# Will water be enough, will food be enough?

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**IHP-V Project 4.2**

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## FOREWORD

Water and food, food and water, this seemingly uneven couple cannot be separated. There are regions in the world with abundant water resources but without food demand or food production, similarly there are other regions which lack water but have high demands in food.

The problem is not new; ancient cultures were as prosperous as their ability was to master the water supply and to create a system which today would be called an ecological equilibrium. History is full of examples of grand civilizations, their emergence and decay reflecting the success and failure of land and water development.

Global development theories often end with controversial conclusions. While an uneven distribution of water resources on earth can not be avoided, the global trade network is supposed to supply enough food at global scale. Another conclusion, which still surfaces quite often is that as disparity between world population growth and food production, despite improving technology, is becoming greater and an insurmountable crisis will follow. At present pessimistic views still prevail, all revolving around the collapse of an ecological and food security system. Despite many disaster scenarios, others believe in an enhanced future and a new world order.

The present study firstly investigates the potential for food production, in the future, at both global and regional scales. This potential is related to different scenarios concerning population growth, again both globally and regionally. Case studies throw light on particular solutions for water - food related issues, successful ones, and those which, until now have failed. These case studies depict the interrelationship of many factors: population, climate, land use, water availability and demand, water quality, cultural and socio-economic constraints. An attempt is being made to assess the possibilities of putting modern techniques such as water-saving practices, recycling, water transfer, agricultural innovations to use.

The conclusion of the present report is cautiously optimistic as far as the water and food problem as a worldwide challenge is concerned. This global judgement does not exclude that water deficiency, overpopulation, educational deficiencies and unfavorable climatic conditions or the combination thereof might trigger serious water and food related regional imbalances. Consequently, the report calls for improvements in land-use techniques, better coordination of agriculture, education, industry and trade, all within more efficient political systems.

The report outlines the scientific foundation on which future policies and future economies should be based. If well coordinated, many water problems could be solved in the future for longer periods. The food needed for an ever-growing population could be secured through global effort and cooperation. In spite of unavoidably decreasing indicators of freshwater availability, both water and food could and should be enough in the future.

The present publication is a contribution of the Finnish National Committee for the International Hydrological Program to Project 4.2. Comprehensive environmental risk and impact assessment of the fifth phase of the programme. Beyond this association with IHP, the present report with its in-depth analysis of food security and its interactions with water resources can be seen as a contribution to the ongoing deliberations on "Water and Food" within the Long Term Vision for Water, Life and the Environment". While the report represents the author's views and conclusions, the International Hydrological Programme is pleased to publish this valuable contribution to the ongoing debate.

# Will water be enough, will food be enough?

**P. Vakkilainen*, O. Varis***

## INTRODUCTION

Two Centuries ago, Thomas R. Malthus, the British cleric and economist, presented his famous population theory, according to which population increase is geometric whereas food production grows only arithmetically. This conflict leads to famine that regulates the population growth (Figure 1). Along with the development of fertilizers and other agrochemistry, improved water management regulations, new varieties of plants and more sophisticated agricultural machinery yields have risen to a level unimaginable in the late 18$^{th}$ Century.

Fig. 1: Malthusianism: Population growth is geometric, whereas the growth in food production is arithmetic.

This theory has not proven true even if the population growth has continued. The thoughts by Malthus have been regarded as an example of erroneous conclusions wherein human inventiveness in science and technology are not taken into account when solving problems of the future.

The level of education has risen, and as a result the birth rate in industrial countries has fallen. Population in these countries is stable and food production exceeds consumption. Developing countries are now in quite a different state, population in these countries increasing greatly despite the fact that 800 million people suffer from undernourishment. Both optimistic and pessimistic prognoses have been made about the future of global food production (Figure 2). These prognoses do not, however, take into account uncertainties, characteristic of human activities and nature.

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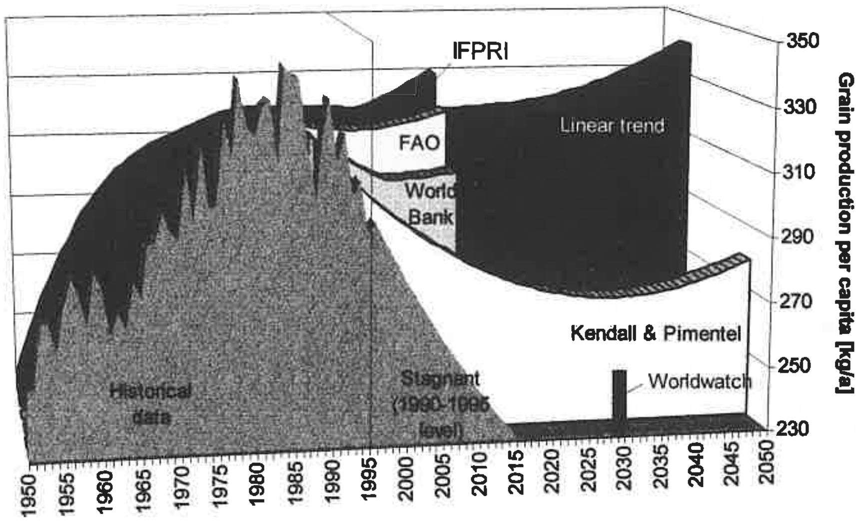



Fig. 2: Food projections are highly uncertain, showing notable mismatches. The references are IFPRI (Agcaoili and Rosegrant 1995), FAO (Alexandratos 1995), World Bank (Mitchell and Ingco 1993), Kendall and Pimentel (1994), and Worldwatch (Brown 1996).

The optimists do not see the problems as insurmountable. They realize that the situation has not changed markedly over the last decades and they believe that deregulation of world trade and the market price for food will balance the demand and the supply of food. The core of their proposal is to cancel subsidies for agriculture which would increase the producer price. This proposal, on the other hand, would initiate growth in production and problems could be found only in areas where unforeseen drought destroys the crop or in areas where war or other political conflicts make farming difficult.

Those with a more pessimistic view point out that clearing new land is becoming more and more difficult at the same time when old area under cultivation moves out of production due to changes in land use and soil degradation. Some of them point out the crucial effect of water in plant production and comment that water is not an unlimited resource. The fundamental uncertainty of water availability is emphasized, in their opinion, by the fact that many important river basins are shared by several countries. Water management systems in such basins are particularly sensitive to political instabilities.

Plants do not grow without water. There is a clear dependence between water evaporation and vegetation growth, which is affected by the geographical position of the area (Figure 3). If there is not enough rainfall, irrigation becomes necessary. Precipitation varies from one period of growth to the next. Roughly speaking, where the need for irrigation is greatest, the uncertainty of water supply is greatest. Man has tried to minimize this uncertainty, by building, over a period of 5,000 years, dams and reservoirs to store water during flood periods to be used during dry seasons. During the last decades water has been stored in the soil for the same purpose. These measures have significantly minimized the uncertainty in many areas, but because of the population growth and the unpredictable nature of hydrological phenomena, humankind is compelled to live with the uncertainty of water availability.

Possible climatic changes contribute to this uncertainty as well as massive changes in land use and vegetation. In particular, reduction of forest areas diminishes the storage capacity of catchment areas. In this way they are more exposed to changes in precipitation and other climatic factors.

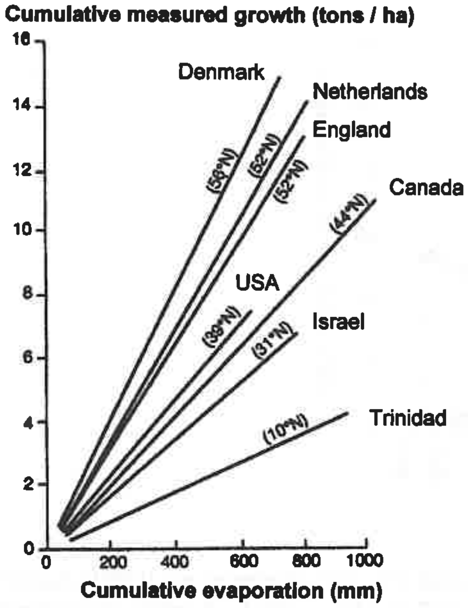



Fig. 3: The relation between pasture growth and evaporation in different climates (Stanhill 1960, Feddes and Koopmans 1995).

Water has often been ignored in discussion of the future of mankind. In the Club of Rome reports of the early 1970s, which received public attention, water was treated as a superfluous subject, even if the epilogue of the latter report states that the amount of irrigation water ultimately limits population growth (Meadows and Pestal 1974). The well-known Brundtland Committee report sees the principle of sustainable development as the foundation for mankind activities but overslides the question of water as a development factor. The UN has held meetings where water has been on the agenda, but only at the Mar del Plata Conference in 1977 was water the focus of public debate. The Conference on Development and Environment in Rio de Janeiro in 1992 was much criticized because water sufficiency was not considered an important factor. The follow-up meeting in June 1997 did, however, focus more attention on water sufficiency, among other topics.

The scope of this report is to debate the sufficiency of the world's food and water resources with reference to the statistical information and published written material. The authors' aim is to highlight the development and future visions based on factors which have an enormous impact on the development of mankind, and to provide a background for conclusions, on which basis the critical constituents of factors constraining the development of societies can be detected. The particular focus is on water, hunger, poverty, and urbanization in this uncertain world.

## THE CHANGING WORLD

Today almost one billion people live in industrialized countries, most of them in urban areas (Figure 4). Population growth in these countries has been slow during the last few decades whereas economic growth has been fast. Most of the world's population, almost five billion people, live in developing countries where population growth is fast, i.e., almost two billion people over 25 years, and economic growth is slow. We can compare economic potentialities between these two groups of nations by comparing their GNP. In industrial countries the average GNP per person is about US$ 20,000 and in developing countries only about US$ 1,000. Developing countries have rather small chances to finance even the most necessary infrastructure projects (Varis and Somloyody 1997).

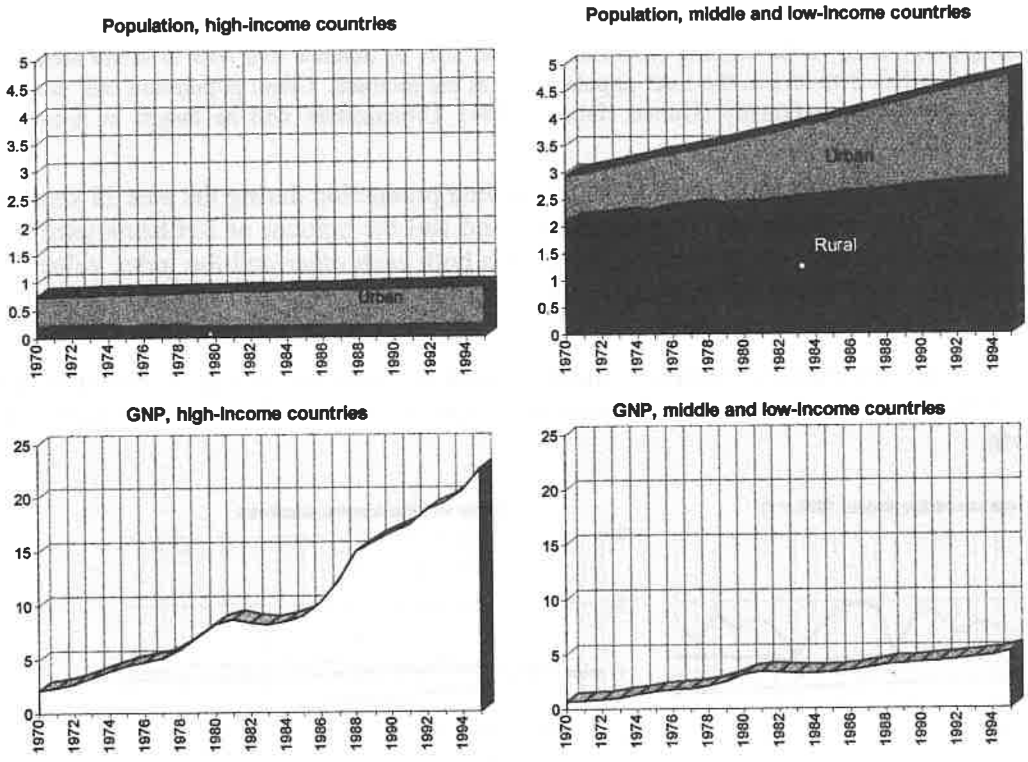



Fig. 4: Population and GNP (US$ $10^{12}$ per year) in high-income countries, and in middle and low income countries (data: World Bank, 1997).

Population growth is expected to continue almost exclusively in the developing countries (Figure 5). Around the year 2000 the boundary of six billion people on earth will be passed and in twenty years the population will be almost eight billions. Economic inequality is predicted to increase. The average GNP per person is expected to be US$ 40,000 in industrial countries and US$ 2,000 in developing countries in the year 2025 (SEI 1997a).

Population will become urbanized; today rural population is about 50 per cent and is predicted to decrease to about one third by the year 2025 (United Nations 1994). A rural person will have to feed two city dwellers instead of one.

There are about 1,345 million hectares of arable land in the world, of which about one half, 695 million hectares, in grain production. The irrigated area is 235 million hectares, i.e.16 percent (World Bank 1997). The yield is higher on the irrigated areas and their share of the total production is as much as one third (Postel 1993).

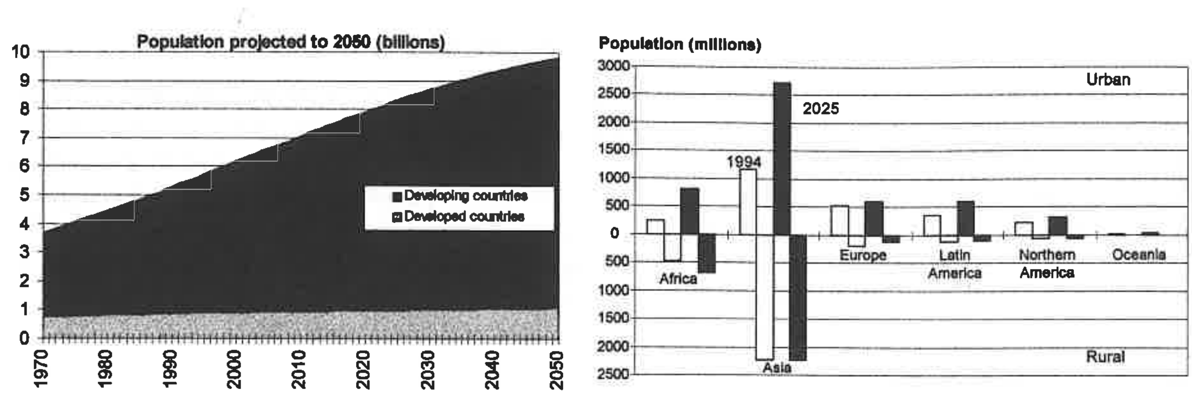



Fig. 5: Population grows mainly in developing countries. Around 50% of humans live now in urban areas. In 2025, there are as many urban dwellers as the total population is at the moment. Urban population will double, rural population will grow only marginally (United Nations 1994). Urbanization will be fastest in Asia and Africa.

