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Trends in water availability and accessibility and potential impact on nutrition in Africa

Lannerstad Mats
Stockholm, Sweden

Abstract

Water is the bloodstream of the biosphere and the base for all socio-economic development and thus the key to almost every aspect of nutrition. In this paper water availability and water accessibility in relation to nutrition are analyzed for sub-Saharan Africa (SSA) considering domestic and agricultural uses, blue and green water sources, and changes of demand and supply over time.

Domestic water is necessary as drinking water, for food preparation, and for personal hygiene, all three of which are prerequisites to secure a person's nutritional status. In 2050, the urban population in SSA will have tripled and the rural population will have increased by one-third. To supply domestic water to all will be a major challenge. In the urban areas the domestic water demand might increase by as much as 650-1,300%.

To provide food for 900 million newborn and the present 220 million under-nourished by 2050 will be another huge undertaking. Translated to agricultural water demands, more water will be required than appear to be available. Improved agricultural water productivity and irrigation expansion will assure food self-sufficiency in some SSA countries. Other water- scarce countries which have economic capacity can rely on food import. However, the majority will face major difficulties to both produce and import necessary food quantities. Lowered per capita food supply levels might be necessary to assure food security.

The linkages between water availability, accessibility and nutrition are manifold and a number of research questions need to be formulated to address future challenges.

The most important and overarching objective must be to assure that water resources are sustainably used. The overall complexity to secure nutrition in SSA in the coming decades calls for interdisciplinary approaches. Nutritional researchers of SSA, with unique local knowledge, play a key role when developing the necessary research agenda to find successful development avenues for the future.

1. Water and nutrition – a three-dimensional issue

Water availability and water accessibility in relation to nutrition is a three-faceted issue:

- I. Two main water uses – domestic and agricultural
- II. Different water sources used – blue and green water
- III. Changes over time - demand and supply, and availability

The optimal daily water supply for domestic use, including a couple of liters of drinking water, is in the range of hundreds of liters per person per day, which is less than one-tenth of per capita human food water requirements, estimated at several thousand liters per day.

There is a fundamental difference between domestic and agricultural water uses. Most of the domestic water use is related to washing, cleaning or other uses that allow a reuse "after use". Although the quality of water in most cases is deteriorated, only a fraction of the water is evaporated, and most of the quantity of water remains and can potentially, after proper treatment, be reused downstream. In contrast, agricultural water use is, in principle, entirely related to evapotranspiration (ET) during crop cultivation or fodder growth, and cannot be reused. The water use in agriculture is thus a "consumptive water use" resulting in a vapor flow back to the atmosphere, and the domestic water use a "through flow" based use, generating return flows (**Figure 1**).

The terms **green water** and **blue water** were introduced in the beginning of the 1990s[1]. Blue water stands for the liquid water in streams, rivers, wetlands, lakes and aquifers that can be abstracted and used for irrigation and other human uses. Green water stands for the rain-fed soil moisture, i.e. the water source naturally available to plants. Globally, the consumptive water use in agriculture amounts to 7,130 km^3, with 78% being green water and only 22% being blue. On the other hand, municipal and industrial consumptive water uses, all blue, only amount to 53 and 88 km^3, respectively.[2]

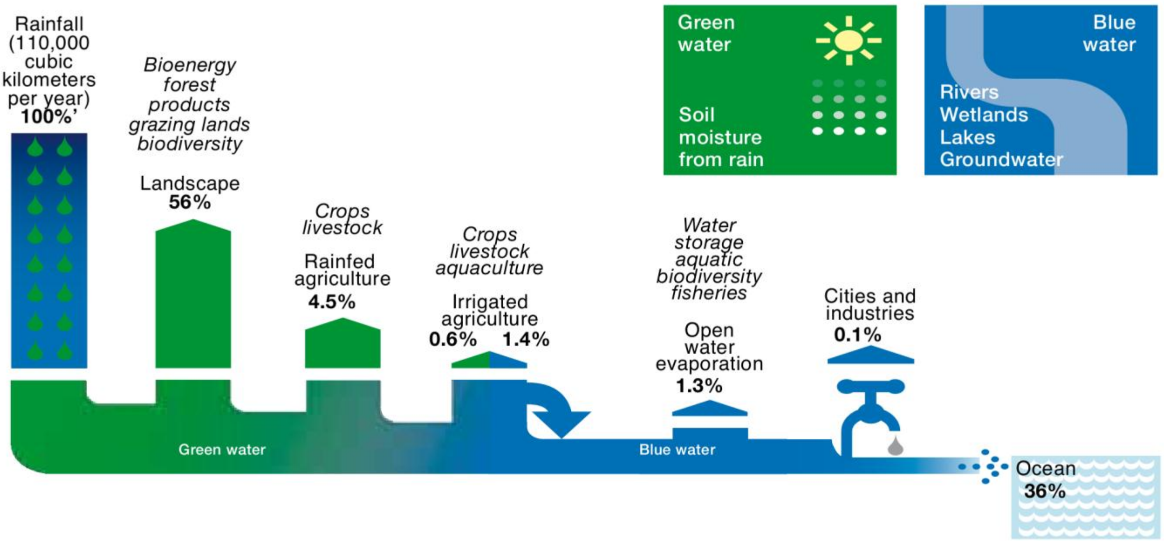


Figure 1 | Global water use by sectors, showing consumptive water use of water-infiltrated rainfall, green water, and of water from surface water bodies and aquifers, blue water.[2]

The third important aspect to consider for both domestic and household water use is the change in demand and supply of green and blue water over time. With continued population increase and urbanization, the demand for blue water for domestic use will grow in many parts of the world, and with more people and changed food preferences green and blue water for food requirements might in many countries, and at the global level, multiply to unsustainable levels. With limited water resources to be shared, the idea of “water crowding” is a relevant standpoint when thinking about the future (**Figure 2**).

