Chapter 9
Shift in Water Thinking Crucial for Sub-Saharan Africa's Future

Malin Falkenmark

Abstract With large development optimism and seen as rich in water resources, Africa is—except for the humid equatorial area—an arid continent, dominated by vast savannas, which require skilful manoeuvring between unreliable rain, very thirsty atmosphere, sharpening droughts and low runoff generation. With a four-folding population and six-folding water demand in just 70 years, the pressure on the water resources is rapidly increasing and already approaching basin closure level in several regions. Since the *blue water* is concentrated to transnational river corridors, food production is 95% rainfed, i.e. depending on *green water* in the soil; subsistence farmers' yields remain low (some 1 ton/ha), and hunger is widespread. An African green revolution is slowly developing as a water harvesting supported agriculture, foreseen to allow even three-folded crop yields. Many countries cannot expect long-term food self-reliance, making national economic planning essential to secure an industrial development for generating necessary foreign currency. Africa's future is closely linked to its demographic changes, demanding due attention: both towards reducing extreme fertility; and to adaptation to the rapid expansion of middle-age population strata in response to growing life expectancy. Currently, two blindnesses are blocking the road to a sustainable future: city planners' lack of concern for megacities raw water supply; and the United Nations' (UN's) Sustainable Development Goal's (SDG's) total unawareness of green water's crucial role for hunger alleviation. Foreseeable water shortages will demand *water-security oriented policies*, based on blue water for urban, industrial and energy water supply; green water for food production; and widespread leap-frogging and water decoupling for manoeuvring water supply.

Keywords Africa · Blue water · Green water · Water scarcity
UN Sustainable Development Goals · River corridors

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Ingress
This article is a wakeup call for African leaders to be adequately aware and take urgent action to avert an entirely foreseeable danger of regional instability, conflict and outmigration linked to both demand-driven and population-driven escalation of water scarcity.

9.1 The Challenge

Africa is a continent dominated by drylands and a very thirsty atmosphere, leaving only some 20% of the rainfall to form runoff. Half of the countries are dominated by high-level poverty and hunger. This paper explains why conventional solutions addressing poverty and hunger used in Asia, relying on runoff water for irrigation, will not work in the vast dryland parts of Africa. Instead, direct management of scarce rainfall will have to be an integral part of the development agenda, a critical insight that seems absent in the proposed United Nations' (UN's) Sustainable Development Goal's (SDG's) hunger goal (UN 2015, goal 2).

The African Development Bank (2011) characterises Africa as one of the driest continents of the world, where savanna takes up almost half of the continent (Fig. 9.1), and hosts some 25 African countries that tend to remain low-income countries with widespread hunger and poverty. Agriculture is mainly rainfed and highly vulnerable to droughts, and the dry season typically lasts more than seven months. The continent is subject to three physical drivers of change: climate change, land use change/leasing and water under rapidly increasing pressure.

Currently, Africa's population density, although relatively low, is changing rapidly: UN projections indicate that the continent's overall population will more than quadruple before the end of this century (Gerland et al. 2014; UN 2015). Indeed, most of the world growth is expected to occur in Africa (Fig. 9.2). This fact is now raising increasing concern (Fisher 2013): '*The rapid growth itself will likely transform political and social dynamics within African countries and thus their relationship with the rest of the world*'.

In 2010, almost 500 million people lived in the vulnerable arid and semi-arid zones, and 245 million people in the dry sub-humid zone (Falkenmark and Rockström 2015). Rapid population growth will multiply these populations to altogether 1.1 billion in 2030 and 1.6 billion in 2050—another India! As a consequence, the region can be foreseen to suffer increasing difficulties of producing sufficient food for its expected population, in the long run making a sustainable future critically dependent on a sustainable food import. This will demand access to foreign currency, achieved by successful development of an export sector, building on low water-based industrial production based on accessible raw materials or other resources.

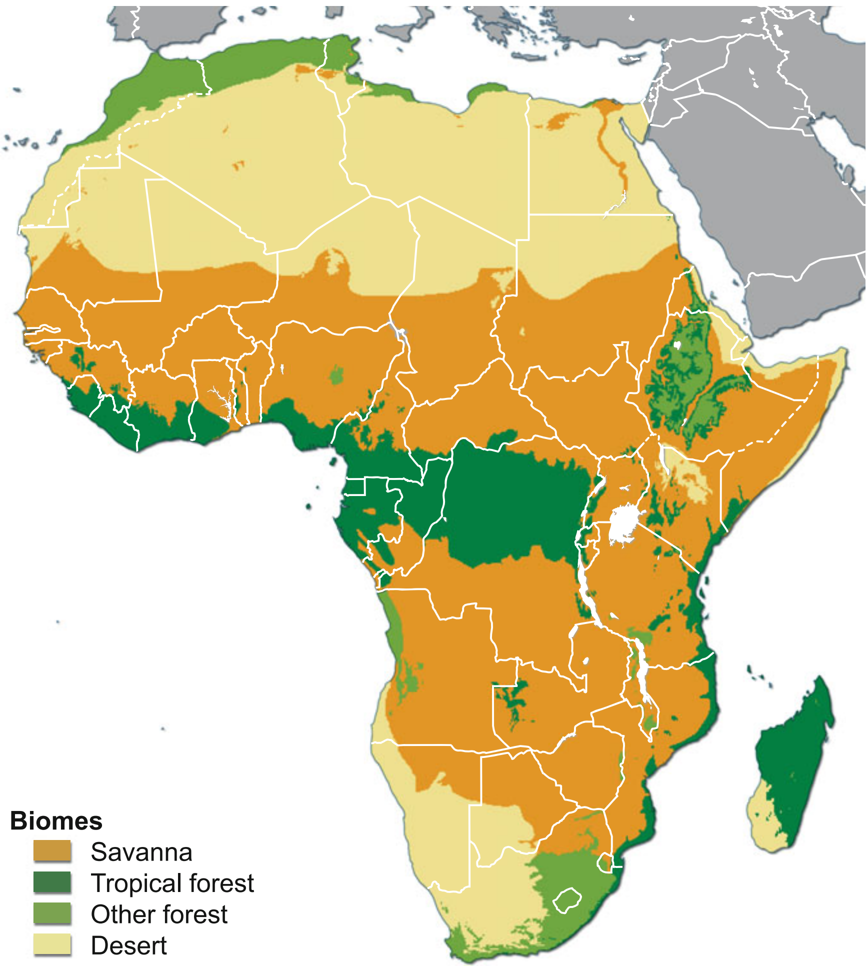


Fig. 9.1 Sub-Saharan Africa is dominated by tropical grasslands/savanna (based on Olson et al. 2001)

The continent's urbanisation rates are among the highest in the world, while '*the ability of African cities to cope with these numbers is questionable since they generally lack the institutional and infrastructural capacity to absorb the additional urban dwellers*' (Sturgis 2014). The State of African cities (UN-HABITAT 2014) stress that '*the massive population growth in a context of wide-spread poverty … generates complex and interrelated threats to the human habitat*'. Not much attention has yet been paid to potential implications of water shortage constraints to societal development, for instance, complications related to where to find the next generation of raw water sources to support the rapidly expanding multimillion urban populations (Falkenmark and Tropp 2016).

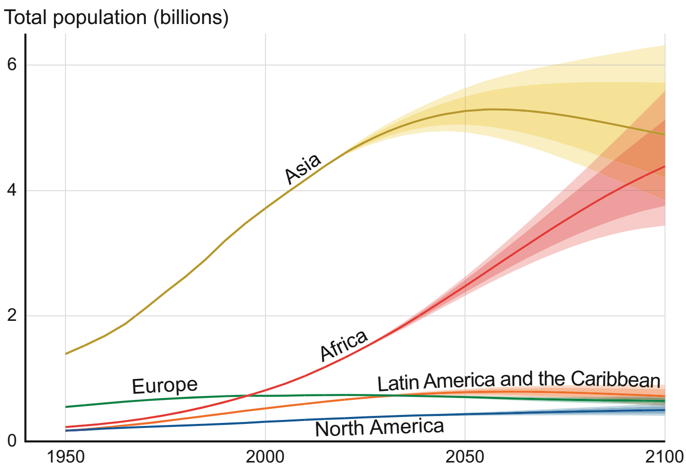


Fig. 9.2 Population growth this century is projected to occur at highest rates in Africa. Shaded areas indicate ranges for lower/upper projections (data from UN DESA 2015)

All these facts suggest that water awareness, strategies and policies will indeed constitute core elements on Africa's pathway to a sustainable future. Two fundamental water-related activities will be of particularly central importance for the future of Sub-Saharan Africa (SSA):

- secured *water supply* of the rapidly expanding cities foreseen already in this century, to be housing 70% of an overall population of four billion;
- water-secure *food production* for the rapidly growing population, most of which is living in the savanna-dominated region.

