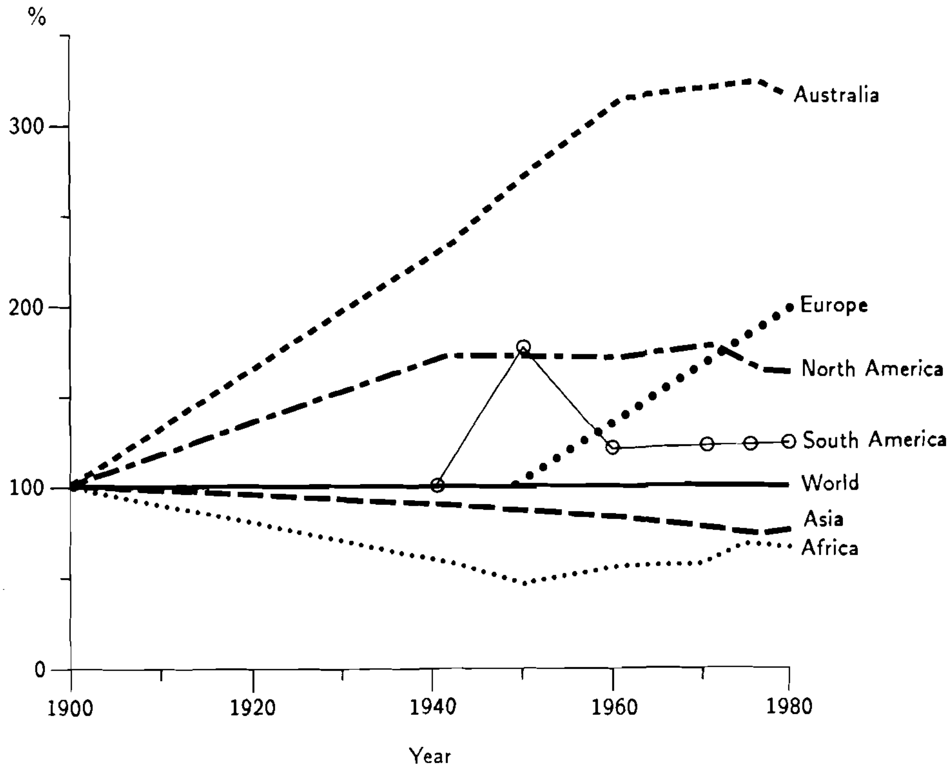


Figure 1.1. Relative increase in water use levels by continents, 1900–1980, in percent of world consumption.

levels in Asia and Africa have been below the world average levels. Furthermore, in Australia, North America, and South America (continents with a higher than average growth in water use), there was a slowdown in water consumption in 1980.

Relative to the global increase in water use, industrial and municipal water uses have increased at a more rapid rate. The only countries where the increase has been slower than in the world as a whole are in Africa. Most of these increases are a reflection of trends in population growth and increasing industrial activity.

1.2 Problematic Situation

Population and industrial activity in various parts of the world continue to grow at an alarming rate. Although, as shown in *Table 1.2*, water use in 1980 was only 8 percent of the total, and the highest use/supply ratio observed, on a continent basis, was 18 percent (in Asia), the picture may be

Table 1.2. Relative freshwater availability and use, in 1980, by continents.

Continents	Water supply Total (km^3)	Water supply Per capita (m^3)	Water withdrawal Total (km^3)	Water withdrawal Per capita (m^3)	Per capita use/supply ratio (%)
Africa	4,184	4,905	168	197	4.0
Asia	10,485	2,954	1,910	538	18.2[a]
Australia & Oceania	2,011	67,033	29	967	1.4
Europe & USSR	6,705	8,157	435	529	6.5[a]
North America	6,945	23,227	663	2,217	9.6
South America	10,377	18,664	111	200	1.1
World	40,707	6,647	3,316	543	8.2

[a]Figures should be interpreted with caution since the former USSR extends over both Europe and Asia.

completely different if we view the world not as a homogeneous entity with a ubiquitous distribution of water resources. In fact, given seasonal variations, fluctuations in rainfall from year to year, and location-specific water supply–availability levels, one can arrive at a totally different conclusion. In many countries, population growth has been rapid, and the level of industrialization has also grown at a very fast pace. These changes have both direct and indirect strains on water resources. An increasing population requires water not only for domestic use, but also for sewage disposal. The latter, if not properly handled, may raise serious water-quality problems. Indirectly, more water may be needed for food production and for energy (hydropower as well as thermal power) generation. Industrial production, similarly, would require some water for direct use, but would have an indirect effect on water quality through air and water pollution.

Climate changes may also threaten the sustainable development of many of these regions in a variety of ways:

- A warmer climate may lead to a decrease in the availability of water.
- The year-to-year variability in water may increase, significantly increasing the chances of disastrous events.
- The level of water use and its composition by type of use may be altered significantly. This may lead to a major change in the level of water consumption.
- Climatic changes could play havoc with a country's food supply. The region may have three options to choose from: (1) the region may improve productivity of agricultural land; (2) it may irrigate more land; or (3) it may depend upon other countries to meet its requirements. Each option has implications for the region and its water use.

However, climate change may be only one of the global changes that would affect the sustainable development of many regions. Regional acidification from industrial activity, water pollution (indirectly through air pollution and directly through discharge of pollutants from industrial activity and sewage disposal), desertification, and soil erosion may also be major threats to water resources. The carrying capacity of the biosphere may be affected under a changing climate, and limits may be reached in terms of sustainable level of development.

Major questions need to be answered. What would be the likely impact of current population trends and increased industrial activity in various regions of the world on water use levels? How constraining would water resources become under these conditions to the region's sustainable development? Does climate change and its impact on water availability pose a major threat to some regions? Would the stress on water resources increase under a combined effect of population growth, increased industrial activity, and climate change?

1.3 Objectives and Scope of the Study

This study was designed to provide a *preliminary* investigation of the global water resources with a regional disaggregation. In particular, the study was designed to meet the following objectives:

- Examine water availability in different regions of the world, and compare it with water use levels by type of use.
- Estimate the water use levels, by type of use, under different population and industrial development scenarios.
- Examine the water use–availability balance in various regions under a climate change scenario.
- Draw implications of the results in terms of vulnerability of various regions to water resources and water management.

The study was carried out using *secondary* data collected by various international agencies. These data, except for minor adjustments, were accepted at face value. Because of time and budget restrictions, no attempt was made to collect primary data or to seek advice from water resources managers and policy makers in different countries. Use of these data, however, is not without a penalty. Secondary data for countrywide jurisdiction, pertaining to annual time spans, may conceal significant spatial and temporal differences for a country. This should be kept in mind while interpreting the results of the study.

1.4 Organization of the Report

In Chapter 2, we present a conceptual model of various linkages in socioeconomic–ecological subsystems, leading to the problem of regional vulnerability. A review of various factors affecting water use levels, along with data sources from different regions of the world, is presented in Chapter 3.

Current water availability and water use levels are discussed in Chapter 4. In Chapter 5 a simulation of the effect of population growth, industrial development, and climate change is presented, which is followed, in Chapter 6, by a discussion on vulnerable regions in the world. In this chapter, conclusions and implications for water management are also treated.

Chapter 2

Conceptual Model for the Study

Water resources have been the subject of a significant number of studies. However, when these studies are viewed from their disciplinary focus, one finds that most of them have been carried out in the field of hydrology, with a few pertaining to project planning and appraisal. The socioeconomic aspects of water resources planning and management have not been the focus of many studies.

The primary purpose of this chapter is twofold: (1) to review various studies that have examined issues related to water resources availability in the world; (2) to develop a conceptual framework for the examination of vulnerability of a region to water availability, first based on a review of other studies and then focusing on the one used in this study.

Four ways of measuring a country's vulnerability to water resources are presented: demand–supply balance, water dependency, water resource constraint, and water deficit. This review suggests that none of these measures are entirely satisfactory on a theoretical basis. Conceptually, the vulnerability involves supply of water, its seasonal distribution, water quality, and water use/demand levels. However, the availability of data, particularly secondary data, is a serious obstacle to the application of such a measure. This study uses a combined availability–use criterion.

2.1 Review of Previous Studies

Various studies that have been devoted to the subject of water resources can be divided into four broad categories:

1. Study of global water resources at a disaggregated level with particular reference to water supply.[1]
2. Study of regional water resources at a disaggregated level.
3. Study of phenomenon/activity in which water may be a key input.
4. Descriptive studies of water resources.

The first type is the most common, whereas those studies falling in the second category are relatively few. Water resources have also been discussed in connection with various water use sectors, particularly agriculture; these studies are classified in the third category. The descriptive studies of water availability and use have been prepared by many international organizations, commissions, and other agencies. A thorough and comprehensive review of all the studies dealing with global water resources is beyond the scope of this report. Only selected, but major, studies dealing with this subject are reviewed in this section.

2.1.1 Global-disaggregated studies

As noted above, of all the studies reviewed in this report, those falling into the first category are the most common type. One of the first reviews of world water balance was made by Baumgartner and Reichel (1975). These results were reexamined in a Soviet study on global water resources, which showed that the earlier study had underestimated the runoff in Africa and North America by 32 percent and 40 percent, respectively (Shiklomanov, 1990a, p. 35). Another comprehensive study of global water resources was carried out by L'vovich (1979). Water resources in different countries of the world were estimated in this study. Estimates for both surface water and groundwater were made. Total water resources of the world were estimated at 31,000 cubic kilometers (km^3). A study of the adequacy of water was carried out in terms of per capita, and on this basis the USSR was found to be richer in water resources than the globe as a whole.

Using information on water runoff data collected by L'vovich (1979) and by Baumgartner and Reichel (1975), the report prepared by the Council on Environmental Quality (1980) in the United States estimated the water supply in various countries in the world. These data were supplemented by water use estimates for various purposes in different countries of the world. Projections were also made to the year 2000. Water availability on a per capita basis was compared with projections of water use. The study concluded that "because of the regional and temporal nature of the water resources, water shortages even before 2000 will probably be more frequent and more severe than those experienced today" (p. 158).

Table 2.1. Estimates of world freshwater resources, by continent.

Continent	Quantity (km^3) surface water and groundwater, 1975[a]	Streamflow (km^3/year), 1987[b]	Freshwater (km^3/year), 1990[c]
Europe & USSR	6,475	7,950	6,705
Asia	9,865	9,670	10,485
Africa	4,225	4,570	4,184
North America	5,415	8,200 (North and Central America)	6,945 (North and Central America)
Central America	545		
South America	10,380	11,760	10,377
Australia & New Zealand	731	348	2,011
World excl. Antarctica	37,636	42,538[d]	40,673[d]

[a]Based on L'vovich (1979), except for South America which is from Shiklomanov (personal communications).
[b]Based on Shiklomanov (1990b).
[c]Based on World Resources Institute (1990).
[d]Figures do not add up to world total.

Shiklomanov and Markova (1987) and Shiklomanov (1990b) have updated the estimates of water availability in different countries of the world, as well as compared them with those by L'vovich and by Baumgartner and Reichel. An overview of the estimates from various studies of water supply is noted in *Table 2.1*, along with recent estimates provided by the World Resources Institute (1990).[2] The study by Shiklomanov (1990b) also compared water demand for agriculture, industry, and municipal supply, continent by continent, based on data in an earlier study (Shiklomanov, 1990a). Forecasts were made for the year 2000. The study concluded that more investigations on hydrological seasonal variations and on the impact of human activities on various regions are needed.

2.1.2 Studies of regional water resources

Although several studies deal with regional (national) water resources at a disaggregate level, two are particularly noteworthy. Brouwer and Falkenmark (1989) have analyzed water resources in European countries. They compared water availability and its demand in various European countries. Elements of climate change were also examined. Countries were grouped under one of the following categories: water surplus, water management problems, water stress, and absolute water scarcity. The study concluded that "the issue of water availability is already important in some parts of Europe.... This issue could become even more important, as demonstrated by the analysis of changes in hydrological shifts due to a change in climate" (p. 96).

A regional analysis of US water resources needs and availability has been carried out by the US Army Engineer Institute for Water Resources (1990). Various regions of the USA were examined for trends in water demand as well as in water supply. Of particular interest is the comparison of past forecasts of water use (p. 17). The water withdrawal for the year 2000 was forecast to range between 330 and 1,450 billion gallons of water per day (equivalent to between 1,249 and 5,488 million m^3). This rather large range reflects both the complexity in forecasting use and the large degree of uncertainty in predicting such phenomena.

Falkenmark (1989) has also examined the situation of water scarcity and food production in Africa. In this study countries were classified by availability of water and their respective population.

2.1.3 Indirect study of global water resources

Global water resources have also been studied by examining the primary use sectors. For example, Harris (1990) in reviewing world agriculture has examined current trends in irrigated agriculture, and has made projections for the future (*Table 2.2*). In 1982, about 213 million hectares of land were irrigated in the world. Assuming that 1,435 million hectares of land are arable (a 1975 estimate), this would suggest that about 15 percent of the world's arable land is irrigated. By the year 2050, the irrigated area in the world has been projected to be 461 million hectares, or almost one-third of the total arable land. Although the Harris study presented estimates of water availability in various continents, these estimates were based on earlier studies. The study presented estimates of irrigation and other water demands and compared them with estimates of availability. A major observation in this report regarding regional water resources can be stated as follows:

> In the United States, 46 percent of cropland is in the watershort west.... The Soviet Union is also experiencing significant overdraft in major food producing regions. China and India are already close to the limit of available water supply.... In arid areas of Africa, expansion of water supply for agriculture is falling well below population growth rates, contributing to a decline in per capita food supply. (p. 164)

In other words, several regions of the world are already facing water shortages, or soon would, under the trend of increasing population.

Table 2.2. World irrigated area, observed and projected.

Year	Area in million hectares World	Developed market economies	Developing market economies	Former centrally planned economies
1950	94	–	–	–
1961–1965	149	24	75	50
1974–1976	188	32	93	63
1982	213	38	104	71
% Increase per annum 1975–1982	1.8	2.3	1.8	1.7
2000	297	–	–	–
2010	356	–	–	–
2050	461	–	–	–
% Increase by 2050 over 1982	116	–	–	–

Source: Harris (1990).

2.1.4 Descriptive studies of global water resources

Descriptive studies of global water resources could be broadly divided into two types: (1) prognostic discussion of problems; (2) description and/or interpretation of statistics. For example, Stanhill (1982) has regarded "the current view of the world water problem as one of shortage rather than surplus developed slowly during the last two centuries" (p. 453). However, this view has only been formed regarding regions where such problems have already occurred.

The United Nations (1989) in a report on water management issues in European countries has provided statistics on selected non-European countries both in terms of water use and in terms of water supply. However, the coverage of countries was not comprehensive.

A comprehensive set of statistics on world water resources is reported yearly by the World Resources Institute in its annual publication. In total, data on 146 countries in the 1970s and 1980s are provided on freshwater and other physical and economic variables. In addition to the data, a feature article in each annual examines problems and issues related to water resources. Many of these reports, however, tend to focus on current issues.

2.1.5 Summary

The study of global water resources has not been a very popular subject. This is not to suggest that internal country-based studies of water resources have not been carried out. However, with the exception of Brouwer and Falkenmark (1989), many of these studies have concentrated on hydrologic aspects of water resources; very little emphasis has been placed on water use or on the impact of climate changes on both supply and use of water in different countries of the world.

2.2 Identifying a Region's Vulnerability to Water Resources

2.2.1 Concept of regional vulnerability

A geographic region may become vulnerable to changes in water resources in a variety of ways. Before discussing these, let us define the term "vulnerability." According to *Webster's Dictionary*, vulnerable means "open to attack or damage." This meaning of the word is extended in this report to a region. A region becomes vulnerable to a certain natural resource's availability if it cannot pursue its accepted policy goals at the desired level. Thus, the vulnerability[3] of a region due to water resources is interpreted as the inability of the region to sustain economic and social activity in commensuration with the stated goals of socioeconomic policy.

2.2.2 Contributors to regional vulnerability to water resources

Four aspects of water resources are important in an examination of a region's vulnerability: water quantity, intertemporal distribution, water quality, and water use/requirements. The first and the second aspects are directly related to water supply, whereas the third aspect is indirectly related to supply. In fact, one could describe the supply of water as a three-dimensional concept: its annual level, distribution within the year, and its quality. These three factors interact with each other, as shown in *Figure 2.1*, to make a region vulnerable to water resources. The origins of this vulnerability, however, may lie in various socioeconomic–physical characteristics. Three of these characteristics are identified in the figure: population growth, change in the economic development of the region, and climate variability. Although population growth coupled with economic activity may have some impact on the climate change, it is not of sufficient interest to this study.

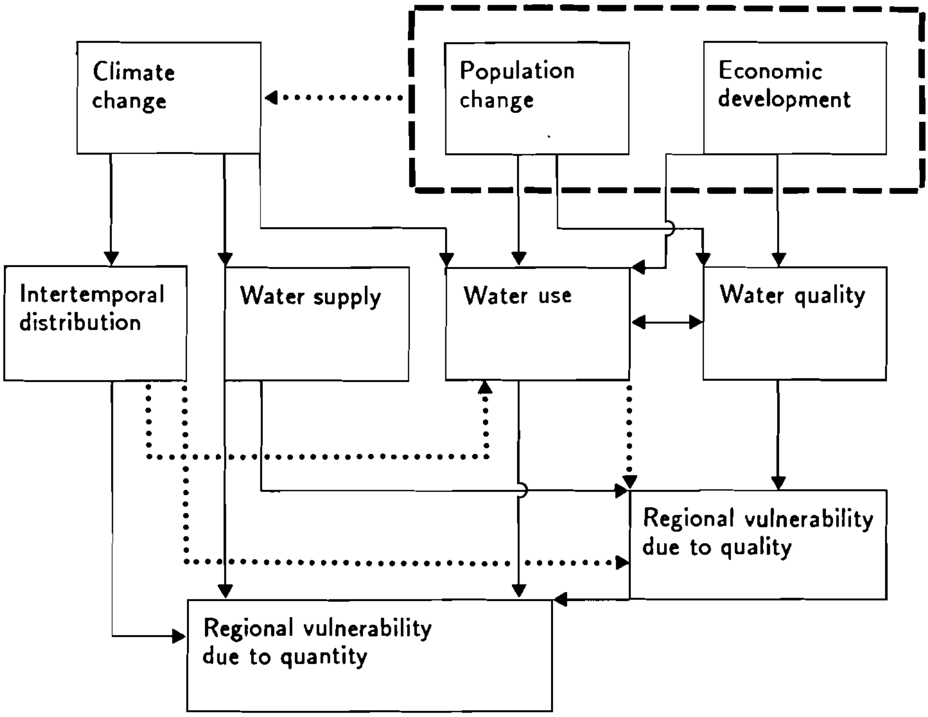


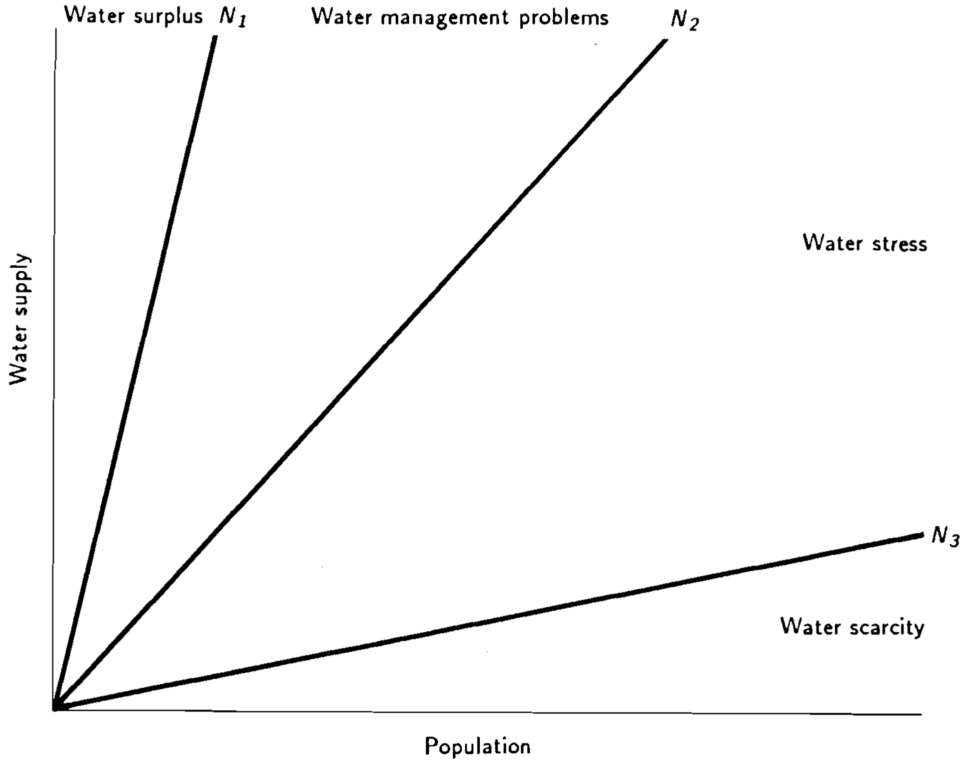
Figure 2.1. Interrelationships among water supply and use leading to regional vulnerability. (The dotted lines show a relatively weaker effect.)

A major source of a region's vulnerability is generated through water use levels and the quality of water discharged into the river streams. If the quality of this water is poor, the region would become more vulnerable not only to changes in quantity, but also to the deterioration of water quality.

In any measurement of regional vulnerability, one must take into account the four aspects of water resources noted above. However, in an empirical estimation, such an approach may present problems, unless primary data are collected.

2.3 Past Approaches to Measurement of Regional Vulnerability

Although the true vulnerability of a region could come through all four characteristics – intertemporal distribution, annual availability, water use level, and water quality – in most studies the measurement has been limited to water quantity on an annual basis. Vulnerability of a region can be



N = Number of people per unit of water.

Figure 2.2. Identification of vulnerability of a region using the notion of dependency on water criterion. Source: Adapted from Brouwer and Falkenmark (1989).

expressed in one of four alternative ways: water dependency, water resource constraints, water deficit, and demand–supply balance.

2.3.1 Water dependency criterion

This approach to measurement has been suggested by Brouwer and Falkenmark (1989). In this approach, as shown in *Figure 2.2*, regions become more vulnerable as the number of inhabitants per unit (quantity) of water increases. Brouwer and Falkenmark (1989) divided various regions into four categories:

- Water surplus: less than 100 persons per million m^3 of water.

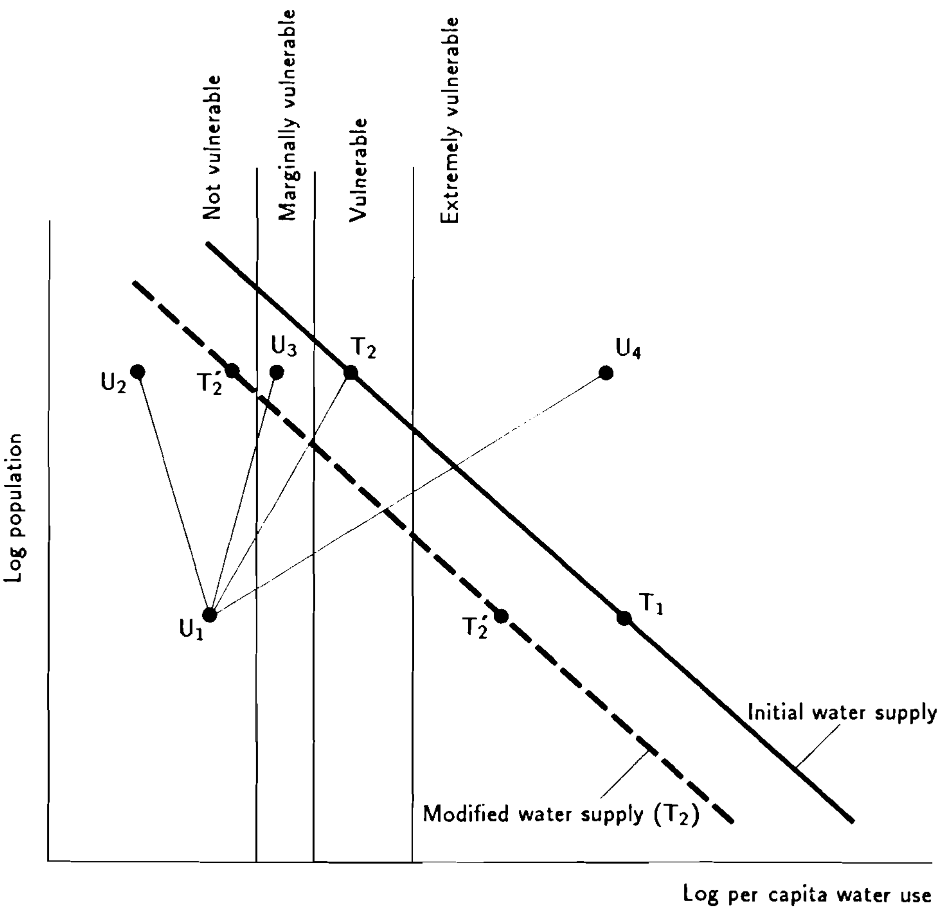


Figure 2.3. Identification of vulnerability of a region using the water availability as a constraint criterion. Source: Adapted from Shaw *et al.* (1991).

- Water management problems: 101 to 500 persons per million m^3 of water.
- Water stress: 501 to 1,000 persons per million m^3 of water.
- Water scarcity: more than 1,000 persons per million m^3 of water.

Using the connotation of vulnerability, these categories are labeled as not vulnerable, marginally vulnerable, vulnerable, and extremely vulnerable.