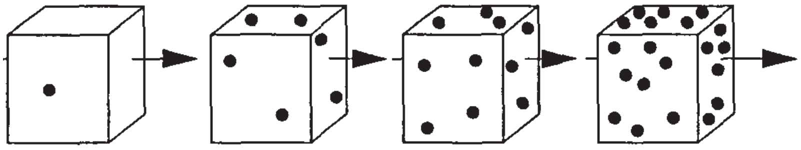


Figure 2 | With increased population more people have to share the same water resource, thus increasing the risk of water scarcity. The figure visualizes a twentyfold increased population pressure for the same water quantity, i.e. “water crowding”. [3]

Water resources accessible to human use also change over time. More blue water can be supplied with new technologies and water infrastructural investments enabling earlier discarded blue water of inferior quality to be treated and used, and previously spatially unreachable water resources to be appropriated. The availability of both green and blue water is due to climate change expected to be reduced in many areas in sub-Saharan Africa (SSA), with altered rainfall patterns and temperature-driven evaporation demand. Upstream activities can also reduce the availability of blue water and usability for downstream use, with changed land use reducing run-off formation, water diversions to other basins, or different activities irretrievably degrading the water quality. Due to human alterations of vegetation cover and land management both green and blue water sources change.

2. Water resources in SSA - preconditions and water scarcity

The precipitation pattern in Africa is characterized by extreme variability at inter-annual, decadal and longer-time perspectives. Unreliability of rainfall translates to a general unreliability in green and blue water resources at all scales impacting domestic, industrial and agricultural uses, and water scarcity and water stress limit livelihoods and economic development in large parts of the sub-Saharan African region. Large parts of the arid or semiarid water-constrained areas in SSA coincide with the savannah climatic zone, that stretches as a band from Senegal in the west across the Sahel region to the Horn of Africa in the east, and down along the eastern coast to South Africa. Seasonal wet and dry periods are particularly manifest in these drought-prone areas.[4]

Surface water and groundwater are blue water sources that can be developed for domestic, industrial and irrigation uses. However, unpredictable rainfall, high evaporation losses and low run-off generation call for increased blue water storage as an adaption to compensate for both erratic accessibility of blue water and unreliable availability of green water. In Africa, sufficient water storage is still lacking in many areas.[5] Small-scale water harvesting reservoirs for supplemental irrigation of presently rain-fed croplands will be a crucial undertaking to lift sub-Saharan agriculture in the future.[6]

Aquifers constitute natural sub-surface blue water storages of high strategic value that can be easily developed, and they offer access to water resources during periods without rainfall or river flow. Although groundwater only stands for 15% of the renewable blue water resources in Africa, it is of vital importance in many dry areas in sub-Saharan Africa receiving inadequate precipitation. Across Africa, 75% of the population depend on groundwater as the major source for drinking water, and in a country like Botswana 80% of domestic and livestock demands is met by groundwater. Increasing demands and improved technology lead to abstractions often exceeding the recharge rate from rainfall, with rapidly falling groundwater tables in some areas.

Semiarid and sub-tropical sub-Saharan Africa is predicted to belong to the areas where climate change in particular, through higher temperatures, more rainfall variability and greater frequency of extreme events, will affect availability of water resources and agricultural production. However the pattern will not be the same everywhere. Less rainfall is expected to increase the soil moisture stress, i.e. green water stress, in southern Africa, with falling crop yields and decline in food security. In contrast, in eastern Africa higher rainfall might potentially open up irrigation expansion and more water for domestic and industrial uses.[7]

3. Domestic water use

The domestic water use is the prime societal water use in both urban and rural areas. Safe drinking water is crucial for human nutrition. In some countries, water is by itself is regarded as a nutrient and thus treated by the same standards of, and regulations for, as food. Safe domestic water supply meets two basic water uses:

A. To meet basic human physiological water requirements, i.e. adequate hydration.
B. To ensure human hygienic conditions, both crucial for humans to stay healthy and thus highly linked to nutritional aspects.

3.1. Adequacy of supply – quantity and quality

A number of basic service parameters are used to assess the adequacy of domestic water supply: quality, quantity (service level), accessibility, affordability and continuity.[8]

Good quality, characterizing safe drinking water, includes microbial, chemical, radiological and acceptability aspects. The most important aspects in relation to immediate health concerns are microbial agents as pathogenic bacteria, viruses, protozoa and helminths. To prevent drinking water from such contamination is essential and best achieved using multiple barriers along the distribution chain from the abstraction point to the consumer.

Water supply, i.e. the service level, should fulfill three needs:

I. Drinking water.
II. Water for food preparation.
III. Water for personal hygiene.

The water demand per capita per day ranges from a minimum level of a few liters to an optimal of 200 liters. From the perspective of a developing country, and thus highly relevant for sub-Saharan Africa, an important aspect to take into account is the time required to retrieve the daily water quantities.[8] In Africa about 70% of the duties of water collection are performed by women, thus losing valuable hours carrying water over long distances.[9] Four service levels are shown in **Table 1**.

Table 1 | Service level and quantity of water collected.[8]

Service level	Distance/time	Likely volumes of water collected	Public health risk from poor hygiene	Intervention priority and actions
No access	More than 1 km/ more than 30 minute round-trip.	Only 5 litres per capita per day.	**Very high** Hygienic practice compromised. Basic consumption may be compromised.	**Very high** Provision of basic level of service. Hygienic education. Household water treatment and safe storage as interim measure.
Basic access	Within 1 km/ within 30 minute round-trip.	On average, 20 litres per capita per day.	**High** Hygiene may be compromised. Laundering may occur off-plot.	**High** Provision of improved level of service. Hygienic education. Household water treatment and safe storage as interim measures.
Intermediate access	Water provided on-plot through at least one tap (yard level).	On average, 50 litres per capita per day.	**Low** Hygiene should not be compromised. Laundering likely to occur on-plot.	**Low** Promotion hygiene still yields health gains. Encourage optimal access.
Optimal access	Supply of water through multiple taps within the house.	On average, 100–200 litres per capita per day.	**Very low** Hygiene should not be compromised. Laundering will occur on-plot.	**Very low** Promotion of hygiene still yields health gains.