In this chapter, we will discuss the African megatrends with particular focus on the vast savanna region (Fig. 9.1), and the challenges of managing a situation of rapidly growing population.

9.2 Western Views Have Been Misleading

Many African authors have expressed concern over the dominance in past literature of conventional 'western views'. The fact that so little attention is given the issue of how to find safe raw water sources for booming multimillion cities suggests that, in spite of the massive scale, this issue may, in fact, have been seen as a purely technical task, like it has often been in the better water endowed developed world. Moreover, when it comes to the rapid expansion of food production, needed to feed the exploding African population, literature is dominated by the hope of rapid expansion of irrigated agriculture (African Development Bank 2011; Economic

Commission for Africa 2006). The South African scholar Turton (2012) has expressed the concern that '*many conventional economists and financial analysts are unaware of the fact that the national economy is based on a national hydrology*'.

9.2.1 Sub-Saharan Africa's Achilles' Heel

Similarly, the South African scholar Schulze (2001, 2007) has stressed the "*strong need for an 'Africanized' model, for use at appropriate smaller scales, physical-conceptual in structure, so that it is sensitive to local land use/management conditions, and addresses the rural issues to which Africa needs answers*". He has pinpointed a number of phenomena that sets Africa much apart from temperate climates of many developed countries:

- very high potential evaporation;
- very high aridity;
- low runoff generation;
- very concentrated rainfall seasonality;
- strong response to the El Ninõ-Southern Oscillation signals in terms of high inter-annual rainfall variability;
- many small rivers that tend to be ephemeral.

Criticising the dominance of Eurocentric hydrological models, developed for data-rich temperate climate situations, he raised the crucial question '*Are we asking the right questions?*'

His colleague Odbiambo (2001) has called for a '*paradigm shift that moves well beyond the purely technocratic and economic approaches, which particularly identify the skills necessary for immediate solutions to freshwater management*', and asked for '*the longer term and much broader governance of freshwater resources. which constitutes, in fact, humankind's ultimate goal*'. He remarked that one cardinal pillar in the new African doctrine of governance of freshwater resources is '*that the operating quantum must be the entire watershed, and its functional subsets, such as city conurbations*'.

9.2.2 Sub-Saharan Africa's Hydroclimatic Reality

Taking, in line with Schulze (2001), a physical-conceptual approach to the SSA, the hydroclimate can be seen as the product of the interaction among rainfall, potential evaporation and resulting runoff generation (Fig. 9.3). What primarily distinguishes the regions (central basin) from the northern temperate region (left basin) is the very large 'thirst of the atmosphere', i.e. the extreme potential evaporation. The higher

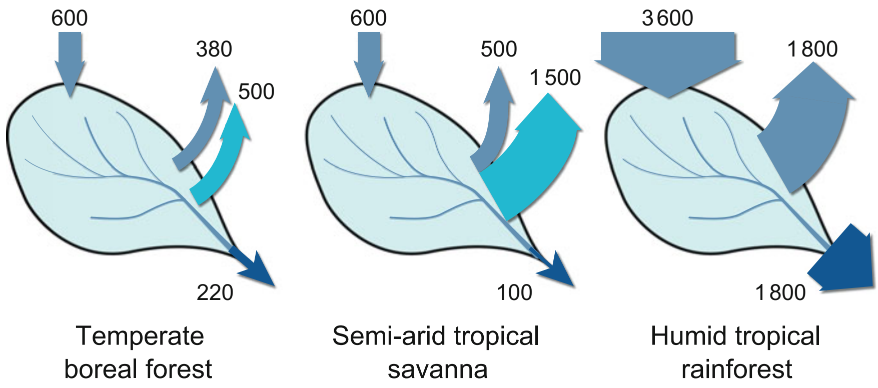


Fig. 9.3 Water balance differences between three main hydroclimatic regions, presented through typical basins (top arrow, precipitation; dark right arrow, actual evaporation; light right arrow, potential evaporation (thirst of the atmosphere); lower arrow, runoff). The semi-arid tropical savanna is distinguished by the extreme potential evaporation (based on Falkenmark and Rockström 2004)

this vertical water flow, the lower will be the rainwater surplus turning into horizontal runoff. Where the runoff generation is low, it may even evaporate before reaching the river, resulting in river stretches carrying water only during rainy periods.

Similar to Schulze, Weiskel et al. (2014), has maintained that up till now, the globally dominating water resources development approach has been characterised by a *blue-water bias* by mainly focusing on the particular situation in the humid, mountain-source regions, serving just 20% of the world population. Such an approach is poorly fitted to the situations in the dry climate half of the world's land area, where most of the rain evaporates, resulting in limited runoff generation—as demonstrated by the central basin in Fig. 9.3. This is, in fact, the region where poverty and hunger continues to dominate—problems that the SDGs, declared by the UN in 2015, aim at alleviating (Falkenmark and Rockström 2015; UN 2015). Two basic conditions for moving towards poverty mitigation and hunger alleviation are adequate urban raw water supply, and safe water for local food security.

For understanding the specific Sub-Saharan water availability dilemma, a clear idea of water's existence in the landscape will be essential. The water balance distinctions illustrated in Fig. 9.4 focus on different combinations of, respectively, horizontal and vertical water inflows to and outflows from a landscape unit. In *humid regions*, flow-through regimes are dominated by *blue water* inflows and outflows, whereas in *drylands*, with low runoff generation, vertical water flows or *green water* flows (rainfall and evapotranspiration), are dominating the water resource situation. There, since blue water withdrawals and return flows would tend to deplete or churn the natural systems, development will depend on green water practices to protect or restore soil moisture (the green water reservoir) and to carefully manage green fluxes, i.e. precipitation and evapotranspiration.

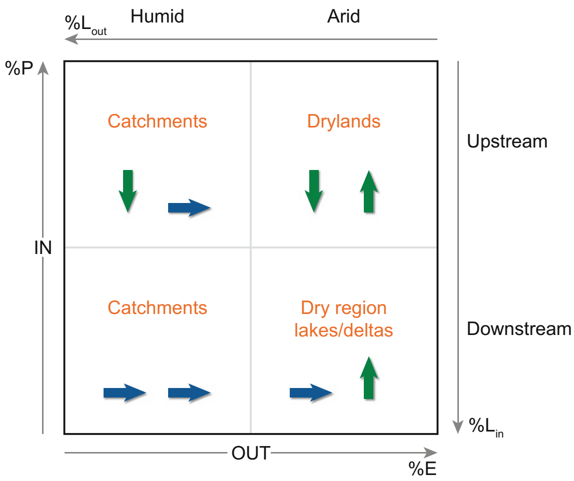


Fig. 9.4 Categorisation of different hydroclimatic landscape situations, based on composition of water inflow and outflow. according to Weiskel et al. (2014). Axes show percent vertical water. *P*, precipitation; *E*, evaporation; L_{in}, river inflow; L_{out}, river outflow. In *humid regions*, flow-through regimes are dominated by blue water inflows and outflows, whereas in *drylands*, with low runoff generation, vertical water flows or green water flows (rainfall and evapotranspiration), are dominating the water resource situation

In 2005, Vörösmarty et al. (2005) presented an essential contribution to our current understanding of Africa's hydroclimatic reality, with blue water largely concentrated in river corridors. This understanding will have significant development implications for SSA where its dry climate, exacerbated by climate change and increasing rain variability, is expected to result in even more frequent and severe drought years.

Furthermore, Africa's rapid population growth makes attention to population-driven water shortage, i.e. water crowding, essential. As showed later, when the population, already before the end of this century, is expected to have increased four-fold, all the savanna zone countries can be foreseen to be suffering from chronic water shortage. The Sub-Saharan hydroclimatic reality therefore demands an urgent shift in thinking towards incorporating adequate attention to green water/infiltrated rain—fundamental for finding the way to a sustainable future for the continent.