2.3.2 Water resources constraint criterion

This type of approach has been used by Shaw *et al.* (1991), and is shown in *Figure 2.3.* The population and per capita use of water are related in a linear

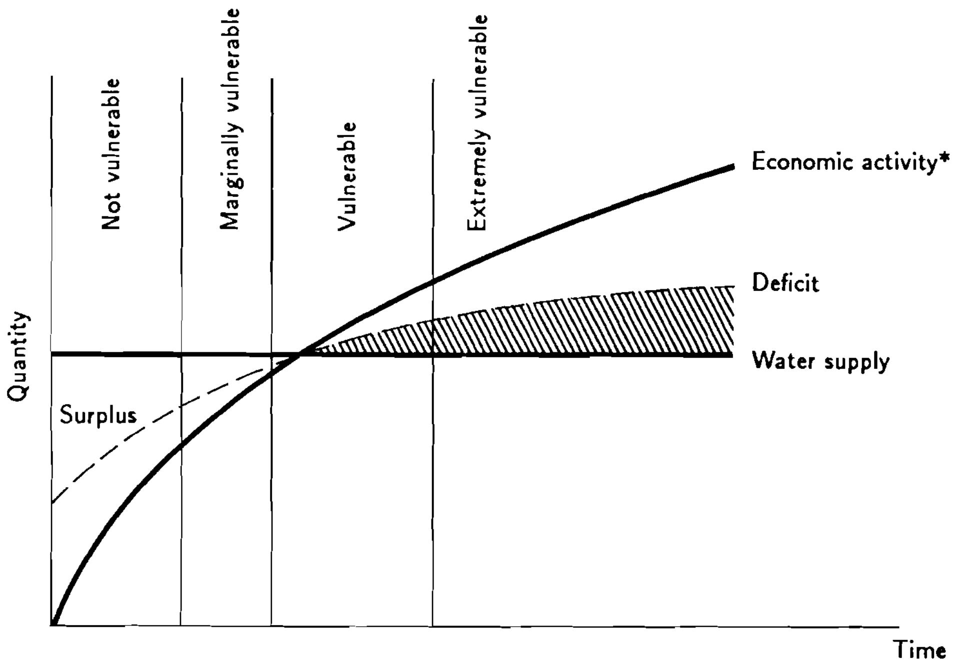


Figure 2.4. Identification of regional vulnerability using the water deficit criterion. Source: Shuval (1987).

fashion (if both are measured in logarithmic terms). For time t, this value is shown by point T_1, in *Figure 2.3.* The water use for a given time period (U_1) lies to the left of this line. At this point, the region is not vulnerable. However, over time the water supply may change, and that point may lie at T_2 or T_2'. The region would not be vulnerable if its water use was lower than the availability of water (U_2), but the degree of vulnerability increases as this point moves closer to U_4, at which point it becomes extremely vulnerable.

2.3.3 Water deficit criterion

In this criterion, water availability and its use are studied over a period of time. A certain level of water supply is assumed to remain unchanged. As the water use increases, as a direct result of economic activities in the region, the region may change from not vulnerable to extremely vulnerable, using the quantity of water deficit as the criterion (*Figure 2.4*).

Water supply per capita	Water use/capita		
	Low	Medium	High
Low	☆☆☆☆	☆☆☆☆	☆☆☆☆
Medium	☆☆	☆☆☆	☆☆☆☆
High	☆	☆	☆☆

Figure 2.5. Identification of regional vulnerability using the demand–supply balance criterion. Source: Adapted from Brouwer and Falkenmark (1989).

Supply per capita (m^3)	Use–Availability ratio (%)			
	<40	40–60	60–80	>80
<1,000	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆
1,001–2,000	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆
2,001–10,000	☆	☆☆	☆☆☆	☆☆☆☆
>10,000	☆	☆	☆☆	☆☆☆☆

* Water surplus
** Marginally vulnerable
*** Water stress
**** Water scarcity

Figure 2.6. Combined availability–use criterion of vulnerability of a region to water resources.

2.3.4 Demand–Supply balance criterion

In this approach, water supply (availability) and use are compared on a per capita basis. Such an approach has been used by Brouwer and Falkenmark (1989). The degree of vulnerability of a region increases as, for a given supply, its use increases. Details are shown in *Figure 2.5.*

2.4 Joint Availability and Use Level Criterion

Each criterion discussed in Section 2.3 has some limitations in the context of this study. The demand–supply balance criterion is qualitative and its use to identify vulnerability depends upon how homogeneous a study region is. The dependency criterion ignores water use explicitly, although it is implicit in the population of the region. Even then, if different regions do not have similar use levels, this criterion may produce misleading results. The water availability as a constraint criterion is ideal for presentation of results of more than one scenario, but its application to identify vulnerability remains open to interpretation. The water deficit criterion requires continuous time series data, which were not available for this study.

In this study, the criterion used for determining a country's vulnerability to water resources was based on a combination of available supply (*per capita basis*) and its relative utilization. In *Figure 2.6* the column on the left is the criterion of dependence on water. However, this criterion is used in conjunction with the relative utilization of water. A country may have a surplus, for example, if the availability is more than 10,000 m^3 per capita, and its utilization is less than 60 percent of the total. Similar interpretations of the other three categories of vulnerability can be made.

Notes

[1] In this study, the terms "supply" and "availability" are used interchangeably.

[2] Readers should be warned against comparing estimates of one study with another.

[3] In subsequent discussions, a region's vulnerability is used to mean a "region's vulnerability to water resources."

Chapter 3

Study Methodology

In this chapter we describe the study methodology, including sources of data. The chapter is divided into six major sections. In Section 3.1, we discuss various types of water use and how these uses would be altered under selected global changes. Factors that may determine the regional vulnerability to water resources are described in Section 3.2. The geographical scope of the investigation is presented in Section 3.3. In Section 3.4, the method of estimation and the sources of data are described, which is followed by an explanation of the procedure for projecting water use in Section 3.5. In the last section, a description of various study scenarios is provided.

3.1 Major Types of Water Uses

3.1.1 Water use typology

The various uses of water can be broadly divided into two types: withdrawal use and *in-situ* or in-stream use. Under the first type of water use, water is withdrawn from its original source. The quantity withdrawn is commonly called "water intake." Part of this water is lost (or consumed) in the specific use. The remaining quantity is returned to the original source in some form. The amount of water not returned back to the water body is commonly termed the "water consumption."

The second type of water use refers to that use which is associated with activities that do not require the withdrawal of water from its original source. For example, water in rivers or lakes that is used during water-based recreation activities. In this case, water need not be withdrawn from the

Table 3.1. A general structure of typology of water use.

Sector	Withdrawal use	*In-situ* use
Domestic	Residential water use[a]	Recreation Waste assimilation
Agriculture	Irrigation[a] Livestock Other farm uses including dryland farm use	
Industrial	Industrial use[a] Commercial use[a] Thermal electric power generation	Hydroelectric power generation Transportation
Other primary sectors	Mining water use[a] Forest fire fighting	Forestry water use Timber floating
Ecosystem	Support of wildlife	Wildlife habitat wetlands Flora & fauna
Institutional	Apportionment	
Natural	Net evaporation	

[a]Some return flow.

body of water. This type of water use is commonly referred to as "non-consumptive" or *in-situ* use of water.

Various types of withdrawal and *in-situ* uses of water are listed in *Table 3.1.* Major withdrawals of water are made for domestic, agricultural, and industrial purposes. These uses are also partially consumptive in that only part of the water withdrawn is returned back to its original source. However, in some regions, thermal electric power generation and support of wildlife habitats may also be important uses of water. When a water course is shared with other jurisdictions (national or international), a certain amount of water is to be released (or left in the water body). This water use is commonly called "apportionment water use." Part of the water left in the bodies of water (rivers and lakes) is lost to the atmosphere. Withdrawal from natural evaporation is also a significant use, particularly in arid and semi-arid climates.

Various *in-situ* uses of water include recreation, generation of hydroelectric power, and support of the ecosystem. Since water is not withdrawn for these uses, it is almost impossible to estimate the actual quantity of water required.

3.1.2 Concept and scope of water use in the study

The water use in this study was measured as "water withdrawn" from a body of water. Thus, only major withdrawal types of water uses were included in the study. The *in-situ* uses of water were not included partly due to difficulties in their measurement and partly due to specific data needs which could not be fulfilled from available secondary sources.

Of the various withdrawal types of water uses, only three were included in this study: domestic, agricultural, and industrial. The choice was determined primarily by the availability of data.

3.2 Global Changes Affecting Regional Vulnerability due to Water Resources

A region's water resources may become vulnerable as a result of the following changes:

- Decreased water availability (in absolute terms).
- An increased level of water use.
- A combination of decreased water availability and increased water use level.

The availability of water is determined through natural factors – precipitation, percolation, and evaporation resulting in runoff. Factors affecting precipitation and evaporation would eventually affect water availability. Changes in water use levels may result from two major driving forces: change in population and regional policies to achieve a certain level of economic development.

From the above discussion, it is clear that a region's vulnerability to water resources may be determined through three major types of changes: change in population, change in level of economic activity, and global climate change. Each change is discussed below.

3.2.1 Population growth

The growth in the population of a region would have both a direct effect and an indirect effect on the water use level. The direct effect would come through increased domestic water use and the use of bodies of water for waste disposal. Several factors, notably, the urbanization pattern, the degree of adoption of water-conserving technology, and institutional factors governing directly or indirectly the degree of demand management in the region, may

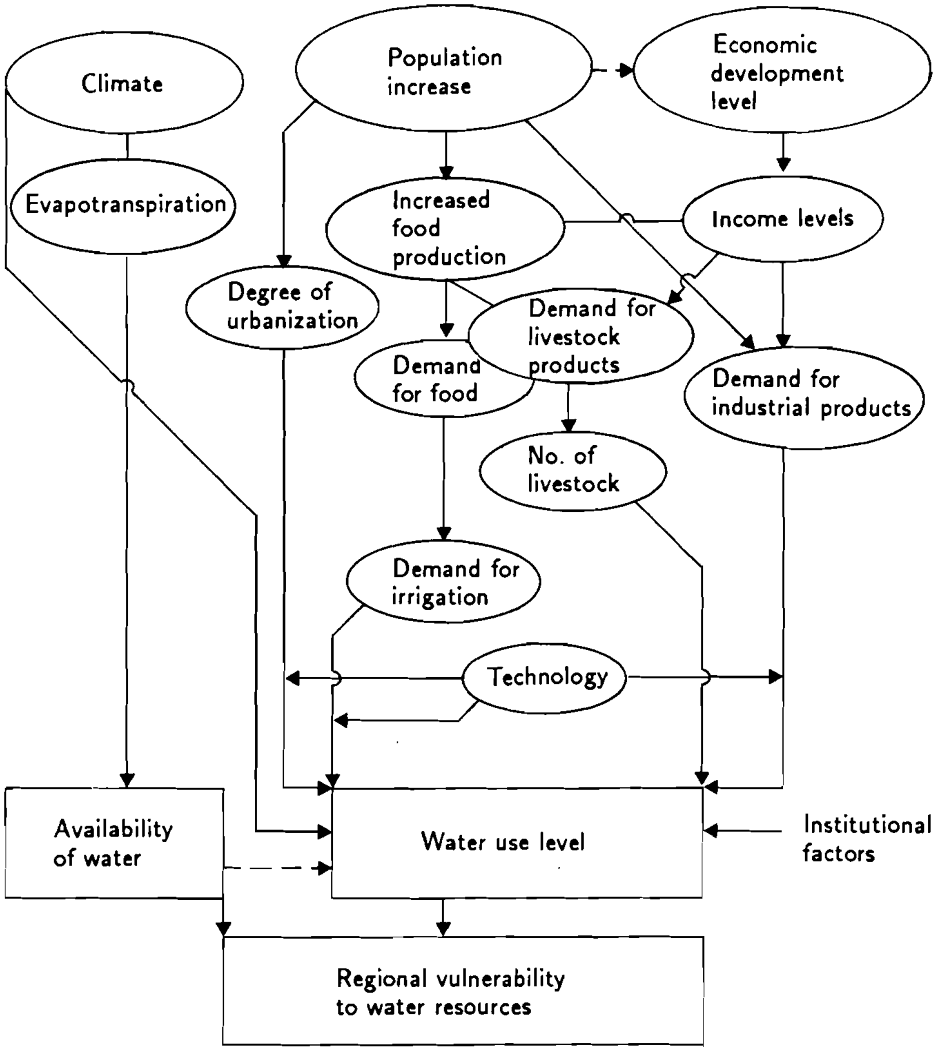


Figure 3.1. Interrelationships among forces determining a region's vulnerability to water resources. Water-quality effects are excluded.

also play a significant role in determining the water use level for domestic purposes.

The indirect effect of an increasing population would be the growing need for food and nonfood products, as shown in *Figure 3.1.* The demand for agricultural products would have an impact on water use through two major streams: firstly, the demand for food; secondly, the demand for nonfood (industrial) products, including inputs to farm production. The increased demand for food products can be met through one or more of the following measures:

1. Expanding rain-fed (dryland) area.
2. Improving the productivity of rain-fed (dryland) agriculture.
3. Expanding irrigated area.
4. Improving the productivity of irrigated agriculture.
5. Importing food from other countries.

The measures to be adopted in a country (region) would be determined through a political process and would vary from one region to another. However, assuming that this increased food deficit has to be met by increasing the size of an irrigated area, there would be significant impacts on the water use level.

In many countries a major portion of food intake is through poultry and livestock products, notably, milk, eggs, and meat. An increasing population would demand more of these products, which would then translate into an increased number of livestock to be maintained. This would result in further increased water use level, either for stockwatering (water used for livestock) or for growing forages and feeds for livestock.

The second major effect of an increasing population would be an increase in the demand for industrial products and their inputs. One such input is electrical energy, which would have some significant implications for industrial water use levels.

3.2.2 Economic development level

Besides agricultural pursuits, major economic development activities include boosting industrial production and, through that, personal income levels. In this study, the impact of economic development is limited to nonagricultural industrial activity.

Subject to limitations of financial resources through investment and other natural resources, most developed and developing countries aspire to achieve a higher level of industrial development as a means to improve the quality of life for their citizens. Such aspirations translate into higher income levels and increases in the demand for food and nonfood products. These demands then translate into an increased water use level in a manner similar to that described in Section 3.2.1.

3.2.3 Global climate change

Although, according to Kerr (1990), predictions of a global climate change are far from being specific, there is a virtual unanimity among the greenhouse-gas experts that a warming is on the way and, barring strict controls on the emission of greenhouse gases, the consequences will be serious. A climatic change translates into serious repercussions on water resources. Some of the main direct impacts include:

- Warming of atmosphere speeds drying. According to Waggoner (1990, p. 10), the capacity of air for evaporated water rises about 6 percent per Celsius degree. Thus, a warmer atmosphere would have a relatively faster rate of evaporation and this could result in a higher precipitation in some regions. In some regions there may be more runoff available, while in other regions there may be a reduction in the availability of water.
- Under a warmer climate, distribution of precipitation within a year may change.
- Global warming may result in an increased variability of climate. In some regions, this may result in higher probability of droughts, while in other areas, floods may occur more frequently.
- Global warming may also result in the rise of sea level. This would result, for some coastal areas, in a loss of arable land, as well as loss of freshwater through salinization.

In addition to these direct impacts, there may be several indirect impacts of a global climate change on water resources. The following impacts are particularly noteworthy:

- A warmer climate would increase the water requirements for irrigated agriculture.
- Some livestock and poultry may also require more water for their survival in a warmer climate.
- Domestic water use may also increase due to increased requirements for hygienic as well as for aesthetic purposes.
- Industries using water for cooling purposes may also experience a higher water use per unit of output than their current levels.
- The demand for electric power may be altered under a warmer climate, which would translate into a change in the amount of water used for power generation.
- Loss of agricultural areas resulting from sea level rise may increase the stress on the remaining arable land.

Implications of all the direct and indirect impacts of global climate change on water resources, thus, would be felt both on water availability and on its level of use. In most regions, there may be two lines of impacts – one through supply of water and the other through water use levels.

Table 3.2. Geographical coverage of the world by study regions.

Study region		No. of countries
1	North America	2
2	Central America	13
3	Northern South America	8
4	Southern South America	4
5	USSR	1
6	Northern Europe	11
7	Southern Europe	10
8	Eastern Europe	7
9	Northern Africa	5
10	Sahel Africa	24
11	Central Africa	14
12	Southern Africa	6
13	Middle East Asia	14
14	Southern Asia	12
15	Eastern Asia	4
16	Southeast Asia	4
17	Japan	1
18	Southwest Pacific	2
19	Other Pacific	3
Total world		145

3.3 Regionalization of the World

Because water resources are not distributed in a uniform manner, some degree of disaggregation of the world is imperative. The question is, what is an appropriate level of aggregation in the study of water resources? An ideal resolution would be a "catchment basin," which may be a river basin or a lake system. In some regions this may be part of a country, whereas in other regions it may be a group of countries. However, the availability of data is a major obstacle in pursuing this resolution. For this reason, this approach, although meritorious, has not been pursued.

Since most secondary data are available on the basis of political boundaries, one could follow previous studies and address the issues on a continental basis. However, such results were considered not to be of much use, because both the water resources and the factors affecting water use may not be uniformly distributed within a continent.

In this study, analysis was carried out on a country basis; however, various countries were aggregated into 19 regions. A list of the countries included in each region is presented in Appendix A. The number of countries in each region is listed in *Table 3.2*, and the geographical location is given

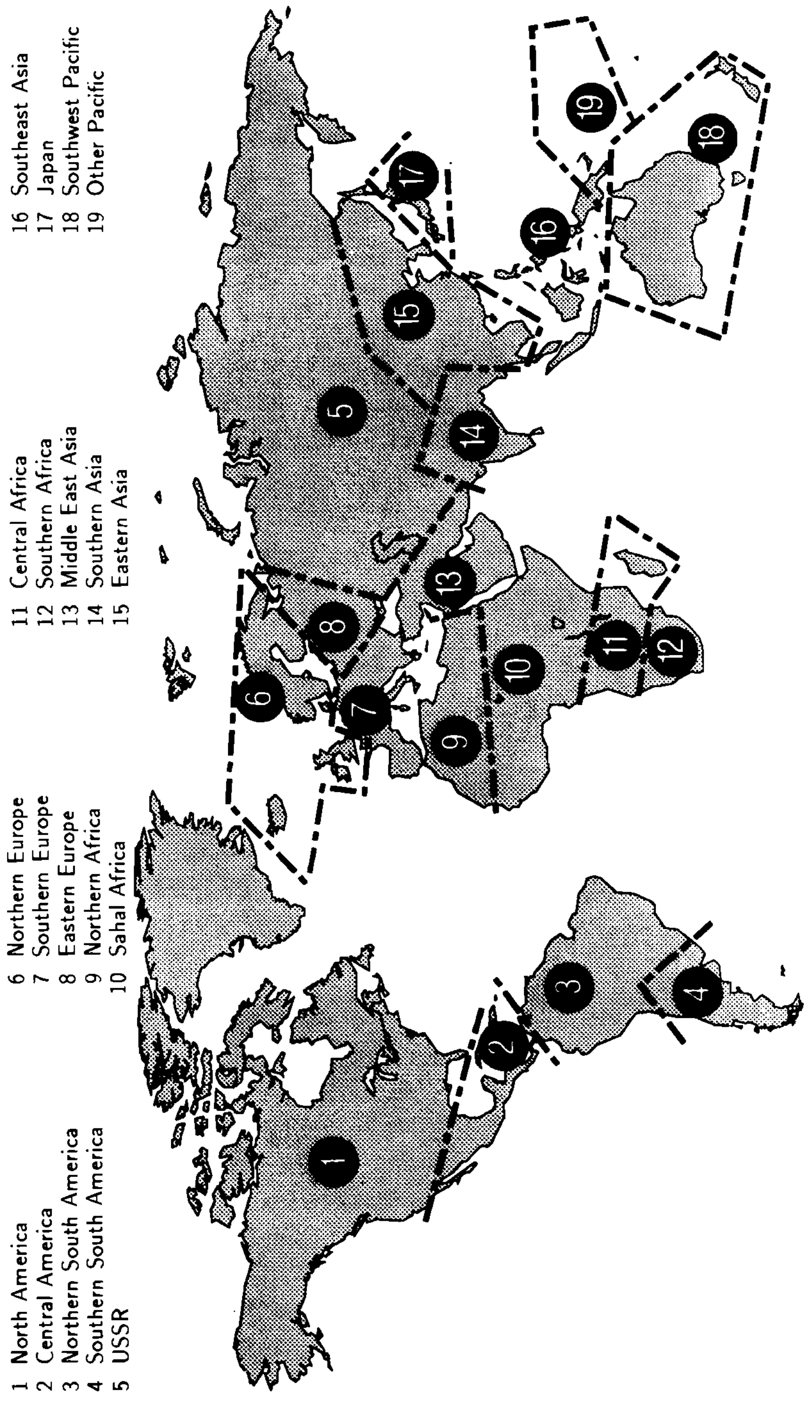


Figure 3.2. A map of the world showing study regions.

in *Figure 3.2.* The study is based on 145 countries. The choice of countries was guided almost entirely by the availability of data.

Admittedly, the subdivision of the world into 19 regions is far from optimum. Large countries such as the former USSR, the USA, Canada, and Brazil would appear to be homogeneous under this scheme, but this is not the case.

3.4 Estimation of Availability and Use of Water in Various Regions

3.4.1 Sources of data

This study is based on secondary data collected from various publications. These sources are listed below:

- Most of the surface water supply and use data were obtained from various annual reports of the World Resources Institute (1990).
- Agriculture data on land use and food production were obtained from the *FAO Yearbook.*
- Data on groundwater resources were obtained from L'vovich (1979).

Some adjustments in the available data were made, which are described in the following sections.

3.4.2 Estimation of water availability

Water supply (availability) in this study was based on water estimates obtained from three sources:

- Net precipitation (precipitation minus evapotranspiration) within the boundaries of a country. This yields an estimate of annual internal surface water resources of that country.
- Net inflow of surface water from neighboring countries.
- River flow through groundwater on an annual basis.

These three data sets were obtained from the World Resources Institute (1990) and L'vovich (1979).

There was one major problem with these data sets. The estimates of inflow/outflow of water were not balanced for any continent. Thus, a manual adjustment was made in the outflow estimate to balance with the data on inflow. This adjustment was based on the level of inflow into a country, which was distributed on the basis of adjoining countries and watercourses.

Table 3.3. Distribution of countries by year of water use data and by study regions.

Region	Year of data 1987	1980–1982	1976–1979	1974–1975	1970–1972	1965	1960
North America	1	1	–	–	–	–	–
Central America	2	–	–	7	3	–	1
North. South America	6	–	–	–	2	–	–
South. South America	1	–	1	1	–	1	–
USSR	–	1	–	–	–	–	–
Northern Europe	1	7	2	–	1	–	–
Southern Europe	3	6	1	–	–	–	–
Eastern Europe	–	6	–	–	1	–	–
Northern Africa	4	1	–	–	–	–	–
Sahel Africa	18	1	2	–	3	–	–
Central Africa	9	–	–	1	3	–	–
Southern Africa	4	1	–	–	1	–	–
Middle East Asia	2	1	1	9	1	–	–
Southern Asia	8	–	–	3	1	–	–
Eastern Asia	3	1	–	–	–	–	–
Southeast Asia	1	–	–	3	–	–	–
Japan	–	1	–	–	–	–	–
Southwest Pacific	–	1	–	1	–	–	–
Other Pacific	3	–	–	–	–	–	–
Total	67	28	7	25	16	1	1
% of total	46	19	5	17	11	2	

The revised inflow and outflow data were very close on a continental basis, and for the world as a whole.

The total water availability was measured in cubic kilometers (km^3), which is equivalent to one billion cubic meters of water. This water availability was assumed to be a stable supply, reflective of both current and future situations, barring any major natural environmental change.

3.4.3 Estimation of current water use

The most recent data available for many countries were from the late 1980s. However for several countries only data as old as 1965 were available. A detailed breakdown of various countries is shown in Appendix B. For almost half of the countries, available data pertained to the late 1980s, as shown in *Table 3.3.* These estimates are based on those prepared by the USSR Institute of Geography and reported by the World Resources Institute (1990).

Table 3.4. Estimated water requirements for livestock and poultry.

Category	Unit	Quantity per day
Cattle	liter/head	25.00
Sheep and goats	liter/head	2.25
Pigs	liter/head	4.00
Horses	liter/head	15.00
Buffalo/camels	liter/head	25.00
Poultry	liter/1000 birds	28.00

Source: UN (1986).

However, for almost one-third of the countries in the sample available data reported on conditions which were at least 15 years old.

For almost one-third of the countries, the latest water use information available is from the 1970s. Some of these countries are large water users. Lack of recent information is definitely a significant limitation of this study.

Data on the level of water use were obtained from the World Resources Institute (1990). This information included total water use in km^3 and its distribution to the three major uses: domestic, industrial, and agricultural. Total water use for each type of use was simply a product of the total use multiplied by the proportion of the total water used for that type of use. For domestic and industrial water use, no further adjustments were necessary. However, this was not the case with the agricultural water use, as described in the next subsection.

3.4.4 Disaggregation of agricultural water use

Agricultural water use contains at least two distinct types of uses: water used for irrigating crops and water required for livestock. Since these uses are governed by different sets of factors, and because their composition for different countries is different, there was a need for further disaggregation of this water use.

In order to disaggregate agricultural water use into its two major types, data on irrigated area for the year 1988 for various countries were obtained from the FAO. Similarly, estimates of the 1986–1988 average number of livestock and poultry were obtained from the World Resources Institute (1990). The livestock water use was estimated by multiplying the estimated herd size by the water requirements per animal as shown in *Table 3.4*. The estimated water use for livestock and poultry was deducted from the total agricultural water use, to yield irrigation water use. The irrigation water use was checked for consistency, and was further adjusted if the country had no irrigated area. In this case, an "unaccounted" category of water use was created. In all cases, the estimated unaccounted water use was very close to zero.

3.5 Projection of Water Use

In order to assess the degree of vulnerability of various countries to water resources, projections of water use were made for the year 2025. The selected year for which projections were made was 2025. The selection of this year was guided by the availability of future population forecasts made by the United Nations and reported by the World Resources Institute (1990). This year may be a little premature for the full impact of climate change. However, the projections of population size for the year 2060, when the full impact is expected to be realized, are not available for all countries. Thus, a compromise was made and the year 2025 was selected as the year of future scenario impact. The methodology followed for estimating the future water use is presented in the following section.

At the outset one major limitation of this methodology should be mentioned. The future level of water use is determined to a significant extent by the behavior of the agents (consumers, firms, institutions), which in turn may be altered by water management policies as well as by their attitudes toward water conservation. Admittedly, inclusion of these factors was not possible in this study, partly due to time constraints and partly due to non-availability of appropriate data.

