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Butterworths

Macro-scale water scarcity requires micro-scale approaches

Aspects of vulnerability in semi-arid development

Malin Falkenmark, Jan Lundqvist and Carl Widstrand

This paper shows that water scarcity is a complex problem when it affects countries with a semi-arid climate, ie countries for which there are fluctuations between a dry season and a season when rain occurs. The paper discusses the general vulnerability of the semi-arid zone in terms of four different types of water scarcity, the effects of which are being superimposed on each other: two are natural (type A, arid climate, type B, intermittent drought years) and two are man-induced (type C, desiccation of the landscape driven by land degradation, and type D, population-driven water stress). When fuelled by a rapid population increase, a risk spiral develops, manifesting itself in social and economic collapse during intermittent drought years. The paper concludes that many countries in Africa are heading for severe water scarcity –in fact two-thirds of the African population will live in severely water-stressed countries within a few decades. This severe water stress will largely be the result of unfettered population growth.

Many of the economic development problems in the semi-arid regions of the world are second generation problems which owe their origin to the heavily sectorized policies of the bilateral and multilateral aid agencies. Those policies were based on laudable aims intended to improve human health, increase food production, reduce famine and poverty and generate foreign exchange by developing natural resources including the growing of cash or export crops. Although they provided temporary relief, many of those aid policies were ineffective or even counterproductive for the long-term, sound use of the resource base. In general, they were based on a development thinking, where the significance of both natural resource limitations and climate were underestimated, and the importance of technology and large-scale projects was overestimated. This came about because of the poor understanding of the implications of hot climate and semi-arid conditions for development strategies.

Descriptions of soil degradation processes have been characterized by repeated references to phenomena such as 'droughts' and 'desertification'. However, rather than blaming a natural phenomenon such as drought years, our way of meeting drought and desertification should be challenged. Only by doing so will it be possible to identify and develop management and conservation practices appropriate to those countries which face chronic and/or recurrent water scarcity.

This paper will examine water scarcity phenomena, primarily taking a hydrological perspective. The intention is to demonstrate how climatic aridity, intermittent droughts, land degradation and population growth combine to produce increasingly critical conditions. It is essential to develop a new awareness of these relationships among policy-makers of developing countries and among bilateral and multilateral development agencies involved in technical assistance.

Dr Falkenmark is Professor of International Hydrology at the Natural Science Research Council, Box 6711, S-11385 Stockholm, Sweden. Jan Lundqvist and Carl Widstrand are Professors at the Department of Water and Environmental Studies, Linkoping University.

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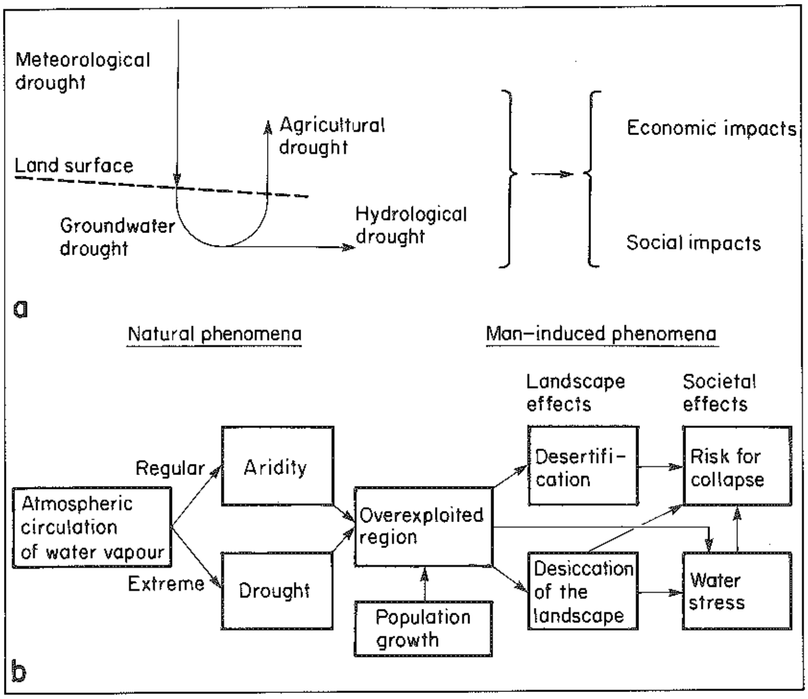

Figure 1. Various categories of dryness and their effects: (a) different types of droughts and their interrelations; (b) involved interdependencies between natural phenomena and population growth, generating both landscape effects and social effects.