The development of some of the most important factors in food production during the past 25 years is presented in Figure 6. Arable land area, irrigated arable land and the amount of fertilizers used per person has been indexed so that they can be compared with both each other and the index values of grain production per person. The per capita area of arable land has decreased markedly and the area of irrigated arable land has remained unchanged.

The yield per person has not changed, however, and this could be explained to a great extent by the increased use of fertilizers. Nevertheless, the increase in the use of fertilizers has not kept pace with population growth.

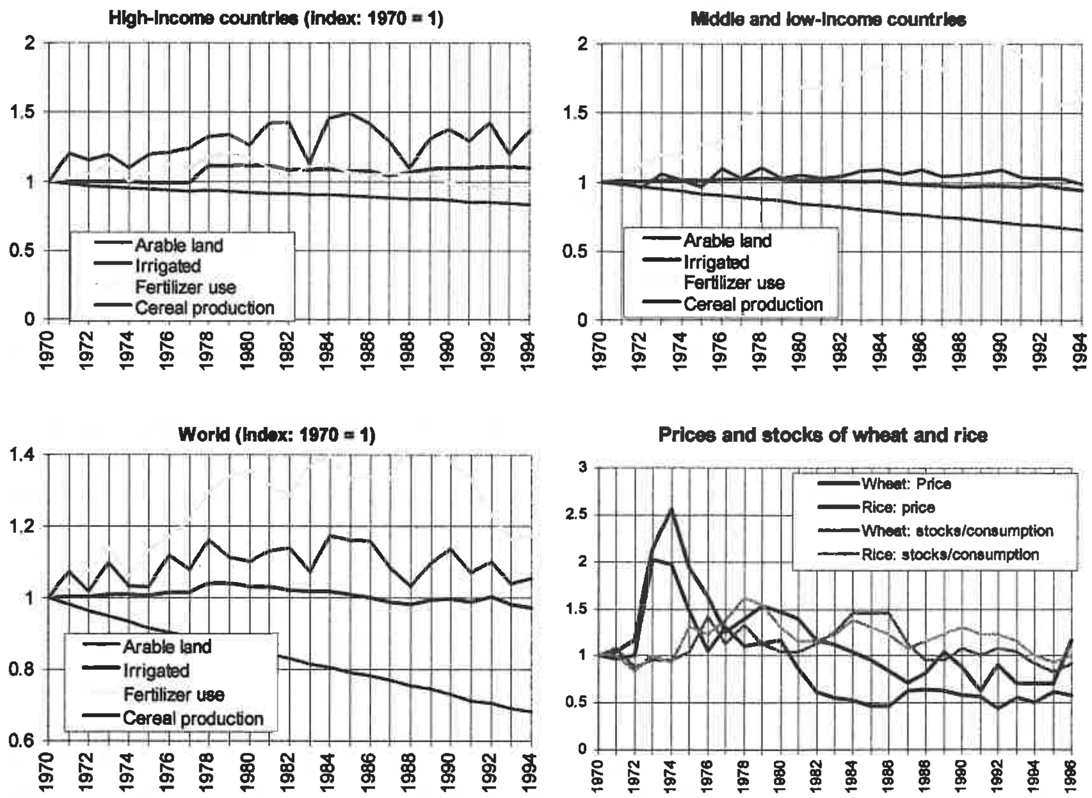



Fig. 6: Indexed values of arable and irrigated land, fertilizer use, and cereal production per capita in developing and developed countries, and the development of cereal prices and stocks (data: World Bank 1997).

After the disintegration of the Soviet Union the whole world firmly believed in the blessings of market economy. Privatization, removal of trade barriers and financial deregulation are measures which together will probably have important positive effects. Government-regulated influence is considered to slow down development and is therefore kept to a minimum. It is essential to the market that money is directed into projects which give a higher yield on capital than in competing projects. The chances of agricultural investments to succeed in this competition are slight. In general their yield is small in relation to the capital that is needed and divided equally over a long period of time. Instead ordinary profitability studies favour investment objects which yield profit as fast as possible. The rate of interest used in calculations has a strong impact on the final result in these comparisons, because the higher the interest used the more successful the projects which yield profit rapidly.

The price of grain is an important regulating factor in agricultural investments. It has been falling for the past 20 years. Investments in safeguarding the preconditions for agriculture have become less inviting. The downward trend of the price of grain can be explained to a great extent by the fact that there is no interest in sacrificing money for expensive clearing of new land but increase in yield can be achieved by more fertilization instead (Figure 6). The price trend of grain can be seen as part of the reason why fewer reservoirs are being constructed than before.

The changes in global forest areas (Figure 7) are part of the explanation, especially in Asia and Africa, also due to projects of clearing new land (FAO 1997). More arable land is lost than produced, however. It is estimated that about 12 million hectares of arable land is lost annually because of soil degradation (Pimentel et al. 1995). Soil degradation is caused by erosion, the ground becoming waterlogged and saline, and impoverishment and acidification of the soil. The widely discussed desertification can be defined as the process of soil degradation within dry areas.

Settlement, industry and agriculture also compete for land, and it is often agriculture that loses out. This is especially common in the best agricultural areas, in river valleys and estuaries where urban and industrial growth usually concentrates.

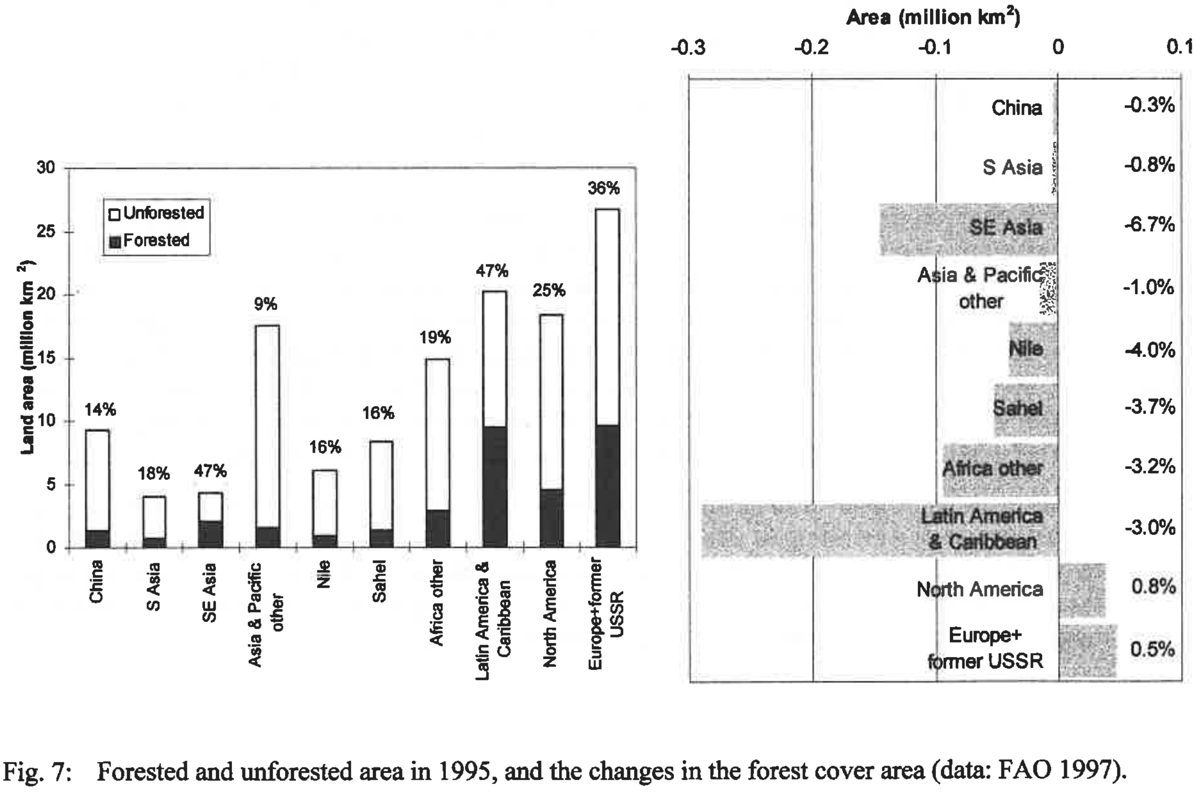



Fig. 7: Forested and unforested area in 1995, and the changes in the forest cover area (data: FAO 1997).

Erosion by water and wind makes the topsoil thinner and in the worst case unfit for growth. About one third of agricultural land on the earth is arable and two thirds grassland. Around 80 per cent suffers from erosion to some extent. Arable land is more susceptible to erosion because it is regularly cultivated and is without vegetative cover for some months during the year. As for grassland, overgrazed areas suffer most from erosion, such areas comprise more than half of the total grassland area. Erosion has a negative effect on plant production because it makes the topsoil layer thinner and in this way changes the water and nutrient balance of the soil and makes the living conditions for micro-organisms more difficult. The effect is case-dependent, however ,and there is no reliable total assessment of the effect of erosion. There is no reason to understate the problem caused by erosion; in agricultural areas of Asia, Africa and South America it amounts to, on average, 30-40 tons per hectare per year and in Europe and the United States 17 tons per year (Barrow 1991). Natural generation of the topsoil is, according to Pimentel (1995), 20-40 times slower than soil degradation caused by erosion.

The fact that soil becomes saline is mostly problem of irrigated areas but it can also take place in non-irrigated areas where a high rate of evaporation cumulates salts to the topsoil. The salts carried by the irrigation water get stored in the root layer if water is not used to such an extent that salts are washed out from the soil. Waterlogging is another important problem of irrigated areas. It is due to insufficient dewatering of soil. Irrigation in these areas causes groundwater to rise to the root layer which renders the areas unsuitable for cultivation. According to the FAO (Alexandratos 1995) 0.2-1.5 million hectares annually vanish from cultivation because they become waterlogged and saline.

The soil becomes less fertile if the nutrients and trace elements are constantly used without taking proper care of the mass balance of the soil. This is a problem especially in Africa, but also elsewhere. The total effects of this impoverishment are not known. The effect of the increasing acidity of the environment on the quantity and quality of plant production is also highly uncertain.

The changes in the global climatic patterns, particularly those due to the greenhouse effect, have been addressed by innumerable studies in recent years. Rosenzweig and Parry (1994) propose that the increase of carbon dioxide in the atmosphere and the rising temperature will have a minor, even if decreasing, effect on total plant production. In industrialized countries in the temperate zone the situation will be more favourable than today, in the developing countries it will deteriorate even further, according to their scenario. If the climatic change takes place as predicted it will continue to increase global inequality. The studies appear, however, to pay only minor notice to extreme events such as droughts and floods, and in their possibly changing patterns and durations. The recent observations of the changes in the El Niño-Southern Oscillation pattern have already shifted some of the focus from the analysis of average situations to periodic and extreme events, but still the variabilities and uncertainties are too often overlooked (Varis 1998b).

From the food production standpoint the central issue is whether there will be enough agricultural land for the needs of a growing population. The FAO finds no reason for concern about land sufficiency (Alexandratos 1995). The FAO estimates that in developing countries, China excluded, the total amount of used and potential arable land amounts to 1.8 billion hectares, of which 48 per cent is in Latin America and 44 per cent in Africa. On the other hand, in South Asia and the Near East, for example, there is little possibility of taking new areas into use. The FAO foresees that by the year 2010 the amount of arable land will increase by 90 million hectares from the present. The additional need for irrigated arable land is estimated to be 23 million hectares or approximately 20 per cent.

As the standard of living improves more meat tends to be consumed. In order to produce meat, plant production must increase. According to Brown (1995) an inhabitant of the United States will consume approximately 800 kg grain per year while in India the consumption is only 200 kg per year. If people eat more meat in developing countries the quantity of arable land must increase as well. Increased meat consumption will also presuppose that more irrigation water is needed.

Calculations of the total quantity of water runoff from the continents to the sea (Figure 8) range from 33,500 to 47,000 cubic kilometers, the average estimation being 40,700 cubic kilometers (Gleick 1993). If this mass of water were distributed chronologically evenly and regionally according to the size of population there would not be any problems regarding water sufficiency on the earth. In reality the uneven geographical position and seasonal changes create a situation of water insufficiency.

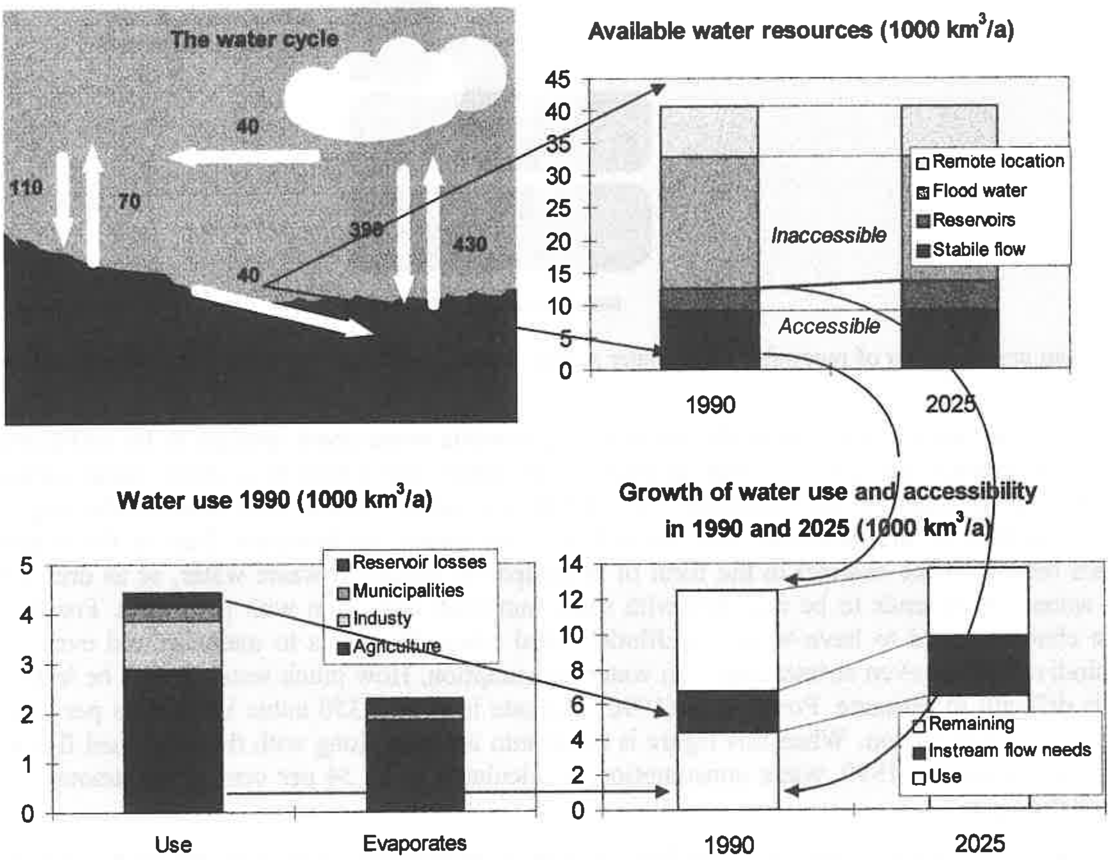



Fig. 8: The global hydrologic cycle (net flows), the available water resources, their growth potential, and water use, 1000 $km^3$ per year (Postel et al. 1996).