3.5.1 Future domestic water use

The domestic water use for the year 2025 was estimated by assuming that the per capita use in the year 2025 would be at the same level it was in 1990. Thus, the only factor that affects the level of water use for domestic purposes is the growth in population. Implicit in this estimate are the following assumptions:

- Distribution of population by size of urban (vs. rural) centers remains unchanged.
- No significant institutional policy is implemented that would promote water conservation during the 1990–2025 period.
- There is no significant decrease (or increase) in the availability of water or change in its location within a country.

These assumptions must be kept in mind in interpreting the forecasted level of domestic water use.

3.5.2 Future industrial water use

Projected water use by industries is a complex subject. It is complicated by several factors:

- Over the course of time, water requirements of various industries may change.
- Composition of industries in a country may be different in the future than at present.
- Level of economic development may be regulated by economic or other policies pursued by the public sector.
- As a result of changes in economic development, demand for different industrial products may be different, which would alter the future composition of industries in a country.

Predictions of the effect of any of these forces require an intimate knowledge of the country. Even with the past records, forecasts of economic development of a region may be very difficult. For these reasons, no attempt was made in this study to forecast the level of economic activity in the year 2025.

The methodology followed in this study was much more restrictive. Data on gross national product (GNP, a standard measure of economic development) and the share of industrial GNP for various countries were obtained from the World Resources Institute (1990). The GNP data pertained to the year 1987.

The level of industrial water use in the year 2025 was obtained by multiplying the 1987 level of industrial water use per dollar of GNP (1987) by the projected per capita industrial GNP (2025). The projection of industrial GNP to the year 2025 was made under the assumption that various countries would grow at a modest rate of 1 percent per annum during the 1987–2025 period.

3.5.3 Future agricultural water use

As noted above, agricultural water use was subdivided into two uses – irrigation water use and stockwater use.

- Irrigation Water Use: No satisfactory country-by-country estimates of irrigation area are available, although some studies have forecasted measurements of world (or by major continents) irrigated areas by taking into account past trends and water availability. In this study, however, such an attempt was not made. Instead, we use the concept of food self-sufficiency. If a country were to achieve food self-sufficiency by using an irrigated method of production, what would be the level of water

Table 3.5. Description of study scenarios.

Scenario	Population level	Food self-sufficiency	Industrial development[a]	Climate change
Base	1990	No	IGNP, 1990	No
1	1990	Yes	IGNP, 1990	No
2	2025	No	IGNP, 1990	No
2A	2025	Yes	IGNP, 1990	No
3	2025	No	IGNP, 2025	No
4	2025	No	IGNP, 2025	Yes
4A	2025	Yes	IGNP, 2025	Yes

[a]Industrial gross national product.

use. This estimate was contrasted with a situation where irrigated lands increased at the same rate as population growth.

- Stockwater Use: Projections of livestock, by type of animal, requires information, on one side, on future demands for livestock products and, on the other side, on the carrying capacity of land and natural growth rate in livestock herds. Both of these are unavailable through secondary data sources. Therefore, in this study, assuming that the consumers' tastes and preferences do not change, livestock herd sizes were increased by the same magnitude as the increase in population. This implicitly assumes that per capita consumption of animal products remains unchanged from the respective 1990 levels. Details on climate-impacted water use and supply are provided along with results of these scenarios.

3.6 Study Scenarios

A summary of various scenarios under which vulnerability of various countries to water resources was examined is presented in *Table 3.5.* Three parameters – population growth, level of industrial development, and global climate change – were the guiding factors. This resulted in four categories of scenarios.

In addition to water use levels under these three parameters, food self-sufficiency policies in many countries have a significant impact on irrigation development and, through that, on the level of agricultural water use. Thus, three alternative scenarios were formulated where this goal was superimposed over the three basic scenarios. In total, there were seven scenarios.

1. *Base – Current Situation.* This scenario reflects the situation in 1990 with respect to regional vulnerability. The population estimate was for the year 1990, and the industrial gross national product was based on activity in 1987. Food self-sufficiency was not included under this scenario.
2. *Scenario 1 – Food Self-Sufficiency under Current Situation.* Under this scenario, the goal of food self-sufficiency was imposed. Other parameters were the same as those used in the Base Scenario.
3. *Scenario 2 – Projected Population.* The base scenario was adjusted to reflect a population growth in 2025. Other parameters for this scenario remained unchanged from the Base Scenario.
4. *Scenario 2A – Projected Population and Food Self-Sufficiency.* This scenario is parallel to Scenario 1, except the population estimates reflected the situation in 2025.
5. *Scenario 3 – Projected Population and Industrial Growth.* Scenario 2 was further adjusted to reflect the industrial activity expected. Thus, in this scenario, the effect on water use was through a combined effect of population and industrial activity in a country.
6. *Scenario 4 – Projected Population and Industrial Growth under Climate Change.* This scenario reflects the combined effect of all three changes: population growth, increased industrial activity, and global climate change.
7. *Scenario 4A – Projected Population, Industrial Activity, Climate Change, and Food Self-Sufficiency.* This scenario considers all the parameters in this study. The water use under this scenario would be the largest among all previous scenarios.

Chapter 4

Current Water Availability and Use Patterns

In this chapter, a discussion of the current situation in various study regions, with respect to the degree of vulnerability to water resources, is provided. The term "current" in these discussions refers to the period from 1987 to 1990, depending upon the year for which data were available. This chapter is divided into four sections. In Section 4.1, a review of relevant factors affecting water use levels is presented, which is followed by a discussion of water availability in Section 4.2. In Section 4.3, a discussion on total and per capita water use patterns is provided. The last section gives an assessment of the current degree of vulnerability of various regions to the availability of water resources.

4.1 Factors Affecting Water Use Levels

Various countries in the world are at different levels of demographic and economic development which may determine a region's (country's) vulnerability to water resources. The effects of population growth and economic development may already have started to appear, or may appear on the horizon at some future time. These forces are reviewed in this section. Two major factors contribute to a country's vulnerability: (1) population growth, which leads to pressure to provide water for domestic purposes as well as to provide food either through irrigated agriculture or through raising of livestock; (2) industrial growth, which requires water for industrial production and power generation. The first factor leads to many anthropogenic changes, such as changes in water use practices and land use patterns, which further lead to significant impacts on water resources.

Table 4.1. Population change in study regions, 1960–1990.

	Population (millions)		
Study region	1960	1990	% change
North America	199	276	30
Central America	67	146	118
Northern South America	114	244	114
Southern South America	33	53	63
USSR	214	288	35
Northern Europe	169	186	10
Southern Europe	184	244	33
Eastern Europe	100	124	24
Northern Africa	54	117	117
Sahel Africa	130	300	130
Central Africa	64	163	155
Southern Africa	30	65	117
Middle East Asia	53	137	158
Southern Asia	665	1,323	99
Eastern Asia	694	1,204	73
Southeast Asia	134	263	96
Japan	94	124	32
Southwest Pacific	13	20	54
Other Pacific	2	5	108
Total world[a]	3,013	5,282	75

[a]Refers only to those countries are included in the study.

4.1.1 Population growth

During the period from 1960 to 1990, world population increased from 3 billion inhabitants to 5.3 billion (*Table 4.1*).[1] This marked a 75 percent increase during the period. Not all regions (countries) have shown the same rate of growth. In fact, the data presented in *Table 4.1* indicate that the highest relative increase during this period was in the Middle East Asian countries (158 percent), which was closely followed by the Central African region (155 percent). In fact, all of the African regions have shown population growth in excess of the average rate for the world. A similar situation is observed for the Central American and the Northern South American regions where the population has more than doubled during the the period from 1960 to 1990.

4.1.2 Level of economic activity

A common measure of economic activity in a country is its gross national product (GNP), which is the value of its economic output excluding any

Table 4.2. Total and industrial gross national product, by study regions, in 1987.

Study region	Total GNP (billion US$)	Per capita (US$) GNP	Per capita (US$) Industrial GNP	Industrial GNP % of total
North America	4,709	17,804	5,425	30.5
Central America	200	1,371	437	31.9
Northern South America	426	1,748	647	37.0
Southern South America	102	1,928	745	38.6
USSR	2,357	8,375	2,094	25.0
Northern Europe	2,331	12,555	4,434	35.3
Southern Europe	1,904	7,812	2,633	33.7
Eastern Europe	500	4,034	1,290	32.0
Northern Africa	140	1,196	428	35.8
Sahel Africa	96	321	97	30.1
Central Africa	39	239	48	20.1
Southern Africa	345	535	230	42.9
Middle East Asia	340	2,485	814	32.8
Southern Asia	384	290	81	28.1
Eastern Asia	446	371	170	45.8
Southeast Asia	161	614	203	33.1
Japan	1,925	15,764	6,400	40.6
Southwest Pacific	206	10,264	3,310	32.2
Other Pacific	4	793	191	24.1
Total world	16,615	3,184	–	–

double-counting.[2] Different regions of the world differ markedly in terms of the share of world GNP and its distribution on a per capita basis, as shown in *Table 4.2.* Average per capita GNP of the world in 1987 was estimated at US$3,184 per annum. With the exception of North America, Europe (Northern, Southern, and Eastern), the USSR, Japan, and the Southwest Pacific region, GNP per capita in the rest of the world was less than the world average. One should keep in mind the many limitations of using GNP as a measure of economic development, particularly when comparing one country (region) with another.[3]

The level of industrial activity in different countries also differs from one another. However, the average industrial share of the total GNP for various regions does not show any appreciable difference. On average, the Eastern Asian region is more heavily dependent on industry than, say, a region like Central Africa. In terms of per capita GNP derived from industries, Japan (at least US$6,400) leads all the countries followed closely by the countries

Table 4.3. Cropland relative to population and net trade in cereals, by study regions.

Study region	Per capita cropland (ha)	Net trade in creals[a] (million tons)	Cereal production (tons) Per capita	Per ha of cropland
North America	0.855	−97.7	1.144	1.337
Central America	0.258	8.6	0.193	0.747
Northern South America	0.398	10.1	0.212	0.532
Southern South America	0.850	−14.3	0.541	0.637
USSR	0.807	32.1	0.684	0.847
Northern Europe	0.188	3.6	0.469	2.494
Southern Europe	0.364	−17.0	0.552	1.516
Eastern Europe	0.391	1.3	0.864	2.211
Northern Africa	0.216	17.9	0.321	1.484
Sahel Africa	0.338	5.9	0.112	0.330
Central Africa	0.239	1.6	0.094	0.395
Southern Africa	0.323	−0.6	0.223	0.739
Middle East Asia	0.218	22.4	0.162	0.745
Southern Asia	0.190	−4.8	0.210	1.102
Eastern Asia	0.085	15.7	0.313	3.661
Southeast Asia	0.128	5.5	0.233	1.830
Japan	0.038	26.9	0.119	3.130
Southwest Pacific	2.369	−21.5	1.147	0.484
Other Pacific	0.137	0.3	0.007	0.051

[a]Imports minus exports.

in North America and Northern Europe. The regions of Central Africa and Southern Asia depend the least on industrial activities.

4.1.3 Food self-sufficiency

One of the indirect consequences of an increasing population is increased water use in order to increase food production. Two measures can be used to show the pressure of population growth in various countries: (1) the number of people supported by one unit of arable land; and (2) net trade (imports minus exports) in cereals by that country (region). Data on these two measures are presented in *Table 4.3*.

Pressure on land, as measured by per capita arable land, is relatively high in Asian regions and in Japan, Northern Europe, and the other Pacific region. This may be a result of less arable land available in the Asian regions or of the interaction between arable land and growing masses of people. However, one should not take this as a valid measure of pressure on land, since land could have a different productivity level. A very crude measure

Table 4.4. Irrigation in the world, by study regions, in 1988.

Study region	Irrigated area (thousand ha)	% of world total	% of total cropland
North America	18,922	8.3	8.0
Central America	6,836	3.0	18.2
Northern South America	5,579	2.4	5.7
Southern South America	3,176	1.4	7.1
USSR	20,782	9.1	8.9
Northern Europe	1,869	0.8	5.4
Southern Europe	11,847	5.2	42.4
Eastern Europe	5,814	2.5	12.0
Northern Africa	4,725	2.1	18.6
Sahel Africa	3,720	1.6	3.7
Central Africa	1,593	0.7	4.1
Southern Africa	1,553	0.7	7.4
Middle East Asia	10,123	4.4	34.0
Southern Asia	70,763	30.8	28.1
Eastern Asia	47,533	20.7	46.2
Southeast Asia	93,49	4.1	27.9
Japan	2,889	1.3	61.4
Southwest Pacific	2,125	0.9	4.4
Other Pacific	1	–	0.1
Total world	229,199	100.0	15.6

of the differences in land capability is shown in *Table 4.3*; this is indicated by the measure of cereal production per hectare, which is relatively low in the Pacific regions and in the African regions.[4]

A somewhat more valid measure of food self-sufficiency is the level of imports (or exports) into a region. Here, the USSR, Japan, Middle East Asia, and Northern Africa top the list. One should bear in mind that the level of imports reflects not only shortages of food, but also the paying ability of a country (and its masses of people) for imported goods. In many countries, there may exist a demand for food, but this demand may not be an effective demand.

4.1.4 Irrigated agriculture

Increasing pressure to produce more food generally results in the adoption of measures to increase the productivity of croplands. One such measure, particularly in arid and semi-arid climates, is the conversion of rain-fed (dry-land) agricultural lands into irrigated land.

Table 4.5. Livestock population by study regions, average in 1986–1988.

	Number of animals (million head)				
Study region	Cattle	Sheep & goats	Pigs	Horses	Buffalo & camels
North America	114	13	59	11	0
Central America	52	20	25	16	0
Northern South America	184	65	46	16	1
Southern South America	256	129	7	5	0
USSR	121	148	78	6	1
Northern Europe	53	39	79	1	0
Southern Europe	55	119	47	4	1
Eastern Europe	32	48	61	3	0
Northern Africa	7	55	0	5	3
Sahel Africa	101	213	7	11	13
Central Africa	47	43	4	0	1
Southern Africa	22	42	2	1	0
Middle East Asia	13	95	0	4	1
Southern Asia	269	258	33	8	108
Eastern Asia	77	186	346	28	22
Southeast Asia	9	20	16	1	6
Japan	5	0	11	[a]	0
Southwest Pacific	31	223	3	1	0
Other Pacific	[a]	[a]	2	[a]	0
Total world	1,448	1,716	826	121	157

[a]Less than one-half million.

Table 4.6. Change in the world livestock population, by type of livestock in 1986–1988.

Type of livestock	% increase since 1976–1978
Cattle	5
Sheep and goats	12
Pigs	17
Horses	4
Buffalo and camels	17

In 1988, nearly 16 percent of all croplands in the world were irrigated, as shown in *Table 4.4*. It is estimated that about 229 million hectares of cropland in the world were irrigated by 1988. The largest proportions of these lands are found in the Southern and Eastern Asian regions, which together account for half of the total world irrigated area. Differences in the relative magnitude of irrigated area in different countries is reflective of both the need for irrigation and the ability of a country to be able to allocate financial resources. The former situation is encountered in humid climate regions, while the regions under an arid or semi-arid climate would likely face the latter situation.

4.1.5 Livestock population

Besides supporting over 5 billion people, the earth's resources also support over 4 billion livestock, consisting of cattle, sheep, and pigs, to a major extent, and horses, buffalo, and camels, to a minor extent. The distribution of livestock in various regions of the world is shown in *Table 4.5.* Relatively large cattle populations are supported in Southern Asia, Southern South America, Northern South America, and North America. The Eastern Asian region has the largest number of pigs in the world, whereas the Southern Asian and Southwest Pacific regions have the largest sheep and/or goat herds.

In the 1980s, the livestock population increased as shown in *Table 4.6.* The largest increase in livestock population has been observed for pigs and buffalo and camels. If the livestock populations continue to increase at these rates, more water resources will be needed to support them.

4.2 Water Availability in Various Regions

4.2.1 Total water availability

Water resource availability in different parts of the world varies significantly, in part due to the size of the country and in part as a result of differences in the natural conditions. In *Table 4.7,* the countries are grouped according to the total quantity of surface water and groundwater resources available. Of all of the countries in the world, only 13 have water resources exceeding 500 km^3. Most of these countries also have a large surface area.

Many countries, particularly in Europe, Africa, and Middle East Asia, have a relatively small amount of water resources; the annual availability of water is less than 100 km^3.

4.2.2 Source of water

Water supply in a country (region) consists of internal surface water, net inflow of surface water, and annual recharge of groundwater in its aquifers. Groundwater is the most important contributor to total water resources in the Southwest Pacific, Southern Europe, Central Africa, and Northern South America, as shown in *Table 4.8.* On average, for the world as a whole, groundwater contributes roughly 29 percent to the total world water supply.

Table 4.7. Distribution of countries by availability of water resources and by study regions, in 1990.

	Availability (km^3)				
Region	Small (≤5)	Sm–Med (6–99)	Medium (100–200)	Med–Lge (201–500)	Large (≥501)
North America	–	–	–	–	Canada USA
Central America	Barbados Trinidad	Costa Rica Cuba Dom. Republic El Salvador Haiti Jamaica	Guatemala Honduras Nicaragua Panama	Mexico	–
Northern South America	–	Guyana Peru	Bolivia Colombia Suriname	Ecuador Venezuela	Brazil
Southern South America	–	–	Uruguay	Chile Paraguay	Argentina
USSR	–	–	–	–	USSR
Northern Europe	Luxembourg	Belgium Denmark Netherlands UK	Finland Germany Iceland Ireland Sweden	Norway	–
Southern Europe	Cyprus Malta	Austria Greece Portugal Spain Switzerland	France Italy Turkey	–	–
Eastern Europe	–	Albania CSFR Hungary Poland Yugoslavia	Romania	Bulgaria	–
Northern Africa	Libya Tunisia	Algeria Egypt Morocco	–	–	

Table 4.7. Continued.

Region	Availability (km³) Small (≤5)	Sm–Med (6–99)	Medium (100–200)	Med–Lge (201–500)	Large (≥501)
Sahel	Cape Verde	Benin	Cameroon	Guinea	–
Africa	Djibouti	Burkina Faso	CAR	Liberia	
	Mauritania	Chad	Sierra Leone	Nigeria	
		Ivory Coast			
		Eq. Guinea			
		Ethiopia			
		Gambia			
		Ghana	Senegal[a]		
		Gu. Bissau	Somalia		
		Mali	Sudan		
		Niger	Togo		
Central	Burundi	Kenya	Angola	Zaire	Congo
Africa	Comoros	Madagscar	Gabon		
	Mauritius	Malawi			
		Rwanda			
		Tanzania			
		Uganda			
		Zambia			
Southern	Lesotho	Botswana	–	–	–
Africa		Mozambique			
		South Africa			
		Swaziland			
		Zimbabwe			
Middle	Bahrain	–	Iran	–	–
East Asia	Israel		Iraq		
	Jordan				
	Kuwait				
	Lebanon	Syria[a]			
	Oman	UAE			
	Qatar	Yemen (R)			
	Saudi Arabia	Yemen (RP)			
Southern	–	Afganistan	Laos	Cambodia	Bangladesh
Asia		Bhutan	Thailand	Pakistan	India
		Nepal	Vietnam		Myanmar
		Sri Lanka			

[a]Countries belong to the category shown on the left side.

Table 4.7. Continued.

Region	Availability (km^3) Small (≤5)	Sm–Med (6–99)	Medium (100–200)	Med–Lge (201–500)	Large (≥501)
Eastern Asia	–	Korea (PR) Korea (R) Mongolia	–	–	China
Southeast Asia	Singapore		–	Malaysia Philippines	Indonesia
Japan	–	–	–	–	Japan
South Pacific	–	–	–	Australia New Zealand	–
Other Pacific	–	Fiji Solomon Islands	–	–	Papua New Guinea
No. of countries	27	61	27	17	13

In addition, almost one-third (52 of 145) of the countries rely on water inflow from other countries for their own supply.

4.2.3 Per capita water availability

On a per capita basis, the availability of water resources is different from the availability of total water resources. As shown in *Table 4.9*, on average, we have 7,824 m^3 of water for every individual inhabitant in the world. This water is available in plentiful quantities in the other Pacific region, the Southwest Pacific, Northern South America, and Southern South America. However, the situation in Northern Africa, the Middle East region of Asia, and the Eastern Asian region is remarkably different. In these regions the availability of water on a per capita basis is less than 2,400 m^3 per annum.

4.2.4 Inter-year variability in water availability

An investigation of year-to-year variability in water availability in different countries of the world is a major undertaking and, therefore, not attempted in this study. A crude proxy for variation in the water availability is the level of a region's precipitation. In *Figure 4.1*, variability in annual rainfall is shown for the world. The regions with a relatively high variability are also those which have a relatively small availability of water on a per capita

Table 4.8. Source of water, by study regions, in 1990.

Study region	Total surface water and groundwater (km^3)	Total groundwater[a] (km^3)	Groundwater % of total	No. of countries dependent on inflow to total no.
North America	5,379	1,385	26	0/2
Central America	1,087	355	33	0/13
Northern South America	7,931	3,361	42	2/8
Southern South America	1,595	332	21	3/4
USSR	4,568	1,020	22	1/1
Northern Europe	1,266	371	29	11/11
Southern Europe	773	337	44	8/10
Eastern Europe	495	125	25	7/7
Northern Africa	111	23	21	3/5
Sahel Africa	1,707	601	35	6/24
Central Africa	1,832	794	43	1/14
Southern Africa	160	42	26	1/6
Middle East Asia	237	90	38	4/14
Southern Asia	5,839	876	15	5/12
Eastern Asia	2,875	1,022	36	0/4
Southeast Asia	3,310	477	14	0/4
Japan	547	185	34	0/1
Southwest Pacific	740	416	56	0/2
Other Pacific	874	48	5	0/3
Total world	41,326	11,860	29	52/145

[a]Represents the base flow component of the river flow through groundwater sources.

basis, i.e., Sahel Africa, Middle East Asia, Northern Africa, and Southeast Asia.

4.3 Water Use Levels

4.3.1 Total and per capita water use

Water is used for three major purposes – domestic, industrial, and agricultural. The last activity includes irrigation water and stockwater use. On average, as shown in *Table 4.10*, in the world, we use almost 3,609 km^3 of water annually, or 9,888 m^3 of water every day. A relatively large portion of total water use takes place in North America, the USSR, Southern Asia, and Eastern Asia. These four regions use two-thirds of the total world water use.

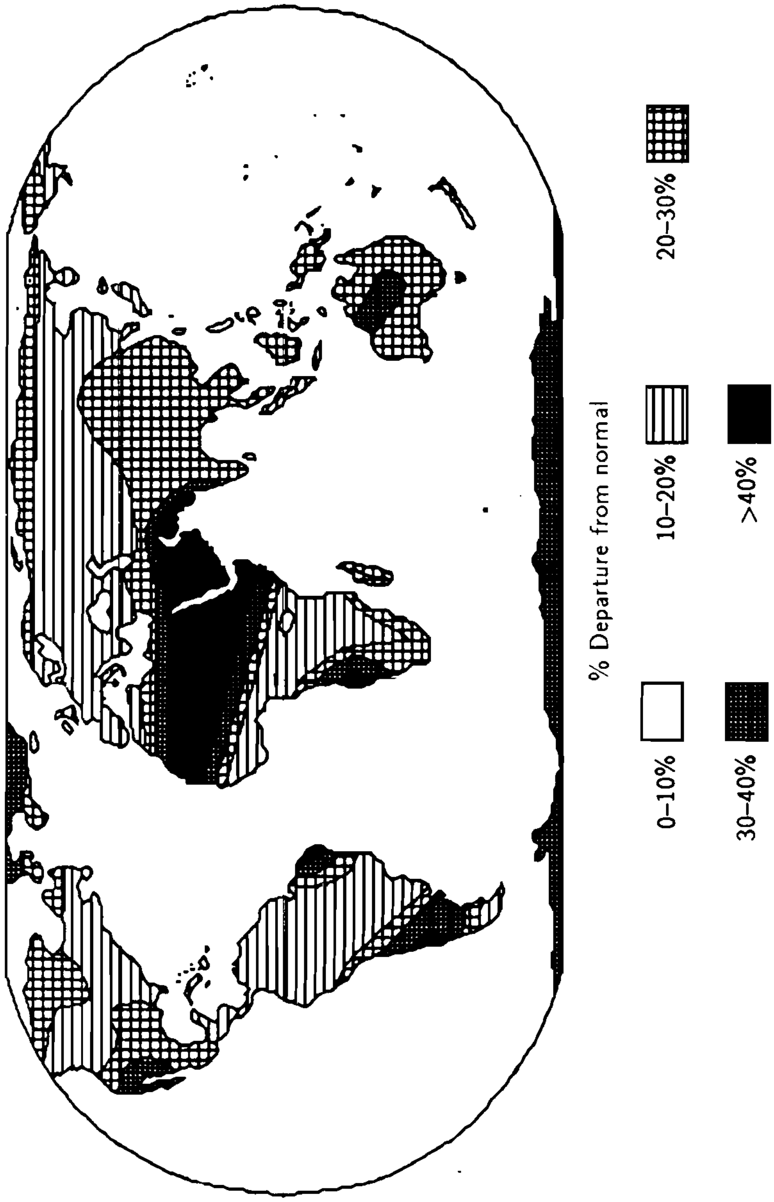


Figure 4.1. Distribution of regions by per capita supply and use of water, in 1990.

Table 4.9. Availability of water per capita, in 1990, by study regions.

Study region	Amount in m^3
North America	19,510
Central America	7,468
Northern South America	32,544
Southern South America	30,151
USSR	15,861
Northern Europe	6,817
Southern Europe	3,171
Eastern Europe	3,993
Northern Africa	950
Sahel Africa	5,692
Central Africa	11,225
Southern Africa	2,480
Middle East Asia	1,735
Southern Asia	4,414
Eastern Asia	2,387
Southeast Asia	12,589
Japan	4,429
Southwest Pacific	36,815
Other Pacific	174,850
World	7,824

On a per capita basis, we use 683 m^3 of water per annum, or 1,870 liters of water per day per person. The North American region uses the most water where an average of 2,098 m^3 of water is used per person per year. This is followed by Middle East Asia, the USSR, Southern South America, the Southwest Pacific, Japan, and Northern Africa. Other parts of Africa use relatively small quantities of water. More details on each country's water use patterns are provided in Appendix B.