Both have to realize that the challenge to living conditions brought about by the macro-scale lack of water has to be and, indeed, can be approached in new ways. The relevant question to ask is *not*: how much water do we need and from where do we get it, but rather: how much water is there and how can we best benefit from it? In other words, the challenge is to promote a strategy which aims at proper management of the demand aspect of water, and not at continued supply-oriented water management.

Water scarcity results from much more than droughts

The drought concept

Basically, droughts are manifestations of climate fluctuations, conceived as variations around an average [8]. Those variations are associated with large-scale anomalies in the planetary circulation of the atmosphere, which in the tropics lead to the subsidence of air masses and therefore the absence of precipitation. Local factors are invariably superimposed on the large-scale planetary circulation patterns and contribute to local climatic anomalies.

Large-scale anomalies, when they affect an area, tend to produce drought in various phases of the water cycle, which is reflected both in soil moisture deficiency (agricultural droughts), and in a lack of groundwater recharge. The latter manifests itself in low water tables (groundwater droughts), and in low river flows (imprecisely called hydrological droughts). Drought tends to produce higher order effects, generated by society's water dependence, which have both economical and social impacts (see Figure 1a).

Four modes of water scarcity

The concept 'drought' is being used rather haphazardly, more or less equivalent to water scarcity. As illustrated in Figure 1b, when lack-of-precipitation phenomena are 'filtered' through an overpopulated/overexploited area, the results are the desiccation of the landscape and the risk of collapse of the socio-economic system.

In principle, we may recognize four different types of water scarcity [5] which tend to be superimposed on each other. Two of them are natural and related to the hydro-climate. These are:

- type A, *aridity*, which is reflected in a short length of the growing season; and
- type B, *intermittent droughts*, which is reflected in recurrent drought years in which there is risk of crop failure.

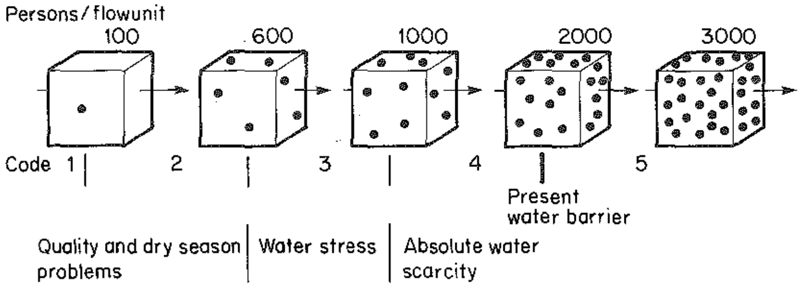

Figure 2. Visualization of different levels of water competition. Each cube indicates one flow of 1 million m^3/year available in terrestrial water systems, each dot 100 individuals depending on that water.

Two are man-induced. They are:

- type C, *landscape desiccation*, which is due to soil degradation and reduces local accessibility of water and sometimes referred to as man-made drought; and
- type D, *water stress*, which is due to too large a population per unit of water available from the water cycle (Figure 2).

By distinguishing between these four types of water scarcity, we may distinguish between water scarcity to the root zone of plants, ie water needs for biomass production, from water scarcity brought about by water demands for other societal needs. The remaining man-induced water scarcity, manifested as desiccation of the landscape (type C), has both dimensions simultaneously: no water to the root zone, interrupting plant growth, and reduced availability of water for other needs.

Finite fresh water supply but growing population

Easy access to water is a basic condition for habitability. The water available in a country or region, whether visible water or invisible water, is derived from the water cycle. The amount is determined by the geographical position of the country, which determines on the one hand the endogenous supply from rainfall over the territory, and on the other any exogenous supply imported by international rivers or aquifers from upstream countries in the same river basin. Thus, the renewable freshwater supply is basically finite. It may, however, change considerably between different years in response to climate fluctuations.