9.3 Blue Water Realities and Water Supply Challenges

Ultimate base for the Sub-Saharan socio-economic development is the precipitation, systematically increasing from the deserts to the humid tropics. Precipitation tends to be higher over local mountains, which function as water towers and source areas feeding water flow into river corridors. As a consequence, the locally available blue water will have to be shared between primarily societal water supply of cities and industry, while food production to feed a rapidly growing population will primarily have to remain rainfed, and based on soil moisture from infiltrated rainfall, i.e. green water. Many countries suffer from endemic water scarcity, increasingly constraining their socio-economic development—particularly in eastern and southern Africa.

9.3.1 Water Towers and River Corridors

Blue water appears in basically two forms: as *river corridors*, basically originating from isolated water towers in the landscape (Fig. 9.5a), and as locally generated runoff over the savanna, where it might in the future be locally harvested before it evaporates. The map shows that the drainage pattern—except for passing large rivers—is quite sparse in arid and semiarid zones, including Mali, Niger, Chad, Sudan, Zimbabwe, Botswana and Namibia. Large African rivers are transnational requiring international water management agreements for use as raw water sources (Turton 2012).

The groundwater situation is shown in Figs. 9.5b, c. Basically, there is plenty of groundwater stored under the African soil but in the drylands, the depth to the water table is generally more than 25 m, deepening towards the Sahara (MacDonald et al. 2012). Aquifer productivity is generally low (below 1 l/s), except in central Sahel and in Angola. Only northern Africa has large sedimentary aquifers, most of which are however no longer recharged.

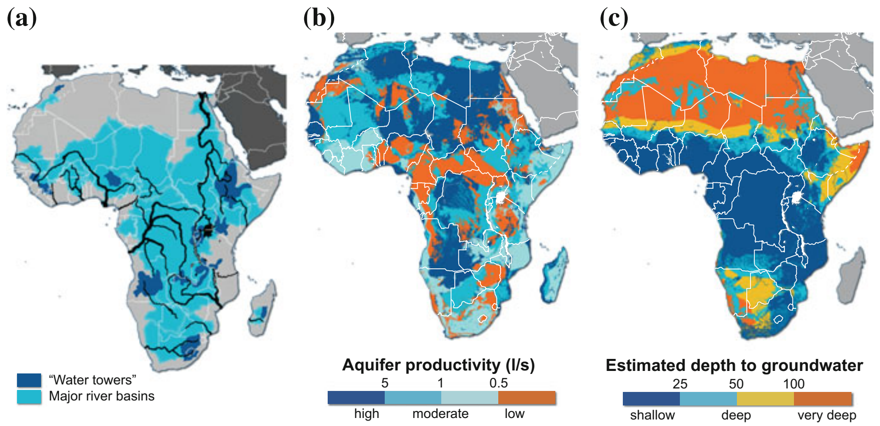


Fig. 9.5 Blue water availability: **a** water towers, major rivers with main tributaries and selected drainage basins (based on UNEP 2010), **b** aquifer productivity is generally low in SSA, with the exception of central Sahel and Angola (based on MacDonald et al. 2012), **c** groundwater is shallow in dryland regions, deepening towards Sahara, eastern and south eastern Africa (based on MacDonald et al. 2012)

9.3.2 City Water Supply Challenges

Currently, some 50% of the African population is urban, and urbanisation increases continuously. The African urban population is expected to grow faster than in any other world region and absorb practically all the population growth (Varis 2006). By the end of the twenty-first century, 70% of the population is expected to be urban. According to UN DESA (2014), Africa had, by 2014, 39 large cities (more than 1 million inhabitants), by 2025, projected to amount to 80 cities.

A current Stockholm International Water Institute (SIWI) study has looked at the urban raw water problem (Falkenmark and Tropp 2016), revealing that, in coming decades, the water supply challenges will be massive, and the 'booming city future' in Africa will demand the Herculean task of securing, in only 15 years, water supply for hundreds of millions of African city dwellers. Water supply infrastructure will have to be a core component of liveable cities (Ng 2018). The size of the task will be compounded by the size of the population growth and the related stress on the city's infrastructure with its services in terms of both food, water and electricity.

Figure 9.6 illustrates the massive task and the relatively short time available, for securing safe water supply for African cities, with urbanisation estimates from African Development Bank (2011). Since the overall blue water availability now amounts to 4000 km^3/year, it may, by 2100, be down to only 1000 m^3/capita/year (4000 billion m^3/year divided with 4 billion people) i.e. will have reached so-called chronic water shortage on a sub-continental level. Assuming 200 m^3/capita/year for gross urban water supply (Falkenmark and Xia 2012), combining human, industrial

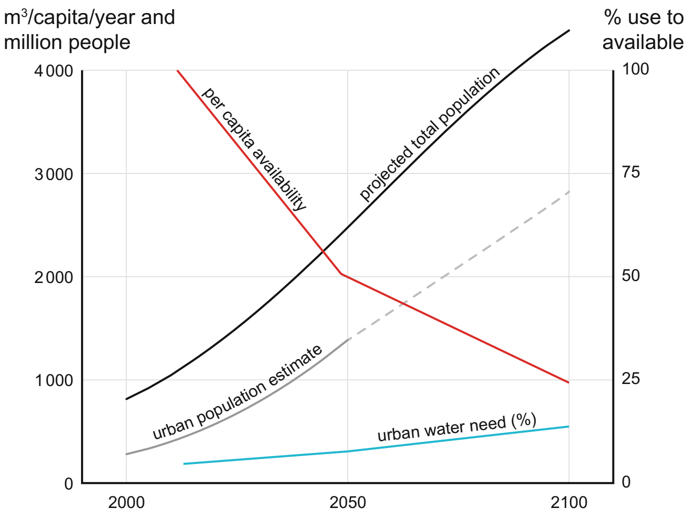


Fig. 9.6 Foreseen regional water scarcity development in Africa 2010–2100. Presented on the left scale is *per capita* availability (m^3/capita/year) and total and urban population (millions, UN DESA 2014, 2015). The right scale shows estimated relative urban water demand (% of availability)

and energy water supply, the city water requirement will, by 2100, have grown to 560 km^3/year for gross urban water supply (2.8 billion people multiplied by 200 m^3/capita/year), i.e. some 14% of the overall blue water availability.

When considering the urban population growth, and the risk for social unrest if allowing uncontrolled growth to alienate citizens, city authorities will evidently have an instrumental role to play in balancing the housing and infrastructure needs against pace of growth.

9.3.3 Three Contrasting Raw Water Situations

According to the SIWI study, the urban water supply systems will have to be built up under an era of rapid increases in water demand and increasing efforts to link the city to outer world economy. In view of the variability in geographic/hydrological and financial constraints, many different types of raw water sources will have to be contemplated. Table 9.1 exposes one possible way of predicament distinctions, based on the type of water appearances in the landscape: closeness to river corridor, savanna land with low blue water generation, accessible groundwater aquifer, exposure to large-scale flooding, etc.

Even though smaller and mid-sized cities are those growing relatively faster compared to larger ones, the larger cities will be important economic engines. For example, Nairobi is not only a critical national economic hub, but increased and secure water supply to Nairobi will be a cornerstone of the Kenya government's Vision 2030 to develop the region into a world-class commercial centre (Varis 2006). The city is expected to grow from 3.2 million inhabitants to 5.5 million in 2030, and the increasing urban populations and expanding economic activities will evidently involve rapidly mounting water pressures (both municipal, industrial and energy production).

Table 9.1 Hydrological raw water source predicament categories with city illustrations, based on landscape characteristics

	Lean source	Rich source
River	A: Small river/seasonal source *Nairobi, Johannesburg, Addis Ababa*	B: Large river/perennial source *Niamey (Niger)*
Savanna	C: Arid/semi-arid landscape dependent on rainwater harvesting/pumped groundwater *Lusaka, Gaborone*	

9.4 Water for Food Production—A Massive Green Water Challenge

We now turn our focus to water for feeding the African population, in line with the Malabo declaration (African Union 2014) and the UN's SDG goal 2 to eradicate hunger by 2030 (UN 2015). Except for the wet equatorial areas, the Sub-Saharan landscape is dominated by subsistence agriculture on savanna land, Fig. 9.7a, characterised by low rainfall increasing from the desert towards the rainforests.