4.3.2 Composition of total water use

In different regions, and in various countries of the world, water is used for different uses in different proportions. For example, as shown in *Table 4.10*, domestic water use is relatively high in regions such as the Southwest Pacific, Japan, and North America. Similarly, except for industrialized North America and the European regions, agriculture is the largest user of water in the world.

Relative water use and degree of available water utilized is shown in *Figure 4.2*. Of the total amount of water available in the world, only 9 percent is used for the three withdrawal uses included in the study; agricultural use

Table 4.10. Water use level, by type of use and study regions, in 1990.

Study region	Total withdrawal of water in km^3	Per capita withdrawal (m^3) Total	Domestic	Industrial	Agricultural
North America	578	2,098	260	1,000	838
Central America	104	497	47	44	406
Northern South America	60	248	86	33	129
Southern South America	117	1,077	85	138	854
USSR	383	1,330	80	386	864
Northern Europe	114	616	84	438	94
Southern Europe	150	616	94	235	287
Eastern Europe	80	646	76	314	256
Northern Africa	86	729	57	35	637
Sahel Africa	44	147	11	4	132
Central Africa	26	157	13	4	140
Southern Africa	17	261	42	41	178
Middle East Asia	184	1,344	68	93	1,183
Southern Asia	879	664	17	20	627
Eastern Asia	576	478	31	37	410
Southeast Asia	74	282	50	57	175
Japan	114	923	268	55	600
Southwest Pacific	23	1,149	734	28	387
Other Pacific	[a]	26	7	6	13
Total world	3,609	683	[b]	[b]	[b]

[a]Less than 1 km^3.
[b]Not estimated.

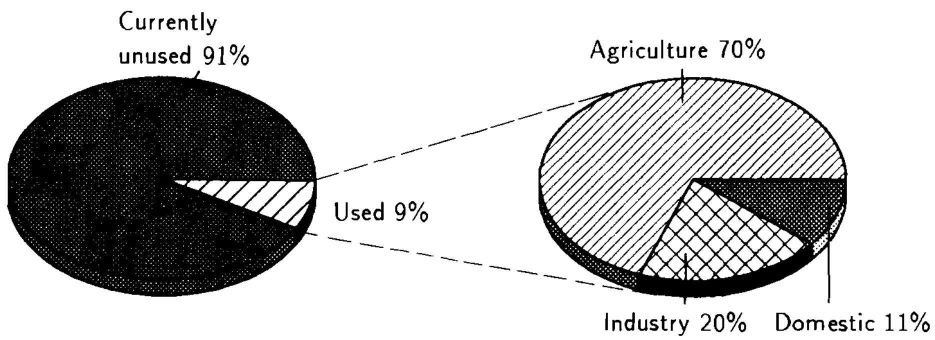


Figure 4.2. Relative supply and use of water in the world, in 1990.

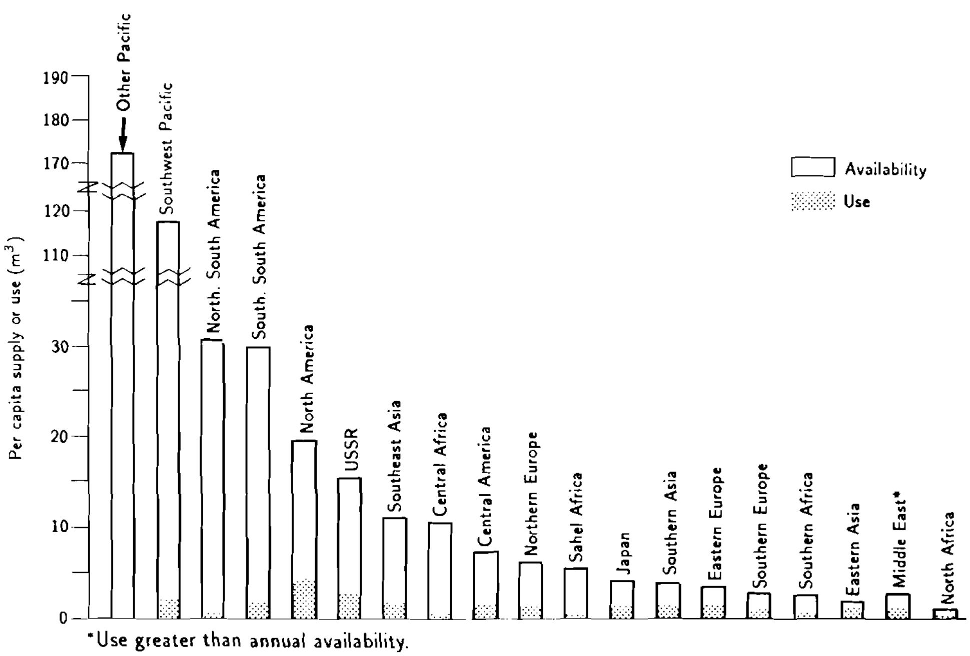


Figure 4.3. Global distribution of variability of annual rainfall, expressed as percentage from normal. Source: Landsberg (1975).

predominates. For the world as a whole, 70 percent of all water used is for these purposes. Of the agricultural uses, irrigation accounts for almost 90 percent of the total, thereby making it the largest single user of water.

4.3.3 Degree of water utilization

In different regions, we noted that available water resources are utilized by different magnitudes. For the world as a whole (see *Figure 4.2*), only 9 percent of the available water resources are utilized. For individual regions (*Figure 4.3*), the degree of utilization varies from 68 percent of supply in North Africa to 1 percent in Southern South America and less than 1 percent in the other Pacific region.

4.4 Current State of Regions Vulnerable to Water Resources

A discussion of vulnerability of a region (country) to water resources is presented in this section using the combined water availability–use measure expressed on a per capita basis. First, various countries are shown by per capita availability and use (*Tables 4.11* to *4.14*). For considerations of space, more than one region is presented in each table.

In the North American and Central American regions, although the USA, Chile, and Canada are relatively large users of water, none of the countries would be vulnerable to water resources due to large availability. However, three factors should be kept in mind:

1. The balance of supply and use of water is based on country average. There may be significant regional differences in some regions (river basins), where the situation may be different than the average.
2. Inter-year variations in water availability are not taken into account. It is conceivable that during low supply years, some countries may become vulnerable to water resources.
3. Seasonal variability in the availability of water and in its use is also not considered.

In Canada, for example, water availability is high in Eastern Canada, whereas its use is high in the arid and semi-arid regions of the Prairie provinces. Similarly, in the USA, water availability is low in the Northern states, and very high in Alaska, as shown in *Table 4.15*. For example, based on the 1975 estimate (L'vovich, 1975), per capita availability in the Northern USA was only 5,400 m^3 compared with 2,033,000 m^3 per capita in Alaska. The Western and Southern part of the USA were closer to the US average.

A similar (in terms of regional heterogeneity) situation exists in the former USSR (*Table 4.16*). According to L'vovich (1975), the Asian part of the USSR has a per capita supply of 39,100 m^3, but only 6,230 m^3 per capita on the European side. Water resource availability in various new republics and countries of the former USSR varies from 3,023 m^3 per capita in Moldavia to 28,969 m^3 per capita in the Russian Federation. Furthermore, use in different regions is not increasing at a uniform rate. From 1986 to 1988, Turkmenia increased water use by 31 percent, while Georgia reduced water use by 18 percent. These regional differences in these large countries must be kept in mind when interpreting the degree of vulnerability of the country as a whole.

Using the combined criterion of availability and relative use of water (*Figure 2.6*), various countries are classified by degree of vulnerability. Four categories were used: water surplus region, marginally vulnerable region, water stress region, and water scarce region. In marginally vulnerable regions, a country may experience occasional water shortages but, through proper management, may be able to alleviate some of them. In the water

Table 4.11. Distribution of countries by per capita availability and use of water, in 1990. North America, Central America, and South America.

Water availability per capita in m^3	Water use per capita in m^3 < 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	–	–	–	–	–
100–500	–	Barbados	–	–	–	–	–
500–1,000	–	–	Peru	–	–	–	–
1,000–2,000	Haiti	–	–	Costa Rica	–	–	–
2,000–5,000	–	Colombia El Salvador Jamaica Trinidad	Dom. Rep.	Cuba Mexico	–	–	–
5,000–10,000	–	–	–	–	USA	–	–
>10,000	–	Bolivia Brazil Guatemala Paraguay Uruguay	Nicaragua Venezuela	Ecuador Guaya Honduras Panama	Argentina Canada Chile Suriname	–	–

Table 4.12. Distribution of countries by per capita availability and use of water, in 1990. USSR and Europe.

Water availability per capita in m^3	Water use per capita in m^3 < 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	Malta	–	–	–	–	–	–
100–500	–	–	–	–	–	–	–
500–1,000	–	–	UK	–	–	–	–
1,000–2,000	–	–	CSFR Hungary Poland	Belgium Cyprus Germany	–	–	
2,000–5,000	–	–	Denmark Turkey Yugoslavia	France Italy Spain	–	–	–
5,000–10,000	–	Albania	Austria Switerland	Greece Netherlands	Portugal Romania	–	–
>10,000	–	Ireland Luxembourg	Iceland Norway Sweden	Finland	Bulgaria USSR	–	–

Table 4.13. Distribution of countries by per capita availability and use of water, in 1990. Africa.

Water availability per capita in m^3	Water use per capita in m^3 < 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
100–500	–	Cape Verde Libya	–	–	–	–	–
500–1,000	Burundi Djibouti Ethiopia Kenya Rwanda	Algeria	Tunisia	–	–	–	–
1,000–2,000	Chad Niger	Somalia	Morocco Mauritius South Africa	–	Egypt	–	
2,000–5,000	Burkina Faso Comoros Ghana Lesotho Nigeria Tanzania Togo Uganda	Mali Senegal Mozambique Zimbabwe	Mauritania	–	Madagascar Sudan	–	–
5,000–10,000	Benin	Ivory Coast	Swaziland	–	–	–	–
>10,000	Angola Cameroon CAR Congo Eq. Guinea Gambia G. Bissau Zaire	Botswana Gabon Guinea Liberia Sierra Leone Zambia	–	–	–	–	–

Table 4.14. Distribution of countries by per capita availability and use of water, in 1990. Asia, Japan, and Pacific regions.

Water availability per capita in m^3	Water use per capita in m^3 < 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	Kuwait	Qatar	–	–	–	–	–
100–500	–	Jordan Singapore UAE Yemen (R)	Israel Syria	Bahrain	–	–	–
500–1,000	–	–	–	–	Yemen (PR)	–	–
1,000–2,000	–	Nepal	Korea (R) Lebanon	India Oman Thailand	–	–	
2,000–5,000	–	Vietnam	China	Sri Lanka	Afghanistan Iran Korea (PR) Pakistan	–	–
5,000–10,000	–	–	–	Philippines	–	Iraq	–
>10,000	Bhutan Fiji Papua NG Solomon Is.	Bangladesh Cambodia Indonesia Laos Myanmar	Mongolia N. Zealand	Malaysia	Australia	–	–

Table 4.15. Regional availability of water in the USA, in 1975.

Region	Availability in m^3/capita
USA	11,400
Northern states	5,400
Southern states	11,600
Western states	12,000
Alaska	2,033,000

Source: L'vovich (1975).

Table 4.16. Regional availability of water in the former USSR, in 1988.

Republic	Availability in m^3/capita	% change in use of water between 1986 and 1988
Russia	28,969	94
Ukraine	4,062	89
Belorussia	5,490	95
Uzbekistan	5,427	117
Kazakhstan	7,516	112
Georgia	11,296	82
Azerbaijan	4,000	97
Lithuania	6,216	116
Moldavia	3,023	90
Latvia	11,852	91
Kirghizia	11,395	103
Tadzhikistan	18,600	95
Armenia	2,424	106
Turkmenia	20,286	131
Estonia	9,412	91
USSR	16,463	102

Source: Compiled using data presented by Bond (1990) and Cole (1991).

stress regions, more frequent water-related problems occur; regions in the last category experience frequent and very severe water problems.

Results of regional vulnerability are shown in *Table 4.17* for the 19 study regions. With the exception of Middle East Asia, few regions have countries that are currently facing water stress or water scarcity. Countries such as Cyprus and Malta, being island economies, do face a slightly higher degree of vulnerability. Regions endowed with large sources of freshwater, such as those located in the Alps (Austria, Switzerland, and Italy), do not face any serious vulnerability to water resources.

In some countries, such as Saudi Arabia, water use is higher than their current water supply; this situation has significant implications for their sustainable development in the future. Because the rate of water withdrawal exceeds the net recharge, mining of groundwater occurs, which may result, as suggested by Al-Ibrahim (1991) in a variety of problems including fast depletion of groundwater resources and deterioration of their quality. This would have serious socioeconomic implications for the region.

Notes

[1] World in this report refers to all the countries included in this report. According to the World Resources Institute (1990), the world population was 5,292 million in 1990. The study has captured 99.8 percent of this total.

[2] The double-counting occurs because output produced by one industry becomes an input to some other industry. In the GNP estimation, only the value-added by the industry is included.

[3] These differences arise because different countries take into account different commodities and services as a part of GNP. In addition, the government sector performs a different role in different types of economies; this makes a comparison of GNP over a range of countries misleading.

[4] This measure is crude because cereal production per hectare would also be determined by the intensity of cropping and land use pattern. For example, a higher proportion of pasture and range land would decrease this value, yet the productivity of land may be high.

Table 4.17. Distribution of countries by type of vulnerability to water resources, in 1990.

Study region	Surplus	Marginal	Stress	Scarcity
North America	Canada USA	–	–	–
Central America	Costa Rica Cuba Dom. Rep. El Salvador Guatemala Honduras Jamaica Mexico	Barbados Haiti Nicaragua[a] Panama Trinidad	–	–
Northern South America	Bolivia Brazil Colombia Ecuador Guyana	– Suriname[a] Venezuela	Peru	–
Southern South America	Argentina Chile Paraguay Uruguay	–	–	–
USSR	USSR	–	–	–
Northern Europe	Denmark Finland Iceland Ireland Luxembourg Netherlands	Germany Norway[a] Sweden	Belguim UK	–
Southern Europe	Austria France Greece Italy Portugal	– Spain[a] Switzerland Turkey	Cyprus	Malta

[a]Countries belong to the category shown on the left side.

Table 4.17. Continued.

Study region	Surplus	Marginal	Stress	Scarcity
Eastern Europe	Albania	Poland	–	–
	Bulgaria			
	CSFR			
	Hungary			
	Romania			
	Yugoslavia			
Northern Africa	–	Algeria	Tunisia	Egypt
		Morocco		Libya
Sahel Africa	Benin	Cape Verde	–	–
	Burkina Faso			
	Cameroon			
	CAR			
	Chad			
	Ivory Coast			
	Djibouti			
	Eq. Guinea	Mauritania[a]		
	Ethiopia	Niger		
	Gambia	Nigeria		
	Ghana	Senegal		
	Guinea	Sierra Leone		
	Gu. Bissau	Somalia		
	Liberia	Sudan		
	Mali	Togo		
Central Africa	Angola	Madagascar	–	–
	Burundi	Mauritius		
	Comoros			
	Congo			
	Gabon	Tanzania[a]		
	Kenya	Uganda		
	Malawi	Zaire		
	Rwanda	Zambia		
South Africa	Botswana	South Africa	–	–
	Lesotho			
	Mozambique			
	Swaziland			
	Zimbabwe			

[a]Countries belong to the category shown on the left side.

Table 4.17. Continued.

Study region	Surplus	Marginal	Stress	Scarcity
Middle East Asia	–	Lebanon Oman	Iran UAE[b] Yemen (R) Yemen (PR)	Bahrain Iraq Israel Jordan Kuwait Qatar Saudi Arabia Syria
Southern Asia	Afganistan Bangladesh Bhutan Cambodia Laos Myanmar Nepal	India Pakistan Thailand Sri Lanka[a] Vietnam	–	–
Eastern Asia	China Mongolia	Korea (CR) Korea (PR)	–	–
Southeast Asia	Indonesia Malaysia Philippines	Singapore	–	–
Japan	Japan	–	–	–
Southwest Pacific	Australia New Zealand	–	–	–
Other Pacific	Fiji Papua New Guinea Solomon Islands	–	–	–
No. of countries	107	18	6	14

[a]Countries belong to the category shown on the left side.
[b]Countries belong to the category shown on the right side.

Chapter 5

Water Vulnerable Regions Under Alternative Scenarios

The degree of vulnerability of various countries to water resources may change as factors affecting supply of or demand for water change over time and/or as a country's policy objectives are altered. In this chapter, selected sets of factors and policy objectives are analyzed with respect to their effect on a country's vulnerability. The aim of this chapter is to answer the following question: Would a country become more vulnerable to water resources as certain events take place or certain policy objectives are instituted? A major policy objective that a country can pursue is that of food self-sufficiency. An obvious question that needs answering is: What impact would the goal of food self-sufficiency have on a country's degree of vulnerability to water resources? This analysis is presented in Section 5.1, as Scenario 1.

As noted in *Table 3.5*, three sets of factors were selected as events that may alter the degree of vulnerability of a country to water resources:

- Population growth to the year 2025 (Scenario 2).
- A goal of moderate industrial growth (Scenario 3).
- Global climate change (Scenario 4).

Two scenarios with population growth and global climate change were combined with the food self-sufficiency goal (Scenarios 2A and 4A).

The first two factors affect the water use levels, whereas the third one may affect both water availability as well as water use levels. In Section 5.2, implications of future population growth are explored, which are followed by a discussion in Section 5.3 on implications of pursuing a goal of food self-sufficiency under future population growth. Implications of industrial growth are explored in Section 5.4, and those of global climate change are treated in Section 5.5.

5.1 Scenario 1: Food Self-Sufficiency and Availability of Water Resources

5.1.1 Estimation of food self-sufficiency level of water use

Under this scenario, the level of water use was estimated under the assumption that, given the 1990 population level, the country is pursuing a policy of being self-sufficient in food products. This translates into a situation where, on average, the level of net trade (imports minus exports) is zero or negative. A number of assumptions were made during this estimation:

- The domestic and industrial water uses remain unchanged under this scenario.[1]
- A country pursues a policy of expanding its irrigated area, in light of perceived higher yields of cereal crops under irrigation.[2] Thus, the entire short-fall in cereal consumption is met by converting rain-fed agriculture into irrigated agriculture, subject to availability of cropland in the country.
- The yields of rain-fed and irrigated crops remain unchanged from the average during the 1984–1987 period. This negates any effect of productivity gains.
- Water application rates remain unchanged.

Under these simplifying assumptions, irrigated water use was projected by first estimating the area required to be converted into irrigation to cover the shortfall of food in 1990. This shortfall in food supplies was equated to the level of imports into that country, on a per capita basis, using the level of imports in the 1986–1988 period.

5.1.2 Vulnerability of various countries

Several countries may find it difficult to attain the goal of food self-sufficiency because of limited water availability (*Table 5.1*). Major regions affected include various countries in the Northern African and the Middle East regions. A few countries in the Sahel Africa, such as Sudan, Mauritania, and Ethiopia, may also find water resources limiting to produce sufficient quantities of food. One should keep in mind the various assumptions used in estimating these results, in particular, that there is sufficient arable land in the country for expanding irrigation.

These results suggest that few countries that are not already vulnerable to water availability will have adequate water resources to meet the goal of food self-sufficiency. This is not to imply that these countries have

Table 5.1. Change in the vulnerability status of countries under the goal of food self-sufficiency, in 1990.

		Vulnerability status	
Region	Country	Without s-s	With s-s
North America		No change	
Central America		No change	
Northern South America	Peru	Stress	Scarcity
Southern South America		No change	
USSR		No change	
Northern Europe		No change	
Southern Europe	Cyprus	Stress	Scarcity
Eastern Europe	Poland	Marginal	Stress
Northern Africa	Algeria	Marginal	Scarcity
	Morocco	Marginal	Stress
	Tunisia	Stress	Scarcity
Sahel Africa	Cape Verde	Marginal	Scarcity
	Ethiopia	Surplus	Marginal
	Mauritania	Surplus	Scarcity
	Sudan	Surplus	Marginal
Central Africa	Mauritius	Marginal	Stress
Southern Africa		No change	
Middle East Asia	Iran	Stress	Scarcity
	Lebanon	Marginal	Stress
	Oman	Marginal	Scarcity
Southeast Asia		No change	
Eastern Asia	Singapore	Marginal	Stress
Japan		No change	
Southwest Pacific		No change	
Other Pacific		No change	

s-s denotes food self-sufficiency.

the capability and/or resources to attain this goal. Food self-sufficiency is also determined by factors which are not based on water resource availability. Although water availability is a limiting factor for very few countries, availability of financial resources to develop irrigation infrastructure may be a severe constraint to utilizing the available water resources for irrigation purposes.

In addition, there are regions at present where availability of water is already a serious constraint. Under the present population level, Northern Africa, Middle East Asia, and Southeast Asia stand out as the regions where food self-sufficiency may be affected by availability of good quality water. More details on the distribution of various countries is shown in Appendix C.

5.2 Scenario 2: Population Growth to the Year 2025

If current population trends were to continue to the year 2025, would some countries/regions be facing shortages of water to meet their needs? To answer this question, population forecasts for different countries of the world for the year 2025 were obtained, a summary of which is presented in Chapter 4.

5.2.1 Methodology

In making projections under this scenario, three assumptions were made:

1. Changes other than population are not significant determinants of vulnerability to water resources.
2. Water use patterns remain unchanged from the 1990 level on a per capita basis.
3. Water supply remains unchanged from the 1990 level.

The level of water use in 2025 was estimated under these assumptions.

5.2.2 Distribution of countries

Figures 5.1 to *5.4* provide a visual display of countries with relative degrees of vulnerability. Countries were grouped into three types according to the endowment of water resources: large (if water supply was over 200 km^3), medium (between 10 and 200 km^3), and small (less than 10 km^3). Details on each country's water availability and population in the year 2025 are provided in Appendix D.

Of those with large endowments of water resources (*Figure 5.1*), India, Nigeria, and Mexico would face water scarcity under this scenario. Although the situation in India would be more acute, both Nigeria and Mexico would be close to the boundary of water stress and water scarcity regions. Two countries that would fall into the category of water stress regions are: Pakistan and China. Marginally vulnerable conditions would occur in countries like Bangladesh, Indonesia, the Philippines, and Japan in Asia, and Zaire in

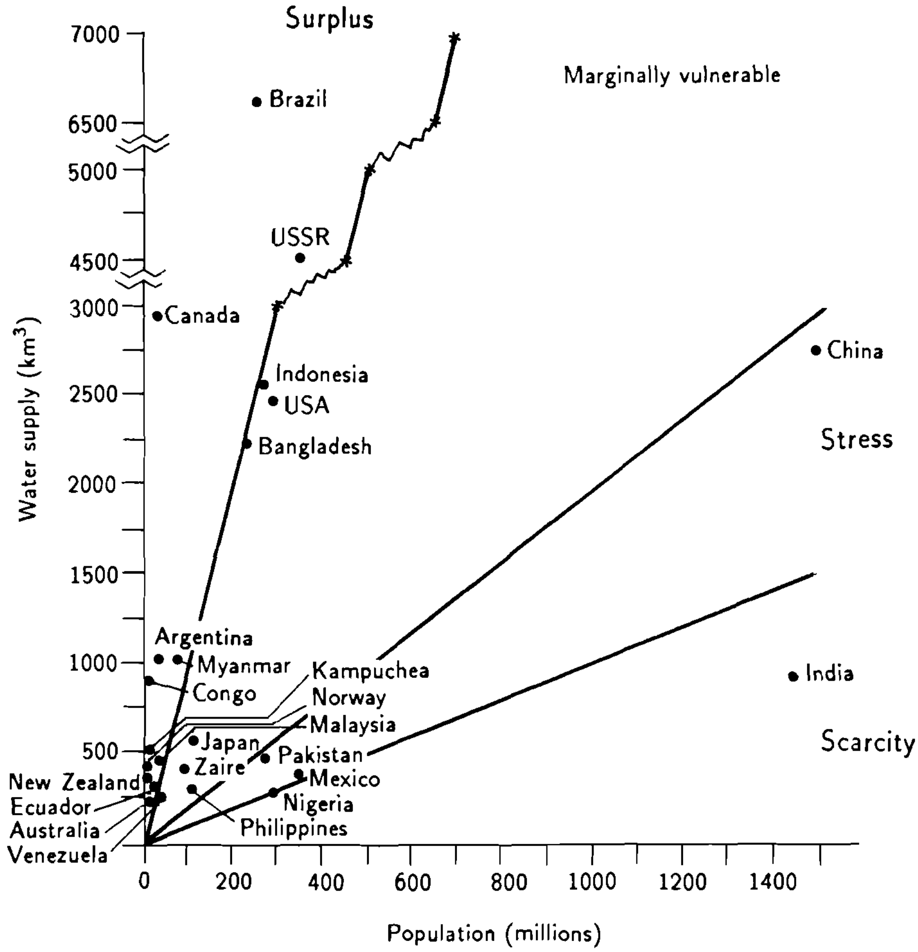


Figure 5.1. Water supply and population in 2025, in large water resources countries.

Africa. Occasional water stress may be associated with those years with relatively low runoff. This is not to suggest that there would not be subregions within these countries with relative water scarcity. In fact, some regions in the USA (for example, California) are already facing water shortages which would intensify by the year 2025. A similar situation can be found in the former USSR. Although the USSR as a whole has adequate water resources to deal with demands in the year 2025, republics such as Armenia, Moldavia, Azerbaijan, and the Ukraine may face some water-related problems.