The amount of rainfall, not returned to the atmosphere but feeding the local aquifers and rivers, is the amount available to support societal needs, in other words there are a finite number of flow units of fresh water. In this paper, one flow unit of water corresponds to one million cubic metres per year. The question then arises: how many people can be supported by each flow unit within given technological and managerial capabilities? Given a finite amount of water, with increasing population, competition for water will obviously increase. Figure 2 illustrates this fact graphically, along with the water management problem that is likely to occur.

How much water is needed for livelihood security and quality of life

As earlier discussed by Falkenmark [2,3], experience from the industrialized countries indicates that as competition for water increases so do water management problems. The nature of the problem and the difficulty in dealing with it are directly related to population per flow unit:

	Water stress level code
below 100 persons/flow unit, limited water management problems	= 1
100–600 persons/flow unit, general water management problems	= 2
600–1000 persons/flow unit, water stress	= 3
1000-2000 persons/flow unit, chronic water scarcity	= 4
2000 persons/flow unit, beyond the 'water barrier' of manageable capability	= 5

Water stress level codes are shown in Figures 2 and 3.

The amount of water needed for household, cattle, industry and irrigation, and the possibility of satisfying that need can be seen in Figure 3. Water needs are expressed as multiples of household demand, assumed to be 100 litres/person/day. In principle, the water utilization level can be increased up to