Part of the world's water resources are inaccessible and cannot be used. In the Amazon catchment, e.g., roughly one sixth of the total global runoff flows into the sea but only 0.4 per cent of the world population lives there. This kind of water comprises 19 per cent of the total runoff (Figure 9).

Even more significant is water from short periods of flooding which cannot be used when human settlements, industry and agriculture need it. Postel et al. (1996) estimate that the amount of constantly accessible stable runoff is 9,000 cubic kilometers per year. As reservoirs can store, in addition to this, approximately 3,500 cubic kilometers of water it amounts to 12,500 cubic kilometers per year. When evenly distributed among people now living on earth it amounts to six cubic meters per day.

The water is consumed 69 per cent by agriculture, 23 by industry, and 8 by human settlements. Estimations of the total amount of water consumption keep changing. According to Gleick (1993) 3,240 cubic kilometers was consumed by water withdrawals in 1990. Postel et al. (1996) estimated the amount used in 1990 to be 4,155 cubic kilometers. The FAO's (1996) estimate is 4,430 cubic kilometers per year but SEI (1997b) estimates the consumption at only 3,500 cubic kilometers in 1995.

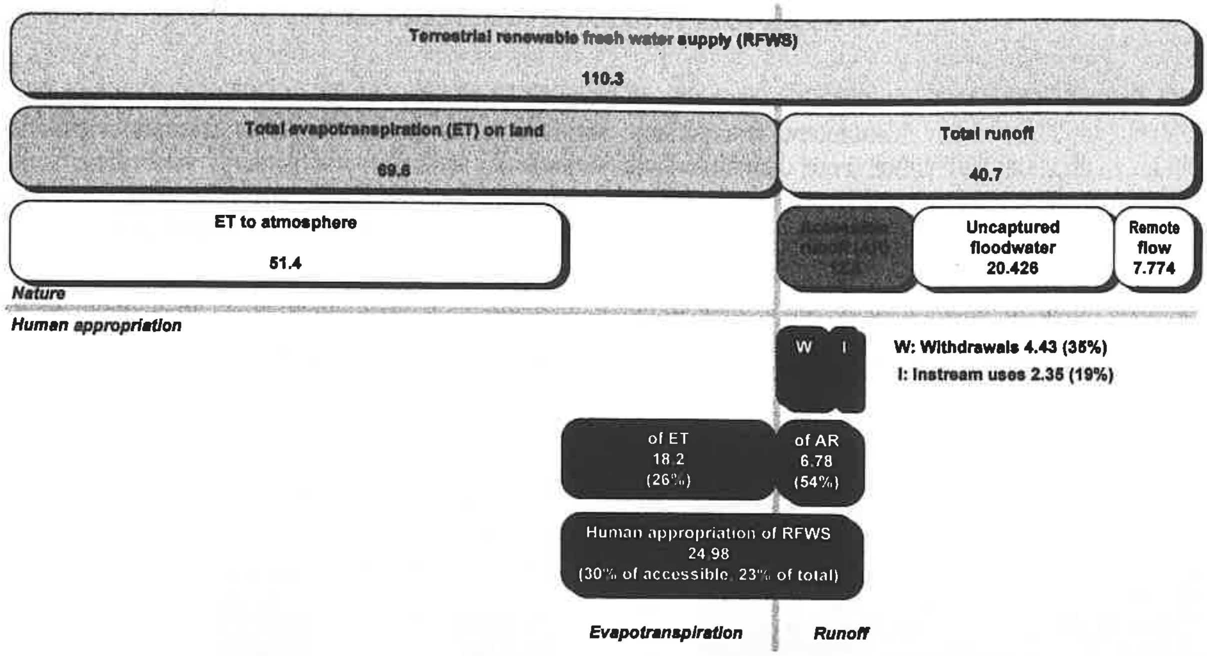



Fig. 9: Human appropriation of renewable fresh water supply. Unit is 1000 km$^3$ per year. Data from Postel et al. (1996).

When these figures are compared with the amount of accessible water there appears to be sufficient water for even greater consumption than at present. In reality the situation is more complicated because water is consumed in many different ways. Firstly navigation sets its own limits to the stages and water quantities of the channels. Also recreational use makes its demands. Part of the water withdrawals returns to the channel in the form of municipal or industrial waste water, or as drained irrigation water which tends to be enriched with salts, nutrients, and often with pesticides. For this reason the channels need to have water for diluting used water. Demands to maintain and even to increase biodiversity set even stricter limits on water consumption. How much water should be left in channels is difficult to estimate. Postel et al (1996) estimate it to be 2,350 cubic kilometers per year according to their calculation. When this figure is taken into account along with the published figure for water consumption in 1990, water consumption is calculated to be 54 per cent of the amount of water in constant use.

All water that is consumed is not ultimately lost but can be recycled through different treatments. It can be estimated that of the water used for irrigation around 35 per cent returns to its channel and for industry and human settlement the corresponding figures are 91 per cent and 83 per cent (Shiklomanov 1993, Postel et al. 1996). The last-mentioned estimate the real "consumption" to be approximately 2,285 cubic kilometers per year, which is approximately18 per cent of the amount of accessible water. In addition to this figure must be included used waters which run from coastal areas directly to the sea.

The volume of accessible water can be increased by man. The drawbacks caused by temporal irregularities can be reduced by storing water in reservoirs or the soil during flood periods. Reservoirs are being constructed continually in different parts of the world but the number of large reservoirs, constructed per year, is continuously falling. Whereas about 1,000 dams over 15 meter high were built between 1950 and 1980 per year, in 1990s the figure has fallen to 260 dams (International Rivers Network 1997). The rate of construction has slowed down because the best sites have been taken and due to the growing appreciation of the negative effects of dams. Also the continuous downward trend in the price of grain has contributed to the reluctance to construct new dams.

Sea water desalination is often put forward as a means of water production in areas which suffer from water scarcity. In comparison with total water consumption this is insignificant since desalination can only solve the problems of coastal areas in rich countries. Towing icebergs and letting them melt is an exotic method by which it is possible, at least in principle, to meet the water demand of coastal cities.

There is no experience, however, in how to use icebergs and they do not give an answer to the main problem: how to bring the massive quantities of water needed for irrigation to inland areas.

The uneven geographical division of water resources can be improved by transporting water from an area rich in water to a water-deficient area. On a small scale plenty of these transfers has been carried out in different parts of the world. Really gigantic plans have been drawn up but their realization has been held back by enormous costs and environmental protests. Perhaps the most notable plan is water transfer from the big rivers in Siberia flowing to the Arctic Sea to redirect them towards Central Asia (Box 1).

An even more noteworthy project is the so-called NAWAPA plan in North America. The suggestion is that 300 cubic kilometers of water per year would be transferred from Alaska to dry areas in the south, comprising Canada, the United States and Mexico. The so-called Peace Pipeline Project suggests conducting water from Turkey to the Arab countries suffering from drought. Transporting water from Turkey by tanker has also been suggested (Turan 1993). Alaska is also ready to transfer water by tankers to California. According to the calculations it would be less expensive to use ships than desalination (Fredriksen 1996).

Contamination of water reduces the amount of accessible water. Waste water from human settlements contains organic material which consumes oxygen, and contains nutrients, making watercourses eutrophic. Waste water reduces the hygienic state of watercourses. Much industrial waste water contains heavy metals and complex, insoluble chemical compounds which are harmful to people, animals and plants. Traffic burdens air, soil and water. Effective agriculture uses fertilisers and pesticides, some of which dissolve in surface and groundwater. Increased irrigation generates more and more drainage water, the salt content of which is as much as ten-fold greater than irrigation water itself.

Quantitative estimations of the extent to which water usability has fallen as a result of water contamination are not available. The situation in developing countries is, however, deteriorating rapidly. Wastewater treatment in these countries is only minimal because only approximately 10 per cent of local wastewater is treated (SEI 1997a). In contrast many industrial countries have attended to their wastewater problems successfully over the last thirty years.

Increasingly attention has been paid to the fact that treated wastewater and drain water from irrigation areas is an important resource which should not be undervalued. Wastewater that has been treated can be recycled for irrigation and industry. Often it can also be returned to the soil as artificial groundwater in which case it is also suitable for human settlement.

Water use is also made more difficult because many watercourses that are important water suppliers are located in areas that belong to two or more countries. According to Biswas (1992) there are 214 catchments spanning the territory of two or more states. If there is sufficient water for everybody there will be no problems but if water is scarce the situation can become difficult. In the worst cases water can be the cause of wars. Water that extinguishes fire can become an explosive in these areas. The situation in the Near East is an example of such a situation (Box 2).

Estimation of future water demand is difficult because water use has to be matched to the accessible water resources eventually. Some estimates are summarized in Figure 10. Postel et al. (1996) base their estimation on the hypothesis that water consumption per capita will remain on the present level and predict a demand of 6,400 cubic kilometres per annum in the year 2025.

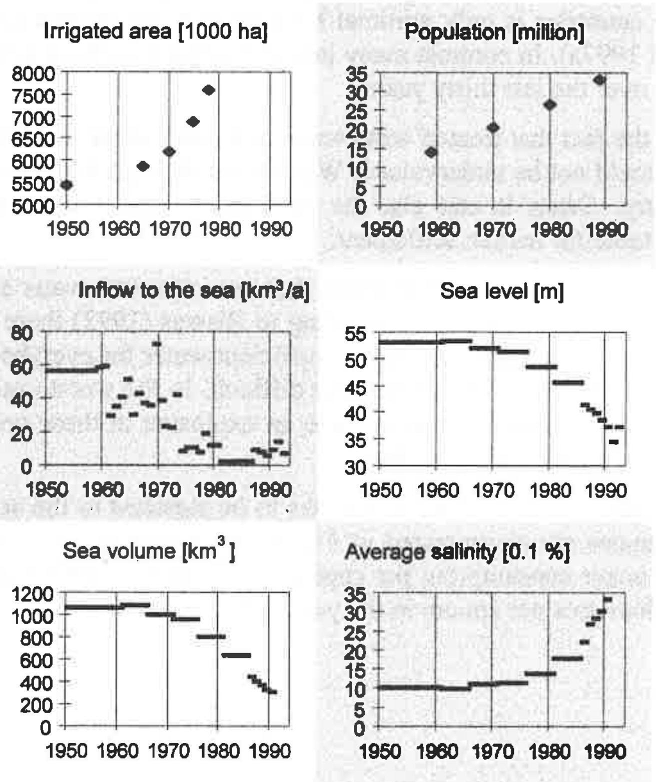
**BOX 1. THE ARAL SEA CASE**

The Aral Sea was the fourth biggest lake in the world until the1950s. The Soviet Union concentrated the cultivation of cotton in its drainage basin from the beginning of the 1960s. Cotton requires a lot of irrigation water. Water levels in the rivers flowing into the Aral Sea have fallen and the lake has lost three quarters of its volume and half of its area. Four decades ago inflow from the drainage basin into the Aral was around 55 km per year. In the 1980s it was only one tenth of that amount. Most of the year the rivers emptying in the lake are dry in their lower reaches. The riverine forests have almost disappeared and the wetlands have shrunk by 85 per cent. Chemicals that have been used excessively in agriculture have leached into the water and adversely affected its biodiversity. The salinity of the Aral has increased drastically. Fishing, which in the 1950s still provided 60,000 jobs, is no longer possible.

To restore the water balance of the area there were plans to transfer additional water from the rivers flowing into the Arctic Sea. However, as early as in the1980s, enthusiasm for this massive project began to decline and the disintegration of the Soviet Union put an end to the project.

The problems of the Aral Sea are now international. The abatement of the environmental damage has been addressed a regional problem that will require regional solutions. UNEP (1993) has produced an action plan for conservation of the Aral Sea. A summary statement of the report which captures the essence of the difficulties of addressing the current problem (and which we fully agree): *"It is a fundamental mistake to assume that long-term issues of water and land degradation can be effectively addressed without considering the associated problems of population growth and a stagnant economy."*

The report lists a number of actions that are categorized as short-term, mid-term, and long-term actions. The first category includes first-aid type of actions aimed at immediately improving drinking and household water supply and health care and reducing harmful waste emissions. The second action point consists of technical and economic measures aimed at re-orientating the agricultural practices and structures. The third category includes strategic changes in demography and production structures, with the aim of widening the scope and adding new economic branches, and institutional arrangements.




Changes of selected indicators of the Aral Sea and its basin. Data are from UNEP (1993), except inflow 1959-1975 and irrigated area from Rafikov (1983). The UNEP data gives average annual values for 1911–1960, 5 year averaged annual values between 1961–1985, and annual values thereafter.

**BOX 2. THE NEAR EAST: WATER AS AN ISSUE FOR DISPUTE**

In the Near East population growth is rapid and agriculture almost entirely dependent on irrigation. Water is scarce and the most important catchments, those of the Nile, the Jordan, the Tigris and the Euphrates, spread out over the area of several countries. Water is only one among many problems in the Near East but it is a burning issue. Prerequisite for lasting peace is that the issue of water consumption can be agreed upon.

The focus of the problems lies in the Jordan river catchment. Israel, Jordania and the occupied West Bank share the waters of this area. The importance of water in this area can be understood by the fact that both Israel and Jordan use one fifth of their electricity to pump water (Brooks 1993). Agriculture is the most important consumer. The share of irrigation of total water consumption is 80 per cent in Israel and 70 per cent in Jordan.

Israel's water use has exceeded the amount of usable water by 15 per cent. The main water source of the country is Lake Kinneret, from where water is pumped for distribution by means of a national water carrier, a net of pipes and open channels. Water is conducted to different parts of the country as far as the town of Eilat via this network. In addition to surface waters there is groundwater in Israel and areas of the West Bank, which is also distributed by the national water carrier. The amount of usable water is increased by wastewater recycling and seawater desalination.

Israel has striven to secure the largest possible part of the Near East water resources for its own use. This can be easily understood because water per capita is little more than 400 $m^3$ per annum. In Palestinian areas the situation is definitely worse. Water contamination makes the problem more difficult, especially since the quality of groundwater is deteriorating (Brooks 1993).

In Jordan the water situation is even more alarming than in Israel. Jordan has built its own distribution system, which directs water from the catchments that collect surface and groundwater to the biggest population centers. The state of Jordan has monopolized supervision of more than 60 per cent of disposable water resources. Shortage of water already limits economic growth and the situation will be extremely difficult because of the rapid population growth. According to the population prognosis water per capita will be less than 200 cubic meters per annum in the year 2010. The joint project with Syria to dam the river Jarmouk would provide Jordan with additional water amount of 0.1 cubic kilometers per annum (Al-Weshah Al Mubarak 1992), however, even this would only help temporarily.