Accessibility is defined as the proportion of the population with reliable improved drinking water supply. Improved sources include: piped water into dwelling or yard; public tap or standpipe; bore well; protected spring or dug well; and rainwater collection. Unimproved water sources are: unprotected spring and dug well; vendor supplying water via small tanks or tanker trucks; surface sources like rivers, dams, streams, irrigation canals; and bottled water from unimproved sources.

On average about 35% of the urban population and only 5% of the rural population in SSA have access to domestic water supply from piped water into dwelling, yard or plot. More than half of the population in the rural areas, and but less than one fifth of the urban population only, have access to unimproved water sources (**Figure 3**).

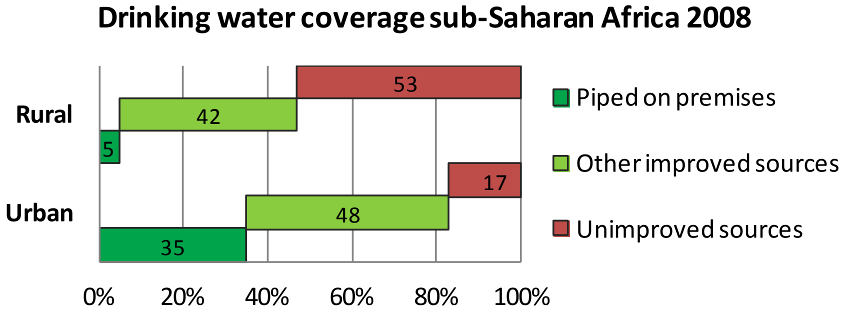


Figure 3 | Drinking water coverage for rural and urban areas in sub-Sahara in 2008.[10]

In 2008, about 40% of the SSA population, 350 million, lacked access to improved drinking water. Although the proportion has fallen from 44% since 1990 the total number of people lacking improved water supply have, due to the rapid population growth, increased by more than 100 million. While three-quarters of the urban water supply in many sub-Saharan African countries comes from improved sources, the coverage in rural areas is still often critically low (**Figure 4**). South Africa, Namibia and Botswana are positive exceptions, both regarding urban and rural water supply.

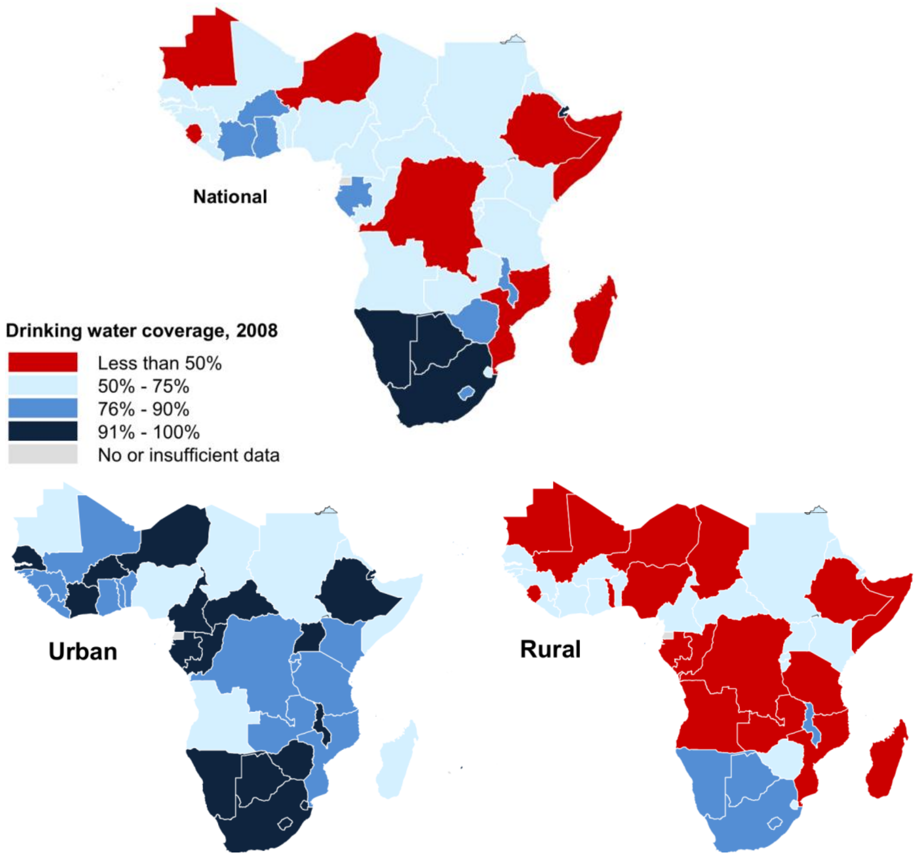


Figure 4| Percentage of the population using improved drinking water sources in sub-Saharan Africa in 2008. From the left: urban, rural and national coverage.[9]

Affordability is a key issue to ensure that the least privileged population stratum can gain access to safe water supply. However, in informal settlements lacking piped infrastructure water is often provided by private water vendors. Then the poorest people usually have not only to pay more per water quantity but get water of poor quality, compared to the more fortunate in formally recognized neighborhoods with piped supply.

Continuity in water supply is particularly important to ensure good quality. All water networks have leakages, and with interruptions in water supply there is an immediate risk for in-pipe contamination. Polluted water carrying waterborne diseases can enter the pipe through cracks during low pressure, and eventually reach the consumer when water pressure is restored. Unreliable water supply also forces households to build up water storage, with stagnant water becoming a health risk. Lack of supply can also drive people to acquire water from inferior sources[8].