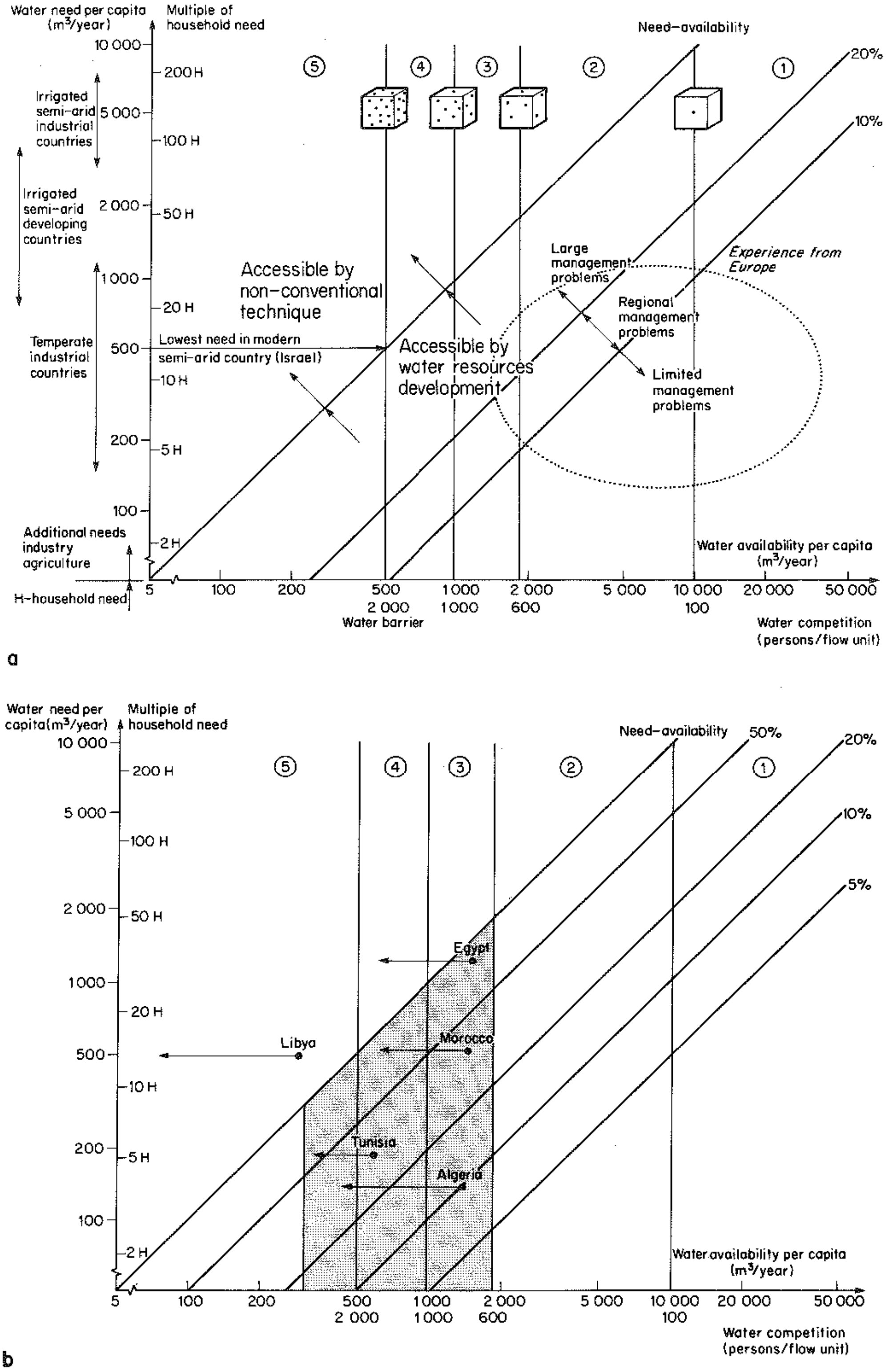

Figure 3. Water demand possible to supply at different levels of water availability.
Water demand given as multiples of household demand, assumed to be 100 litres/person/day. Crossing lines indicate different levels of water utilization, achieved through storage reservoirs and other measures of water resources development. Both horizontal and vertical scales are logarithmic and give *per capita* amounts. Figure 3a presents the general principles of the diagram and indicates experienced demand levels in different regions. The arrows in Figure 3b show the predicament expected in some African countries by the projected population growth between the mid-1970s and 2025. The tinted area indicates water-stressed conditions, characterized by water competition code numbers 3, 4 and 5. Data from reference [6] based on country reports.

a maximum of 100% of the water available by conventional resource development measures, whereas – beyond 100% – non-conventional measures are needed (desalination, iceberg towing, import of water, reclamation of waste water etc). It should be noted, however, that non-conventional measures, for all practical purposes, are solely relevant in an urban–industrial context. For economic and administrative capability reasons, non-conventional measures are out of reach for the majority of poor developing countries.

Based on country data from Forkasiewicz and Margat [6], past experience on water demand levels in different world regions suggests the general intervals indicated in the left margin of Figure 3a [4] where H equals an assumed household water demand of 100 litres per person and day. Some water demand levels in flow units are as follows for:

irrigated semi-arid industrialized countries	75–200 H
irrigated semi-arid developing countries	20–100 H
temperate zone industrialized countries	4–25 H

How much water is there to meet human needs?

Given the current trends in population growth, Falkenmark [3] has shown that by 2000 and 2025 respectively, 250 and 1100 million Africans will be living in countries characterized by water stress, chronic water scarcity or beyond the barrier of manageable capability, ie water stressed at least to the present level of the Lower Colorado basin in the USA. In other words, in three decades from now, two-thirds of the African population are likely to face severe water shortages. This means that they will be occupying the vulnerable triangle under the 100% curve, lying within water stress level code intervals 3,4 and 5 (Figure 3). It also means that because of the arid conditions in which they find themselves, they will not have access to the large quantities of water required to meet their needs. As a general rule, those countries may not be able to reach an overall average of more than 5 to 10 H, ie much less than average 20 to 100 H, needed to irrigate in semi-arid developing countries.

Temperate experience gives poor guidance

Semi-arid conditions are very different from conditions in the temperate zone, especially in terms of the low need in the latter for irrigation to protect agricultural production from drought-related crop failures or to compensate for the short aridity-related growing season. The experiences in relation to water management problems at different water utilization levels may, however, have some relevance. According to a report by the ECE [10], water management problems are of limited difficulty as long as the utilization level is below 10% of the available water. Between 10% and 20%, regional problems are likely to develop, and beyond 20%, large water management problems may arise due to difficulties in terms of storage, flow control, local transfers, waste water etc.