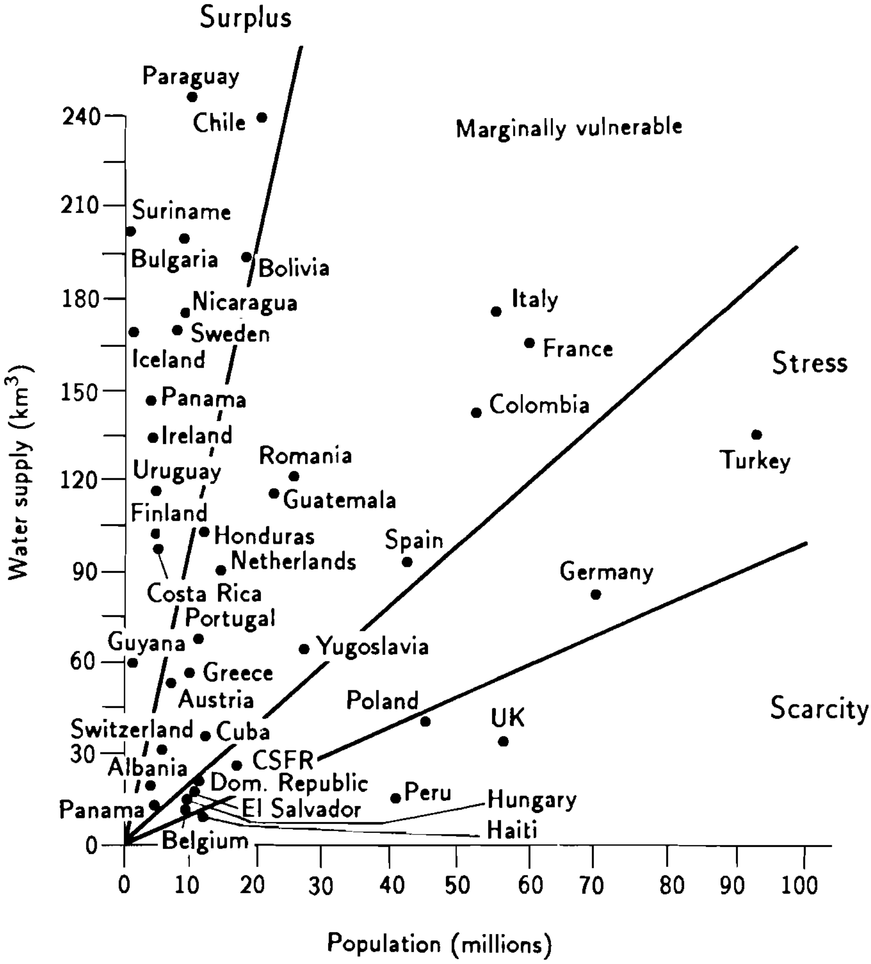


Figure 5.2. Water supply and population in 2025, in medium water resources countries in North America, South America, and Europe.

For countries with a medium level of water supply (*Figure 5.2*), marginal vulnerability to water may be evident in several European countries – Albania, Romania, Portugal, Yugoslavia, the Netherlands, France, Italy, and Spain. Turkey, Belgium, and Germany will most likely become water stress regions, whereas Poland and the United Kingdom will face water scarcity. These problems may be enhanced if pollution of water resources remains unchecked, making some available water unfit for use in industrial or even agricultural activities.

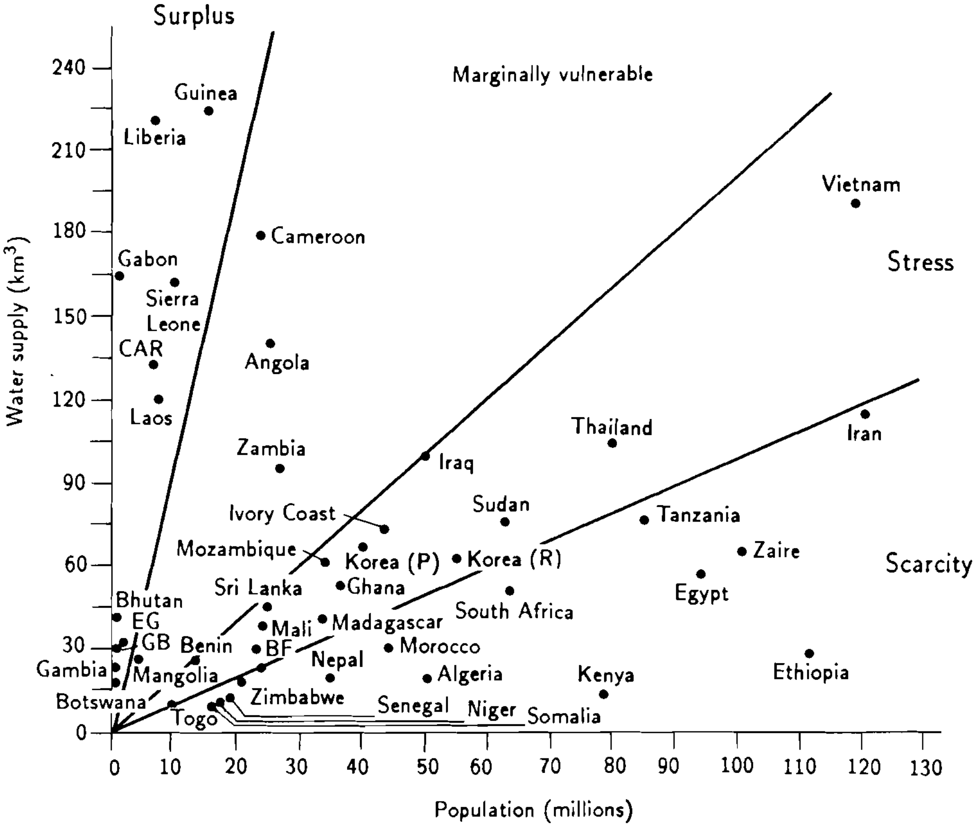


Figure 5.3. Water supply and population in 2025, in medium water resources countries in Asia and Africa.

In the African continent and Asia, a number of countries with medium size water resources would face water stress or water scarcity. In these regions, except for some countries that would still be water surplus, most countries, as shown in *Figure 5.3*, would face water stress and/or water scarcity. The entire Middle Eastern region and the North African region, under current water use patterns, show a situation that is not sustainable in the future.

Among the small water resources countries, a majority of which are in Middle East Asia or in the Northern African region or are small islands, water stress is the predominant feature. Very few countries, as shown in *Figure 5.4*, would have a water surplus status; therefore, management problems would become more complex over time.

A summary of the vulnerability of various regions under these scenarios is shown in *Table 5.2*. The regions that would have surplus resources, in

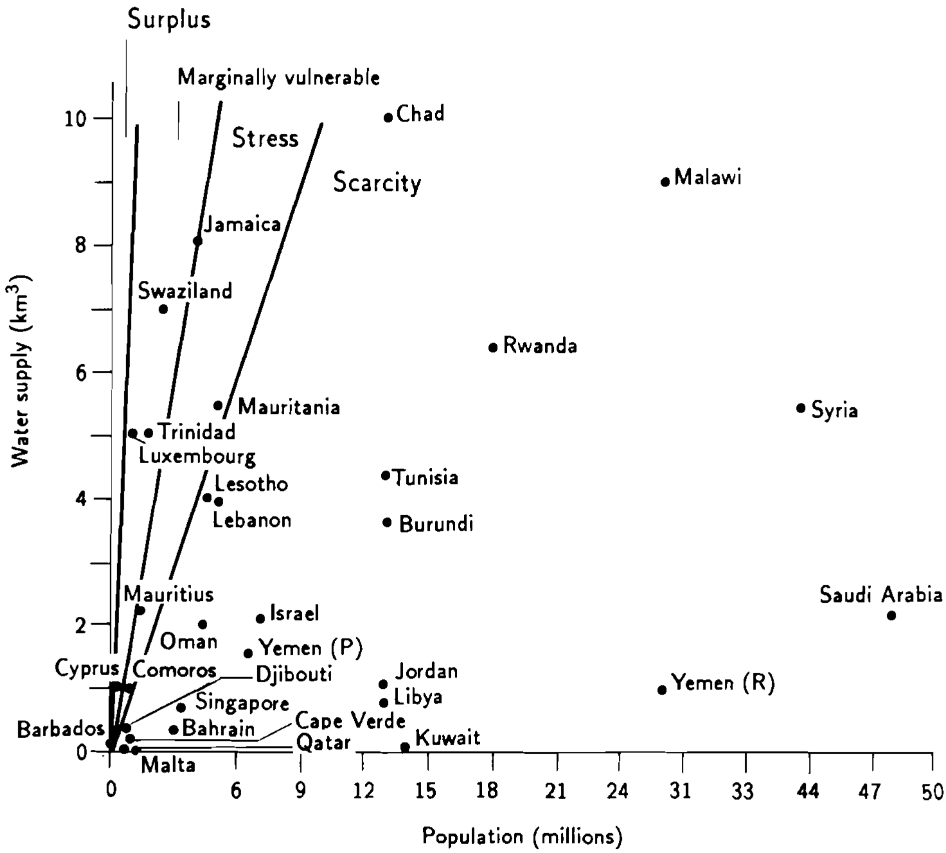


Figure 5.4. Water supply and population in 2025, in small water resources countries.

aggregate, would be North America, South America, the USSR, and the Pacific regions.

The Northern African region and the Middle East, on the other hand, would become a water scarce region, while the Southern Africa region may face marginal vulnerability as well. Water resources in these regions are much too small for a sustainable use of water to the year 2025.

The number of countries in various study regions by degree of vulnerability to water is shown in *Table 5.3.* Only 94 of 145 countries maintain a surplus in water resources. Over one-third of the countries in the world could face marginal vulnerability, water stress, or water scarcity by the year 2025 if current water use patterns were to continue and projected population growth were to occur.

Table 5.2. Water vulnerability status of world regions, under population growth scenario, in 2025.

Study region	No. of inhabitants per million m^3 of water	Region's status[a] Surplus	Marginal	Stress	Scarcity
North America	62	*			
Central America	234	*			
Northern South America	53	*			
Southern South America	49	*			
USSR	77	*			
Northern Europe	143	*			
Southern Europe	365	*			
Eastern Europe	279	*			
Northern Africa	1,930				****
Sahel Africa	448		**		
Central Africa	254	*			
Southern Africa	813		**		
Middle East Asia	1,378				****
Southern Asia	402		**		
Eastern Asia	534			***	
Southeast Asia	123	*			
Japan	235	*			
Southwest Pacific	36	*			
Other Pacific	12	*			

[a]Does not imply that all countries in the region belong to that category.

5.2.3 Distribution of population affected

A distribution of the number of countries, as shown in *Table 5.3*, masks the degree of human suffering. Since many countries facing severe vulnerability to water in the future are also those with rapid population growth, an examination of vulnerability by a country's population size may present a different picture.

In *Table 5.4*, population size of different regions by each country's vulnerability to water in 1990 is presented. According to these estimates, Northern Europe, Northern Africa, and the Middle East will become more vulnerable to water resources by the year 2025. The size of the world population affected is shown in *Table 5.5*. According to these estimates, about 300 million people live in countries now facing water stress or water scarcity. Many of these people live in Southern Asia, Middle East Asia, and Northern Africa. By the year 2025, the situation would change markedly. The population would increase to 8.4 billion inhabitants, of which almost 3 billion would be

Table 5.3. Distribution of countries, by world regions and degree of vulnerability, under population growth scenario, in 2025.

	No. of countries				
Study region	Surplus	Marginal	Stress	Scarcity	Total
North America	2	0	0	0	2
Central America	8	4	1	0	13
Northern South America	7	0	1	0	8
Southern South America	4	0	0	0	4
USSR	1	0	0	0	1
Northern Europe	8	0	1	2	11
Southern Europe	8	0	1	1	10
Eastern Europe	6	0	1	0	7
Northern Africa	0	0	1	4	5
Sahel Africa	16	3	4	1	24
Central Africa	10	1	2	1	14
Southern Africa	5	0	0	1	6
Middle East Asia	0	0	1	13	14
Southern Asia	8	0	1	3	12
Eastern Asia	2	1	0	1	4
Southeast Asia	3	0	1	0	4
Japan	1	0	0	0	1
Southwest Pacific	2	0	0	0	2
Other Pacific	3	0	0	0	3
Total World	94	9	15	27	145

living in countries facing water stress or water scarcity. Even on a relative basis, this suggests, as shown in *Figure 5.5*, that one-third of the world population in the year 2025 would be living in regions facing severe vulnerability (water stress or water scarcity) to water resources, as compared to less than one-tenth at present.

5.2.4 Water vulnerability and international conflicts

As competition for water increases, conflicts among various water users, within a country as well as between various countries sharing a water resource, are bound to arise. Which countries may most likely be the candidates for more international conflicts related to water? To answer this question, two criteria of increased conflicts were selected:

1. The water supply of a country originating in another country (a measure of dependence).
2. The degree of vulnerability of the country to water resources.

Table 5.4. Distribution of population by degree of vulnerability to water resources in 1990 and 2025.

	% of total population in 1990 (2025)			
Study region	Surplus	Marginal	Stress	Scarcity
North America	100 (100)	0 (0)	0 (0)	0 (0)
Central America	0 (22)	0 (78)	0 (0)	0 (0)
Northern South America	91 (90)	0 (0)	9 (0)	0 (10)
Southern South America	100 (100)	0 (0)	0 (0)	0 (0)
USSR	100 (100)	0 (0)	0 (0)	0 (0)
Northern Europe	23 (24)	41 (0)	36 (39)	0 (37)
Southern Europe	100 (100)	0 (0)	0 (0)	0 (0)
Eastern Europe	69 (67)	31 (33)	0 (0)	0 (0)
Northern Africa	0 (0)	44 (0)	7 (12)	49 (88)
Sahel Africa	100 (64)	0 (22)	0 (14)	0 (0)
Central Africa	92 (71)	8 (5)	0 (17)	0 (7)
Southern Africa	46 (52)	54 (0)	0 (0)	0 (48)
Middle East Asia	0 (0)	4 (0)	42 (2)	54 (98)
Southern Asia	22 (22)	78 (0)	0 (3)	0 (75)
Eastern Asia	95 (95)	5 (3)	0 (0)	0 (2)
Southeast Asia	99 (99)	1 (0)	0 (1)	0 (0)
Japan	100 (100)	0 (0)	0 (0)	0 (0)
Southwest Pacific	100 (100)	0 (0)	0 (0)	0 (0)
Other Pacific	100 (100)	0 (0)	0 (0)	0 (0)

Table 5.5. Distribution of world population in 2025 (by country of residence) by degree of water vulnerability.

	Population (millions)		
Degree of vulnerability	1990	2025	Change (millions)
Surplus	3,669	5,083	+1,414
Marginal	1,320	468	−852
Stress	154	369	+215
Scarcity	137	2,529	+2,392
Total	5,280	8,449	+3,169

As the magnitude of each criterion increases, so should the probability of a conflict. Results of this analysis are shown in *Table 5.6.* Countries such as Egypt, Niger, Senegal, Sudan, and Mauritania would face a higher probability of an international conflict. Some countries in Europe, particularly Germany and Belgium, would also face a relatively high probability of such conflicts developing by the year 2025. Once one incorporates water-quality issues, the situation may get even tenser. If water pollution threatens the water supply of a country downstream, it may bring about more conflicts.

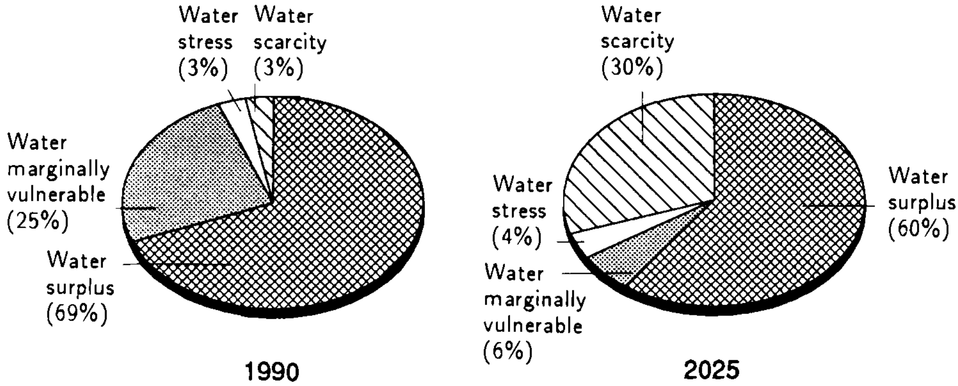


Figure 5.5. Distribution of world population by degree of vulnerability to water resources, in 1990 and 2025.

Table 5.6. Countries with water vulnerability and possible conflicts, in 2025.

Inflow of total water supply	Marginal	Stress	Scarcity
	Low	⟸ Degree of Conflict ⟹	*High*
<25%	Poland	Algeria	Israel
25%–50%		Belgium Nigeria Pakistan	UK Tunisia Jordan Syria India
50%–75%	Iraq	Thailand	–
>75%	–	Germany Mauritania Sudan	Egypt Niger Senegal

5.3 Scenario 2A: Population Growth (2025) and Food Self-Sufficiency

5.3.1 Methodology of projection

To estimate the effect of pursuing the policy objective of food self-sufficiency by the year 2025, the methodology and assumptions similar to those listed in Section 5.1.1 were followed. The food deficit was estimated by using the food requirements for the projected population level in 2025 under the assumption that all increased food demand would be met through increased irrigated area, subject to availability of cropland.

5.3.2 Distribution of various countries

Some countries in the world would have sufficient water to enable them to attain self-sufficiency in cereal products by the year 2025. However, for some, such a goal would be almost impossible to reach. Details are shown in *Tables 5.7* to *5.10*. In the North and South American continents (*Table 5.7*), countries that would face water stress/scarcity under this scenario include Barbados, Cuba, and Peru. Mexico will likely face marginal vulnerability. In the European continent (*Table 5.8*), the UK, Malta, Poland, Cyprus, Germany, Hungary, and Belgium belong to this category, although several other countries such as Turkey would require proper management of available water.

In the African continent (*Table 5.9*), North African countries and Sudan and Mauritania would face severe water shortages in an effort to reach a food self-sufficiency. A similar observation can be made about Middle Eastern countries (*Table 5.10*). Serious problems may also face the Indian subcontinent as the growing population would compete for available water resources directly or indirectly. China, another country with a large population, may also need proper water management policies for available water by the year 2025 in order to attain food self-sufficiency.

5.4 Scenario 3: Future Level of Industrial Development

5.4.1 Methodology of projection

Many countries with a fast-growing population may find another dilemma facing them. Water resources may be constraining not only due to direct demand by the masses of people, but also due to the growing water needs of various industries. In this scenario, a very moderate rate of industrial development was assumed to be pursued by various countries. Each country would experience 1 percent linear growth in the per capita gross national product (in real prices) until the year 2025. The technology of production was assumed to be unchanged from the 1990 level. Simulations were made under the assumption that the food self-sufficiency policy was not pursued.

Table 5.7. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 2025. North America, Central America, and South America.

Water availability per capita in m^3	Water use per capita in m^3						
	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	–	–	–	–	–
100–500	–	Barbados	Peru	–		–	–
500–1,000	–	Haiti	–	–	–	–	–
1,000–2,000	–	–	El Salvador	Dom. Rep.	–	–	–
2,000–5,000	–	Colombia	Trinidad	Jamaica	Cuba Mexico	–	–
5,000–10,000	–	–	Guatemala	Venezuela	Honduras USA	–	–
>10,000	–	Paraguay Uruguay	Bolivia Brazil	Costa Rica Ecuador Guyana Nicaragua Suriname	Argentina Canada Chile Panama	–	–

Table 5.8. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 2025. USSR and Europe.

Water availability	Water use per capita in m^3						
per capita in m^3	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	Malta	–	–	–	–
100–500	–	–	–	–	–	–	–
500–1,000	–	–	–	UK	Poland	Cyprus	–
1,000–2,000	–	–	CSFR Turkey	Belgium Germany Hungary	–	–	–
2,000–5,000	–	Albania	Denmark Yugoslavia	France Italy Spain	Romania	–	–
5,000–10,000	–	–	Austria	Greece Switzerland	Netherlands Portugal	–	–
>10,000	–	Iceland Ireland Luxembourg	Sweden	Finland Norway	USSR Bulgaria	–	–

Table 5.9. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 2025. Africa.

Water availability per capita in m^3	Water use per capita in m^3						
	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	–	–	Libya	–	–
100–500	Burundi Rwanda	Djibouti Malawi	Ethiopia Kenya	–	Tunisia	Algeria Cape Verde	–
500–1,000	Chad Comoros	Lesotho Tanzania	–	Niger Senegal Somalia South Africa	Egypt Madagascar Morocco	–	–
1,000–2,000	Benin Burkina Faso Uganda	Ghana Nigeria Togo	Mozambique Zimbabwe	Ivory Coast Mali	Sudan	–	Mauritania
2,000–5,000	Zaire	Zambia	Swaziland	–	–	–	–
5,000–10,000	Cameroon	Angola Botswana	–	–	–	–	–
>10,000	CAR Congo Eq. Guinea Gu. Bissau	Gambia Gabon	Sierra Leone	–	Guinea Liberia	–	–

Table 5.10. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 2025. Asia, Japan, and Pacific regions.

Water availability	Water use per capita in m^3						
per capita in m^3	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	Kuwait	Jordan	Qatar Saudia Arabia	Bahrain	–	–	–
100–500	–	Singapore	–	Israel Oman	Yemen (P)	UAE	–
500–1,000	–	Nepal	Lebanon	India	Iran	–	–
1,000–2,000	–	Vietnam	Korea (R) China	Sri Lanka Thailand	Afganistan Pakistan Korea (PR)	Iraq	–
2,000–5,000	–	–	Mongolia	Philippines Japan	–	–	–
5,000–10,000	–	Indonesia	–	–	–	–	–
>10,000	Bhutan Papua NG Solomon Is.	Fiji Laos Myanmar	Bangladesh Cambodia New Zealand	Malaysia	Australia	–	–

Table 5.11. Effect of industrial growth on regional vulnerability, in 2025.

Region	Country	Vulnerability status (* – @)
North America	–	
Central America	Cuba	2 – 3
	El Salvador	1 – 2
	Haiti	1 – 2
Northern South America	–	
Southern South America	–	
USSR	–	
Northern Europe	Belgium	3 – 4
Southern Europe	Turkey	1 – 2
Eastern Europe	CSFR	1 – 2
	Poland	2 – 3
Northern Africa	–	
Sahel Africa	Ethiopia	2 – 3
	Sudan	3 – 4
Central Africa	Uganda	1 – 2
Southern Africa	–	
Middle East Asia	–	
Southern Asia	–	
Eastern Asia	–	
Southeast Asia	–	
Japan	–	
Southwest Pacific	–	
Other Pacific	–	

(* – @) = Vulnerability before and after industrial development.
1 = Surplus.
2 = Marginal.
3 = Stress.
4 = Scarcity.

5.4.2 Distribution of countries

The distribution of countries by relative availability and use levels is shown in *Table 5.11.* Under this scenario, more industrialized countries experience water stress. However, according to the *Table 5.11*, very few countries become vulnerable through industrial activity. Two explanations could be given for this. One, industrial use is a relatively small proportion of the total. Two, some countries may reach a water stress level because of population growth, and therefore would not change their status as a result of industrial activity. Countries that appear to be particularly vulnerable under this scenario are Belgium, CSFR, Poland, and Turkey in Europe, and Ethiopia, Sudan, and Uganda in Africa.

Another aspect of water resources not considered in these projections is the deterioration of water quality – both surface water and groundwater. An increase in the level of industrial activity may lead to poor-quality water unless measures are taken to regulate the level of pollutants added by various industrial concerns. If water quality is considered, many of the industrialized countries would face water vulnerability under this scenario.

5.5 Global Climate Change Scenario

The effect of changing climate on water resources is one of the most difficult global environmental changes to assess. Problems arise because:

1. A changing climate may affect both availability and use.
2. A changing level of water availability would have an impact on water quality.
3. The distribution of climate-induced impacts would differ significantly from region to region.
4. The available results of climate models are not consistent with their predictions.

The last point can be illustrated with the help of the preliminary results for Egypt.[3] Various simulations of the Nile River flow, under a climate change scenario, have shown a range between 23 percent and 130 percent, depending upon which global climate change model is used. Similarly, evidence on another major impact of climate change – sea level rise – is also not conclusive. For these reason, this study followed a hypothetical "what if" type of projection.

5.5.1 Assumptions

Four attributes of climate change are particularly relevant in the context of regional vulnerability:

1. Changes in atmospheric variables, such as temperature, precipitation, and wind speed.
2. Inter-year variability in precipitation and temperature, leading to extreme events such as droughts and floods.
3. Intra-year variability in precipitation and temperature.
4. A rise in sea level.

The change in the atmospheric variables would affect the relationships that govern water needs, as well as river flow. Occurrences of droughts and floods can also alter a region's water availability and demands.

In this study, it was assumed that the total effect of climate change would be realized by the year 2025. Although most climate studies suggest that the likely time when these effects would be realized is 2060, population forecasts for this year are sketchy. However, this assumption, although not accurate, would provide us with an accurate impact on regional vulnerability, since if a country is vulnerable under climate change at its 2025 level of population, it is undoubtedly going to be vulnerable under the higher (2060) level of population.

In this study it was assumed that all regions of the world would face the same impact from a global climate change. On the availability of water, it was assumed that the warming earth would increase the evaporation, which would decrease availability by 10 percent of the 1990 level in all regions except those with a humid climate. In regions with a humid climate, water availability was assumed to increase by 10 percent.

On the use side, it was assumed that domestic use would increase by 5 percent; industrial use, by 5 percent; and agricultural use, by 20 percent. The slightly lower rate for industrial water use is due to the fact that some water is required in the process and, therefore, may not be affected by the climate change; part of the water for industrial use is recirculated and, therefore, may not be affected by climate change.

Two scenarios were simulated: (1) countries used agricultural water in a manner similar to Scenario 3, without food self-sufficiency; and (2) countries pursued the goal of food self-sufficiency by converting rain-fed cultivated areas into irrigated areas. Under both scenarios, population and industrial growth was assumed to be at the level of Scenario 3.

Caution is advised in the interpretation of results, since the impacts of climate change assumed in the study are hypothetical and may bear no resemblance to the situation in 2025 for various parts of the world. Nonetheless the results illustrate the challenge facing some countries under the assumed conditions.