The situation in Syria is much better than in the states mentioned above. The amount of water per capita is 2000 cubic meters per annum and, even if population growth is rapid, water is not a critical issue here in the same way as in Jordan and Israel. The Euphrates is the most important water source but there are also other surface and groundwater sources in the country. But even Syria is not without problems. Wakit (1993) estimates the real amount of usable water resources to be 23.5 cubic kilometers per year. Water use will exceed this amount soon after the year 2010 according to his estimates.

Estimates of usable water resources in Turkey vary greatly. Shuval (1992) estimates the amount to be 180 cubic kilometers per year whereas Turan (1993) presents it be only half of that. According to Turan, the annual water use at present is almost 30 cubic kilometers. As Turkey's population is forecasted to almost double in thirty years, Turkey has presented a plan for improved exploitation of water resources early. The implementation costs of this so-called Anatolia Plan are estimated at US$ 30 billion.

Turkey has, however, enough water to offer to other states as well. In 1987, it proposed the construction of a Peace Pipeline to Arab states that suffer from water shortage. According to the plan part of the water in the Seyhan and Ceyhan rivers 70 cubic meters per second would be transported through a 5,000 km-long pipe system. This would be conducted to the most southern states of the Arab peninsula. According to Turan (1993), the cost estimate of the project is US$ 20 billion, the price for one cubic meter being around one dollar. The construction, if undertaken, will take between 8 and 10 years.

The Euphrates and the Tigris originate in Turkey and flow to Iraq via Syria. The Iraqi water situation can be described as satisfactory; renewable water resources are estimated to be 100 cubic kilometers per annum, i.e. almost 4,000 cubic meters per annum per capita. However, as early as1970 water use was, 43 per cent of that amount (Gleick 1993). The Iraqis are worried about the actions taken by the states that are in the upper course of the rivers. Recent history contains plenty of causes for concern. In 1974 and 1975 Turkey and Syria began simultaneously to fill their reservoirs and stream flows became "intolerably low". Only by Saudi Arabian mediation was war avoided. In 1990 Turkey filled its Atatürk reservoir, causing both Syria and Iraq to protest strongly (Altinbilek 1997).

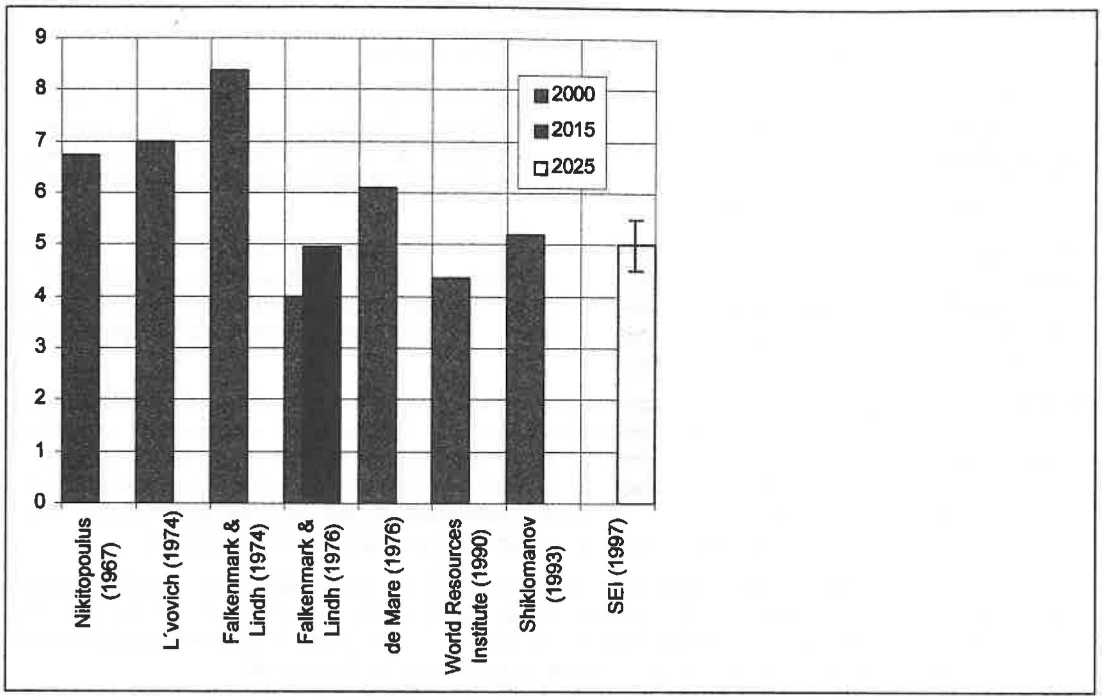



Fig. 10: Global water withdrawal projections (1000 km$^3$ per year) according to SEI (1997).

They estimate that river channels must get each year approximately 3,430 cubic kilometers of water since the need for dilution increases with increasing pollution. Total annual use will then be 9,830 cubic kilometers. This is over 70 per cent of the estimated amount of water in continuous use, which can be, according to their estimation, increased to 13,700 cubic kilometers per annum (see Figure 8).

One of the most recent estimates (SEI 1997b) predicts a remarkably smaller quantity of water. According to an average scenario only 5,000 cubic kilometers water per annum will be used. In the most extreme scenario the amount would be 5,500 cubic kilometers per annum in 2025. The basis for this extreme scenario is the assumption that water consumption will be increased in all sectors. To what extent it is possible to reach this is uncertain as water consumption generally increases along with rising standard of living. At the same time as the population grew from 3.8 billion to 5.4 billion, i.e., by 40 per cent, water consumption doubled (Postel 1992).

The above figures provide a general outlook of water sufficiency as far as the global situation on average is studied. The averages, however, do not tell the whole truth because, from the water availability viewpoint, important quantities are low flows. Geographically water resources and the demand for consumption are unequally distributed. The combined global annual discharge does not vary much but if water availability is examined with the exactitude of the catchments or that of the continents, e.g., the annual runoffs differ from each other. Water availability is made especially difficult by hydrological persistence near the Equator which manifests itself in dry spells lasting for several years. Dry years follow each other.

When difficulties in meeting the water demand are estimated in geographical sectors the rating can be based on the relation of water consumption to annual runoff (Falkenmark and Lindh 1976, SEI1997a).

If water demand is less than 5 per cent of the total runoff. it can be met without problems. When water demand is near 10 per cent the risk of damage caused by temporary disturbances increases and the meeting water demands requires careful planning of water resources. If water demand is 10 to 20 per cent of the annual runoff the situation becomes problematic and large investment is the only solution possible. At between 20 and 40 per cent the situation in developing countries requires massive investment and a large part of GNP has to be sacrificed for water management. A water demand above 40 per cent implies a serious water shortage that usually has to be met by desalination and using groundwater to the extent of groundwater depletion.

Kulshreshtha (1993) has estimated the change in water consumption in major areas until the year 2025 and described three scenarios, shown in Figure 11. Only South America, Northern Europe, Central Africa, South-East Asia and Oceania will be below the critical consumption level of 20 per cent. There will be major problems will be in North Africa and Near East, where water requirement will exceed water supply manifold.

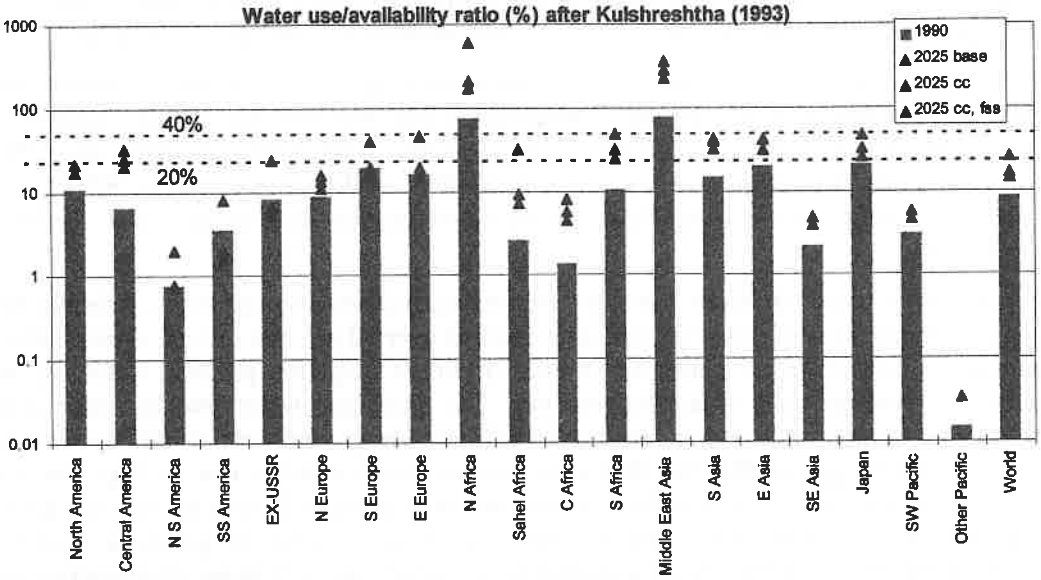



Fig. 11: Water use vs. availability according to Kulshreshtha (1993). The 1990 values, and three scenarios for 2025 are presented. They are: (1) base: the basic situation with steady state climate assumption, (2) cc: averaged climate change forecast taken into account, and (3) cc,fss: additionally assumed, that each country would target to food self sufficiency. The figure also shows the critical limits 20% and 40%.

Shiklomanov (1993) has estimated the change in water consumption in the year 2000 and divided the world in 26 parts. His estimation has been extrapolated until the year 2050 based on the rates of population growth and water consumption. The results can be seen in Figure 12 as a percentage of the average annual runoff. This study by Shiklomanov and his colleagues is a part of a comprehensive assessment project on World Water Resources at the Beginning of the 21st Century, that is carried out as a joint undertaking by UNESCO/IHP and the State Hydrological Institute of St. Petersburg. The project is still in progress, but a brief summary of major results is given by Shiklomanov (1998).

According to Falkenmark and Lindh (1993) 1,000 cubic meters per annum is a critical water quantity, below this areas will suffer from serious water shortage. The study, based on information collected by Shiklomanov, is in agreement with Kulshreshtha's report and shows that major problems in water availability are to be expected in North Africa, China and Mongolia, as well as in South Asia, Central Asia and West Asia (the Near East).

Figure 12 clearly illustrates how difficult the situation will be in certain areas. When water management is conducted in accordance with the principle of sustainable development it cannot in any way be accepted that water consumption could be manifold in comparison with the annual runoff. This is the case, however, in certain states. Libya, for example, consumes ten times more water than its renewable resources (1,000 per cent). This is due to the fact that the water withdrawals exceed the rate of the natural recharge of water storages and aquifers by an order of magnitude (UNESCO 1995).

As a call for a comprehensive assessment of current and future freshwater resources by the UN Commission on Sustainable Development in 1994, the Stockholm Environment Institute (SEI 1997a, b) was commissioned, by the Swedish Government for preparing this assessment together with various UN organizations.

The assessment first describes the availability, quantity, and variability of water resources, and their present use. Second, an analysis on current and future water needs and problems faced is presented. At the end, strategies and options for the sustainable development of global freshwater resources are reported.

The analysis on future water demands is based on a set of scenarios. On the supply side, three different scenarios are driven. One of them is based on the assumption that the climate will remain as it has been in the recent decades, and the two other ones assume the climate be changed due to human influence. On the demand side, the range of water withdrawals are projected using three scenarios: low, middle, and high. The time frame used is to 2025, and the analysis is made on a country level.

The results of the scenarios are presented as a set of vulnerability index values for each country. The five indices used, and the results of the Middle Conventional Development Scenario are shown in Figure 13. Among these indices, which all describe a specific view to the water resources issue, the Composite Water Resources Vulnerability Indices I and II (WRVI-I and II)—in particular WRVI-I—appear to be the most useful ones among those presented to studies such as this, due to their interdisciplinary character.

In order to have sufficient water in areas that have become critical water consumption should be controlled. When the amount of water used for irrigation is often over 90 per cent of total consumption the central issue is whether irrigation could be limited. In single irrigation projects water use is inefficient, on average perhaps only round 40 per cent. The unutilized water that has been lost upstream flows to be consumed in the lower reach or is infiltrated as groundwater. It often produces salinity problems and waterlogging. The fact that effectiveness saves water is due in large part to effective irrigation that makes it possible to reduce salinity and to increase yields per hectare to a great extent. These factors conserve both water and soil on a large scale. When irrigation is studied, effective irrigation in the whole catchment area should be included, not only water consumption in separate irrigation areas (Fredriksen 1996, World Food Summit 1996).

Another typical solution is to set a price for water and in this way include water in the market economy. This measure does not increase water quantities but transports water to an area which can afford it, i.e. industry and human settlements. Without doubt, efficiency in water consumption will increase but at the same time new problems will emerge. Poor farmers in developing countries cannot compete for non-sufficient water resources. They cannot earn their livelihood in the countryside and an attractive alternative for them is to move to urban areas.

With net population growth almost one billion during the next decade, water-related problems must be solved rapidly. Water must be conserved in critical areas but that will not be sufficient. Consumption of treated wastewater will be an important additional resource. Plants requiring less water can still be bred. In addition to these measures water must be stored in both reservoirs and aquifers. We have to remember that important water management projects cannot be implemented, nor technological, human, or institutional capacity can be established in a year or two but will take decades.

Time is a scarce resource.