This macro-scale water scarcity predicament is well illustrated by the example of Tunisia, a country already under conditions of chronic water scarcity [4]. The ultimate water supply level needed to sustain Tunisia in the long term is obviously a function of at what stage it will be possible to stabilize its population. Should the population stabilize at the present level – which is probably impossible – it would theoretically be possible, after subtracting out household demand, to supply about 12 H for non-household use, provided that 100% of the potentially available water is accessible for use. Should the population double before stabilizing, it would be possible to supply only 8 H under the same assumption. And if it were not possible to stabilize the population before it quadrupled, only about 5 H could be provided even at the 100% utilization level. This represents a tremendous challenge especially when water demand levels for irrigation in semi-arid developing countries range from 20 to 100 H. Basically it means that the need to stabilize population in order to achieve socio-economic development is a race against time.

Lack of water for plant growth

In the past, most attention in water resources discussions has been paid to visible water, ie the water available from rivers and aquifers. Less attention has been paid to the invisible water in the root zone, ie that water needed to support plant growth, except when defining the length of the growing season as the time when there is enough water in the root zone to allow plant growth.

Under conditions of water scarcity, and where the different types of water scarcity referred to above tend to be superimposed on each other, it seems relevant to address the different water needs together, as they will in reality be competing with each other. The more water that is consumed in plant production and returned to the atmosphere, the less will remain to support human needs. For example, reforestation can lead to decreasing groundwater levels so that wells tend to dry out, or perennial wells become seasonal.

The root zone water supply needed for uninterrupted plant growth depends on soil permeability and water retention capacity. The root zone water supply

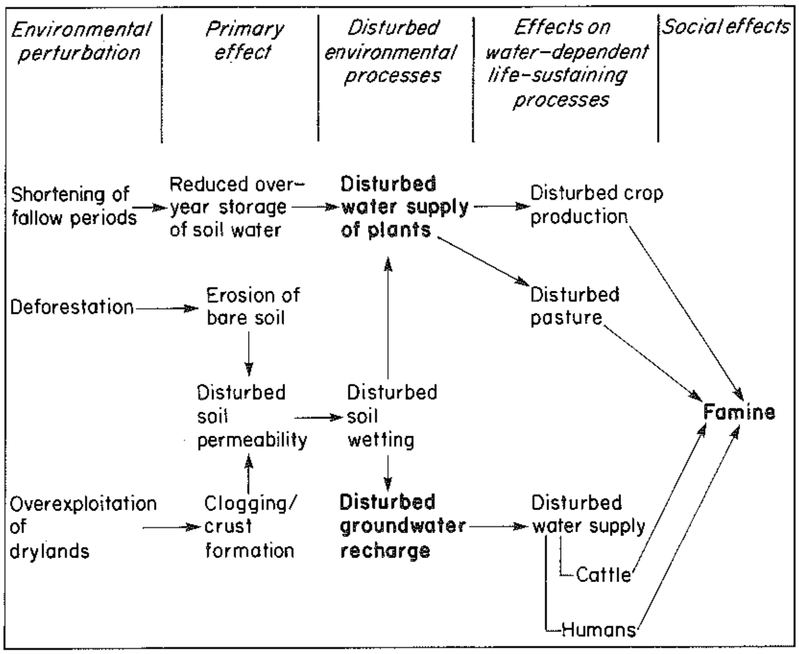

Figure 4. A number of processes related to poor land management tend to produce desiccation of the landscape, leading to crop failure and local famine.

is easily disturbed both by degradation of the land surface so that permeability decreases and by reduction of organic matter in the soil so that water retention capacity decreases. A likely consequence of this will be crop failure and disruption of local food distribution systems, in other words, man-induced famines during recurrent drought years.

Soil degradation leading to landscape desiccation may be produced in several ways: overexploitation, overgrazing, shortening fallow periods, deforestation etc. Figure 4 shows the sequence of disturbances set in motion by these primary perturbations.