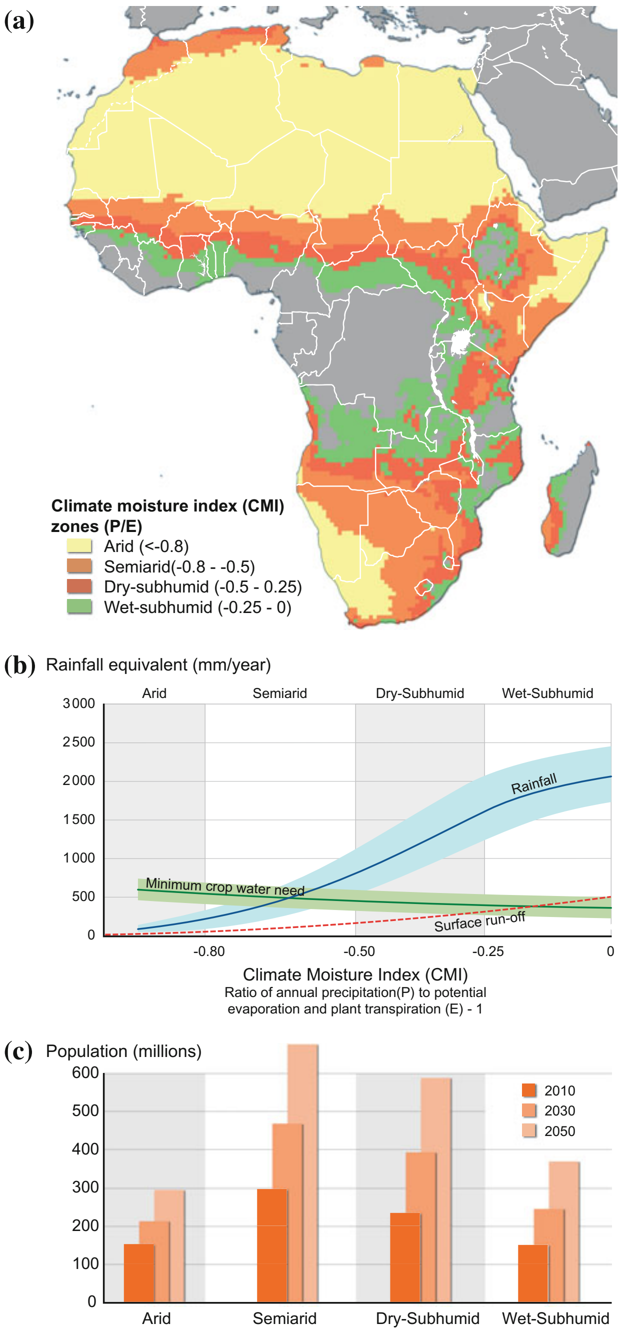
9.4.1 Hydroclimatic Dilemma

Low and unreliable rainfall in the arid and semi-arid zones makes agricultural vulnerability large, presented as the crossing curves in Fig. 9.7b, where the highly variable annual rainfall is related to the crop water requirement (Falkenmark and Rockström 2015). In some years there may be sufficient rain to allow a crop to mature, while in other years, conditions will be too dry to allow a crop to mature. The current situation is mirrored in widespread poverty and hunger in the semi-arid zones, with the highly fluctuating rainfall between good years and bad years. The vertical columns in Fig. 9.7b show population size in the different climatic zones by, respectively, 2010, 2030, and 2050. It visualises the rapidly growing population to be fed, and the vulnerable livelihood situation, that the SDG targets are expected to overcome without much delay.

9.4.2 African Subsistence Agriculture

In view of the particular blue water geography in SSA, it is not surprising that agriculture remains mainly rainfed. Most subsistence farmers live far away from the large river corridors (Vörösmarty et al. 2005) with limited possibilities for conventional irrigation, and hunger and poverty are widespread. The hydroclimatic regime makes rainfed agriculture problematic and unreliable, and involves exposure to frequent droughts and dry spells (Mertz et al. 2012). In regions with easily degradable soils, intensive rains easily form flash floods and erosion, and crops are easily degraded by drought damage, limiting their water uptake capacity of the roots. Agricultural productivity is therefore low with crop yields around only 1 ton/ha.

Since poor soils make water losses large, water use efficiency and crop yields remain low, but opportunities exist for a certain yield gap closure: on the one hand, large blue water losses both as surface water and as surplus percolation down to the groundwater, and on the other hand, large evaporation losses due to poor root water


(a)
Climate moisture index (CMI) zones (P/E)
Arid (<-0.8)
Semiarid(-0.8 - -0.5)
Dry-subhumid (-0.5 - 0.25)
Wet-subhumid (-0.25 - 0)
(b) Rainfall equivalent (mm/year)
Arid
Semiarid
Dry-Subhumid
Wet-Subhumid
3000
2500
2000
1500
1000
500
0
Rainfall
Minimum crop water need
Surface run-off
-0.80
-0.50
-0.25
0
Climate Moisture Index (CMI)
Ratio of annual precipitation(P) to potential evaporation and plant transpiration (E) - 1
(c) Population (millions)
600
500
400
300
200
100
0
2010
2030
2050
Arid
Semiarid
Dry-Subhumid
Wet-Subhumid

◂**Fig. 9.7** **a** Africa's semi-concentric savanna landscapes (data from Vörösmarty et al. 2005). **b** Hydroclimatic zone profile from arid, to the left, to wet sub-humid, to the right. The rainfall curve shows rainfall plus/minus one standard deviation (blue). Crop water requirement curve shows requirements plus/minus one standard deviation (green). **c** Population per hydroclimatic zone, 2010 estimate and projections (based on Falkenmark and Rockström 2015)

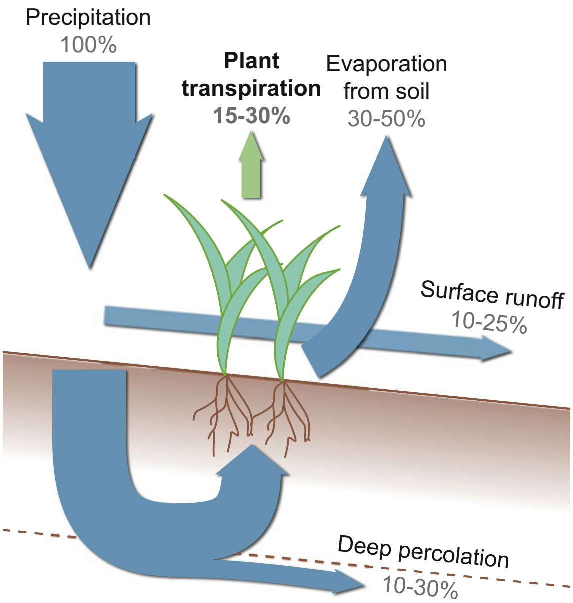


Fig. 9.8 Typical water flows on a subsistence farmer's field in the savanna zone. Losses via run-off, evaporation and drainage are so large that only 15–30% of the rain becomes available for plant growth (transpiration) (based on Rockström et al. 2014)

uptake. Full use of the available rainfall would however allow many times higher yield (Rockström and Falkenmark 2000).

The huge water losses (Fig. 9.8) might, however, be *treated as a resource* and made productive by an integrated approach to soil and water management: soil tillage for improved rainfall infiltration, reducing surface water runoff, and water harvesting to allow supplementary irrigation for protecting crop roots from dry spell damage (Rockström 2003; Falkenmark and Rockström 2004). Supplementary irrigation could be secured based on both rainwater and local runoff harvesting in local ponds (Critchley et al. 2008; Dile et al. 2013; Garg et al. 2012; Joshi et al. 2008).

9.4.3 Towards an African Green Revolution

Since the 1990s, making better use of green water by soil conservation and rainwater harvesting has been intensifying within agricultural sciences. Methods for selecting suitable rainwater harvesting sites in arid and semi-arid regions have been developed (Ammar et al. 2016)—Dile et al. (2013) showed that it was possible in an Ethiopian basin to increase staple crop production by up to threefold after better nutrient application. A green water revolution perspective has, in the past 10 years, begun to enter official documents, as shown by the following examples:

- 2006: Alliance for Green Revolution in Africa (AGRA) committed to launching an African Green Revolution (Bill and Melinda Gates Foundation 2006);
- 2010: building on the 1969–1990 Green Revolution promote a Greener Revolution in Africa, increase irrigation to increase food security; great potential for harvesting water runoff in lowlands and valley bottoms (UNEP 2010);
- 2011: need for biologically based green revolution (African Development Bank 2011);
- 2014: Malabo Declaration: accelerate agricultural growth by at least doubling current agricultural productivity levels by 2025; provision of 'smart' protection to smallholder agriculture; need for efficient and effective water management systems notably through irrigation (African Union 2014);
- 2015: need for climate smart agriculture; better use of green water; avoid reliance on abstraction of blue water (Williams et al. 2015);
- 2016: study on 'Resilience of African Drylands'; irrigation probably not the solution for the vast majority of dryland households (World Bank 2016).