5.5.2 Results on vulnerability of regions without food self-sufficiency

Because of decreases in available supply, many countries would face water related problems. Results for various study regions are shown in *Table 5.12*. Even if various countries do not pursue the goal of food self-sufficiency, a changing climate would create water-related problems for 47 countries, many of which are located in Middle East Asia, Northern Africa, Southern and Northern Europe, and Southern Africa. However, some regions, such as

Table 5.12. Relative water availability and use under the global climate change scenario, in 2025.

Study region	Per capita (m^3) Availability	Use	Use–availability ratio[a]	Use–availability ratio under food self-sufficiency
North America	12,926	2,799	22	22
Central America	3,426	850	25	32
Northern South America	20,777	148	1	2
Southern South America	16,276	326	2	8
USSR	10,396	690	7	24
Northern Europe	5,595	753	14	16
Southern Europe	2,187	432	20	40
Eastern Europe	2,862	558	20	45
Northern Africa	414	874	211	60
Sahel Africa	1,786	164	9	31
Central Africa	3,152	180	6	8
Southern Africa	984	307	31	48
Middle East Asia	580	1,653	85	66
Southern Asia	1,992	802	40	43
Eastern Asia	1,444	590	41	43
Southeast Asia	6,525	320	5	5
Japan	3,403	1,085	32	47
Southwest Pacific	22,089	1,285	6	6
Other Pacific	84,062	29	0	0

[a]Without food self-sufficiency.

the Northern South America, Southeast Asia, and other Pacific regions, are unaffected in terms of vulnerability to water resources.

Although as an aggregate large continental countries, such as Canada, the USA, and the former USSR, seem to escape the brunt of climate change, many regions within these countries may become more vulnerable. For example, the prairie region of Canada and the midwestern states and California in the USA show signs of water stress or even scarcity under this scenario. Similarly, the newly created nations of Armenia, Moldavia, Azerbaijan, and the Ukraine may become water vulnerable regions.

5.5.3 Scenario 4A: Vulnerability of regions with food self-sufficiency

With the food self-sufficiency goal, as shown in *Table 5.12*, water-related problems may arise in several regions. Regions with a significant increase in the use–availability ratio include Central America, the USSR, Europe

(Southern and Eastern), Sahel Africa, and Japan. In these regions, food self-sufficiency may be attained but perhaps at a high price.

In addition to a warming climate, occurrences of extreme events, particularly droughts, may prevent the achievement of food self-sufficiency in many regions. The timing and the amount of precipitation can be important determinants of whether the goal of food self-sufficiency is realized.

The current situation and the situation under a climate change are presented in *Figures 5.6* and *5.7*, respectively. Under current conditions, water is constraining economic activity in only a few countries. This situation is markedly different from that in the year 2025 when countries face population growth, increased industrial activity, and climatic changes. The countries that are most vulnerable are in Northern Africa and the Middle East. However, many regions in Asia and Africa are also vulnerable under a climate change.

Notes

[1] Theoretically, such an assumption is not totally correct, because food production requires inputs, some of which are produced by nonagriculture industries. As food production increases, the demand for farm inputs would also increase. This, in turn, will increase the use of water for industrial purposes.

[2] In reality, this assumption is not very practical. We have ignored the possibility that not all lands may be irrigable and, furthermore, there may not be adequate financial resources to develop irrigation projects.

[3] Based on personal communications with Professor Ken Strzepek, University of Colorado, Boulder.

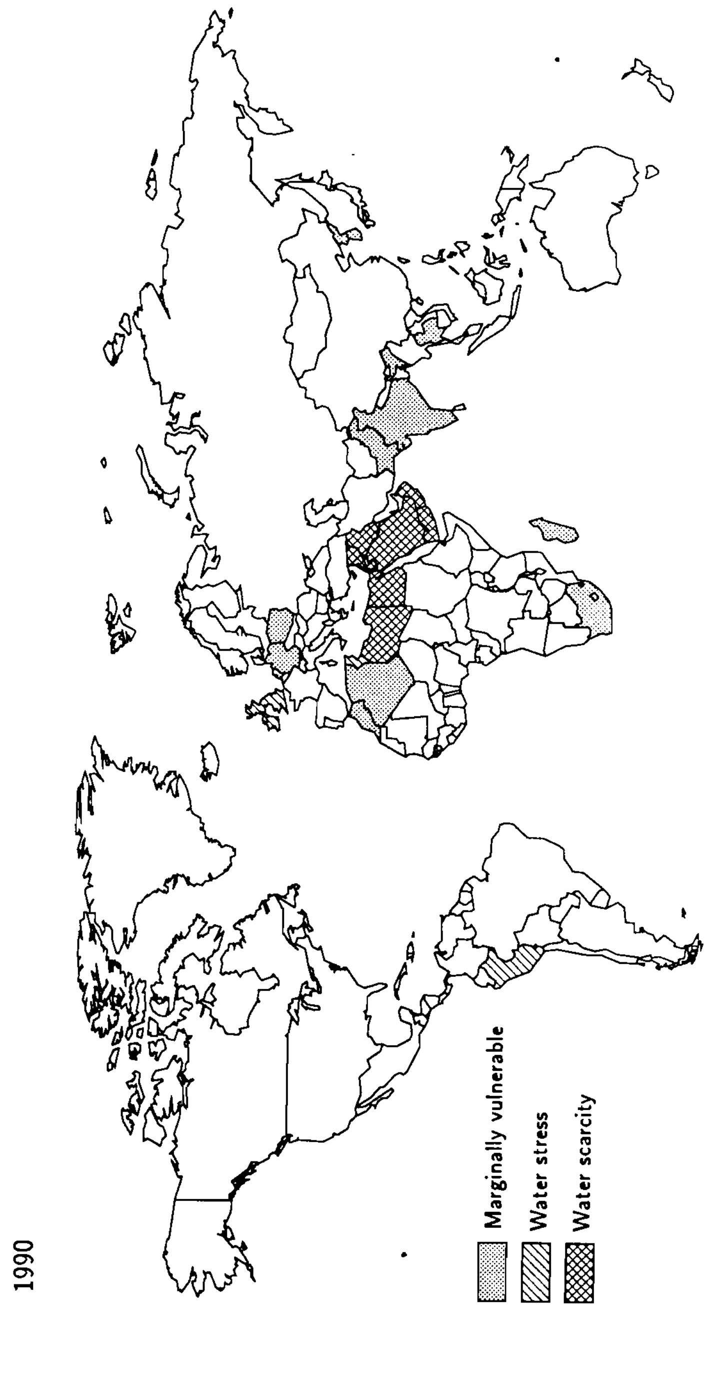


Figure 5.6. A map of the world showing vulnerability of various countries, in 1990.

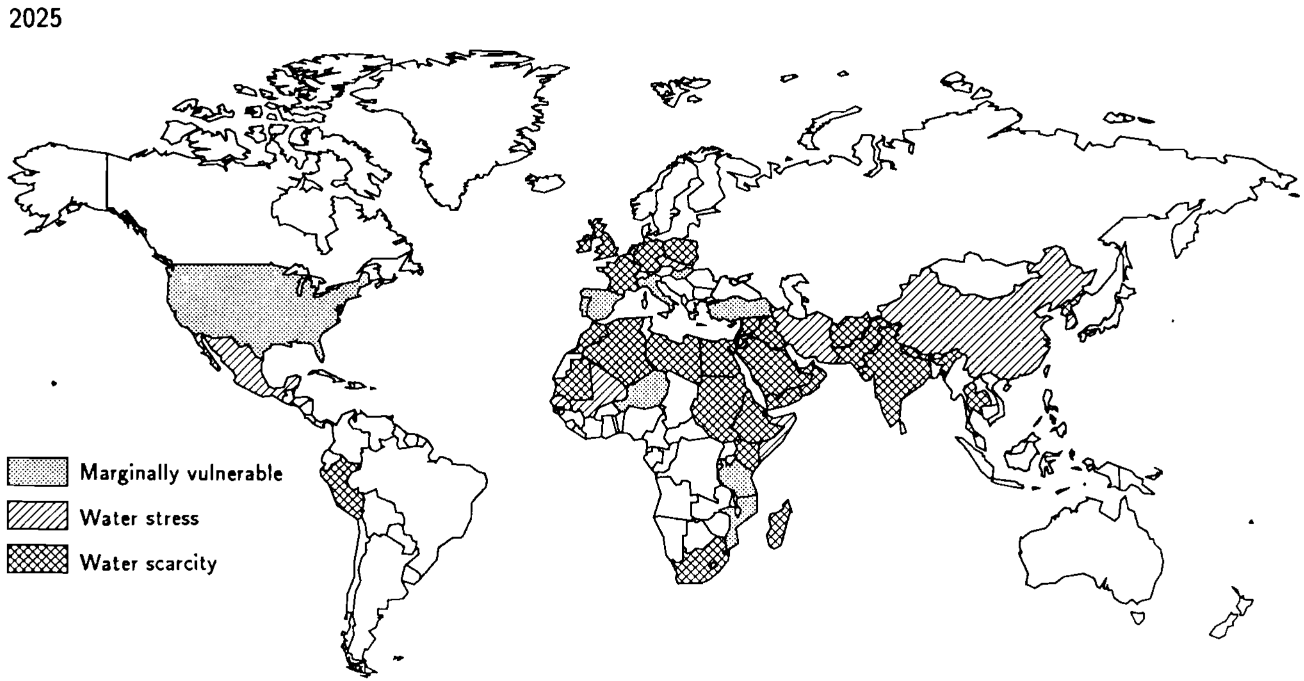


Figure 5.7. A map of the world showing vulnerability under Scenario 4 (population growth, industrial development, and climate change), in 2025.

Chapter 6

Summary and Conclusions

Water is not a ubiquitous resource. Its availability seldom coincides with its use. As a result many countries have already begun to experience water shortages. Meanwhile, future changes in economic and global conditions are expected to have significant implications on the future state of vulnerability of a region to water resources.

6.1 Study Methodology

In this study, changes in population, industrial activity, and the global climate were examined. In addition, the goal of food self-sufficiency is also important in some countries, so this was also considered explicitly in the analysis. This resulted in a total of seven scenarios:

- Base Scenario: 1990 situation.
- Scenario 1: 1990 situation with the goal of food self-sufficiency.
- Scenario 2: 2025 situation, population change only.
- Scenario 2A: 2025 situation, population change with the goal of food self-sufficiency.
- Scenario 3: 2025 situation, population change and industrial growth.
- Scenario 4: climate change.
- Scenario 4A: climate change with the goal of food self-sufficiency.

Four scenarios (including the base scenario) study the continuation of the current food situation, and three scenarios treat a situation in which water is used to augment cereal production to fill the cereal trade deficit.

A total of 145 countries were examined under each scenario, with respect to water availability as well as its use. These countries were grouped into 19 regions, based on climate, economic activity, and economic environment (centrally planned economies vs. market economies). This information was used to determine if the country would become vulnerable under a given scenario.

The vulnerability in this context is defined as the ability of the country to maintain socioeconomic activity at the present level. In other words, if a region is vulnerable, its ability is limited under the present trends in water use. The vulnerability was measured by availability and use on a per capita basis. On this basis, a country was classified into one of the four categories:

1. Water surplus.
2. Marginal vulnerability to water.
3. Water stress.
4. Water scarcity.

Under a water surplus status, the country is able to carry out its desired socioeconomic policies without a significant strain on water resources. In the second category the country faces occasional shortages but through management measures it is able to alleviate these water shortages. However, in the last two cases, it may not be possible to alleviate water shortages through such measures. Water stress limits a country's ability to pursue certain types of socioeconomic activities, particularly in years of low supply. Under the water scarcity condition, the country's water use does not meet the criteria of sustainability over a long period of time.

6.2 Vulnerability of Regions: Summary of Results

Using this set of criteria, the 145 countries in the study as well as the 19 study regions were evaluated with respect to their vulnerable status.

6.2.1 North and Central American regions

An overview of water availability and use for the North and Central American regions is shown in *Figure 6.1*. As a whole, both regions do not face serious vulnerability problems. However, different countries within these regions are heterogeneous in term of both availability and use. A country-by-country summary is given in Appendix E (*Table E.1*). Countries such as the USA in North America and Mexico and Barbados in Central America are relatively more vulnerable to water availability particularly under a global climate change scenario. Food self-sufficiency is not a major issue in these two regions. Barbados, partly due to lower per capita availability of

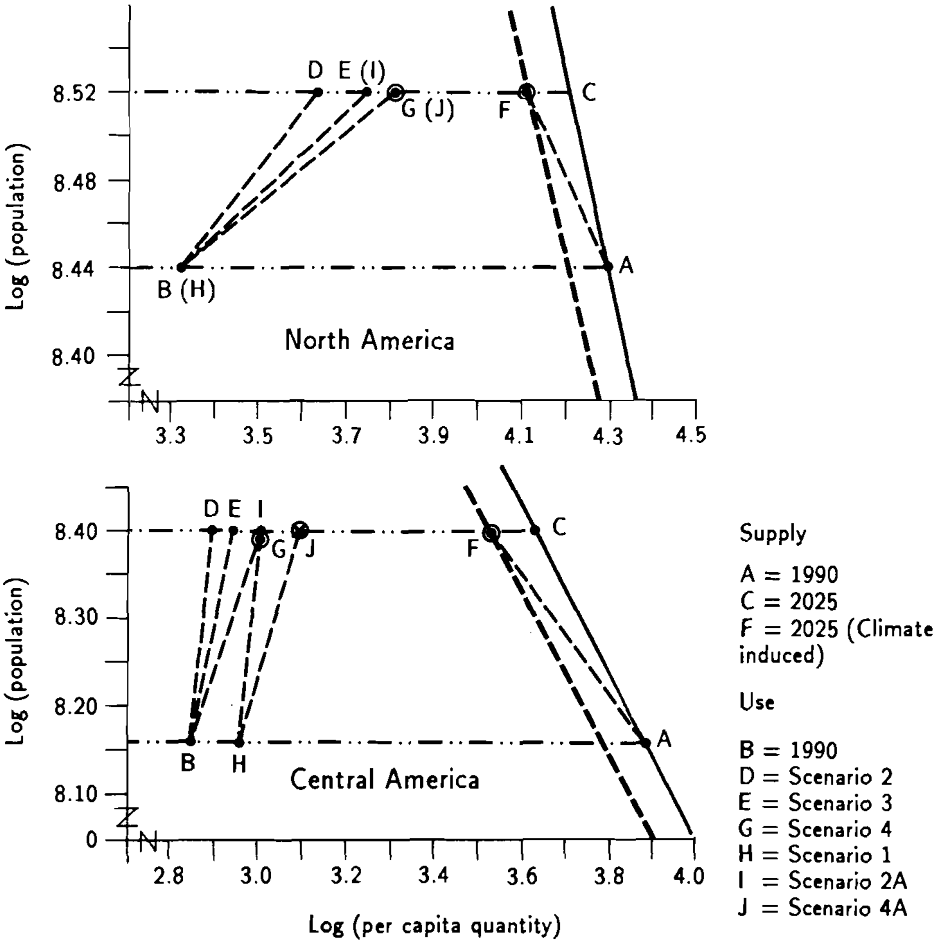


Figure 6.1. Water availability and use under different scenarios in North America and Central America.

water, becomes vulnerable by the year 2025 in all of the future scenarios. A further caveat should be added to these results. Although the country as a whole may be designated to have a certain vulnerability status, it does not imply that the entire country faces the same conditions.

6.2.2 South American regions

The two South American regions – Northern and Southern South America – do not face any severe problems now or under any of the scenarios included in the study. As shown in *Figure 6.2*, the distance between use and availability (at a per capita level) is large enough so that most countries would not face any water availability-related problems. The only exception to this is

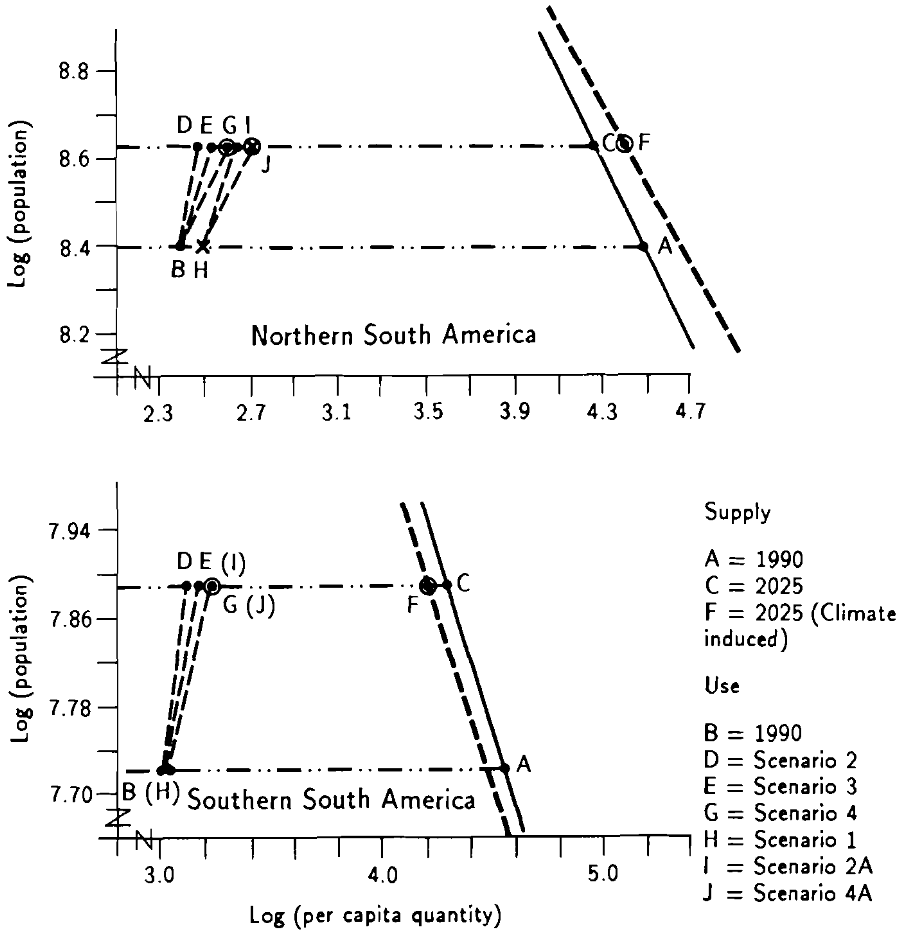


Figure 6.2. Water availability and use under different scenarios in Northern South America and Southern South America.

Peru, where a water stress situation already exists (*Table E.2*). The situation turns into water scarcity under all of the future scenarios. Overall, these two regions are the least likely ones to face any major water-related problems.

6.2.3 USSR

Water availability and its use on a per capita basis in the former USSR is shown in *Figure 6.3*. Under all seven scenarios, the country shows an overall rating of water surplus. However, availability of water differs significantly from one region to another in this large country. To illustrate this point, per capita runoff in the European part of the USSR was estimated by L'vovich (1979) at 6.23 m^3. In contrast the Asian part had a runoff of only 3.91 m^3.

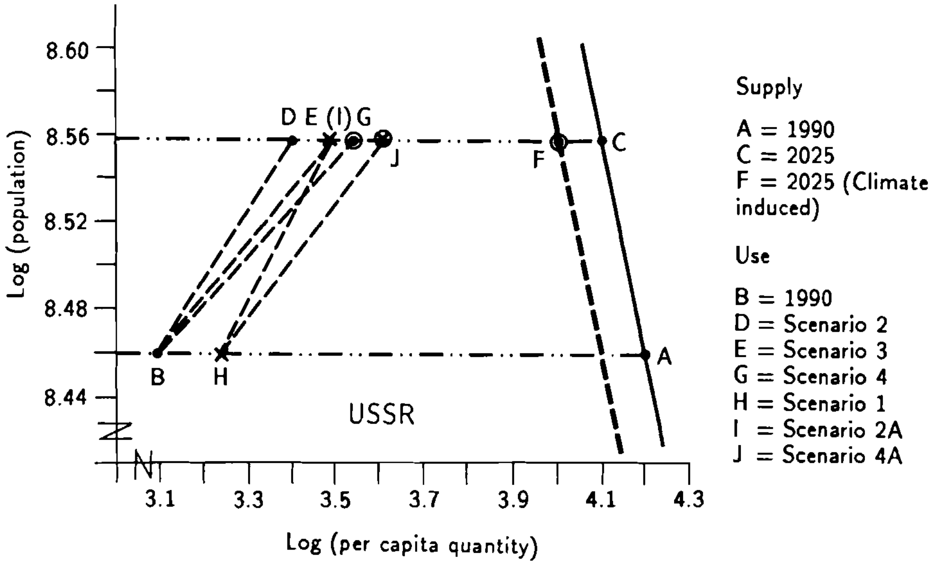


Figure 6.3. Water availability and use under different scenarios in the USSR.

Thus, under some scenarios, it is conceivable that the European part of the USSR, and/or some of the newly created states, such as Armenia, Moldavia, Azerbaijan, and the Ukraine, may be facing water-related problems in the future.

6.2.4 European regions

The three European regions exhibited very different types of vulnerability under various scenarios. Recent studies have shown that Northern Europe is experiencing a decline in population growth. As a result of this phenomenon water availability in 2025 may stay at the present level. An overview of the three regions is presented in *Figure 6.4*. Of the three regions, the Eastern European region is expected to face the most serious water-related problems, while Southern Europe follows close behind. Details on country-by-country vulnerability of the three regions are shown in *Table E.3*. In Northern Europe, Belgium, Germany, the Netherlands, and the United Kingdom are the countries most vulnerable to water resources, due in part to higher levels of industrial activity. In the Southern Europe, Cyprus, Turkey, and Malta, to a major extent, and Italy, France, and Spain, to a minor extent, are the most vulnerable. Among all the Eastern European countries, Poland and

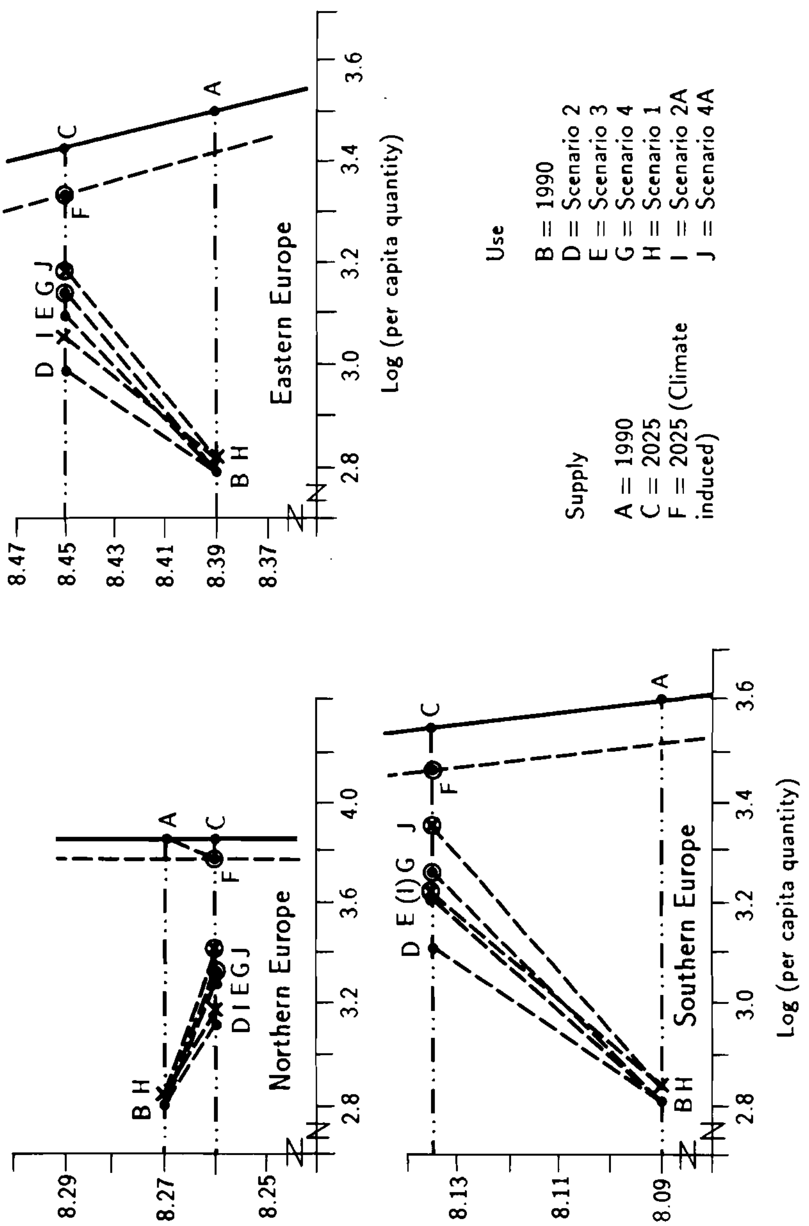


Figure 6.4. Water availability and use under different scenarios in Europe.

the CSFR appear to be the most likely candidates for vulnerability to water resources.

One caveat that should be added to these results is that the analysis excluded any considerations of water quality. In heavily industrial regions of Europe, water quality may become an important limiting factor, which will eventually affect water supply, and through that the vulnerability of a region.

6.2.5 African regions

The African regions exhibit contrasting results. An overview of the four African regions is shown in *Figure 6.5.* Food production and self-sufficiency in food is a major issue in Northern Africa. Available water resources, even at present, are not adequate for this region to attain food self-sufficiency.

An analysis of individual countries, as shown in *Table E.4*, reveals that, at present, in Northern Africa only Egypt and Libya are experiencing water shortages; however, by the year 2025 all countries in the region would experience such shortages.

In Sahel Africa, regions that are most vulnerable to water include: Cape Verde, Ethiopia, Mali, Mauritania, Niger, Somalia, and the Sudan. For all of these countries, food self-sufficiency cannot be attained due to a lack of water availability and the current use of water in irrigation technology.

In the Central African region, Kenya, Madagascar, and Mauritius appear to be the countries most likely to face water stress and/or scarcity. Two of these countries are islands and have obvious limitations to water availability. Tanzania appears vulnerable under a global warming. Except for the Republic of South Africa, all countries in the Southern African regions would either have a surplus of water or face water management problems.

Food security is a major water-resource related issue. About a third of the African population lives in the countries of the drought-prone crescent of the semi-arid tropics, where part of the year is dry and the growing season is too short for reliable rain-fed production (Falkenmark, 1989, p. 187).