The dilemma of the drought prone region

The dilemma in general

In summary, the dilemma of a drought prone region may be described as follows [4]:

Vulnerability	Complication	Triggering	Result
aridity, implying a limited growing season	degraded soils disturbing the recharge of the root zone	intermittent droughts	disturbed water supply to plants
water scarcity type A (aridity)	water scarcity type C (landscape desiccation)	water scarcity type B (intermittent droughts)	

To secure the livelihood of rural inhabitants from the impact of droughts, land desiccation must be avoided by turning to water saving crops which will assure optimal biomass production under conditions of water scarcity A. The best possible use of local rain is necessary, and various agricultural and societal measures to mitigate unavoidable crop failures due to intermittent drought have to be fostered. Integrated soil and water conservation measures on a catchmentwide basis are crucial to the solution of the problem.

The close link between water needed for plant growth and water needed to satisfy other societal needs makes it interesting to combine the information on the length of the growing season with information on water competition levels (ie number of persons per flow unit) for different countries in Africa (see Figure 5) [4]. The hatched rectangles indicate the most vulnerable part of the matrix for plants which have a short growing season and can therefore fall victim to drought and/or erratic rainfall. The tinted area shows levels of water competition at which the resulting water stress may affect plant growth. The water stress level codes 3, 4 and 5 along the left edge of the chart, indicate higher levels of water stress. The figure gives a profile for African countries by region for both 1982 and 2025, at the population levels predicted for those countries. It is clear from the data shown that population increases alone will push many of the countries of Africa into the zone of high water stress. The single most important measure to prevent this water penury from developing is therefore stabilization of the population at near present levels.