3.2. Challenges ahead – more and urban needs

Between 1970 and 2010 the population in sub-Saharan Africa increased by about 90% and communities faced enormous challenges to orchestrate improved water supply.

In fact, as mentioned, more people today lack this service compared to 20 years ago. The projected population increase in the coming 40 years is estimated to be more than 100%, to 1.8 billion by 2050.[12] The global trend in all other world regions is a stagnant or decreasing rural population, with the entire population increase limited to urban areas. With a projected increase of the rural population of 30%, to 710 million, sub-Saharan Africa differs from the rest of the world. However, the 300% growth of the urban population will result in more than 1 billion urban dwellers by 2050 (**Figure 5**).[11]

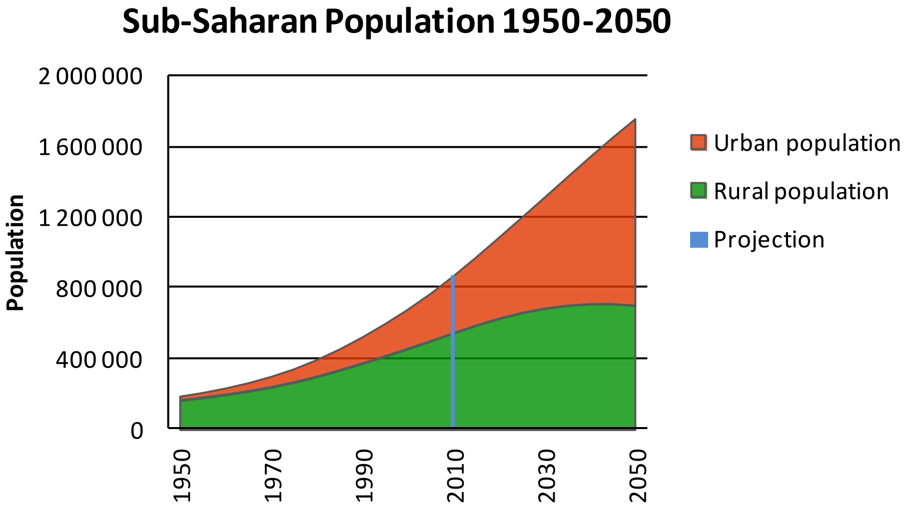


Figure 5 | Sub-Saharan urban and rural population projections, medium projection.[11]

Dramatically, more people will consequently need water in both urban and rural areas. In the cities and peri-urban areas the challenge will be daunting. With the assumption that the average per capita water supply in urban and peri-urban areas in SSA today is about 50 liters per person per day (l $pers^{-1}$ day^{-1}), the present water supply to these areas amounts to almost 6,000 million cubic meters per year (Mm^3 yr^{-1}). With a future optimal water supply of 200 l $pers^{-1}$ day^{-1} (see **Table 1**) and a tripling of the urban population, the water supply challenge amounts to 77,000 Mm^3 yr^{-1}, an alarming increase of 1,300%. With the assumption that a daily per capita supply of 100 liters will be sufficient, the increase would consequently halt at "only" 650% in 40 years. It is also important to realize that many cities today, on average, supply less than 50 l $pers^{-1}$ day^{-1}, and in these cities the amplification factor will be even higher.

Already SSA suffers from poor or no city planning in many of the rapidly growing peri-urban slum neighborhoods. Consequently, to build up a water supply infrastructure, including, for example, drinking water treatment plants, is per se a considerable enterprise. To find enough water is another mammoth endeavor. This will be more complicated compared to the preceding decades, in particular when considering that easily accessible water sources have already been appropriated, and dramatically increasing competition from industry and agriculture. However, urban rainwater harvesting for domestic use or groundwater recharge might, in some areas, represent an alternative untapped potential for supplemental supply. Another possibility is to recycle wastewater for domestic water use. Through wastewater treatment techniques like osmosis the highest drinking water quality standards can be met. Although quite energy-demanding, this path is already practiced in a water-scarce city like Windhoek.[13]

Groundwater is an important source for domestic water supply, generally cheaper to develop compared to other sources, and usually naturally protected from pollution. However, with increased population densities and a lack of sanitation, the risk for contamination is increasing. In sub-Saharan Africa about 70% of the population, a distressing 600 million, lack improved sanitation. Coverage is generally higher in cities compared to less- well-served rural areas. Many million even lack the most basic sanitation alternatives as pit latrines, and between 1990 and 2008 the population practicing open defecation increased from 190 to 220 million.[10] An amplified risk of human waterborne diseases contaminating vital groundwater and surface water resources, spread through faeces or untreated wastewater, underlines the quality dimension. Improved sanitation is thus an important parallel track when aiming to provide safe water supply to all in sub-Saharan Africa.

4. Agricultural water use

Water use for cultivation of food crops, feed crops and fodder is directly linked to nutrition. Availability and accessibility of water for agricultural use are thus also directly linked to food security, which according to the 1996 World Food Summit is "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." The concept builds on the three dimensions: *availability*, *access*, and *utilization*. While food ***availability*** refers to the national or international level of "supply", including food production, stock levels and net trade, ***access*** refers to meeting "demands", i.e. inter- and intra-household food distribution. Effective ***utilization*** defines the nutritional status of individuals and relates to whether individuals and households make good use of the food they have accessed, e.g. if food can be prepared under sanitary conditions and if the health status is such that essential macro and micro nutrients can be metabolized and absorbed.[13] While *domestic water use* is a prerequisite for optimal utilization, *w*ater for *agricultural water use* is a requirement for availability. In SSA many smallholders are subsistence farmers living at the mercy of erratic rainfall and seasonal river flow. The volatile and unpredictable availability of green and blue water directly impacts the fourth component related to food security, i.e. *stability over time*. With low dependability of water for agriculture many people are faced with chronic food insecurity and locked into a nutritional poverty trap. It is more often persistent conditions, like long-term or recurrent water scarcity, that determine the food security situation. Worldwide, in 2004 as much as 92% of hunger deaths were associated with chronic conditions, and only 8% related to humanitarian emergencies.[13]