6.2.6 Japan

Japan would continue to be relatively less vulnerable than other Asian countries under various scenarios. At present, the use–availability ratio of less than 40 percent is maintained under the future scenarios. As shown in *Figure 6.6*, even food self-sufficiency is attainable given the availability of water. However, marginal vulnerability to water may be experienced under global warming.

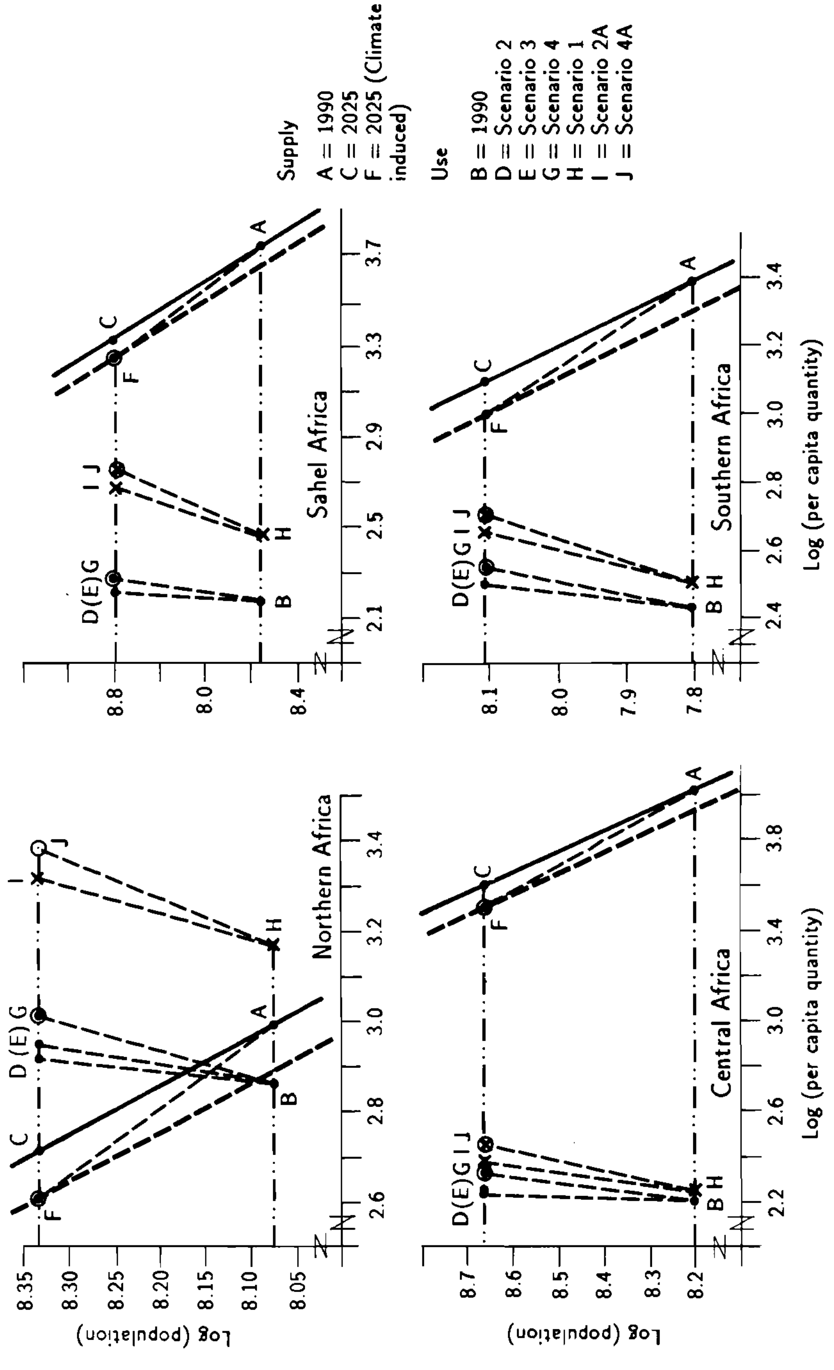


Figure 6.5. Water availability and use under different scenarios in Africa.

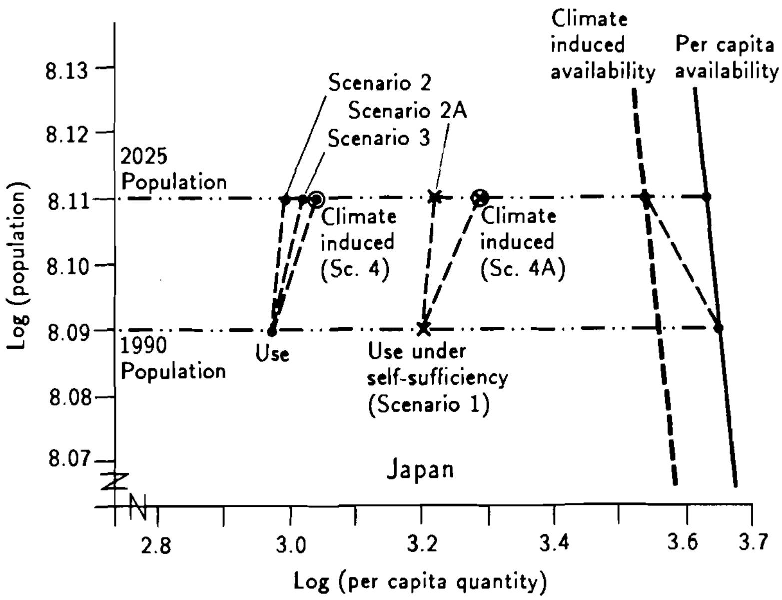


Figure 6.6. Water availability and use under different scenarios in Japan.

6.2.7 Asian regions

In the Asian regions, one observes a vast contrast between different regions. On one extreme is the Middle East region, which, as shown in *Figure 6.7* and *Table E.5*, is already using water beyond what is available on an annual basis. Some of this is through the overuse of groundwater aquifers.

In Southern Asia, rapid population growth creates a situation of water scarcity by 2025 for India and Pakistan. In Eastern Asia, except for the People's Republic of Korea, various countries do not face water stress, except under the climate change scenario. In the Southeast Asian region, water availability is ample except for Singapore which starts to experience water shortage by the year 2025 under all future scenarios.

6.2.8 Pacific regions

Both the South and other Pacific regions enjoy an ample supply of water and will continue to do so in the future. Even under a global warming, the use–supply ratio is relatively very small. An overview of these regions is shown in *Figure 6.8*.

The results of this study support the hypothesis that the regions that are at greatest risk are those that are already arid and/or marginally vulnerable.

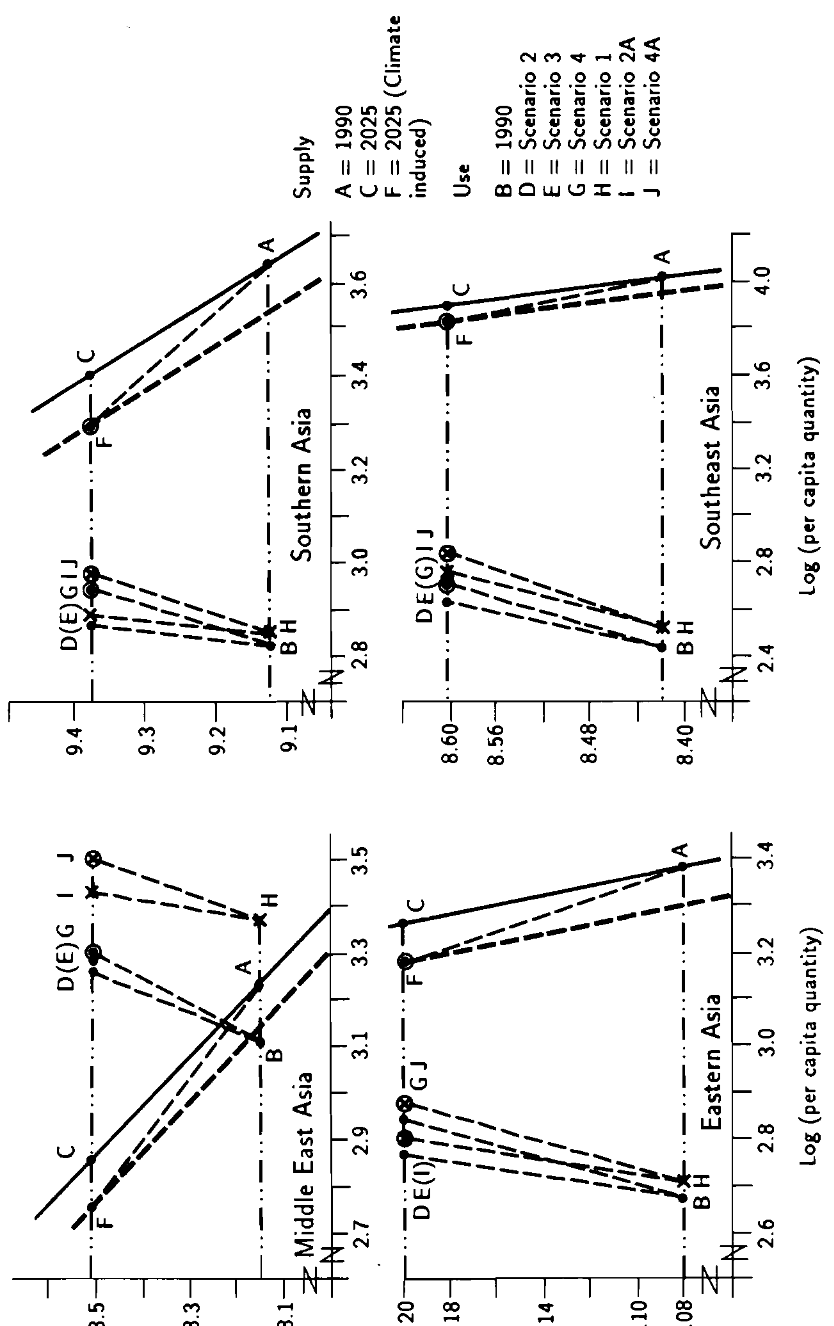


Figure 6.7. Water availability and use under different scenarios in Asia.

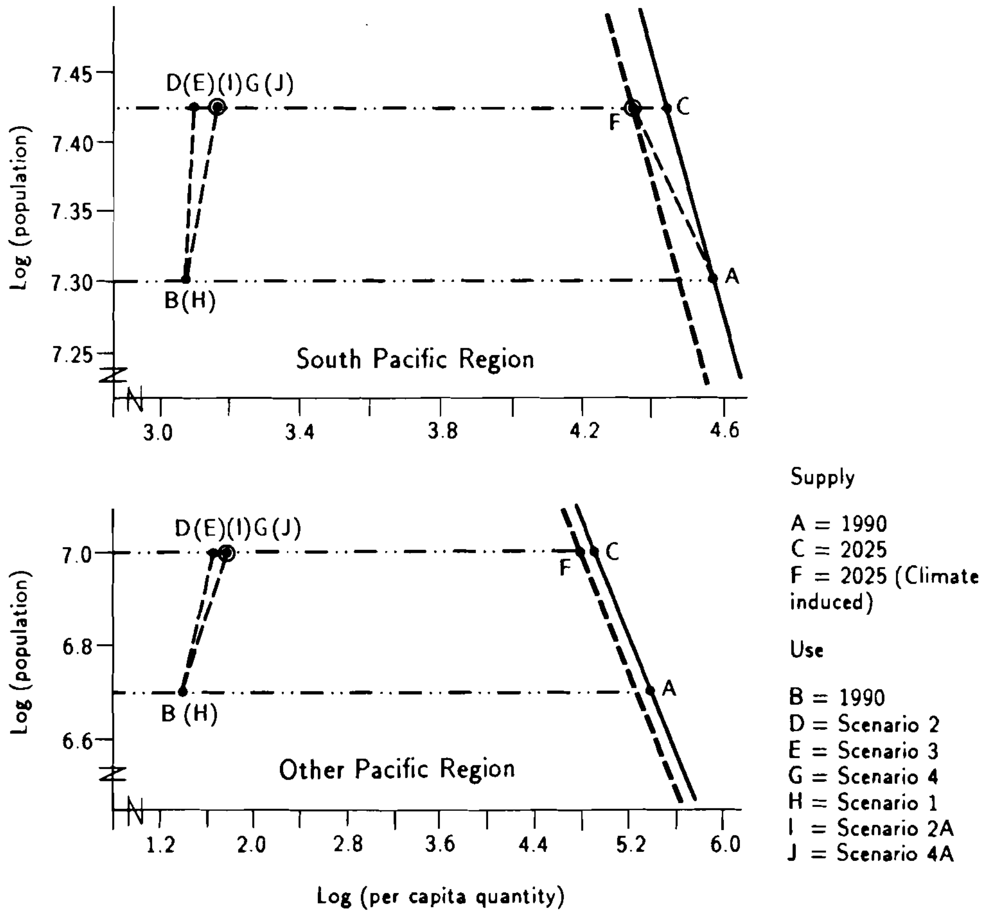


Figure 6.8. Water availability and use under different scenarios in the South Pacific and other Pacific regions.

However, the discussion of vulnerability of a region to water resources would not be complete without a further caveat. The state of vulnerability is not an absolute one; in this manner, water should not be treated as a barrier to growth. Undoubtedly, there would be opportunities for adaptation to these changing situations through technology, education and training, and proper water management policies.

6.3 Ranking of Global Changes

Three types of global changes were examined in this study: population growth, industrial development, and global climate change. In addition,

Table 6.1. Change in world population affected by degree of vulnerability to water, under food self-sufficiency.

	Change relative to base scenario (million people)	
Degree of vulnerability	1990[a]	2025[b]
Surplus	−294	−391
Marginal	−74	−110
Stress	−250	+175
Scarcity	+118	+106

[a]Scenario 1 minus base scenario.
[b]Scenario 2A minus base scenario.

a policy goal of food self-sufficiency was added to this list. Which one of these changes would bring more vulnerability to various countries? This issue is examined in this section.

6.3.1 Food self-sufficiency

To what extent would world water resources become a constraint to achieving food self-sufficiency by various countries? The answer to this question is presented in *Table 6.1* in terms of the number of inhabitants affected. The comparison is made for both 1990 and 2025. In 1990, the magnitude of the population affected by vulnerability to water resources is relatively small. In 2025 there would be 391 million fewer people living in countries with a water surplus than there were living in those countries in 1990, if the policy of food self-sufficiency is pursued. Many of the regions affected would become water stress regions, and some may even face water scarcity. At least 280 million more people would reside in countries facing marginal vulnerability to water.

By 2025, if various countries were to pursue the goal of food self-sufficiency, countries with a combined population of 390 million would not have surplus water resources. In fact, countries with another 175 million people would face water stress. However, if we view these numbers in terms of a total population of 5.28 billion in 1990, and 8.45 billion by 2025, the magnitude of population affected by the goal of food self-sufficiency is rather small. Thus, water may be a constraint to achieving food self-sufficiency in some countries, but it will affect only less than 4 percent of the world population by the year 2025.

This is not to suggest that many countries would not face other problems in trying to attain food self-sufficiency. Land use, declining land productivity, droughts, and soil degradation, including desertification, could become more constraining to achieving food self-sufficiency than availability of water.

Table 6.2. Change in the world population by degree of vulnerability to water, by scenarios, in 2025.

	Change in no. of people[a] (million people) over 1990 base scenario under:		
Degree of vulnerability	Population growth[b]	Population, industrial dev.[c]	Global climate change[d]
Surplus	+1,414	+1,312	−660
Marginal	−852	−991	−677
Stress	+215	+325	+1,628
Scarcity	+2,393	+2,524	+2,879

[a]No food self-sufficiency.
[b]Scenario 2 minus base scenario.
[c]Scenario 3 minus base scenario.
[d]Scenario 4 minus base scenario.

6.3.2 Population growth

Rapid population growth in many countries would bring forth a situation of water stress and water scarcity. This conclusion can be drawn from the data in the second column in *Table 6.2.* Relative to the 1990 situation, there would be at least 2.5 billion more people living in countries that would face water stress or scarcity under this scenario in 2025. This is almost 34 percent of the projected 2025 world population. Marginal vulnerability problems would also be faced by some countries, affecting a combined population of some 800 million individuals, directly or indirectly. This is not to suggest that all these people will be affected by the shortages of water, since the distribution of availability of water within the country may not be uniform. However, under present trends of water use and population growth, vulnerability to water resources would be faced by a much larger region and/or population in 2025 than at present.

6.3.3 Industrial growth

Would pursuing a path of industrial growth in light of growing population be possible given available water resources? The answer to this question is presented in the third column in *Table 6.2.* Indications are that industrial development (with population growth) may create marginal vulnerability for countries with a combined population in 2025 of almost 1 billion more than the population in 1990. The marginal effect of industrial growth is shown in the third column of *Table 6.3.* Thus, countries with a combined population of 240 million would face water stress, some of which may already have been faced with marginal vulnerability to water.

Table 6.3. Marginal change in world population by degree of vulnerability to water, selected scenarios, in 2025.

	No. of people (millions)		
		Marginal change over population scenario	
Degree of vulnerability	Population only[a]	Industrial development[b]	Global climate change[c]
Surplus	+1,414	−102	−2,074
Marginal	−852	−139	−174
Stress	+215	+110	+1,413
Scarcity	+2,393	+131	+486

[a]Scenario 2 minus base scenario.
[b]Scenario 3 minus Scenario 2.
[c]Scenario 4 minus Scenario 2.

Table 6.4. Change in world population affected by degree of vulnerability to water, under food self-sufficiency goals, by scenario.

	Change in population (millions) by 2025	
Degree of vulnerability	Population growth[a]	Global climate change[b]
Surplus	+1,257	−877
Marginal	−668	−492
Stress	+140	+1,672
Scarcity	+2,441	+2,867

[a]Scenario 2A minus Scenario 1.
[b]*Scenario 4A minus Scenario 1.

6.3.4 Global climate change

Many countries would experience water availability problems under a global-warming trend, particularly under current population projections and a moderate program of industrial growth. Compared to the present situation, global warming could affect a total population of 4.5 billion by creating either a water scarcity situation or a water stress situation (*Table 6.2*). Fewer and fewer countries would be in a water surplus situation or situations that can be handled through water management. On a marginal basis, climate change would contribute to vulnerability of countries with a combined population of 2 billion more than that already caused by population growth. If one were to attain food self-sufficiency, the situation would be even more constraining for some region. As shown in *Table 6.4*, an additional (over the 1990 situation) 4.5 billion people would be experiencing water stress or water scarcity.

Table 6.5. Distribution of total world population by degree of vulnerability to water under alternative scenarios.

Degree of vulnerability	1990 base	2025 pop.	2025 population, industrial dev.	2025 pop., industrial dev., clim. ch.
No food self-sufficiency				
Surplus	70	60	60	35
Marginal	24	6	4	7
Stress	3	4	6	21
Scarcity	3	30	30	37
Total	100	100	100	100
Under food self-sufficiency				
Surplus	64	55	–	30
Marginal	24	7	–	9
Stress	8	6	–	24
Scarcity	4	32	–	37
Total	100	100	–	100

6.4 Conclusion

About two-thirds of the population of the world will become more vulnerable to availability and use of water under current projections of population growth and climate change. As shown in *Table 6.5*, the present situation is such that about 70 percent of the world population lives in countries which enjoy a surplus of water. By the year 2025, this proportion will be reduced to between 35 and 60 percent depending on the scenario.

The magnitude of population growth, as well as a comparative overview, is presented in *Figure 6.9.* Under population growth, more countries (with more people) would face water management problems and/or water stress, but under global climate change (and population growth and industrial growth) the situation changes and even more people will face a situation of water stress or water scarcity.

Which regions would become more vulnerable to water resources? The answer to this question is shown in *Table 6.6.* At present, Northern Africa and the Middle East are already facing water scarcity and/or stress. The situation gets more acute for these regions and for Northern Europe, Southern Asia, and some countries in Eastern Europe and Southern Africa. The continuation of industrial growth in light of projected population and under global climate change may be limited in regions such as North America, Central America, and Eastern Asia.

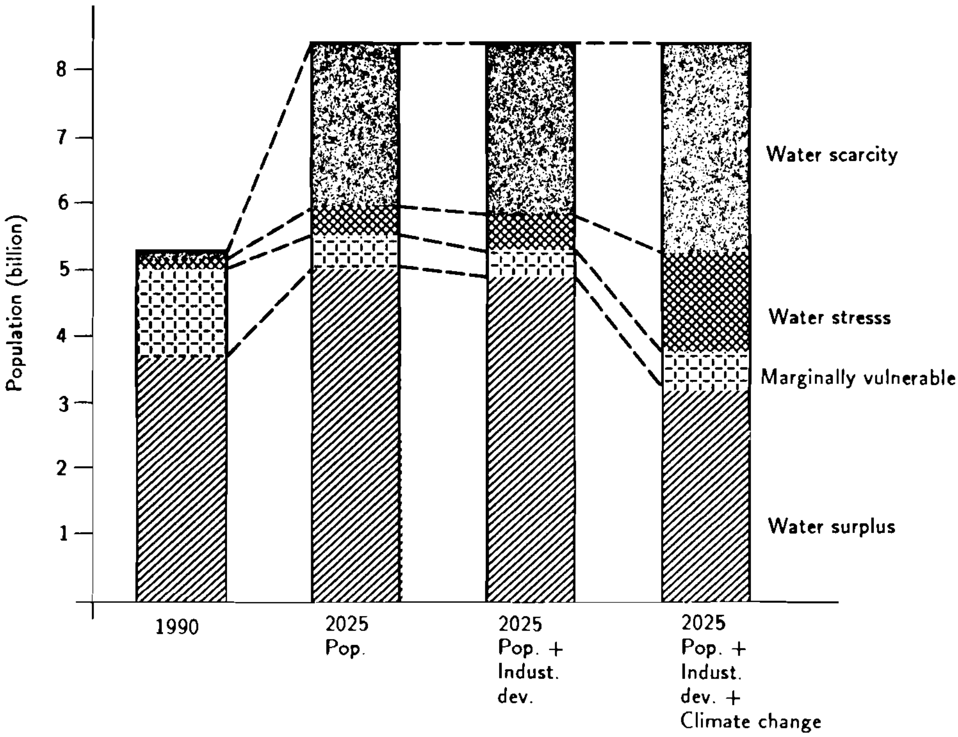


Figure 6.9. World population growth by degree of vulnerability to water, under selected scenarios.

6.5 Implications of Results and Areas for Future Research

Results of this study indicate that unless appropriate measures are adopted, many countries, and the masses of people residing therein, would be experiencing water availability-related problems. In some situations, the conditions may be chronic. Appropriate water management policies, including demand management measures, would need to be adopted in many of these regions before the situation turns unmanageable. Even in the absence of climate change, competition for available water will increase in many countries of the world. In some situations, given the current projections of population for the future, visions of accelerated industrial and water-dependent economic development may have to be curtailed.

Since irrigation is a major user of water in many of these countries, and since it is also associated with another delicate subject (food self-sufficiency),

Table 6.6. Proportion of populations facing water stress and/or scarcity, under selected scenarios.

		2025 scenario	
Study region	Base 1990	Population	Population, clim. change
North America	0	0	0
Central America	0	0	69
Northern South America	9	5	5
Southern South America	0	0	0
USSR	0	0	0
Northern Europe	36	76	76
Southern Europe	0	0	1
Eastern Europe	0	0	45
Northern Africa	55	100	100
Sahel Africa	0	14	31
Central Africa	0	24	24
Southern Africa	0	48	48
Middle East Asia	96	100	100
Southern Asia	0	78	78
Eastern Asia	0	2	100
Southeast Asia	0	1	1
Japan	0	0	0
Southwest Pacific	0	0	0
Other Pacific	0	0	0
Total world	6	34	58

more effort would have to be channeled to improving the efficiency of agricultural water use. Different types of irrigation systems produce different levels of water use efficiency. Although some trade-offs between cost of installing a system and its water conservation potential exist, through proper economic and other management instruments, the gap between demand and supply of water can be closed.

The notion that water is a "free good" and a free gift of nature is almost outdated now. Within the formulation and application of supply–demand interdependence a transition is needed from purely physical terms toward more complex and influential solutions wherein the physical measures of water availability and use are supplemented.

Before, however, undertaking development of demand management measure, further study of each country's situation needs to be carried out. As noted earlier in this report, this study used secondary data, some of which are outdated. Use of countrywide aggregates may have also masked the region's (within a country) water vulnerability. An appropriate unit of measurement for such a study is a river basin. This should be the topic of a future study of water availability and use.

Three important aspects of water management were not included in this study: quality of water; inter-year variability in water supply; and intra-year (seasonal) variability in water use and availability in a river basin. Knowledge of these three aspects and their interaction with each other would provide a better basis for developing sound demand management measures than those based on quantity alone. These factors may be further conditioned by the spatial distribution of water resources within a river basin.

The impact of global climate change on water resources is also an area which deserves future research activity. In particular, water use and its interrelationships with climate change have been a relatively unresearched area.

A future study of vulnerability should also relate water systems with demographic, economic, and social systems in a country. Interrelationships among various river basins should also be examined, and, through that, areas where conflicts among water users may arise should be identified. Some of these conflicts may occur in large metropolitan regions which would develop under future population growth. Conflicts would develop not only because of limited water resources, but also from other related problems, such as land use and environmental degradation. A study of the dynamics of the interrelationships among water, food, and energy systems under a changing environment (economic and noneconomic) is a topic that should be given a high priority in future research.

In interpreting the results of this study, readers are reminded of the limitations of the data (and the ensuing conclusions) used in the study, i.e., use of countrywide averages as opposed to river (catchment) basin data; use of annual averages as opposed to seasonal data; use of secondary (aggregated) data; and exclusion of water-quality considerations.

Appendix A: Regionalization of the World

Table A.1. List of countries by study regions.