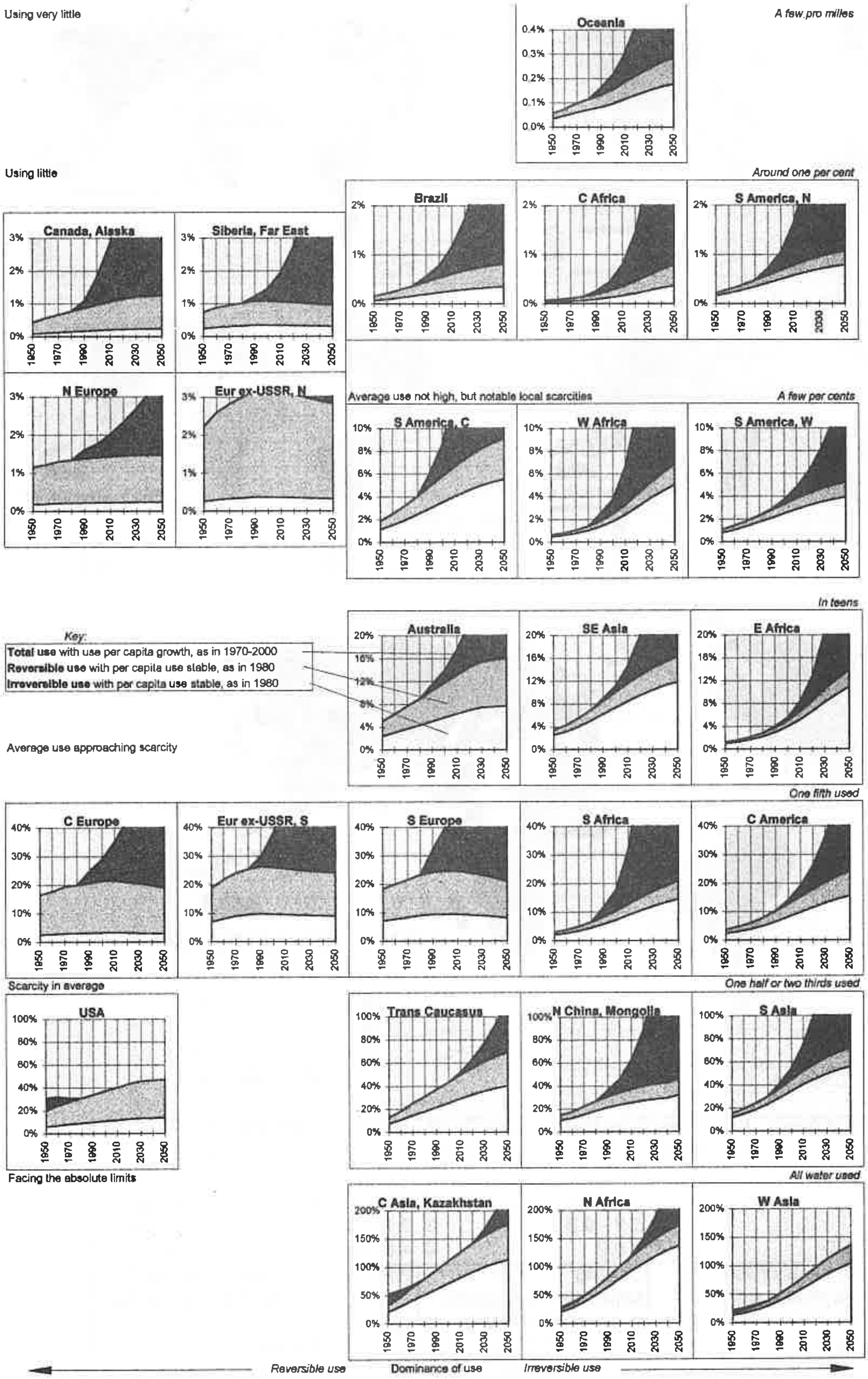
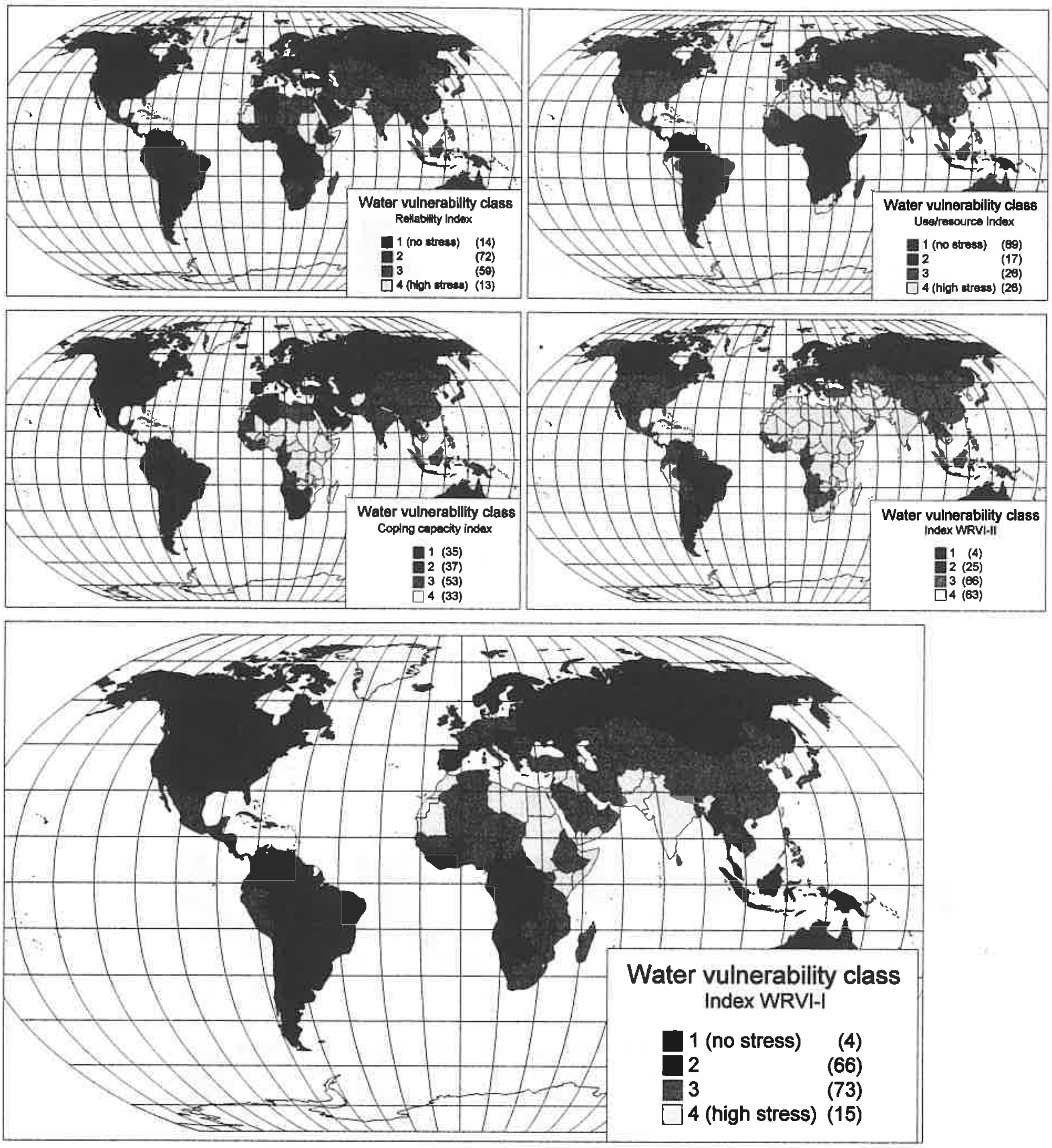



Fig. 12: Growth of water use related to availability. Based on regionalized data and assessments by Shiklomanov (1993). Water use data is from 1980, 1990, and 2000, and water availability data from 1950, 1960, 1970, 1980, and 2000. Other values extrapolated. It can easily be seen, that simple assumptions in one parameter (per capita water use) lead to drastically different outcomes in the analysis.




| **Reliability** | S/Q+COV+ID | *S/Q: Storage-to-flow in river basins* | *COV: Coeff. variation of precipitation* | *ID: Import dependence (%)* |
|---|---|---|---|---|
| | 1 1 - 3 | *1 > 0.6* | *1 < 0.06* | *1 < 15* |
| | 2 4 - 6 | *2 0.3 - 0.6* | *2 0.06 - 0.12* | *2 15 - 25* |
| | 3 7 - 9 | *3 0.2 - 0.3* | *3 0.12 - 0.18* | *3 25 - 50* |
| | 4 10 - 12 | *4 < 0.2* | *4 > 0.18* | *4 > 50* |

| **Use-to-resource** | Withdrawals of average annual resource flows | **Coping capacity** | GNP per capita | **WRVI-I** | Reliability+use-to-resource+Coping cap. |
|---|---|---|---|---|---|
| | 1 < 0.1 | | 1 > 8625 | | 1 1 - 3 |
| | 2 0.1 - 0.2 | | 2 2786 - 8625 | | 2 4 - 6 |
| | 3 0.2 - 0.4 | | 3 695 - 2786 | | 3 7 - 9 |
| | 4 > 0.4 | | 4 < 695 | | 4 10 - 12 |

| **WRVI-II** | Maximum of Reliability, Use-to-resource, and Coping capacity |
|---|---|

Fig. 13: Water vulnerability indices projected to 2025 according to SEI (1997b). The Middle Convential Development Scenario results are shown for all the five indices produced. The used indices are briefly described in the lowest panel.

## AN ANALYSIS OF CRITICAL REGIONS

### *Criteria for the Selection*

It is evident, that some regions of the globe are more vulnerable than the others and are impacted in a more profound manner of global changes and the developments in the water, poverty, food, and urbanization scene. We chose the following six criteria in order to focus the analysis to the most critical regions of the earth:

- The available water resources are already utilised to a great extent, and the situation is rapidly becoming worse,
- A major part of world population lives in these areas,
- Population is growing substantially,
- Urbanization, especially the growth of megacities, is considerable,
- Low level of income,
- Net imports of crops and/or undernourishment already present, and increasing.

Table 1 shows how the macro regions in the world meet these criteria. On these grounds five regions were chosen for closer studies and comparison with each other. They are presented in Figure 14, so as to relate their development until now and possibly in the future to the total global situation (cf. Varis 1997).

Table 1. The world's macroregions with respect to the 6 critical factors. -= does not fulfill, no mark = some risk, + = fulfills the criterion.

| *Region* | *1* | *2* | *3* | *4* | *5* | *6* |
|---|---|---|---|---|---|---|
| N Europe | — | — | — | — | — | |
| C and W Europe | + | + | — | — | — | |
| E Europe | | | — | — | | |
| Ex-USSR/European | — | | — | — | | + |
| N America | | + | | | — | — |
| C America | + | | + | + | | |
| S America | — | + | + | | | |
| N Africa, Egypt excluded | + | — | + | | | + |
| **Nile Basin countries** | + | + | + | + | + | + |
| **Sahel/W Africa** | + | + | + | + | + | + |
| C Africa | — | | + | + | + | + |
| S Africa | + | | + | + | | |
| N Asia | — | — | | | | |
| C Asia, Kazakhstan | + | — | + | | | + |
| **China** | + | + | + | + | + | + |
| Near East | + | + | + | | | + |
| **S Asia** | + | + | + | + | + | + |
| **SE Asia** | + | + | + | + | | + |
| Japan | + | | — | — | — | |
| Australia, New Zealand | | — | | — | — | — |
| Oceania | — | — | | — | — | |

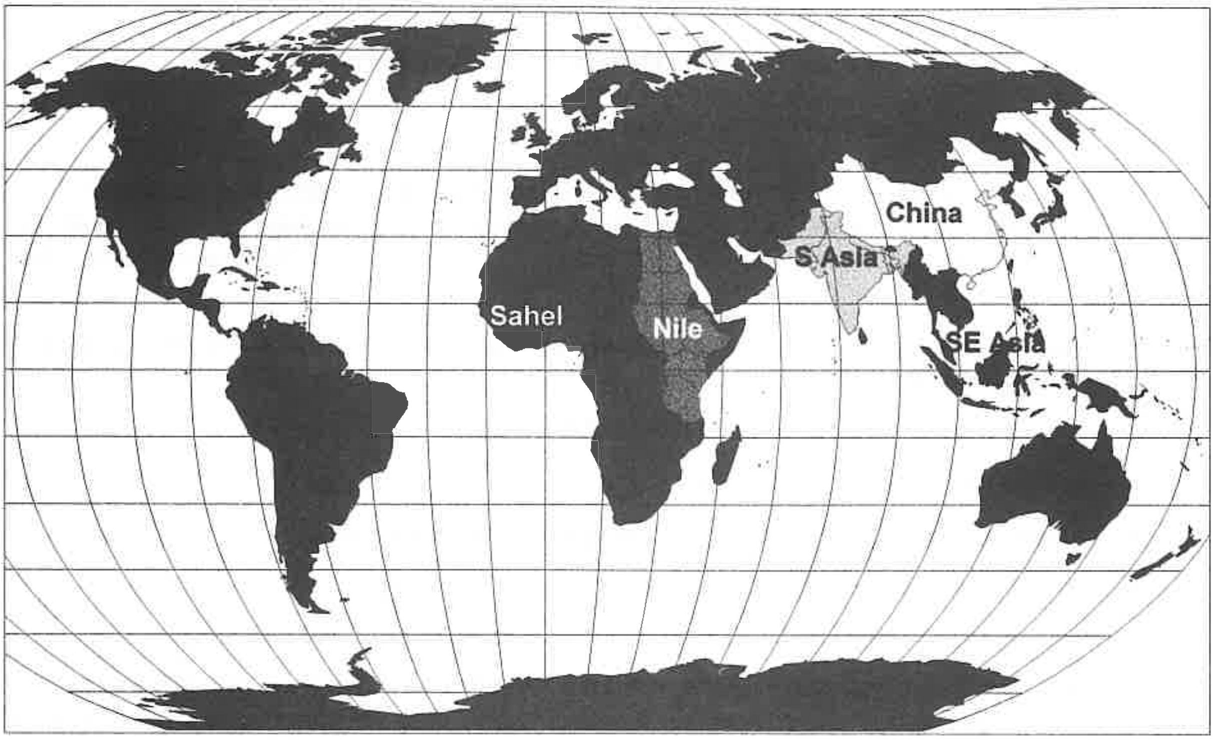



Fig. 14: The regions taken under a closer scrutiny.

Table 1 shows that critical regions with respect to all criteria are the Nile Basin and the Sahel/West Africa regions, China and South Asia. Furthermore South-East Asia was also chosen for study, despite the fact that there are states like Singapore, Malaysia and Thailand, which are rapidly becoming affluent. Population growth in the area, urbanization and shortage of water resources (for instance in Indonesia and the Philippines) is, however, massive even considering the global situation as a whole.

The Near East, from Turkey to Afghanistan, would have been our next choice as an area needing to be studied according to our estimates. Also the vulnerability of the area as far as constant conflicts are concerned would support a more careful analysis. On the other hand, its urbanization rate and income level are higher than in the areas chosen for study. The next chapter presents a short survey of the nature and potential problems in water management and agriculture followed by a comparison between these areas using some significant indicators.

*China*

The population of China is at present around 1.2 billion. In spite of the strict birth control population growth continues and may be as much as 1.6 billion (United Nations 1994) by the year 2050. Estimates of the proportion of urban population vary between 230 and 370 million. The urban population is estimated to increase by as much as 600 million during the next 30 years. The Chinese economy is growing fast but the country will still be poor because the GNP is only US$ 700 per capita per annum.

About 90 million hectares are arable land that, despite the population growth, is decreasing (Brown 1995). The proportion of irrigated arable land is about one half of the whole area. The changing structure of economic life, i.e., industrialization and urbanization, create situations where land is the focus of intense competition. Prime agricultural land is in danger of being used for building or road construction. Arable land will be cleared in areas worse than at present where soil is of poorer quality and irrigation water more difficult to get.

China's renewable water resources are estimated to be approx. 2800 cubic kilometers per annum. Water consumption is approximately 500 cubic kilometers per annum or 18 per cent of the quantity of usable water. The share of irrigation is almost 90 per cent. Quishun et al. (1995) estimate that roughly half of approachable water is in use already. During the last decades China has invested significantly in water resources development. In 1989 China had as many as 83,000 reservoirs. The most important water project at present is the Three Gorges Dam which will be built in the river Yangtze (Chang Jiang) the cost estimate of which is approximately US$ 20-30 billion.