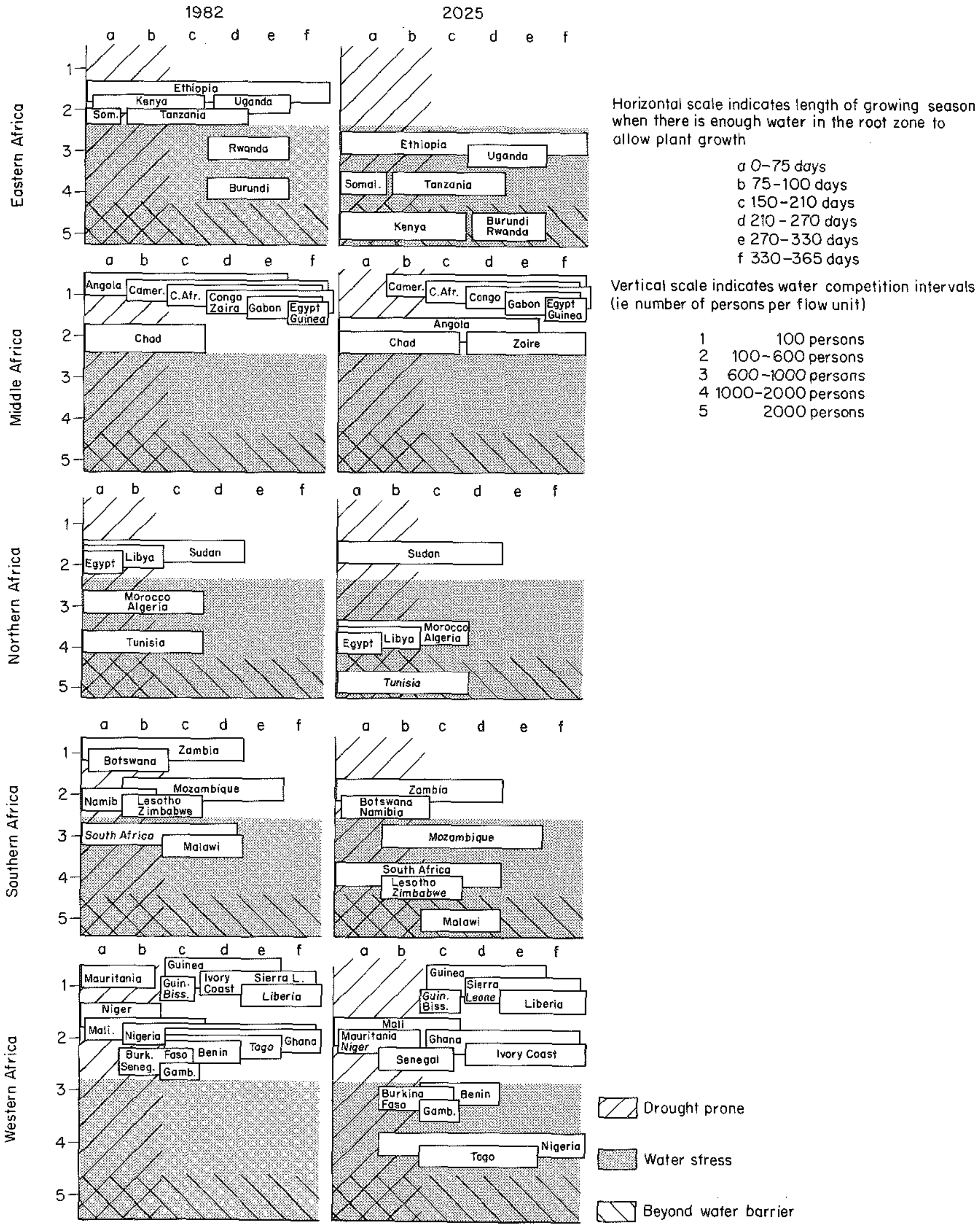

Figure 5. Matrix demonstrating predicament of African countries from a water scarcity perspective. Global data from Lvovich.

Water competition code	Nile 1982	Nile 2025	Zambesi 1982	Zambesi 2025	Limpopo 1982	Limpopo 2025	Congo 1982	Congo 2025	Niger 1982	Niger 2025	Senegal 1982	Senegal 2025
1			Zambia Botswana Angola		Botswana		Zaire, Congo Cameroon Central Africa Zambia Angola	Congo Cameroon Central-Africa	Cameroon Guinea	Cameroon Guinea	Mauritania Guinea	Guinea
2	Egypt, Sudan Ethiopia Uganda Kenya Tanzania	Sudan	Mozambique Zimbabwe Tanzania	Zambia Botswana Angola	Mozambique Zimbabwe	Botswana	Tanzania	Zaire Zambia Angola	Nigeria Niger, Mali Benin, Togo Burkina Faso	Niger Mali	Mali Senegal	Mauritania Mali Senegal
3	Rwanda	Ethiopia Uganda	Malawi	Mozambique	South Africa	Mozambique			Algeria	Benin Burkina-Faso		
4	Burundi	Egypt Tanzania		Zimbabwe Tanzania		South Africa Zimbabwe		Tanzania		Nigeria Algeria Togo		
5		Rwanda Burundi Kenya		Malawi								

Figure 6. Water stress profile of countries sharing international river basins. Populations 1982 and 2025.

Should such water penury develop there is a risk for international conflict. Most of the major African rivers are international rivers passing from one country to another. Figure 6 gives an idea of the macro-scale water stress predicament in the different countries sharing the same river, taking into account population growth as presently predicted. It should be emphasized, however, that the water stress level code numbers relate to the country as a whole and not to that part within the water divide of the particular river. The figure gives a clear indication of the potential for conflicts, produced by the population growth and the water penury generated thereby. Conditions are particularly severe in the Nile basin where all the countries except Sudan will have chronic water scarcity or even be beyond the 'water barrier' (water stress level code 5) by 2025.

Urgent need for a new awareness

There is an urgent need for a new awareness of the problems that have been discussed in this paper. Politicians and high-level decision-makers need to be aware of the water penury problem, and that problems which seem to relate to the land may actually be caused by such penury. New strategies will have to grow out of such an awareness: urgent components of this new strategy need to include water resource assessments, to be followed by upgraded water plans for optimal use of water resources available and by the establishment of best use land criteria. Such an approach is in line with the ideas brought forward by the Brundtland Commission [12] for delineating broad land categories and identifying land according to best-use criteria, based on inventories and descriptions of a country's lands, forests and water. The crucial concept for the new strategy needs to be sustainable development and land husbandry.