An integrated blue-green approach, tends to see the huge water losses in today's subsistence farming in Africa as a resource, benefited from in a so-called t*riply green revolution* (green for, respectively, green water, productivity increase, and environmental protection). Combining soil and water management, a *triply green revolution* would give synergy effects, i.e. increasing productivity, making better use of the green water available, and allowing productive recycling of nutrients and organic matter through productive sanitation (Falkenmark and Rockström 2015). The untapped potential to save water in food production is largest in the lowest yielding savanna regions (Rockström 2003), and these are also the regions where growth in food requirements is fastest due to population growth and where a green revolution is therefore particularly needed.

The productivity of semi-arid Sub-Saharan lands has been addressed over more than 30 years in response to the UN Convention of Drought and Desertification (Falkenmark and Rockström 2008). There, land degradation has been taken as the focus, and much attention has gone into efforts to contain the desert by tree-planting along the desert border. Building on experiences of the Algerian Green Wall and a similar programme in China around the Gobi Desert, a new Sahelian tree-planting-oriented programme was launched in 2012, the Great Green Wall Initiative of the Sahara and the Sahel (AMCEN 2012).

At its First Conference, in May 2016, the World Bank presented a start of the art study on the 'Resilience of African Drylands' (Cervigny and Morris 2016), indicating the shared interest in wise management of green water for sustainable development of the semi-arid zone, indicating a need '*for integrated landscape management to restore degraded areas to functional and productive ecosystems … so that food is more available and more affordable after shock hits*' (World Bank 2016). Similarly, in the SDG activities, land productivity improvement is highlighted both in SDG goal 15, aiming at reaching the Rio+20 goal of a 'land degradation neutral world', and in SDG goal 2, aiming at reaching hunger alleviation (UN 2015).

9.5 Water Scarcity Hotspots

While we, in Sect. 9.4, were clarifying the principal hydroclimatic implications for water-dependent societal sectors (city water supply, water for food production), we will now look for the hotspots by turning our focus to fundamental regional differences. A pixel-based modelling study by Schuol et al. (2008) offers the opportunity to coarsely identify regions particularly vulnerable to sharpening water shortage; both *blue water shortage*, influencing the development of urban, industrial and energy water supply, and *green water shortage*, limiting food production opportunities for expanding populations.

9.5.1 Regional Blue Water Scarcity

It should be recalled that, when analysing blue water scarcity, two aspects have to be distinguished (see Fig. 9.9):

- the difficulty of mobilising an even larger part of the availability, i.e. increase use-to-availability ratio or criticality (increasing the *water stress*);
- water as part of the physical environment in the sense of how many people that are competing for, and contributing pollution to, each flow unit (increasing shortage or *water crowding*).

Box. Water stress versus water crowding

When water shortage, in terms of water per person, is now sharpening in the dryland areas of Africa (cf. Fig. 9.6), it is essential to be aware of two contrasting perspectives, not well distinguished in the past. Figure 9.9 shows the difference between *water stress*, referring to the relative amount of the total water availability being already mobilised and put to use (vertical axis), on the one hand, and on the other *water crowding*, referring to number of people both sharing and contributing pollution to each flow unit of water (horizontal axis).

On the vertical axis, development will step by step be approaching a *peak water level*, beyond which increasing water needs will have to be met in other ways, like water use efficiency, demand management, wastewater reuse, desalinisation, decoupling, etc.

On the horizontal axis, population growth will lead to increased crowding, and can be expected to have social implications with increasing health problems, discontent, xenophobia, etc., and will have to be met by governance efforts well in advance, in order to avoid societal unrest and secure societal order.

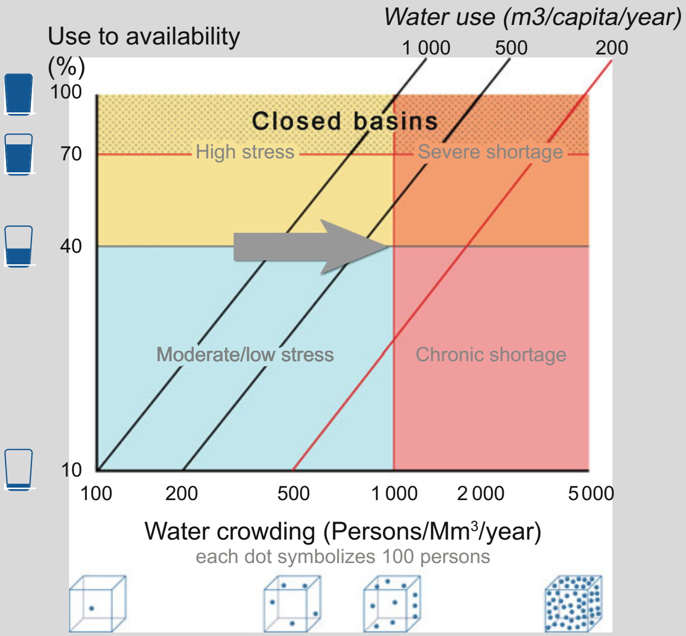


Fig. 9.9 Two modes of water scarcity (based on Falkenmark et al. 2014). The vertical axis presents the mobilisation rate ratio, making increasing amounts of water availability accessible for use (water stress). At the amount to be protected for aquatic ecosystem health (ecological flow, here 70%), the mobilisation level is maximised (peak water). The horizontal axis shows water crowding (people per flow unit of water of 1 million m^3/capita/year) indicating the number of individuals jointly dependent on, and polluting, each flow unit of water. The arrow indicates the effect of population growth. Beyond 1000 people/flow unit, water crowding is characterised as chronic water shortage

The potential per-capita water use in each point of this diagram is indicated by the diagonal lines, moving from high per capita uses possible at the low levels of water crowding, towards low per capita levels in the chronic water shortage regions towards the right in the diagram (Falkenmark et al. 2014).

9.5.1.1 Blue Water Crowding

A presentation of the situation in the last 30 years of the 1900s (based on the pixel level modelling by Schuol et al. (2008), is shown in Fig. 9.10a. Some semi-arid regions are already water stressed. Assuming an additional population of more than one billion, some preliminary conclusions can be drawn on the future situation.

The expected freshwater shortage situation in Africa by 2050 on the national level is shown in Fig. 9.10b, in terms of inverted water crowding (Turton 2012). By 2050, the chronic shortage region will be covering much of the major semi-arid region. Two regions are particularly exposed in SSA: respectively, eastern and southern Africa; the former hosting the water sources of the Nile river, with several

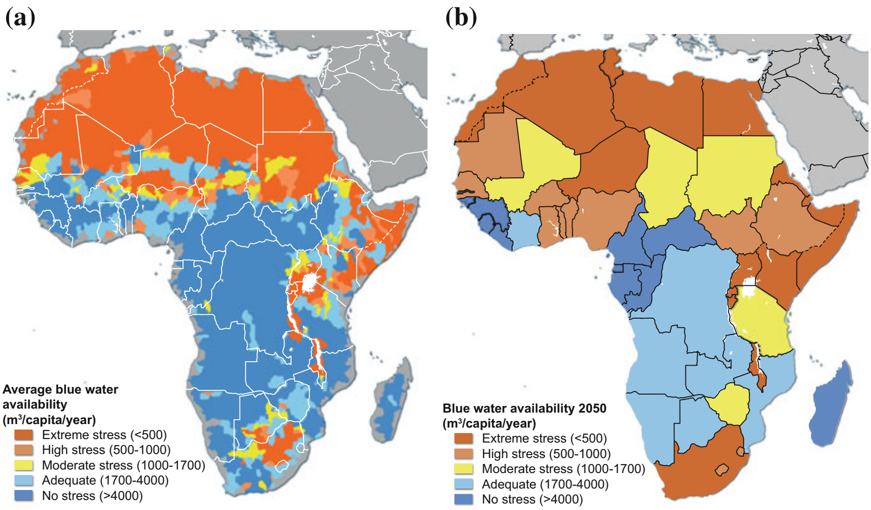


Fig. 9.10 Blue water shortage in Africa; **a** water availability *per capita* situation (i.e. inverted water crowding) in late 1900s with areas of chronic shortage (in figure referred to as "water stress") in the Sahel, eastern and northern Africa among other regions (based on Schuol et al. 2008); **b** country level projections for 2050 present major challenges in water availability for dryland regions (data from Schuol et al. 2008; UN DESA 2015)

large urban water hubs; the latter sitting on the sources of a quartet of transnational rivers, supplying a multitude of downstream countries with the water on which their socio-economic future largely depends (see Sect. 9.5.3).