In spite of massive projects there is not enough water available. As early as in the 1980s one half of the cities suffered from water shortage. In every tenth city the situation can be described as critical. China's special problem is that 81 per cent of water resources are in the southern part of the country but the largest part of arable land, 64 per cent, is in the northern part of the country where the political and economic center of the country is located. 126 million people live in North China on an area of only 426,000 kilometers where renewable water quantity is only 52 cubic kilometers per annum. Water use of northern rivers exceeds now 60 per cent of the annual rate of flow (Qishun et al. 1995) In 1987 the quantity of available water was only 44.5 cubic kilometers per annum and consumption rose to 87.3 per cent of this quantity (Zezhen et al. 1992). The water in the Yellow River has been used so extensively that there was no water running to the sea during five months in 1997.

Ground waters in North China are used with a rate much higher than that with which the aquifers are filled. This has caused ground waters to drop; in some places as much as 70 meters. In the Beijing city area ground water has dropped 40 meters and the city has sunk by over half a meter (Qishun et al. 1995). To improve water situation a plan has been made of conducting water from the Yangtze to the north. For this purpose a conveyor system which will be over 1,400 kilometers has to be built.

Besides water availability the quality of water is also a problem for the Chinese. For instance, only one fifth industrial waste water is treated in some way before being discharged into the watercourse.

China is trying to raise its standard of living and industrialize rapidly. A prerequisite for industrialization is that plenty of water is accessible. With a rising standard of living and urbanization water consumption will increase. Market price determination for water, planned in China also will seriously threaten irrigation water accessibility. In order to secure food production into the future, considerably more irrigated arable land is needed. Acquisition of enough water for this purpose is difficult.

An important question which concerns the whole world is how much grain import China needs. The United States Ministry of Agriculture foresees the need for import to be 32 million tons in 2005. The Chinese Academy of Science's estimation for import is 35 million tons in 2010 and 45 million tons in 2020 (Crook and Colby 1996). According to Brown (1995) the need for import is as much as 207-369 million tons in 2030. The importance of these figures becomes evident when we find out that the net amount of grain bought by developing countries at the turn of the decade was about 80 million tonnes in all (Alexandratos 1995).

### *South-East Asia*

South-East Asia is perhaps the most geographically inhomogeneous region among these under examination. It consists of the countries of Indochina (Myanmar, formerly Burma, Thailand, Laos, Cambodia, Vietnam, Malaysia and Singapore) and the Philippines and Indonesia. The region is 4.3 million square kilometers and the population 480 milllion. Indonesia has 200 million, Vietnam 73 million, the Philippines 69 million and Thailand 58 million. The population is predicted to grow to 600 million by the year 2025. It is exceptional compared with other regions as practically the whole area is pluvial, very fertile and fruitful. In spite of the fact that the region contains some important areas for global grain production and export such as the Central Plain in Thailand, the region is a net grain importer.

The average GNP per capita is US$ 1,300 per yer. It is, however, very unevenly divided. For instance, the GNP of Singapore's 3 million inhabitants is the equivalent of over 13 per cent of the total GNP of the region and is approximately 50-fold compared with the GNP of Laos with 5 million inhabitants. Differences within countries are also very noticeable (Drakakis-Smith 1987); The GNP per capita for Djakarta, Bangkok and Manila is one order of magnitude greater than the corresponding figure for the rural population. In some respects it explains why the metropolises of the region grow so rapidly.

Two important international rivers, the Mekong and the Salween, run through the region. Both have their source in Tibet. The Mekong flows through China (the Yunnan Province) as a border river between Myanmar and Laos and then through Thailand and Laos. It continues to flow through Cambodia and runs from the Vietnam area into the South China Sea.

The river Salween runs through the region of China and Myanmar, and is a border river between China and Myanmar, as well as between Thailand and Myanmar. There are several important rivers in the region which have no major effect on the likelihood of international conflicts. Maybe the situation will change in the future. The amount of water flowing from the river into the sea is already too scarce to prevent salty seawater from penetrating to delta water and soil. As far as the Mekong is concerned, since 1957 there has been the Mekong Committee (presently called Mekong River Commission) supported by the United Nations and other international organizations. It has attempted to solve the regional water controversies with varying success. Its functioning has been made especially difficult by China's absence, and several national and international conflicts and wars in Vietnam, Cambodia and Laos (Jacobs 1995).

Despite of internal disquiets, more or less constantly, in some countries of the region, over the last few decades the region has become more peaceful, but shows signs of underlying instability as the economy or the politics suffer from even modest crises. The biggest concentration of the population is the island of Java in Indonesia. Its area is 127,000 square kilometers and the population 110 million. Its population density is almost 900 persons per square kilometer.

The region has 62 million hectares of arable land, of which 17 per cent is irrigated and 47 million hectares grain production. The irrigated arable land is divided percentually so that Thailand has 37 per cent, Indonesia 23 per cent, Vietnam 14 per cent and Myanmar 11 per cent. In Malaysia and Cambodia, on the other hand, agriculture is largely dependent on direct exploitation of natural rainfall.

*South Asia*

The combined population of India, Pakistan and Bangladesh is 1.2 billion and it is growing fast. In 2025 the population is predicted to approach 1.9 billion. GNP per capita in the area is low; US$ 460 per annum in Pakistan, US$ 340 in India and US$ 240 in Bangladesh.

Over half of India's land area is used by agriculture. Arable land counts for 80 per cent or 166 million hectares. It is difficult to increase this area. To provide enough food for the increasing population agriculture has been made more effective. This demands even more intensified measures. The area of irrigated land has increased by 10 per cent since 1970 and is now about 30 per cent. It is possible to improve irrigation but new projects are economically demanding and more difficult to implement than before. The use of fertilizers per arable hectare has grown sevenfold during the last 25 years.

The source of life in Pakistan is the Indus. Most of the country's arable land is to be found in the valley of this river. The total area of arable land is 21 million hectares of which 80 per cent is under irrigation. As in India most of the available agricultural land is already under cultivation. In order to feed the increasing population more effective measures must be used in agriculture. Irrigated area has been increased by one quarter since 1975 and the use of fertilizers has risen sevenfold. One of the biggest problems is that one fifth of the irrigated area has become saline and one sixth waterlogged. As a remedy for these problems a program financed by the Asian Development Bank is getting started at the moment. Its total costs will rise to approximately US$ 200 million (Asian Development Bank 1997).

The renewable water resources in Pakistan are 298 cubic kilometers per annum and water consumption was estimated to be 153 cubic kilometers per annum in 1990, of which irrigation contributes to 98 per cent (Fredriksen et al.1993). The right of Pakistan to the water resources of the river Indus has been secured by a treaty with India in 1960.

Bangladesh is situated in the delta area of the Ganges and Brahmaputra, in the Bengali Lowland. The population density of the country is high: 920 persons per square kilometer. Agricultural land is 94.5 million hectares. It is fertile and climatic conditions allow even three harvests per year. As the population increases the problem will be a shortage of arable land. The irrigated area has become threefold since 1970 and is now about 30 per cent. The use of fertilizers has increased in the same way and at the same time as in India and Pakistan and has risen sevenfold.

The amount of renewable water resources in Bangladesh is, on average, 1387 cubic kilometers per annum and their use only 22.5 cubic kilometers per annum. These figures, do not, however, give a real picture of the country's water problems. Floods in summer and drought in winter plague the inhabitants. Loggings in the Himalayas has aggravated the runoffs of the rivers flowing through the country. People have had to become accustomed to the fact that both floods and drought destroy crops. During the years 1973-87 floods destroyed grain 1.7 million tonnes on average whereas damage caused by drought was 1.5 million tons (Hasan and Mulamoottel 1994).

The total amount of India's renewable water resources according to Gleick (1993) is 1,850 cubic kilometers per annum but the amount of usable water is only approximately 1,140 cubic kilometers per annum. Water consumption for the year 2000 is estimated to be 750 cubic kilometers per annum, of which irrigation takes 90 per cent. The need for water in 2025 will, according to the prognosis, be 1,050 cubic kilometers per annum i.e.roughly equal to the total amount of usable water and over 50 per cent of the total amount of renewable water resources (Anon. 1991).

Water distribution in the country is unequal. In the north there is plenty of water and in the south it is scarce. This situation has led to the idea of connecting the rivers running in the east-west direction via canals to form a network which could get its water from India's biggest river, the Ganges. In this project we can see Bangladesh's water problems in the lower reaches of the Ganges. The river's runoffs have already decreased, currently during the dry season over 25 per cent. In addition to water shortage salty sea water from the Bay of Bengal is penetrating deeper into the Ganges-Brahmaputra delta affecting all water use (Rabbi and Ahmad 1997). In order to store water India has built many reservoirs, among which the project of the river Narmada has raised objections worldwide (Box 3).

In all these three countries it is the quality of water that has become more problematic. Communities' waste waters are not really treated. The same is true for industrial waste water which contains heavy metals and poisonous compounds that constitute a serious hazard (Fredriksen et al. 1993).

The problem with Indian and with almost all South Asian agriculture has been its ineffectiveness. According to Pike (1995) yields from India's irrigated areas are only about 50 per cent of the respective yields per hectare in other parts of Asia. The great challenge of the region is to improve the efficiency as far as soil and water use are concerned by emphasizing training, technology and irrigation systems management (ICID 1995).

**BOX 3. NARMADA: THE DILEMMA OF FOOD, POVERTY, HUMAN RIGHTS AND THE ENVIRONMENT**

The Narmada River flows through some of the poorest areas of India. There are 40 million inhabitants within the river's sphere of influence and population growth is fast. The situation as far as water use and electricity are concerned is poor and worsening all the time. Solutions to improve the situation and prevent massive migration to towns have been searched for a long time. The result of this work is a general plan which suggests the construction of 30 big and 130 smaller dams directed towards the needs of settlement, industry, irrigation and hydropower production. India's central government and the states through which the river Narmada is running, have accepted the project. Its construction is expected to take fifty years.

The dimension of the project is enormous; the lowest reservoir, Sardor Sadovar, will provide irrigation water for 1.9 million hectares and supply electricity at the power of 450 MW. Another immense reservoir, Narmada Sagar, planned to be constructed in the middle reaches of the river, would supply enough water to irrigate at least 141,000 hectares and allow irrigation of vast areas in the lower reaches. It would also produce 1,000 MW of electricity. The water stored in the reservoirs would secure agricultural work for about five million people. 70,000 people would have to be moved from the area needed for the reservoir in Sardor Sadovar and 80,000 from Narmada Sagar.

The Narmada project has met with strong resistance. The opponents propose that the official resettlement figures are severely underestimated, that the reservoir would increase income disparity, spread diseases, and damage the environment. The World Bank, who had already in 1985 made a decision concerning the financing of Sardor Sadovar Narmada Sagar, withdrew the promised financing in 1993 because of strong protests by Human Rights organizations. The Indian government decided, none the less, to continue with the project.

The project supporters consider their opponents' points of view as classical examples of shortsightedness. They stress that if Narmada is not constructed the area will become very poor and environment can not be managed in absolute poverty. If the means of livelihood is lost in the area, millions of people would have to migrate.

The migration would then be huge in comparison with the immediate resettlement volumes due to the construction of Sardor Sadovar and Narmada Sagar (Dixon et al. 1989, Fredriksen 1996).

It has to be recalled, however, that India has already built enormous irrigation systems which, if made more effective, could double yields in vast areas without additional water use (Pike 1994).

Another regional challenge is lack of cooperation between states. Without adapting the measures taken in Nepal and Tibet to the needs of countries in the lower reaches water resources management will not achieve the best possible results (Upreti 1993, Ahmad et al. 1994).

*The Nile*

The Nile catchment, 2.9 million square kilometers, covers about 10 per cent of the area of Africa. Characteristic of its hydrology and climate is that both its main branches, the Blue and the White Nile, have their sources in pluvial regions in East Africa. They are united at Khartum in the Sudan and flow through a virtually rainfree desert a few thousand kilometers to the Mediterranean.

In the catchment there are eleven states, among which, however, the Democratic Republic of the Congo (previously Zaïre), The Republic of Central Africa and Zambia are of minor importance and so they can be left out of the examination. In the other eight countries (Burundi, Egypt, Ethiopia, Kenya, Rwanda, the Sudan, Tanzania and Uganda) the population is currently about 230 million inhabitants and is expected to grow to 360 million by the year 2025. The total area of these countries is 5.1 million square kilometers. The GNP per capita is US$ 340 per annum.

Arable land makes up 40 million hectares of the Nile region, of which irrigated arable land is 13 per cent, divided between Egypt (57 per cent) and the Sudan (36 per cent). Both these countries account for one quarter of the region's population. Egypt's share of the GNP is more than one half.

Due to the region's climate agriculture in the White Nile countries—except parts of Tanzania and Kenya—is based on the use of natural rain and there is no large scale irrigation. But in Egypt, Sudan and—to an increasing extent in Ethiopia—irrigation is of major importance to agriculture. The most significant evidence for this fact is the many thousands of years of tradition of irrigation systems which, especially in Egypt, also has great cultural value.

Over the past hundred years several significant dams and barrages have been built on the Nile in Sudan and Egypt, the most massive of which is the Aswan High Dam, completed in 1964, which has also an indisputable significance to Egypt's national identity and political stability. With the help of the dam it is possible to collect the Nile's enormous floodwaters of which, before the construction of the dam, 32.5 cubic kilometers per annum were not exploited. At present virtually no Nile water is flowing into the Mediterranean—as almost all 85 cubic kilometers per annum which flow to Aswan evaporate either from arable land, Lake Aswan (11.5 cubic kilometers), or in the form of different losses. Egypt's share of the Nile water increased by seven cubic kilometers , and the Sudan's by 14 cubic kilometers per annum (Figure 15). International treaties on the use of the Nile waters have existed for many decades. The present Nile Water Treaty dates from 1920 and since then the treaty has been strengthened and amended several times. It has proved itself to be functional, especially in the issue of dividing the extra water from the Aswan High Dam between Egypt and the Sudan. The treaty will be under great pressure in the future when Ethiopia, Tanzania and Kenya will want to use the Nile water more and more for irrigation in order to increase their vital agricultural production.

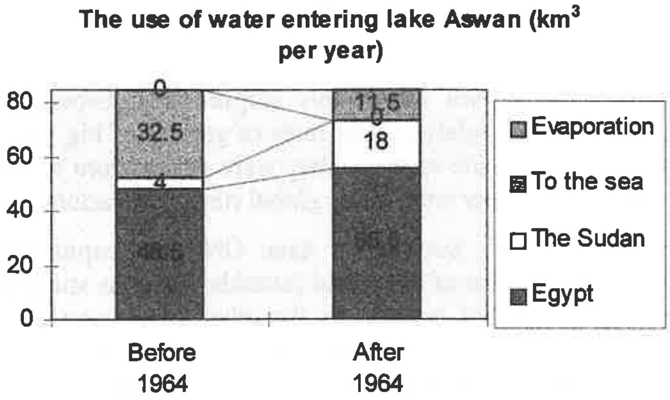



Fig. 15: The Aswan High Dam changed the water use and availability in the lower reaches of the Nile markedly. Since 1964, Egypt and the Sudan share all the usable water entering lake Aswan.