4.1. Nutrition transition - more food for some, others still undernourished

The global shift from prevalent under-nourishment to richer and more varied diets, often leading towards over-nutrition, has been termed "*nutrition transition*".[14] Indigenous staple grains, starchy roots or locally grown vegetables and fruits, are replaced by more varied diets that include more pre-processed food, more added sugar and fat, often more alcohol, and more foods of animal origin. Livestock production generally increases the pressure on natural resources, as only a fraction of the vegetal energy consumed by animals is transformed into meat, milk or eggs.[15]

Economic development and urbanization are key drivers as people move up the food chain and become consumers on the urban and, thus often, on the international market. In SSA, both access to affordable food and persisting under-nourishment and food insecurity are present at the same time, and chronic under-nutrition exists parallel to increasing childhood obesity and adult-onset of diabetes even in poor communities.[16] The shift from subsistence economy to a modern industrialized society, with changed diet patterns, has in some sub-Saharan cities taken place in a span of only 10-20 years.[17] Considering the projected urbanization shown in **Figure 5** and current and projected positive economic development in parts of the region the diet changes are likely to gather speed.

In **Figure 6** per capita calorie food supply from vegetal and animal products for four African sub-Saharan FAO regions (**Appendix 1**) are visualized next to some key developed and rapidly developing regions. The average total food supply level in North America is a staggering 3,700 kcal pers^{-1} day^{-1}, and both North America and Europe have a supply of animal foods of around 1,000 kcal pers^{-1} day^{-1}, or about 27%. Brazil and China are two examples of how economic development and urbanization have driven national average food supply levels to 3,000 kcal pers^{-1} day^{-1} and an animal foods fraction of more than 20%. These estimates include a staggering 130 million under-nourished in China and 12 million in Brazil.[19] It is interesting to notice that the current situation in India is equal to that in Brazil in the beginning of the

1960s and in China around 1980. Out of the sub-Saharan examples, southern Africa, including Botswana, Namibia and South Africa, have the highest regional average per capita food supply, with about 400 kcal pers^{-1} day^{-1} from animal products. While both western and southern Africa since the 1960s have displayed an increasing trend, eastern Africa is stagnant and levels are distressingly falling in middle Africa.

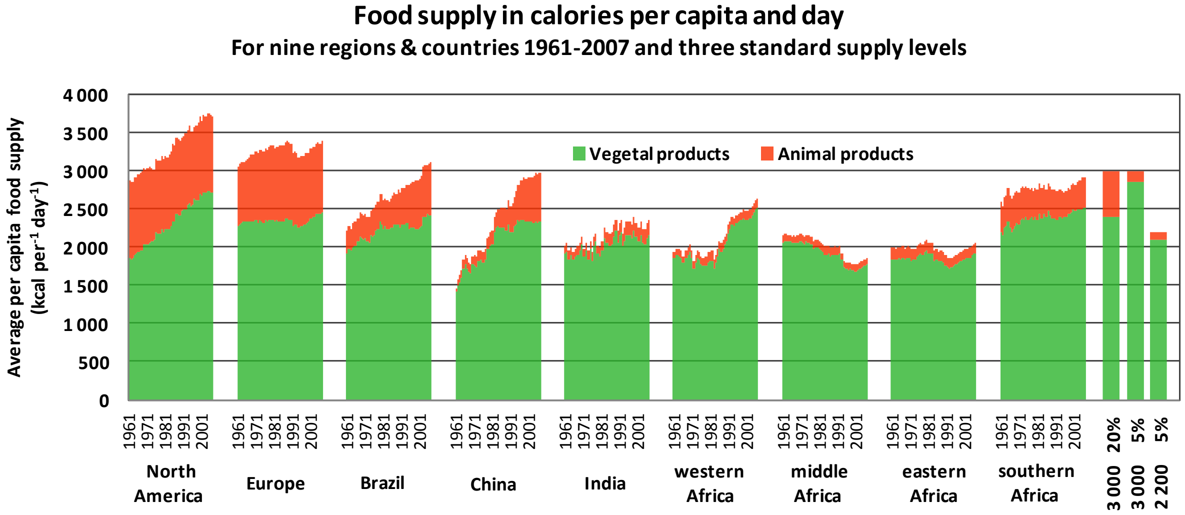


Figure 6| Per capita calorie food supply per day 1961-2007 separated into vegetal and animal calories for nine regions and countries, and three standard food supply levels for comparison.[18]

In the analysis of future challenges for 2050 (given below) the three standard supply levels to the right in **Figure 7** are used, and as can be seen southern Africa is approaching the highest level, western Africa the second highest level, and eastern Africa is close to the minimum level. If the regions in sub-Saharan Africa are to follow the same pattern as in many other developing countries, as China or Brazil, it can expect a pattern with higher levels and more animal products.