9.5.1.2 Peak Water Approaching

Principally, below some 500 m^3/capita/year, i.e. beyond some 2000 people/flow unit, chronic water shortage can be foreseen to be constraining water dependent activities such as industry, energy and economic development. The economy is approaching the *peak water* level, involving transition from water supply being *demand-driven* to being *constraint-driven.* By mid-century, this situation can be foreseen to be dominating most of the Sahel and large parts of eastern and southern Africa. Already now, in the water mobilisation sense, southern Africa finds itself in an economically vulnerable state by '*water resources becoming a constraint to job creation and future economic growth*' (Turton 2012). Unless extremely wisely governing its water management, society may be risking '*a slow erosion of social cohesion as the unemployed become discontent, further exacerbated by the gradual loss of food security*'. This southern African dilemma is being further exacerbated by water quality consequences, such as the aftermath of the ceased large-scale gold mining in the capital area, in terms of a rising badly polluted groundwater, both acidic and radioactive—spilling into a transnational tributary, heading towards downstream Mozambique.

9.5.2 Regional Green Water Shortages, Short Growing Season, Large Drought Vulnerability

Since SSA's food production is mainly rainfed, the green water situation is of crucial importance for judging future food security potential.

While the blue water availability is highly vulnerable to population growth, the green water availability in terms of length of growing season (Fig. 9.11a) and drought vulnerability (Fig. 9.11b) is vulnerable to climate change (Mertz et al. 2012). The maps illustrate large regional, climatically driven green water differences. They show that the savanna zone (see Fig. 9.1) is dominated by semi-arid and dry sub-humid zones (Fig. 9.7) and their growing seasons (Fig. 9.11a) very vulnerable to droughts, reducing the growing season. Figure 9.11b suggests that a variability of about 1 month is quite widespread.

The maps thus indicate that broad regions in eastern Africa and southern Africa are particularly vulnerable to drought-related crop failures, requiring protective

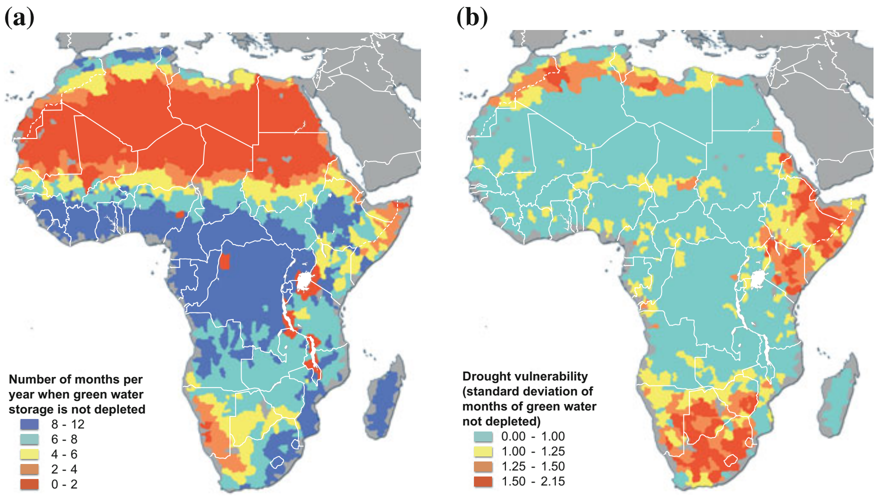


Fig. 9.11 Green water related characteristics in Africa (based on Schuol et al. 2008), **a** length of growing season (number of months when green water storage is not depleted), **b** drought vulnerability presented as the standard deviation of number of months when green water is not depleted, high standard deviation means more unreliable green water situation

irrigation from harvested rainwater and runoff from heavy rain in lowlands and valley bottoms to increase agricultural reliability (UNEP 2010).

9.5.3 Combined Water Scarcity Consequences

The highly water-shortage stressed situations in eastern and southern Africa with their increasingly water crowded societies makes an outlook to future water resources arrangements essential. Basically, precipitation provides the base for national economy and is thereby to be partitioned among:

- biomass production (green water);
- societal water requirements for development and security (blue water);
- downstream flow for co-riparian countries, crucially dependent on water from the same draining basin (blue water).

9.5.3.1 Hard or Soft Landing, Hydropolitical Risk

A fundamental conclusion when comparing Figs. 9.10 and 9.11 is the great vulnerability of eastern and southern Africa in terms of the combination of blue water shortage and drought vulnerability. The combined green-blue predicament of southern Africa is particularly interesting to look closer into, recalling its topographical functions as water tower for four transnational rivers of fundamental importance for the future of the whole southern region: Orange, Maputo, Incomati, Limpopo (Turton 2005). Population growth is pushing all these rivers towards water shortage related tipping points. While south Africa is hosting the water sources for these rivers, some of these basins are already in a state of river closure, and the basins all contain critically water-dependent downstream states. Southern Africa suffers from high drought vulnerability of its crop production which means that it would itself have clear interest in blue-water based irrigation development.

Conventionally, the river flow is seen as the blue water resource available for withdrawal up to a point where the remaining flow is required to secure aquatic ecological services (in dry climate of the order of 70% on the use-to-availability level). At this point of water withdrawal, the basin is considered *closed for further withdrawal* (Falkenmark and Molden 2008). There is, today, a tremendous concern that, over the last 50 years, many river basins in the world supporting important economies—indeed, many of the world's breadbaskets—have reached the closed limit, implying an increasingly water supply-constrained economy, requiring efforts such as increased water use efficiency, waste water reuse, desalination, green water use, decoupling solutions, etc. In that situation, a pertinent question is whether there will be a *hard or soft landing*:

- *hard* if the resource base fails to meet basic societal water requirements, causing hardship;
- *soft* if society is able to adapt to achieving a soft landing.

The potential amount of water supply that can be made available per capita and year at the level of basin closure is the inverted value of the water crowding (population per flow unit of one million cubic meter of water per year, cf. Fig. 9.9). Thus, the per-capita water availability at 1500 people/flow unit amounts to max. 500 m^3/p year; at some 3000 people/flow unit to only some 200 m^3/p year, a situation where most water is needed just for humans, industry and energy, but none for large scale irrigation (see below).

9.5.3.2 Constraint-Driven Urban Water Allocation

When water crowding increases, urban water supply difficulties will also increase, and early water supply preparedness get increasingly essential for social security. With the extremely rapid growth foreseen of the urban populations, rising from currently of the order of 0.5 billion, to more than five times as much by 2100, this will, in fact, be a core key to a sustainable future of Africa, involving a *supply-constraint driven urban water supply*.