## *Sahel*

When speaking of the Sahel region we usually mean the zone directly south of the Sahara where the annual precipitation is less than 700 mm. In this context we have extended the area to include a Central and West African region with similar characteristics such as poverty and economic backwardness. We have therefore included the following states: Burkina Faso, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Cameroon, Central African Republic, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Chad.

These countries have a population of 230 million people, half of whom live in Nigeria. The population has doubled during the last 25 years and is growing rapidly. In 2025 the region will, according to the United Nations (1994) prognosis, have about 400 million people. The region is poor. If the criterion for wealth is GNP per capita, Cameroon is the wealthiest, with its US$ 650, while Chad is the poorest with US$ 200. None of the states in the region is self-sufficient in grain production and only Nigeria, Niger, Chad and Burkina Faso reach self-sufficiency of 90 per cent.

The long-lasting drought explains the low level of agricultural production to a great extent but attention has to be paid also to underdevelopment of irrigation. The most striking feature in Africa which differentiates it from other underdeveloped areas in the world is that the extent of the irrigated arable land is very small, usually only a few percent of the total arable land area (World Bank 1997).

The Sahara is extending to the south all the time. Previously nomads moved back and forth in the region but since the construction of drill wells they have been able to stay. The result is overgrazing which removes the modest vegetation covering the soil leaving it open to erosion. An exceptionally long dry period has helped to destroy the vegetation and made afforestation projects futile, which have tried to prevent the advance of desertification.

These problems affect mostly the states from Senegal and Mauritania to Chad. On the other hand, in the coastal states of the Guinea Bay the annually renewable water resources can be considered abundant. Mauritania consumes the highest proportion of its renewable water resources, yet only ten per cent (Gleick 1993). Annual averages do not tell the whole truth as variations in river runoff are normally large. Over the few last decades droughts have worsened the situation. However, there is enough water to make the region's food supply secure, if flood water could be stored for irrigation. The lack of funds is evident. It is estimated that the costs for extensive irrigation projects in West Africa vary from US$ 2,000 to 6,500 per hectare (World Food Summit 1996). In the project for the river Senegal the costs are estimated to rise to US$ 10,000 per hectare (Le Marquand 1990).

Because of fragmentation of the area one of the characteristics of rapid urbanization will be migration across the state borders, especially from the dry desertificated states to the coastal metropolises like Dakar, Abidjan, Accra, and Lagos.

## RECIPROCAL COMPARISON OF THE REGIONS

The shares of the regions on global population has grown remarkably (Figure 16). Especially noticeable has been their proportion of the global urban population. The rates of growth of big cities were from 3 to 5 per cent per annum at the turn of the decade whereas they were almost zero in the rest of the world. However, these areas still have almost 80 per cent of the global rural population.

The GNP statistics indicate that in the wealthiest region, South-East Asia, GNP per capita has remained an order of magnitude below the average for the rest of the world (outside the areas studied) during the last 25 years in spite of fast growth. The rates of growth for the other areas have been remarkably slower, the African areas have had virtually no growth during the last few decades. The proportion of the world GNP in the African regions has fallen from 1.4 per cent to less than 0.6 per cent during the period 1970-1995, even if the population has risen from 6.3 per cent to 8.1 per cent. The joint proportion of global GNP in all study regions has fallen at the same time from 11 to 7 per cent although their proportion of the population has risen from 55 to 59 per cent. It should be noticed that about one sixth of China's GNP comes from Hong Kong area, and a significant part of Southeast Asia's GNP from some metropolises like Singapore, Bangkok, Manila, Jakarta and Kuala Lumpur.

Figure 17 shows the development of the major food production factors in the period 1970-1994/5. The first thing to attract one's attention is that both total arable land area and grain production area have had a downward trend during the past decade, both in the regions studied, as well as elsewhere in the world. The regions' share of the former has remained almost the same, one third, whereas their share of grain production has increased a little; from 45 per cent to 48 per cent. Arable land area has fallen by about one third except for the Sahel region where the fall has been only about 20 per cent.

At the same time the extent of both irrigation and fertilization has increased markedly. However the former, if calculated per capita, has decreased in more areas than it has increased. The use of fertilizers has increased substantially, especially in China, South-East Asia and South Asia. The regions' share of the total irrigated arable land on the earth has remained at 42 per cent, the share of the use of fertilizers of the global use has risen from 13 per cent to 45 per cent. China's share has merely risen from 6 to 24 per cent. In countries outside the regions studied, the irrigation area has remained unchanged whereas the use of fertilizers has decreased significantly. This can be explained to a large extent by political changes over the last ten years in the former USSR and in the states within its influence, and their effect on production structures.

The effects of these major production factors—arable land area, irrigation and fertilization—can be seen in Figure 18. Total global production per capita increased until the end of the 1980s but since then has turned downwards and is now on the same level as it was 20 to 25 years ago. As far as the studied regions are concerned it can be noticed that in China, South-East Asia and, to some extent, the Sahel region, production per capita has increased since the 1970s. Yields per hectare have substantially increased, especially in China. In this case attention should be given to the noticeable increase in fertilizer use during the last couple of decades. As far as the Sahel is concerned it should be noticed that considerably more land has been taken over for cultivation during the last ten years without, however, increasing yields per hectare. In this respect it clearly differs both from the trends in the other regions and areas outside this study.

These trends seem to be very logical. The Asian regions are densely populated and it is not easy to obtain land for cultivation there. They are also becoming industrialized; South-East Asia at the greatest speed and China and South Asia after it. Egypt is in the same situation; there is no space, and basic industry—often heavily subsidized—has been developed gradually. In the Sahel area and countries further south around the Nile, industry and foreign currency are scarce but more space is available.

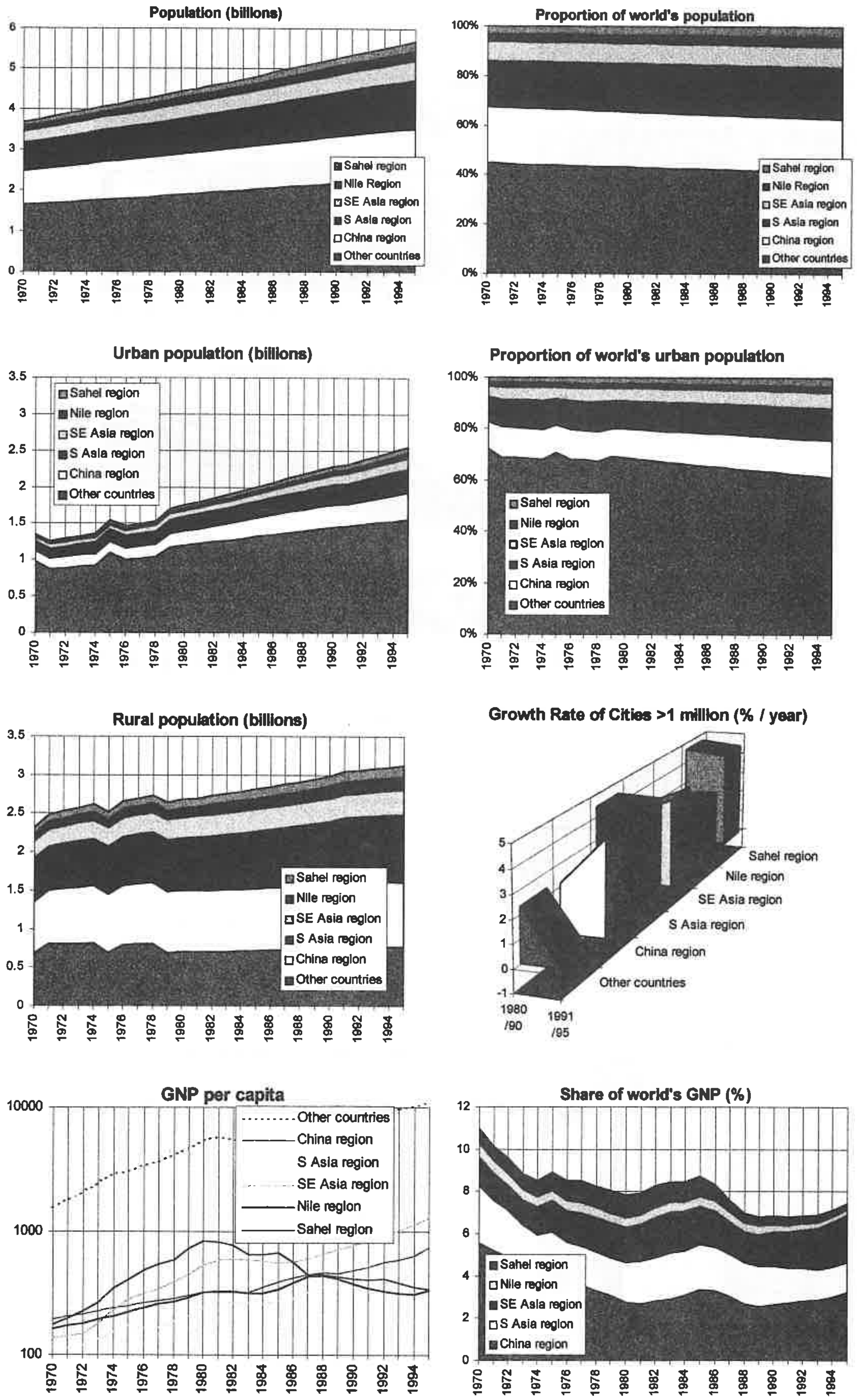



Fig. 16: Population, urbanization, and GNP by regions (data: World Bank 1997).

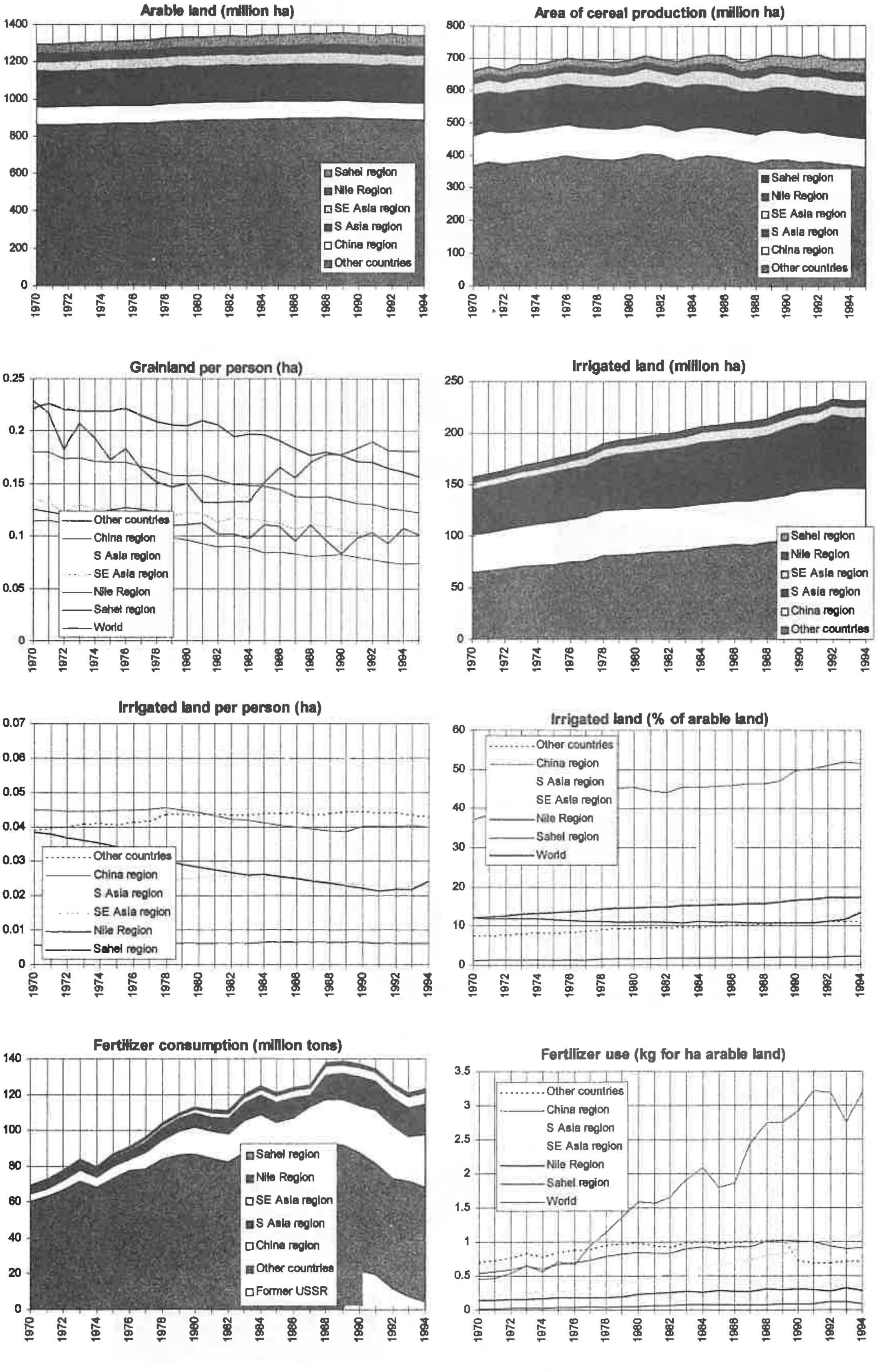



Fig. 17: Arable land, irrigation, and fertilizer use by regions (data: World Bank 1997).