The very low food supply levels in middle and eastern Africa coincide with the widespread under-nourishment in many countries as visualized in yellow to red in **Figure 7**. This highlights the role of agricultural water use, not only to meet future higher demands, but to secure fundamental nutrition and basic food security. In 2006-2008, the total number of under-nourished in SSA was almost 210 million, or 27% of the population.[19] Accordingly, the low average food supply values for sub-Saharan Africa regions shown in **Figure 6** can be partly explained by large numbers of under-nourished. Overall, the picture has changed dramatically over the last 40 years, since most of SSA at the time of independence was food self-sufficient.[20]

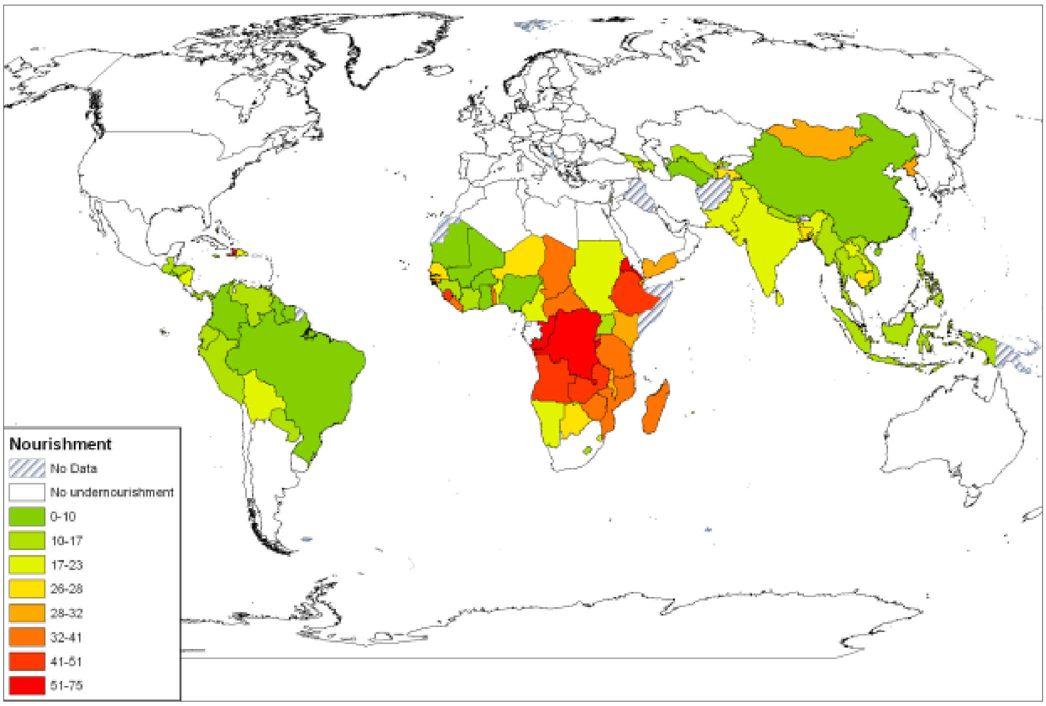


Figure 7| Undernourishment on country level in percentage of the population.[21]

4.2. Food water requirements – for vegetables, animal foods and losses

The consumptive water use for different food compositions varies with regard to total calorie level, proportion and combination of different vegetal components, and share and mix of animal food items. The consumptive water use for different diets is basically derived from the water productivity in plant growth for vegetarian foods, of feeds and fodder used for livestock, and the conversion efficiency from vegetal feeds to animal foods.

4.2.1. Vegetal products

ET is an inevitable part of all plant growth. For a given crop and climate there is, in principal, a linear relationship between transpiration (T) and the yield of total crop biomass, i.e. the dry matter in the roots, stems, leaves and fruits/grains. The main variable part of the total ET is the E.[22] While transpiration thus contributes to productive crop growth, evaporation represents "collateral" unproductive water losses.[23]

Two main categories of crops are grown for food production. Plants like wheat, barley, rice, potato, lucerne, soybean and pea belong to the least-water-efficient category and are consequently often grown in the temperate climate zone. Plants like maize, sugar cane, sorghum, and several other grasses are adapted to hotter climates and are more water- efficient. As an example, global data show a crop water requirement, i.e. ET per kilo, of 0.6 to 1.7 m^3 kg^{-1} for wheat (mean 0.9) and 0.4-0.9 m^3 kg^{-1} for maize (mean 0.6).[24]

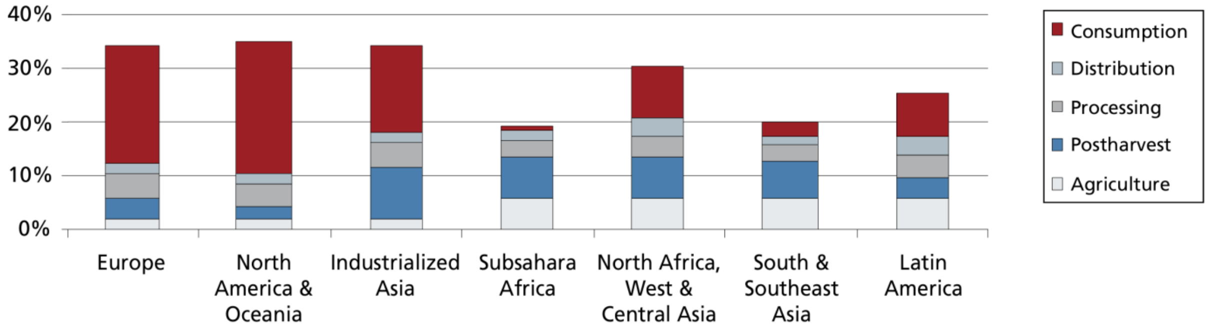
4.2.2. *Animal products*

Livestock water productivity depends on how efficient an animal can convert the feed to animal meat, dairy, egg or other produce, all depending on how and where production is taking place, e.g. the livestock system, breeds, management and different environmental conditions. The feed conversion efficiency rate denotes the amount of feed necessary to produce one unit of meat or other animal product.