Northwest China offers an interesting comparison in terms of such urban water allocation (water for urban/industry, secured environmental flow, water for irrigation) (Falkenmark and Xia 2012). Figure 9.12 shows one example of reasonable

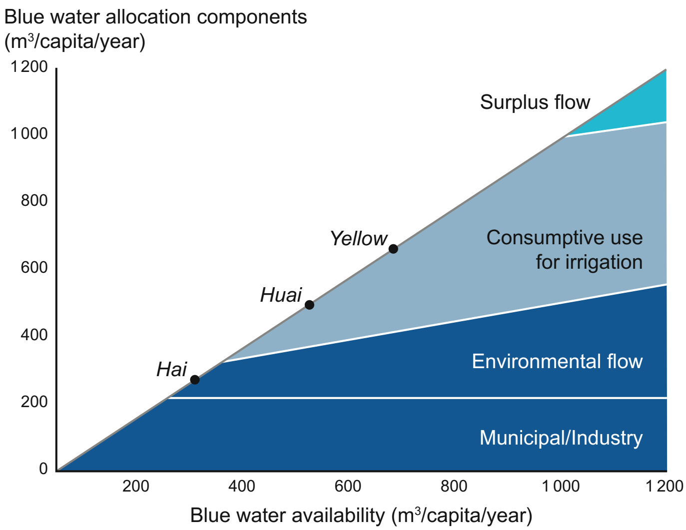


Fig. 9.12 Blue water allocation constraints in water short regions, example from northeastern China (Falkenmark and Xia 2012). The figure illustrates one possible supply-constraint driven allocation model, assuming municipal/industrial supply of 200 m^3/capita/year and giving second highest priority to ecological flow protection, and the implications for the Three H-rivers (Hai, Yellow, Huai rivers).

allocation for the highly water crowded three large rivers in north eastern China (Huai, Yellow and Hai rivers). It demonstrates one possibility of supply-constraint driven water allocation (gross city supply 200 m^3/capita/year, second highest priority to ecological flow protection). An alternative would be to reduce the urban and industrial water supply level to gain water for irrigation—this has been the solution actually preferred in northeastern China, limiting the city water demand to 90 m^3/capita/year.

9.5.4 Triply Green Revolution, Food Production Outlook

When related to the agroclimatic constraints, the very rapid population growth projected for SSA raises the issue of how far the region can, for hydroclimatic reasons, be able to feed their future populations. Many analyses tend to stress the importance of expanding irrigation (African Development Bank 2011) and hope for 25% increase by 2025 (Economic Commission for Africa 2006). One fact that tends to be neglected is that, in the savanna region, blue water availability is basically concentrated in the—often international—river corridors (Vörösmarty et al. 2005), while the majority of poor savanna farmers tend to reside far away from these blue water corridors.

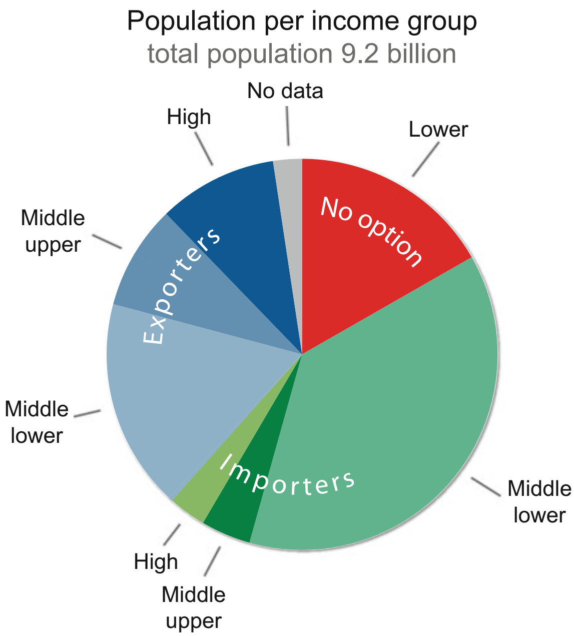


Fig. 9.13 Global overview of country estimates of water surplus (food exporters) and deficits (food importers) by 2050, grouped according to economic situation for a nutrition scenario with 3000 kcal/day/5% animal protein, assuming 25% yield gap closure (Rockström et al. 2014). Climate change and acceptable irrigation potentials are included. The comparison suggests that food water requirements will be too large to be possible to meet in a large number of countries. Groups to the left show populations living in countries expected to be able to export surplus, while sectors to the bottom and right show those dependent on food import for food self-reliance; the *no option* sector constitutes those possibly too poor for ability to carry the cost of food import

Assuming ability in terms of yield gap closure by productivity increase, Rockström et al. (2014) has thrown light on future food security in water short countries with rapid population growth. Figure 9.13 shows that extremely water short countries without possibility to increase food production will be critically dependent on ability to compensate their food deficiency by import, for which they—as already stressed—will be needing access to the foreign currency. This means that they will depend on developing a land-water integration based national planning to secure the industrial water required for that purpose. The blue countries would be able to produce food surplus; the green would depend on a certain level of food import.

Many countries in the importers and *no option* sectors are located in SSA and may be expected to suffer by 2050 from water scarcity constraining their food security. Several water rich countries in equatorial Africa (exporters) can provide surplus through inter-African food trade—'*Africa can feed Africa*' as formulated by the World Bank (2012). By 2050, many Sub-Saharan countries may remain too poor for import-based food security (no option group) and therefore depend on other non-conventional solutions, such as technical assistance, adapted diets, etc. An overview over nine such countries identified on what dietary level they would remain 'food self-sufficient' (Falkenmark and Lannerstad 2010), showing that on 2500 kcal/day/10% animal protein level, Ethiopia and Zaire would be able to be food self-sufficient; on only 2000 kcal/day/10%, also Burkina Faso, Eritrea, Gambia and Uganda might be just able to balance their diet. Most vulnerable would be Benin, Togo and Burundi, foreseen not to be able to feed their population even on a diet as low as 2000 kcal/day, vegetables only.

9.6 Discussion and Conclusions

Summarising, while the African population density still remains fairly moderate, many poor and medium income countries have high fertility rates, and more than 20 countries are already approaching chronic water shortage situations in the next few decades. Currently eastern Africa is advancing towards water-shortage related tipping points, while south Africa has already reached severe water shortage (Turton 2012), particularly serious in view of the implications for transnational rivers, fed by south Africa's water towers. Large regions can be said to suffer under a rapidly growing hydropolitical risk, composed of collision between dry climate, extreme population growth, and growing water needs. Since both water supply, food production and energy production all critically depend on access to water—blue as well as green—their sectoral interdependence will make a nexus approach among the three sectors essential.

9.6.1 Africa's Demographic Transition

The future of SSA is closely linked to its demographic changes (Canning et al. 2015; Varis 2006). The dry climate with low runoff generation, which makes food production mainly rainfed, matches poorly with the dominating blue water paradigm that tends to overemphasise blue (liquid) water, even in reports on Africa's future. This means that the earlier mentioned broad water blindness among societal economic planners will have to be addressed, securing proper water awareness in societal governance and infrastructure, to make possible development of skilful modes of water decoupling and successful leap-frogging in meeting rapidly expanding water demands whether green or blue. Particularly essential will be to identify adequate raw water sources for more than 80 big cities in the next 3–4 decades.

The activities needed to steer towards a safe Sub-Saharan future are no less than mindboggling: on the one hand efforts to reduce the time bomb, represented by the very high fertility rates, on the other successful adaptation to the rapid life expectancy-driven doubling of the grown-up population. The former is difficult to predict since they are aggregates of individual preferences. S*peeding up fertility decline* will have to involve a set of parallel types of activity: changing social norms regarding family planning, elementary knowledge of contraception, longer education of girls and later marrying ages, family planning programmes, easy access to affordable contraceptives, and social acceptability, etc., As fertility declines, reducing the number of children, the share of the working-age population will increase, improving the possibility to invest in its potential to contribute to economic growth.

Successful *adaptation to the increasing life expectancy* will demand development of decent livelihood condition*s,* realising that the current around 0.5 billion between 15 and 64 years of age can be expected to amount to more than 1.2 billion persons already by 2060 (another India as earlier pointed out).

9.6.2 Mastering the African Achilles' Heel

SSA's particular hydroclimate, with its extremely high evapotranspiration and limited runoff generation (only some 20% of the continent's rainfall), makes agricultural production unsecure, exposed to large water losses, low crop yields, and crop failures. The extremely rapidly growing population, complicates both the water management task and the water governance guiding it.

Not well adapted for addressing the continent's water challenges are conventional forms of blue water management (Williams et al. 2015), following examples from northern regions (Schulze 2007). In dryland regions such as those typical for the large savanna zone, attention needs to be paid to the water in the soil—the green water—brought by infiltration of rainfall. In view of currently large water losses in subsistence agriculture, a first step would involve productivity increase, based on conservation agriculture and protective irrigation, seeing non-productive evaporation losses as a water resource. This would include benefiting from two types of water harvesting: rainwater harvesting and/or harvesting of runoff from heavy rains. Today, the savanna surface runoff is increasingly thought of as a resource for supplementary irrigation (Ammar et al. 2016; UNEP 2010).