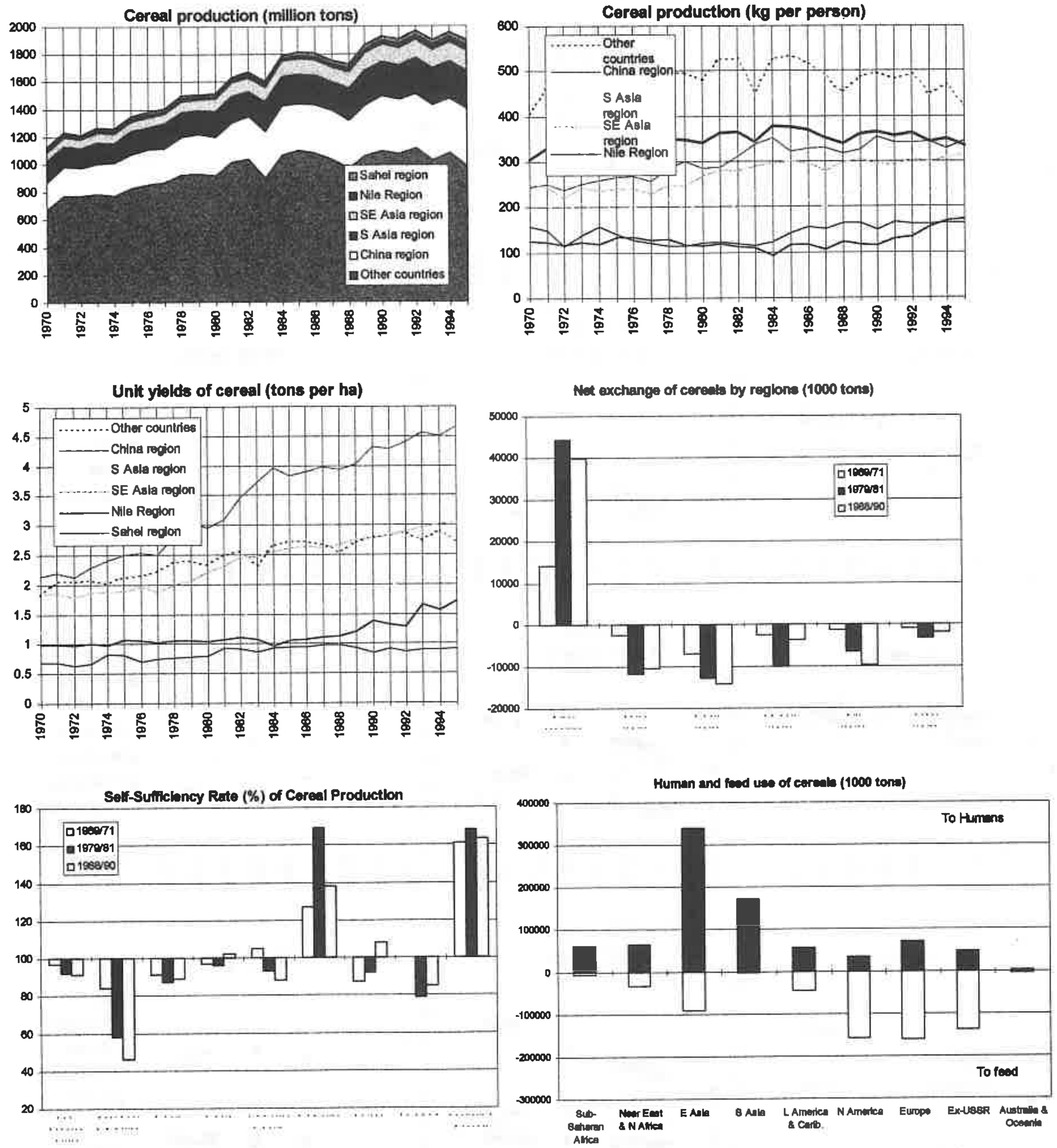



Fig. 18: Cereal production and self-sufficiency rate by region (Alexandratos 1995, World Bank 1997).

Among the production factors people's educational level is not be forgotten. Education and literacy are the most important prerequisites for development, whether it is measured by economic or human criteria (e.g. UNDP 1996). If levels of education and literacy are low, development of water resource management and agriculture are slow, too, and it is unlikely that outside aid will improve the situation permanently.

In considering educational levels (Figure 19) the differences in the countries of these areas are large. In China and South-East Asia, except Laos and Cambodia almost everybody completes at least the lower level of comprehensive school. In South Asia, except in Pakistan, the situation will gradually become similar as in some African countries as well. There are, however, several countries in Africa, e.g., Sudan, Ruanda, Guinea, Burkina Faso, Niger, Liberia and Mali, where only one half of all children begin school.

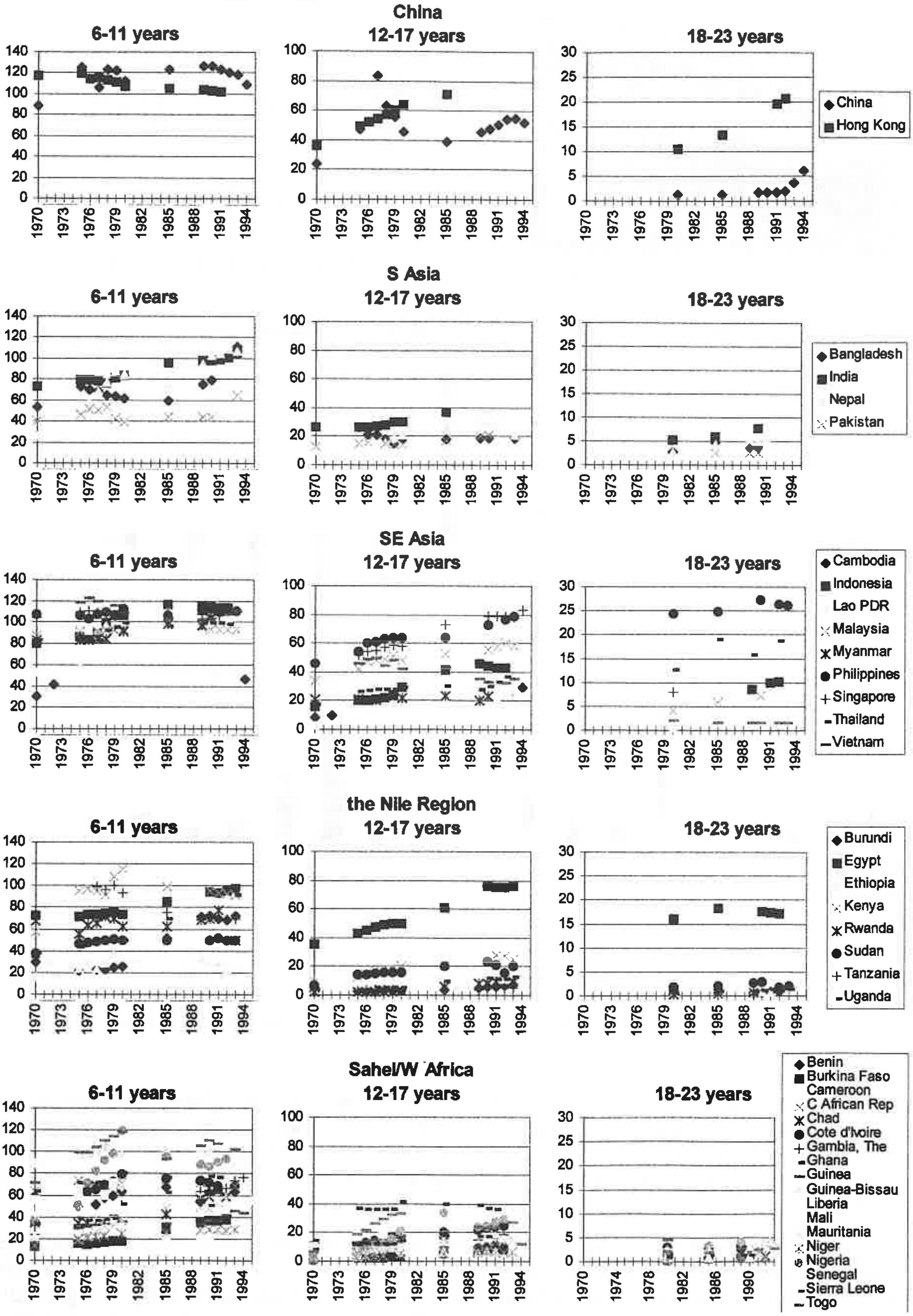



Fig. 19: Access to education by regions. Gross enrolment ratios (%) (data: World Bank 1997).

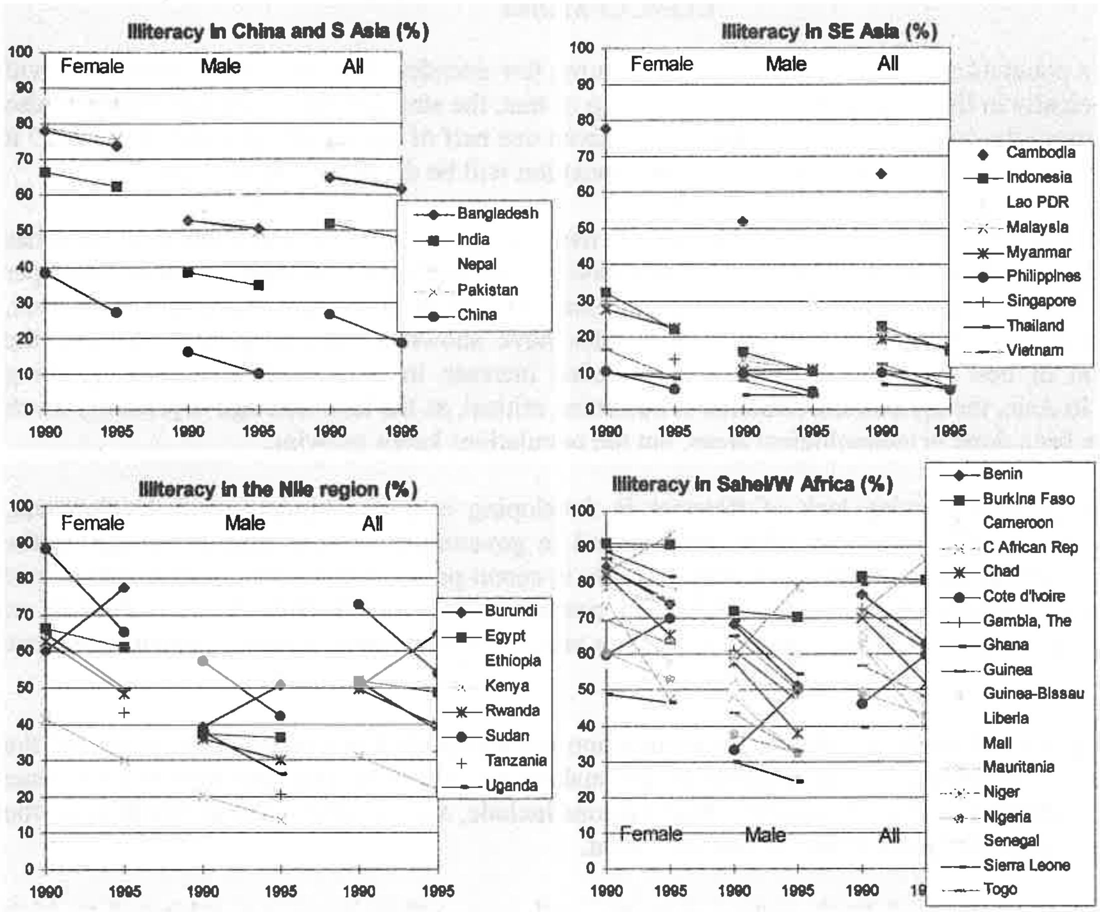



Fig. 20: Adult illiteracy (over 15 years) of women, men, and the total population by the regions (data: World Bank 1997).

Even more variation can be seen in the educational level for 12 to 17 year-olds than for the lower levels. At best it is about four out of five children in Singapore, the Philippines and Egypt , and at lowest less than 20 per cent in many African countries and South Asia except India. Also in these countries the rate of growth is almost zero.

The educational level for 18 to 23 year-olds is very low in most of these countries and the rate of growth is not high either. There are exceptions: several South-East Asian countries, Hong Kong and Egypt. The best educated people educate the rest of the population and develop the means of livelihood and national institutions. Without them the country is incapable of helping itself out of the treadmill of poverty and famine.

As far as illiteracy is concerned (Figure 20) it can be said that rapid progress is being made in almost all the countries of the areas studied, except in three African states. It is worth noticing that rising the level of education will have an effect on the average illiteracy of the adult population, with a delay of decades. In China and South-East Asian countries except Laos and Cambodia illiteracy was less than 20 per cent in 1995. An illiteracy rate of 70 to 80 per cent is the highest found in the countries studied, for instance in Nepal, the Republic of Central Africa and Burkina Faso. In almost all the countries studied the literacy gap between gender is wide. Women's educational level is closely linked to population growth and its control (UNDP 1996).

## CONCLUSIONS

The earth's population continues to grow in the coming few decades. This increase in population will occur principally in the developing countries. On top of that, the strong trend of urbanization will also go on. Whereas the rural population stands now at about one half of the world's population, by 2025 it will be around one third. At that time, the urban population will be double as big as today.

Until the end of the 1980s, the world's food supply has kept up with the growing population. This has occurred in spite of the fact that earth's cultivated land has not grown. Accordingly, the arable land per capita has been in rapid decline over the past few decades. Due to increased fertilization, irrigation, new varieties, and other improvements, unit yields have shown a notable growth. Without the introduction of new land for agriculture, the needed increase in food production faces growing problems. In Asia, the agricultural situation is becoming critical, as the land shortage is pressing, much has already been done in technological areas, but the populations keeps growing.

The permanent and growing lack of finances in developing countries hinders rural development, together with strong priorities to urban development in government policies almost throughout the world at present. Because of the continuing decrease in cereal prices in the world market, agriculture of developing countries lacks attractiveness and competitiveness of investments in comparison to manufacturing industry, tourism, and other areas in which the short-term economic profits are more evident.

In many regions and countries, the water consumption has approached or exceeded 40 per cent of the runoff average. This value is seen as being critical, making water scarcity and vulnerability a key issue in economic development of the country. Such regions include, among others, China, South Asia, the Middle East, and many parts of the African continent.

The global projections of food, water, economy, and many other issues are subjected to high discrepancies and uncertainties. They typically concentrate their attention into the average situations, but clearly, the extremes such as droughts, floods, conflicts, wars, economic collapses, and so on, are typically much more important than the average situations. The connections between sectors in a society—such as those between water resources, agriculture, education, and industry—should deserve more attention than is the case in present-day global assessments (Vakkilainen and Varis 1998, Varis 1998a).

The uncertainties and inpredictabilities concerning the very basic needs of any human being—water and food—appear to be higher than is admitted at present. Policies that aim at providing increased stability to the supply of these goods in a longer time perspective should be encouraged. The significance of education at all levels should not be underestimated, so that economies would be increasingly capable to take responsible care of their own sustainable development. Much more stable frames than today are needed in many parts of the world. Without a sound social structure, access to education, public awareness, and entitlement to contribute to the social development, the societies are invalid in developing themselves in long term.

Time is a crucial issue in tackling the water resources problems in a sustainable way, because the solutions—such as technical, social, economic, institutional, and human capacity building—cannot be realized in a few years, but need longer insight: a perspective of a few decades. The different components mentioned above are strongly interconnected, and a balance is needed among them. The problems concentrate on low-income countries. Their capacities are small to develop their water resources systems and food production in a sustainable manner. Perhaps the most important component in long term is human capacity, that can only be developed through high quality education starting from primary schools and covering all levels to vocational training and university education. Without that, a country is doomed to be incapable of developing itself from poverty and environmental degradation.

Water and food are too precious and basic issues to be forwarded under control by market mechanisms and business cycles only. The poorest 85% account only for 18% of global cash flows. They are not equitable partners in the world market. A major stabilizing factor is to produce food close to the users, by not forgetting the self-sufficiency paradigm, both in developing and developed countries. This underlines the many-sided, stabilizing role of rural development in a society.

Most of the negative consequences of unbalanced and unstable development are felt by developing countries; by the poor and hungry. From there, they reflect increasingly over the whole globe. In the rapidly globalizing world, the responsibility of industrialized countries is growing as the economies get more open and trade barriers lower. When targeting towards sustainable and equitable development at the global level, the policies in high-income countries are more crucial than many think. Water has many very basic and deep-going roles behind the development process, and its many facets should be appreciated and realized in development co-operation policies of developed countries, and in the policies of international organizations.

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