Region	Name	Countries included	
1	North America	Canada[b]	USA[a]
2	Central America	Barbados[g]	Honduras[e]
		Costa Rica[e]	Jamaica[d]
		Cuba[d]	Mexico[d]
		Dominican Republic[a]	Nicaragua[d]
		El Salvador[d]	Panama[d]
		Guatemala[e]	Trinidad[d]
		Haiti[a]	
3	Northern South America	Bolivia[a]	Guyana[e]
		Brazil[a]	Peru[a]
		Colombia[a]	Suriname[a]
		Ecuador[a]	Venezuela[e]
4	Southern South America	Argentina[a]	Paraguay[a]
		Chile[d]	Uruguay[a]
5	USSR	USSR[b]	
6	Northern Europe	Belgium[b]	Luxembourg[c]
		Denmark[c]	Netherlands[b]
		Finland[b]	Norway[b]
		Germany[b]	Sweden[b]
		Iceland[a]	UK[b]
		Ireland[e]	
7	Southern Europe	Austria[b]	Malta[c]
		Cyprus[a]	Portugal[b]
		France[a]	Spain[a]
		Greece[b]	Switzerland[b]
		Italy[b]	Turkey[b]
8	Eastern Europe	Albania[e]	Poland[b]
		Bulgaria[b]	Romania[b]
		CSFR[b]	Yugoslavia[b]
		Hungary[b]	
9	Northern Africa	Algeria[b]	Morocco[a]
		Egypt[a]	Tunisia[a]
		Libya[a]	

[a]1987. [b]1980–1982. [c]1976–1979. [d]1974–1975. [e]1970–1972. [f]1965. [g]1960.

Table A.1. Continued.

Region	Name	Countries included	
10	Sahel Africa	Benin[a]	Guinea Bissau[a]
		Burkina Faso[a]	Ivory Coast[a]
		Cameroon[a]	Liberia[a]
		Cape Verde[e]	Mali[a]
		Central African Republic[a]	Mauritania[c]
		Chad[a]	Niger[a]
		Djibouti[e]	Nigeria[a]
		Equatorial Guinea[a]	Senegal[a]
		Ethiopia[a]	Sierra Leone[a]
		Gambia[b]	Somalia[a]
		Ghana[e]	Sudan[c]
		Guinea[a]	Togo[a]
11	Central Africa	Angola[a]	Malawi[a]
		Burundi[a]	Mauritius[d]
		Comoros[a]	Rwanda[a]
		Congo[a]	Tanzania[e]
		Gabon[a]	Uganda[e]
		Kenya[a]	Zaire[a]
		Madagascar[a]	Zambia[e]
12	Southern Africa	Botswana[b]	South Africa[e]
		Lesotho[a]	Swaziland[a]
		Mozambique[a]	Zimbabwe[a]
13	Middle East Asia	Bahrain[d]	Oman[d]
		Iran[d]	Qatar[d]
		Iraq[e]	Saudi Arabia[d]
		Israel[a]	Syria[c]
		Jordan[d]	UAE[b]
		Kuwait[d]	Yemen (R)[a]
		Lebanon[d]	Yemen (PR)[d]
14	Southern Asia	Afganistan[a]	Myanmar[a]
		Bangladesh[a]	Nepal[a]
		Bhutan[a]	Pakistan[d]
		Cambodia[d]	Sri Lanka[e]
		India[d]	Thailand[a]
		Laos[a]	Vietnam[a]
15	Eastern Asia	China[b]	Korea (R)[a]
		Korea (PR)[a]	Mongolia[a]
16	Southeast Asia	Indonesia[a]	Philippines[d]
		Malaysia[d]	Singapore[d]
17	Japan	Japan[b]	
18	Southwest Pacific	Australia[d]	New Zealand[b]
19	Other Pacific	Fiji[a]	Papua N. Guinea[a]
		Solomon Islands[a]	

Appendix B: Per Capita Supply and Use of Water, by Country and Study Region, in 1990

Table B.1. Availability and use of water per capita, in 1990. North America, Central America, Northern South America, and Southern South America.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
North America						
Canada	109472	270	1051	180	1501	1.4
USA	9944	259	994	908	2161	21.7
Central America						
Barbados	166	27	21	4	52	30.6
Costa Rica	32667	31	55	693	779	2.5
Cuba	3349	78	17	773	868	25.9
Dom. Rep.	2777	23	27	403	453	16.3
El Salvador	3576	17	10	215	242	6.7
Guatemala	12609	13	24	103	140	1.1
Haiti	1692	11	4	31	46	2.7
Honduras	20000	20	25	462	507	2.5
Jamaica	3320	11	11	135	157	4.7
Mexico	4034	54	54	775	883	22.3
Nicaragua	44872	93	78	200	371	0.8
Panama	60000	89	82	573	744	1.2
Trinidad	3923	40	57	52	149	3.8
Northern South America						
Bolivia	26849	91	36	85	212	0.7
Brazil	44368	18	9	156	183	0.5
Colombia	4497	73	29	77	179	4.0
Ecuador	29074	39	17	505	561	1.9
Guyana	59000	76	0	686	762	1.3
Peru	717	44	26	212	282	41.0
Suriname	50000	71	59	1051	1181	0.2
Venezuela	16751	166	43	178	387	2.3
Southern South America						
Argentina	48010	95	191	773	1059	3.5
Chile	31710	98	81	1446	1625	8.9
Paraguay	137777	17	8	86	111	0.2
Uruguay	46800	14	8	219	241	0.6

Table B.2. Availability and use of water per capita, in 1990. USSR and Europe.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
USSR	15861	80	386	865	1331	8.4
Northern Europe						
Belgium	1262	101	779	37	917	72.6
Denmark	2549	83	75	119	277	10.9
Finland	22000	93	658	23	774	3.5
Germany	1472	69	448	126	643	43.8
Iceland	566666	108	220	21	349	0.1
Ireland	36486	22	100	14	136	0.4
Luxembourg	12500	70	75	22	167	1.3
Netherlands	6081	50	612	34	696	16.5
Norway	97143	98	352	39	489	0.5
Sweden	20964	172	263	43	478	2.3
UK	615	101	390	15	506	82.4
Southern Europe						
Austria	6840	79	304	33	416	6.1
Cyprus	1286	56	16	734	906	62.8
France	2927	97	418	91	606	20.7
Greece	5565	58	211	457	726	13.0
Italy	3044	113	219	478	810	26.6
Malta	75	52	5	11	68	90.7
Portugal	6272	159	393	510	1062	16.9
Spain	2399	62	177	423	662	28.4
Switzerland	5138	115	366	20	501	9.8
Turkey	2410	76	60	181	317	12.1
Eastern Europe						
Albania	6031	6	17	71	94	1.6
Bulgaria	22444	112	608	880	1600	7.1
CSFR	1949	87	258	34	379	19.4
Hungary	1415	45	276	181	502	35.5
Poland	1099	76	283	113	472	42.9
Romania	5193	92	378	675	1145	22.0
Yugoslavia	2731	63	283	47	393	14.4

Table B.3. Availability and use of water per capita, in 1990. Africa.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
Northern Africa						
Algeria	724	35	6	119	160	22.2
Egypt	1078	84	60	1058	1202	111.5
Libya	156	39	36	197	272	168.4
Morocco	1183	30	15	456	501	42.3
Tunisia	530	42	23	260	325	61.3
Sahel Africa						
Benin	5426	7	4	15	26	0.5
Burkina Faso	3111	6	1	13	20	0.6
Cameroon	15893	14	6	11	31	0.2
Cape Verde	500	13	3	132	148	29.6
CAR	45172	6	1	20	27	0.1
Chad	1737	6	1	29	36	2.0
Djibouti	750	8	6	14	28	3.7
Eq. Guinea	75000	9	1	1	11	0.01
Ethiopia	642	8	1	41	50	7.5
Gambia	24444	2	1	30	33	0.1
Ghana	3533	12	5	18	35	1.0
Guinea	32754	12	3	100	115	0.4
Guinea Bissau	31000	6	1	11	18	0.1
Ivory Coast	5873	15	7	46	68	1.2
Liberia	89231	15	7	32	54	0.1
Mali	3830	3	2	154	159	4.5
Mauritania	2700	57	19	397	473	17.5
Niger	1972	9	2	33	45	2.2
Nigeria	2726	14	7	24	44	1.6
Senegal	2122	10	6	185	201	9.5
Sierra Leone	38095	7	4	88	99	0.3
Somalia	1513	5	0	162	167	11.0
Sudan	2917	11	0	1078	1089	37.3
Togo	3286	25	5	10	40	1.2

Table B.3. Continued.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
Central Africa						
Angola	14100	6	4	33	43	0.3
Burundi	654	7	0	13	20	3.1
Comoros	2040	7	1	7	15	0.7
Congo	401000	12	5	2	19	0.01
Gabon	136666	37	11	3	51	0.04
Kenya	589	13	5	30	48	8.1
Madagascar	3333	17	0	1658	1675	50.2
Malawi	1071	7	4	11	22	2.1
Mauritius	2000	66	29	320	415	20.8
Rwanda	875	6	2	16	24	2.6
Tanzania	2784	8	2	27	37	1.3
Uganda	3587	6	2	12	20	0.6
Zaire	11388	13	6	4	23	0.2
Zambia	11294	54	9	22	85	0.8
Southern Africa						
Botswana	13846	5	10	83	98	0.7
Lesotho	2222	7	7	19	33	1.5
Mozambique	3694	13	5	35	53	1.5
South Africa	1420	65	69	270	404	28.4
Swaziland	8700	21	8	385	414	4.8
Zimbabwe	2371	18	9	102	129	5.4

Table B.4. Availability and use of water per capita, in 1990. Asia, Japan, and Pacific regions.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
Middle East Asia						
Bahrain	200	441	265	29	735	367.5
Iran	2076	54	123	1185	1362	65.6
Iraq	5291	137	229	4209	4575	86.3
Israel	467	52	22	353	427	95.6
Jordan	256	50	10	112	172	67.6
Kuwait	12	6	3	1	10	82.0
Lebanon	1313	30	11	230	271	20.6
Oman	1313	17	17	52	86	42.1
Qatar	50	84	61	89	234	468.0
Saudi Arabia	156	144	26	151	321	205.7
Syria	440	31	45	373	449	102.0
UAE	188	47	39	343	476	228.8
Yemen (R)	125	7	4	173	184	147.0
Yemen (PR)	600	58	23	1083	1164	194.5
Southern Asia						
Afganistan	3012	14	0	1472	1486	47.7
Bangladesh	20389	6	2	203	211	1.0
Bhutan	26666	5	2	8	15	0.1
Cambodia	60744	3	1	65	69	0.1
India	1072	18	24	569	611	57.1
Laos	29268	18	23	187	225	0.8
Myanmar	24772	7	3	93	103	0.4
Nepal	10471	6	2	147	155	14.8
Pakistan	3814	21	21	2012	2054	53.8
Sri Lanka	2512	10	10	483	503	20.3
Thailand	1867	24	36	539	599	32.1
Vietnam	2843	11	7	63	81	2.8
Eastern Asia						
China	2395	28	32	402	462	19.3
Korea (PR)	2926	181	264	1303	1748	56.4
Korea (R)	1445	33	42	224	299	20.6
Mongolia	11182	30	73	169	272	2.4

Table B.4. Continued.

	Per capita (m^3) water					% of availability utilized
		Use level				
Region/country	Availability	Domestic	Industry	Agriculture	Total	
Southeast Asia						
Indonesia	14017	12	11	73	96	0.7
Malaysia	26358	176	230	359	765	2.9
Philippines	5176	125	146	423	694	13.4
Singapore	375	38	43	3	84	37.8
Japan	4429	268	55	600	923	20.8
Southwest Pacific						
Australia	20539	849	26	431	1306	6.4
New Zealand	116765	174	38	167	379	0.3
Other Pacific						
Fiji	40786	7	7	22	36	0.1
Solomon Islands	149000	7	4	7	18	0.01
Papua NG	200250	7	6	12	25	0.01

Appendix C: Water Use and Food Self-Sufficiency, in 1990

Table C.1. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 1990. North America, Central America, and South America.

Water availability per capita in m^3	Water use per capita in m^3						
	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	–	–	–	–	–
100–500		Barbados	–	–	–	–	–
500–1,000	–	–	Peru	–	–	–	–
1,000–2,000	–	Haiti	–	–	–	–	–
2,000–5,000	–	Colombia	El Salvador Trinidad	Dom. Rep. Jamaica	Cuba Mexico	–	–
5,000–10,000	–	–	–	–	USA	–	–
>10,000	–	Brazil Guatemala Paraguay Uruguay	Bolivia Nicaragua	Costa Rica Ecuador Guyana Honduras Venezuela	Argentina Canada Chile Panama Suriname	–	–

Table C.2. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 1990. USSR and Europe.

Water availability	Water use per capita in m^3						
per capita in m^3	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	Malta	–	–	–	–	–
100–500	–	–	–	–	–	–	–
500–1,000	–	–	UK	–	–	–	–
1,000–2,000	–	–	CSFR Hungary	Belgium Poland	Germany	Cyprus	–
2,000–5,000	–	–	Denmark Turkey Yugoslavia	Italy Spain	–	–	–
5,000–10,000	–	Albania	Austria Switzerland	Greece Portugal Romania	Netherlands	–	–
>10,000	–	Ireland	Iceland	Finland Norway Sweden	Bulgaria USSR	–	–

Table C.3. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 1990. Africa.

Water availability	Water use per capita in m^3						
per capita in m^3	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	–	–	–	–	–	–	–
100–500	–	–	–	–	Libya	Cape Verde	–
500–1,000	Burundi Djibouti Rwanda	Ethiopia Kenya	–	Tunisia	Algeria	–	–
1,000–2,000	Chad	Malawi Niger	Somalia	Morocco South Africa	Egypt Mauritius	–	–
2,000–5,000	Benin Burkina Faso Comoros Ghana Tanzania Togo Uganda	Lesotho Mali Mozambique Nigeria Zimbabwe	–	Senegal	Madagascar Sudan	–	Mauritania
5,000–10,000	–	–	Ivory Coast	Swaziland	–	–	–
>10,000	Cameroon CAR Congo Equatorial Guinea Guinea Bissau Zaire	Angola Botswana Gabon Gambia Sierra Leone Zambia	Guinea	Liberia	–	–	–

Table C.4. Distribution of countries by relative water availability and use, with a food self-sufficiency goal, in 1990. Asia, Japan, Southwest Pacific and other Pacific.

Water availability per capita in m^3	Water use per capita in m^3						
	< 50	50–250	250–500	500–1,000	1,000–2,500	2,500–5,000	>5,000
<100	Kuwait	–	Qatar	–	–	–	–
100–500	–	Singapore		Saudi Arabia Syria Yemen (R)	Bahrain Israel Jordan	UAE	–
500–1,000	–	–	–	–	–	Yemen (P)	–
1,000–2,000	–	Nepal	Korea (R)	India Lebanon Thailand	–	Oman	–
2,000–5,000	–	Vietnam	China	Sri Lanka	Afghanistan Iran Japan Korea (P) Pakistan	–	–
5,000–10,000	–	–	–	Philippines	–	–	Iraq
>10,000	Bhutan Fiji Papua NG Solomon Is.	Cambodia Indonesia Laos Myanmar	Bangladesh Mongolia New Zealand	–	Australia Malaysia	–	–

Appendix D: Number of People Dependent on Available Water Resources, in 2025

Table D.1. Population–water supply ratios for the Americas and Europe.

Region/country	No. of people per million m^3 of water	Region/country	No. of people per million m^3 of water
North America			
Canada	11	USA	122
Central America			
Barbados	6000	Honduras	113
Costa Rica	56	Jamaica	458
Cuba	348	Mexico	420
Dominican Republic	570	Nicaragua	53
El Salvador	597	Panama	28
Guatemala	188	Trinidad	373
Haiti	1046		
Northern South America			
Bolivia	94	Guyana	28
Brazil	37	Peru	2563
Colombia	362	Suriname	3
Ecuador	73	Venezuela	116
Southern South America			
Argentina	47	Paraguay	38
Chile	83	Uruguay	34
USSR	77		
Northern Europe			
Belgium	792	Luxembourg	60
Denmark	385	Netherlands	168
Finland	47	Norway	12
Germany	620	Sweden	47
Iceland	2	UK	1643
Ireland	38		
Southern Europe			
Austria	137	Malta	1333
Cyprus	1000	Portugal	169
France	368	Spain	451
Greece	182	Switzerland	183
Italy	315	Turkey	669
Eastern Europe			
Albania	260	Poland	1069
Bulgaria	45	Romania	213
CSFR	563	Yugoslavia	405
Hungary	680		

Table D.2. Population–water supply ratios for Africa, in 2025.

Region/country	No. of people per million m^3 of water	Region/country	No. of people per million m^3 of water
North Africa			
Algeria	2750	Morocco	1495
Egypt	1613	Tunisia	3058
Libya	18286		
Sahel Africa			
Benin	510	Guinea Bissau	171
Burkina Faso	811	Ivory Coast	538
Cameroon	148	Liberia	32
Cape Verde	4500	Mali	670
CAR	52	Mauritania	926
Chad	1334	Niger	1350
Djibouti	3667	Nigeria	978
Equatorial Guinea	34	Senegal	1045
Ethiopia	3744	Sierra Leone	60
Gambia	87	Somalia	1644
Ghana	699	Sudan	811
Guinea	70	Togo	827
Central Africa			
Angola	176	Malawi	2534
Burundi	3689	Mauritius	682
Comoros	1275	Rwanda	2874
Congo	7	Tanzania	1116
Gabon	18	Uganda	837
Kenya	5244	Zaire	243
Madagascar	825	Zambia	266
Southern Africa			
Botswana	189	South Africa	1264
Lesotho	1075	Swaziland	317
Mozambique	1034	Zimbabwe	983

Table D.3. Population–water supply ratios for Asia, Japan, and Pacific regions, in 2025.

Region/country	No. of people per million m^3 of water	Region/country	No. of people per million m^3 of water
Middle East Asia			
Bahrain	10000	Oman	2150
Iran	1040	Qatar	45000
Iraq	500	Saudi Arabia	20364
Israel	3210	Syria	5910
Jordan	11910	UAE	9000
Kuwait	140000	Yemen (R)	23300
Lebanon	1270	Yemen (PR)	4267
Southern Asia			
Afganistan	822	Myanmar	71
Bangladesh	100	Nepal	1750
Bhutan	78	Pakistan	571
Cambodia	29	Sri Lanka	565
India	1580	Thailand	778
Laos	65	Vietnam	618
Eastern Asia			
China	549	Korea (PR)	867
Korea (R)	592	Mongolia	220
Southeast Asia			
Indonesia	105	Philippines	345
Malaysia	62	Singapore	5334
Japan	236		
Southwest Pacific			
Australia	67	New Zealand	11
Other Pacific			
Fiji	36	Papua NG	11
Solomon Is.	118		

Appendix E: Vulnerability under Alternative Scenarios

Table E.1. Summary of vulnerability to water resources, by country and scenario. North America and Central America.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
North America							
Canada	1	1	1	1	1	1	1
USA	1	1	1	2	1	1	2
Central America							
Barbados	2	3	3	3	3	3	4
Costa Rica	1	1	1	1	1	1	1
Cuba	1	2	3	3	1	3	4
Dom. Republic	1	2	2	3	1	2	3
El Salvador	1	1	2	2	1	2	3
Guatemala	1	1	1	1	1	1	1
Haiti	1	1	2	2	2	2	2
Honduras	1	1	1	1	1	1	1
Jamaica	1	2	2	3	2	2	4
Mexico	1	2	2	3	1	2	3
Nicaragua	1	1	1	1	1	1	1
Panama	1	1	1	1	1	1	1
Trinidad	1	1	1	1	1	1	1

Table E.2. Summary of vulnerability to water resources, by country and scenario. South America.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
Northern South America							
Bolivia	1	1	1	1	1	1	1
Brazil	1	1	1	1	1	1	1
Colombia	1	1	1	1	1	1	1
Ecuador	1	1	1	1	1	1	1
Guyana	1	1	1	1	1	1	1
Peru	3	4	4	4	3	4	4
Suriname	1	1	1	1	1	1	1
Venezuela	1	1	1	1	1	1	1
Southern South America							
Argentina	1	1	1	1	1	1	1
Chile	1	1	1	1	1	1	1
Paraguay	1	1	1	1	1	1	1
Uruguay	1	1	1	1	1	1	1

1 = Surplus. 2 = Marginal. 3 = Stress. 4 = Scarcity.

Table E.3. Summary of vulnerability to water resources, by country and scenario. Europe.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
Northern Europe							
Belgium	3	3	4	4	3	4	4
Denmark	1	1	1	1	1	1	1
Finland	1	1	1	1	1	1	1
Germany	2	3	3	4	3	3	4
Iceland	1	1	1	1	1	1	1
Ireland	1	1	1	1	1	1	1
Luxembourg	1	1	1	1	1	1	1
Netherlands	1	1	1	2	1	1	2
Sweden	1	1	1	1	1	1	1
United Kingdom	3	4	4	4	4	4	4
Southern Europe							
Austria	1	1	1	1	1	1	1
Cyprus	3	3	3	4	4	4	4
France	1	1	1	4	1	1	4
Greece	1	1	1	1	1	1	1
Italy	1	1	1	2	1	1	2
Malta	4	4	4	4	4	4	4
Portugal	1	1	1	2	1	1	2
Spain	1	1	1	2	1	1	2
Switzerland	1	1	1	1	1	1	1
Turkey	1	1	2	2	1	2	3
Eastern Europe							
Albania	1	1	1	1	1	1	1
Bulgaria	1	1	1	1	1	1	1
CSFR	1	1	2	3	1	1	3
Hungary	1	1	1	2	1	1	2
Poland	2	2	3	4	3	3	4
Romania	1	1	1	1	1	1	1
Yugoslavia	1	1	1	1	1	1	1

1 = Surplus.
2 = Marginal.
3 = Stress.
4 = Scarcity.

Table E.4. Summary of vulnerability to water resources, by country and scenario. Africa.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
Northern Africa							
Algeria	2	3	3	4	4	4	4
Egypt	4	4	4	4	4	4	4
Libya	4	4	4	4	4	4	4
Morocco	2	4	4	4	4	4	4
Tunisia	3	4	4	4	4	4	4
Sahel Africa							
Benin	1	1	1	1	1	1	1
Burkina Faso	1	1	1	1	1	1	1
Cameroon	1	1	1	1	1	1	1
Cape Verde	2	4	4	4	4	4	4
CAR	1	1	1	1	1	1	1
Chad	1	1	1	1	1	1	1
Djibouti	1	1	1	1	1	1	1
Equatorial Guinea	1	1	1	1	1	1	1
Ethiopia	1	2	3	4	2	3	4
Gambia	1	1	1	1	1	1	1
Ghana	1	1	1	1	1	1	1
Guinea	1	1	1	1	1	1	1
Guinea Bissau	1	1	1	1	1	1	1
Ivory Coast	1	2	2	2	3	3	3
Liberia	1	1	1	1	1	1	1
Mali	1	3	3	3	2	4	4
Mauritania	1	3	3	4	4	4	4
Niger	1	1	1	2	1	1	2
Nigeria	1	1	1	1	1	1	1
Senegal	1	3	3	3	2	4	4
Sierra Leone	1	1	1	1	1	1	1
Somalia	1	2	2	3	2	4	4
Sudan	1	3	4	4	2	4	4
Togo	1	1	1	1	1	1	1

Table E.4. Continued.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
Central Africa							
Angola	1	1	1	1	1	1	1
Burundi	1	1	1	1	1	1	1
Comoros	1	1	1	1	1	1	1
Congo	1	1	1	1	1	1	1
Gabon	1	1	1	1	1	1	1
Kenya	1	3	3	4	1	4	4
Madagascar	2	4	4	4	2	4	4
Malawi	1	2	2	2	1	3	4
Mauritius	2	3	3	3	3	4	4
Rwanda	1	1	1	1	1	1	1
Tanzania	1	1	1	2	1	2	2
Uganda	1	1	2	2	1	1	2
Zaire	1	1	1	1	1	1	1
Zambia	1	1	1	1	1	1	1
Southern Africa							
Botswana	1	1	1	1	1	1	1
Lesotho	1	2	2	2	1	2	2
Mozambique	1	2	2	2	1	2	2
South Africa	2	4	4	4	2	4	4
Swaziland	1	1	1	1	1	1	1
Zimbabwe	1	1	1	1	1	1	1

1 = Surplus.
2 = Marginal.
3 = Stress.
4 = Scarcity.

Table E.5. Summary of vulnerability to water resources, by country and scenario. Asia.

	No food self-sufficiency				Food self-sufficiency		
	Scenario				Scenario		
Region/country	Base	2	3	4	1	2A	4A
Middle East							
Bahrain	4	4	4	4	4	4	4
Iran	3	3	3	3	3	3	3
Iraq	4	4	4	4	4	4	4
Israel	4	4	4	4	4	4	4
Jordan	4	4	4	4	4	4	4
Kuwait	4	4	4	4	4	4	4
Lebanon	2	3	3	4	3	4	4
Oman	2	4	4	4	4	4	4
Qatar	4	4	4	4	4	4	4
Saudi Arabia	4	4	4	4	4	4	4
Syria	4	4	4	4	4	4	4
UAE	4	4	4	4	4	4	4
Yemen (R)	4	4	4	4	4	4	4
Yemen (PR)	4	4	4	4	4	4	4
Southern Asia							
Afganistan	1	4	4	4	1	4	4
Bangladesh	1	1	1	1	1	1	1
Bhutan	1	1	1	1	1	1	1
Cambodia	1	1	1	1	1	1	1
India	2	4	4	4	2	4	4
Laos	1	1	1	1	1	1	1
Myanmar	1	1	1	1	1	1	1
Nepal	1	1	1	2	1	1	3
Pakistan	2	4	4	4	2	4	4
Sri Lanka	1	1	1	2	1	1	2
Thailand	2	3	3	4	2	3	4
Vietnam	1	1	1	1	1	1	1
Eastern Asia							
China	1	1	1	3	1	1	3
Korea (PR)	2	4	4	4	2	4	4
Korea (R)	2	2	2	3	2	2	3
Mongolia	1	1	1	1	3	3	3
Southeast Asia							
Indonesia	1	1	1	1	3	3	3
Malaysia	1	1	1	1	1	1	1
Philippines	1	1	1	1	1	1	1
Singapore	2	3	3	4	3	3	4

1 = Surplus. 2 = Marginal. 3 = Stress. 4 = Scarcity.

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