The exploding urban growth will have to be met by early planning of urban water supply—municipal, industrial and energy. Another issue to note is that in nearly all urban centres of Africa, water bodies within or near them tend to be heavily contaminated and are getting more and more contaminated with organic contaminants, chemicals and heavy metals. They are already encountering serious health and environmental costs, and are reducing the quantity of water available for future uses. African Development Bank (2011) has stressed that city growth remains largely unplanned, and that '*few African cities have municipal governments, capable of thinking through the complex set of coordinated decisions needed to deal with explosive urban growth*'. The interesting fact that so little attention seems to have been paid to accessibility of rich enough raw water sources is probably a remaining effect of a technical blue water bias, inherited from water-richer world regions. The extremely sparse interest in the literature paid to the fundamental life support issue of exploding cities is highly disturbing. Not even at the Habitat III meeting in the fall 2016 is the water supply challenges of booming big cities in Africa on the agenda.

9.6.3 An Africanised Model for Better Preparedness

African scientists have for at least two decades been stressing a set of phenomena, distinguishing Africa's hydroclimate from temperate climates of many developed countries. An essential tool for understanding the life support system's functioning in SSA will be a physio-conceptual mental model (Schulze 2001), sensitive to local land use/management conditions, including the current large-scale land-leasing originating from other water-short continents.

The Swiss model study by Schuol et al. (2008) might be useful for generating a preparedness without which today's optimism in many lion states may indeed be highly misleading. The water availability overview provided by that study shows that typical for the semi-arid land ribbon between the desert and the moist savanna land is the combination of high green water scarcity, critically dependent on rain water based supplementary irrigation, and a blue water crowding, that is rapidly, by the population growth, being pushed up into the chronic water shortage interval, when city water supply and water supporting the wanted industrial development is getting increasingly difficult to secure. It furthermore shows that two broad regions are particularly vulnerable from both a green and a blue water perspective: on the one hand eastern Africa, on the other southern Africa.

In future water management, it will also be essential to pay adequate attention to the very large water losses typical for today's urban as well as food water security management, and how they can be radically reduced.

9.6.4 Desertification: Historic Mistake not to Enter the Water that Exists

Quite remarkable has been the failure to see the water shortage perspective of land degradation management, misleadingly discussed as desertification abatement. A fundamental flaw that has most probably contributed has been the long-lasting focusing on soil dryness, i.e. *absence* of water, rather than the *presence* of water, i.e. the soil water that really exists (Falkenmark and Rockström 2008). The lack of awareness that improved land productivity in drylands fundamentally depends on the ability to meet deficient green water functions has been nothing but disastrous.

The World Bank Programme on 'Enhancing the Resilience of African Drylands', in particular, the report 'Confronting drought in Africa's drylands' (Cervigny and Morris 2016), presented at the First Conference of the Great Green Wall, in May 2016, is therefore a fundamental step taken towards approaching a sustainable development of SSA.

9.6.5 National Level Land-Water Integrative Planning

The combined dependence of SSA's life support system on both green water for agricultural production and blue water for cities, industry and energy production, calls for a water-food-energy nexus approach to avoid unexpected surprises. This combined dependence will demand a national level integrative land-water planning, where catchments are seen as the operating quantum, including their city conurbations, as fundamental subsets (Odbiambo 2001). Here, two aspects need attention: on the one hand, the upstream-downstream linkages between water activities, both upstream—green as well as blue—consumptive water use effects on blue availability downstream, and, on the other hand, damaging downstream effects on blue water usability of polluting activities upstream.

9.6.6 Atypical Economic Development—A Cause for Thought?

Not only municipal water supply and food production are critically dependent on access to adequate amounts of water, but also industry, where most industrial processes—including energy supply—involve water in many different functions. It would therefore not be surprising if the widespread Sub-Saharan water shortage would be reflected in industrialisation impediments. Signs of such a problem were, in fact, recently brought up in an article in 'Africa in focus': '*By any measure Africa's failure to industrialize is striking. In 2013 the average share of manufacturing in GDP in sub-Saharan Africa was about 10%, half of what would be expected from the region's level of development … For an institution dedicated to 'ending extreme poverty and promoting shared prosperity', ignoring a sector that has the potential to create millions of well-paid jobs for people of moderate skills … seems a major oversight*' (Page 2016).

9.6.7 Timescale Perspective

It is evident from Fig. 9.2 that SSA is exposed to extremely rapid change, driven not only by climate change, but by a fierce population growth in many poor and medium income countries: '*This isn't just a big deal because Africa will be almost as popular as Asia by 2100... It's a big deal because it's a reminder that growth this rapid changes everything*' (Fisher 2013). This can be foreseen to sharpen water shortage, particularly in eastern and southern Africa.

- ***Short term (2030)***. In a 13-year perspective, it will be found essential to address the destructively high fertility in many low income countries (Cervigny and Morris 2016, box 13.1), and to invest in cities with focus on planning, infrastructure and finance (African Development Bank 2011; UN-HABITAT 2014). Growing attention will be paid to issues such as increasing sharpness and frequency of droughts; how to manage socio-economic development under conditions of widening water shortages; a shift in thinking seeing food-water losses as a potential resource for increased food production; peaceful water sharing challenges in transnational river corridors; and—in view of registered increasingly severe health effects—the need to reduce water pollution in highly crowded river basins, especially in drought years.
- ***Medium term (2050)***. By mid-century, the growing life expectancy will have contributed to almost doubling the population. Food security will be requiring increasing food imports to cover growing food deficits, influencing the industrial development to generate enough foreign income for that purpose. Special attention will be drawn to food security problems in still-poor countries with remaining high undernutrition, to safeguard hunger alleviation, possibly at lower and better adapted dietary levels. Expanding chronic water shortage regions will require focus on increasing hydropolitical risk. Water governance and management will involve methods involving leap-frogging and decoupling to secure water for municipalities and industry.
- ***Long term (2100)***. It is essential to realise that population growth will continue in the middle-age layers of the population. It should not be expected that—due to the effect of life expectancy increase—the demographic transition can be finalised below some 3 billion inhabitants. This will demand increasingly sophisticated adaptation to the Sub-Saharan hydroclimatic realities. Only with highly water-wise governance could a foreseen 3–4 doubling of the population be successfully mastered. The alternative is massive outmigration to avoid very severe problems of social unrest and malcontent.

9.7 Final Remarks

We find ourselves at present in an era of awakening from decades of water blindness without much attention to the characteristics of Africa's arid climate and sharpening water crowding. Sharpening and more frequent drought problems are causing worldwide concern, strengthened by an already evident outflow of African migrants towards Europe. In the water society, worry is growing for the lack of attention to the life support system's fundamental dependence on water, and the risk for a hard landing, causing social hardship, unless rapidly addressed.

Extreme population growth in drylands involves growing hydropolitical risk, reflected in, not only national but also international security disturbances, threatening the intended advances towards the UN SDGs. Especially severe is the lack of understanding among broad societal leaderships of how to find water for both booming cities, with Africa growing to host some 80 large cities already by 2025 (UN DESA 2014) and development towards food security on an increasingly crowded dryland continent, were possible water resources for irrigation are either blocked in transnational river corridors, or flowing across savanna lands, where they tend to evaporate before reaching a river. Good news is that realism is now expanding on the dependence of the same water—the green water in the soil—of both trees and crops. and therefore, the need to coordinate the efforts in the Great Green Wall project with the efforts to intensify food production to make the population in the African drylands food secure.

Concern for Africa's vulnerability is growing also in the general media debate, for instance, in Washington Post recently, where Fisher (2013) stressed that '*right now, many African countries aren't particularly adept at either governance or resource management. If they don't improve, exploding population growth could only worsen resource competition—and we're talking here about basics like, food, water and electricity—which in turn makes political instability and conflict more likely. The fact that there will moreover be a 'youth bulge' of young people makes that instability and conflict more likely. It's a big, entirely foreseeable danger. Whether Africa is able to prepare for its coming population boom may well be one of the most important long-term challenges the world faces right now*'.

And there exists, in fact, encouraging experience in other water short regions of the world, where water shortage challenges have been possible to overcome. Of fundamental importance for success is, however, that politicians become rapidly aware of Africa's Achilles' heel, the great vulnerability that it involves, and the extreme urgency of adequate action, both as regards water supply of rapidly growing cities, and safe and rapid smallholder agricultural development. The latter was recently addressed by an expert *call for an African Walter Revolution* at the 2016 World Water Week in Stockholm.

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