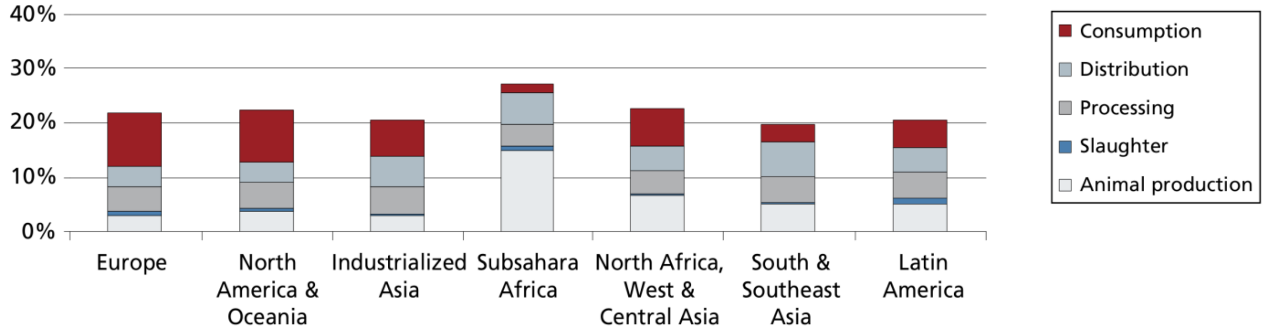
Monogastric animals, like poultry and pigs, have a better conversion ratio than ruminants and consume as a rule only 2-4 kilos of grain per kilo of meat compared to 7 kilos of feed per kilo of meat for cattle, sheep and goats.[25] The actual feed conversion rate for each animal in combination with the ET to produce the feed thus decides the water productivity of livestock. The advantage of ruminant's ability to digest grass makes it possible to base large parts of the feed demand for this category on grazing on pasturelands unsuitable for cultivation and on crop residues like straw. Ruminants can thus partly be produced without competing for green and blue water resources for vegetal crops. In contrast, industrial production of chicken and pigs depends on feed crops. Although these monogastric animals are more efficient and use less feed per kilo livestock product, the feed use directly competes for the same land and water resources as food crops.

4.2.3. *Food losses*

In a world with limited and decreasing water resources for food production food, considerable benefits could be reaped if food losses could be minimized. As shown in **Figures 8a** and **8b,** developing and developed countries clearly differ. In developing countries more than 40% of the losses and spoilage takes place on the field, during transport or processing, i.e. before the produce reaches the market. In contrast, in North America and Europe, losses and waste are marginal in the first steps of the food supply chain, but very large in the latter half. In total, the food waste at consumer level in industrialized countries is almost as high as the total net food production in sub-Saharan Africa (222 vs. 230 million tons).[26]



a) Food losses for ***cereals****.*



b) Food losses for ***meat****.*

Figures 8a and b | Percentage food losses for cereals and meat in seven world regions.[26]

4.3. Challenges ahead – mammoth food water demands in water-scarce SSA

To assure food security for all in SSA will be an ambitious task. **Figure 9** spatially illustrates the close relationship between the population increase and the water constrained savannah climatic zone, which also overlap with the occurrence of under-nourishment as shown in **Figure 7**. Projections for 2050 show that, in the coming decades, the average per capita food supply levels in developing countries will increase considerably (**Figure 10**). In SSA, the average is expected to increase from 2,200 kcal pers^{-1} day^{-1} in 2003/05 to 2,700 kcal pers^{-1} day^{-1} in 2050. However, this forecast still includes a large number of under-nourished in SSA. From the present level of almost 220 million (2006/08) a projected decrease of 40% would mean that still 130 million would be under-nourished by 2050.[27]

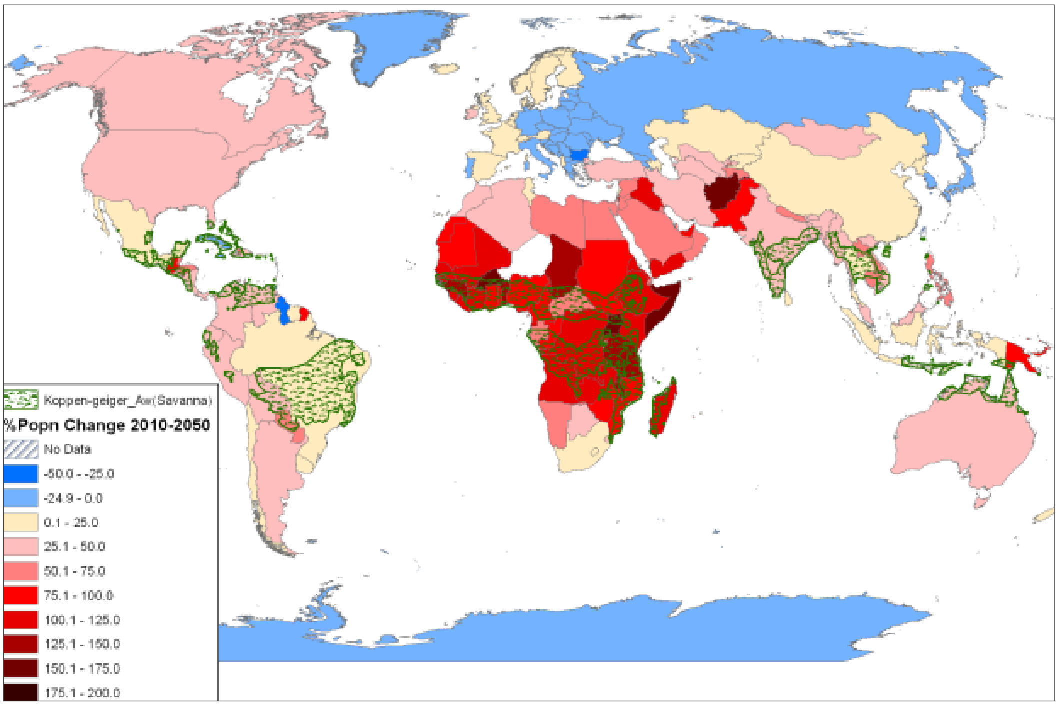


Figure 9| Water importance for future food production. The expected population increase and decrease in percent by 2050, overlaid with the savannah climatic zone.