The overriding challenge is to strike a balance between the acute needs of people in terms of a productive utilization of their resource base and the equally demanding task of conserving the productivity of the resource base in order not to jeopardize future needs. A management strategy must thus be developed which allows the concurrent utilization and conservation of land and water resources. In other words, what is required is environmentally sound and effective management of land and water resources.

For example, such an approach should include conservation to increase infiltration of rain and its retention in the root zone, and water conservation to make the best possible use of local rain to mitigate the effects of landscape desiccation and water stress.

Interregional transfer of a micro-scale solution

Available descriptions and analyses indicate that traditional agricultural systems in temperate climate zones are well adapted to fluctuations in rainfall [5]. Diversification based on a multitude of crop varieties with different water requirements are the farmers' answer to the need to master climatic vagaries. In some cases irrigation is used to master those vagaries with water transferred over long distances. Given the physical geography of Africa, large irrigation systems are, however, no solution to the African problem [7].

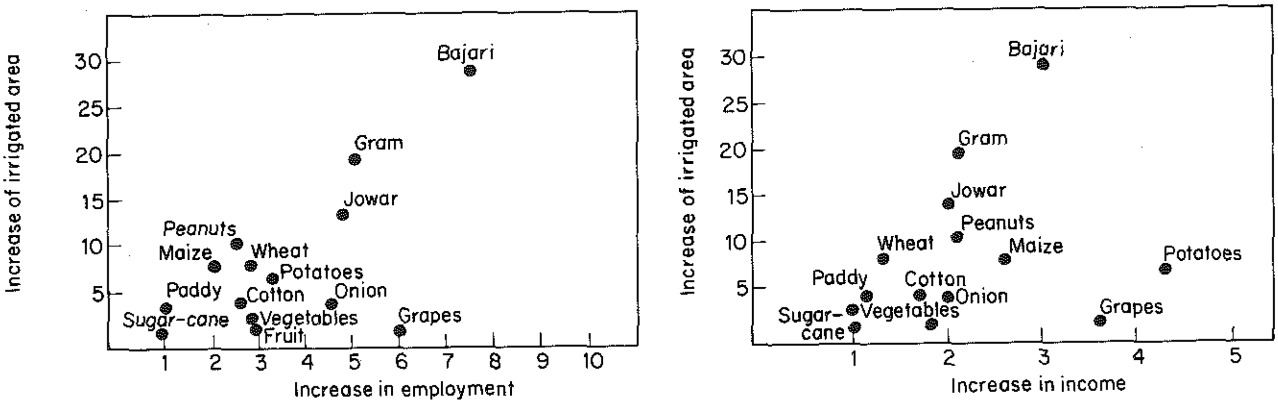

Figure 7. Extent of land that can be irrigated, increase in employment and increase in income possible if the water now used for sugar-cane irrigation were used for alternative crops with lower water demands.
Data from the Pani Panchayat system in Naigaon, S. Maharashtra, India (Salunke [9]).

The main part of the continent's still unused water resources are formed in the humid tropics, and drain westward into the Congo river system. Large-scale transfer of water to the dry regions could be an option only in the distant future. Large parts of semi-arid Africa are dry uplands with an undulating landscape where no exogenous water is available. For those areas and for semi-arid areas in general, water is a most scarce and uncertain resource. Socio-economic development in the medium-term perspective therefore depends on finding alternative ways to master the available fluctuating rainfall.

By making the best possible use of local rain, ie striving to maximize agricultural production per unit of water, rather than per unit of land [1], experience has demonstrated that there is potential for generating both increased income and employment [9, 11]. Figure 7, taken from Salunke [9], illustrates that the area that can be cultivated with a given amount of water can be increased by up to 30 times if crops with low water demand are grown instead of crops with high water demand. The increase in employment and income as a result of being able to irrigate more land with a finite amount of water was shown to be quite significant.

The development and spread of such micro-scale approaches as those presented above could be of crucial importance to semi-arid Africa. The transferability of these principles to the African cultural and geographical environment must be seriously contemplated in decision-making and policy design. There is, however, another more fundamental problem to tackle, the extremely high levels of water stress now developing under the influence of rapid population growth, in many famine-prone African countries. Unless the issue of population is addressed, famine is likely to be a recurring tragedy.

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