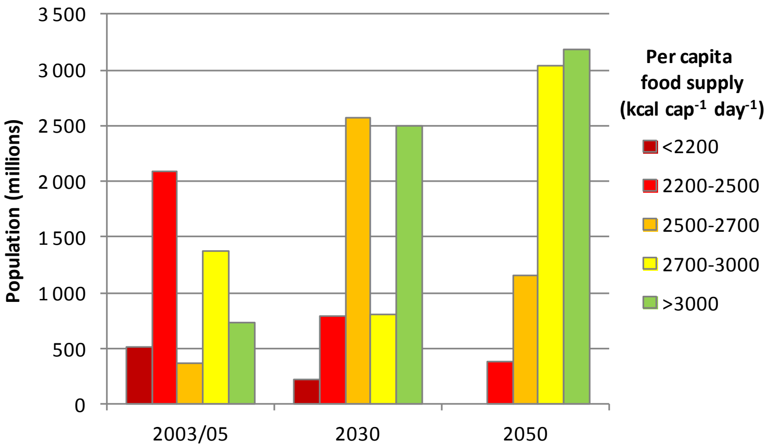


Figure 10| Present and future projection of average per capita food supply for the population living in developing countries, 2003/05 to 2050.[27]

4.3.1. Food water requirements – increased availability, decreased demand

Several factors have to be considered when analyzing water for food production. Basically, the future challenge for sub-Saharan Africa can be divided into two different options when meeting future food demands. On the one hand, more water for food production can be mobilized and, on the other hand, food water requirements can be reduced.

Water use in agriculture is a continuum that stretches from purely rain-fed, as in most cultivated lands in sub-Saharan Africa, to fully irrigated fields as in large areas in Egypt. The potential for collecting surface run-off in large-scale reservoirs in SSA is still not fully utilized, and initiatives are now taken to secure more storage to balance natural rainfall variability, to meet demands from growing populations, and to build buffers to balance climate-change- driven precipitation alterations. However, in largely rain-fed SSA small-scale rainwater harvesting offers a high potential to secure crop growth for smallholders. One option is to build small run-off collecting storage structures such as dams, ponds and tanks in the landscape, for supplemental irrigation of field crops during dry spells, or for continuous garden crops. The other option is to use the soil as storage for infiltrated rainfall, and the capacity can be amplified by soil management techniques, increasing the infiltration and improving the water-holding capacity.[6]

If enough blue or green water cannot be mobilized for crop cultivation to secure national self-sufficiency, one option is to turn to food import. This is thus a way to externalize the water use for food production to meet food demands. The amount of consumptive water use behind food traded from the exporting country is conceptualized as "virtual water." With increasing dependability of food imports, many countries have to rely on virtual water trade, and globally about 10% of the total consumptive water use for food is traded "virtually".[28]

There are also different measures to decrease food water requirements. The first and most obvious option is to increase the water productivity (WP), i.e. "more crop per drop". The WP potential is particularly high at low yield levels and thus an option for many smallholder farmers in SSA.[6] Animal water productivity can also be improved, basically through a combination of three components: the direct water use, i.e. ET from crops for feed, fodder or from grazing lands; conversion efficiency of feed and fodder to animal products; and the "coupled" feed-livestock water productivity which includes, e.g. choice of production system; strategic choice of less-water-intensive feeds, etc.

Reducing losses is a second option. With modern harvest, transport and storage techniques, a large part of the losses in SSA can be overcome, as seen for Europe and North America in **Figures 8a** and **b**. However, regions rapidly becoming middle-class societies risk replacing one wasteful food system with another. As can be seen in **Figures 8a** and **b** food losses have started to shift from the first to the second half of the food supply chain in most regions. Only SSA and South and South-East Asia still have the same pattern. But, for meat losses, SSA alone have more than 50% of the losses in the first production step, indicating the importance of animal health and animal management, etc. A global average per capita food supply level of 2,200 kcal $pers^{-1}$ day^{-1} can be considered to be the loss-free level.[29] This level is also often used as the break-off level by FAO, and is just above the poverty line for food energy intake of 2,100 kcal $pers^{-1}$ day^{-1} used by the World Bank.

A third option is to reduce the amount of animal products in the food supply. As a global average it has been assumed that 0.5 m^3 of ET are required to produce 1,000 kcal of vegetal products and 4 m^3 1,000 $kcal^{-1}$ of animal products. In other words, in this simplified global-level comparison, replacing a calorie from vegetal products with a calorie from animal products requires eight times more water.[15] For a standard per capita food supply of 3,000 kcal $pers^{-1}$ day^{-1} and 20% from animal foods the annual water demand mounts to 1,300 m^3 $pers^{-1}$ yr^{-1}.

Figure 11 visualizes food water requirements for different food supply levels, different animal products fractions, and with and without food-loss reductions under two alternative water productivity levels. The figure reveals the importance of animal products and losses for the overall food water requirements. If the animal foods fraction is reduced from 20% (3,000 kcal and 20%) to only 5% (3,000 kcal and 5%) the gain is as large as 45%, and if instead food losses can be eliminated (2,200 kcal and 20%) the annual per capita water gain is more than 25%. With both a reduction of animal products to 5% and a loss-free food production chain (i.e. 2,200 kcal and 5%) the total gain at the initial water productivity level is almost 60%. In the example it is assumed that the WP gap is 600 m^3 $pers^{-1}$ yr^{-1}. A WP gap closure of 50% (50% of 600) thus reduces the annual per capita demand by 300 m^3 $pers^{-1}$ yr^{-1} down from 1,300 to 1,000 m^3 $pers^{-1}$ yr^{-1} (the four columns to the right in the figure). The figure highlights that even if the WP gap is optimistically closed by 50% the water gain will not be more than 25%, and thus less than if all losses are eliminated. The last pillar summarizes how the annual food water requirements can be theoretically reduced by almost 70%, by combining improved WP, less animal products, and no losses, i.e. from 1,300 down to about 400 m^3 $pers^{-1}$ yr^{-1}.

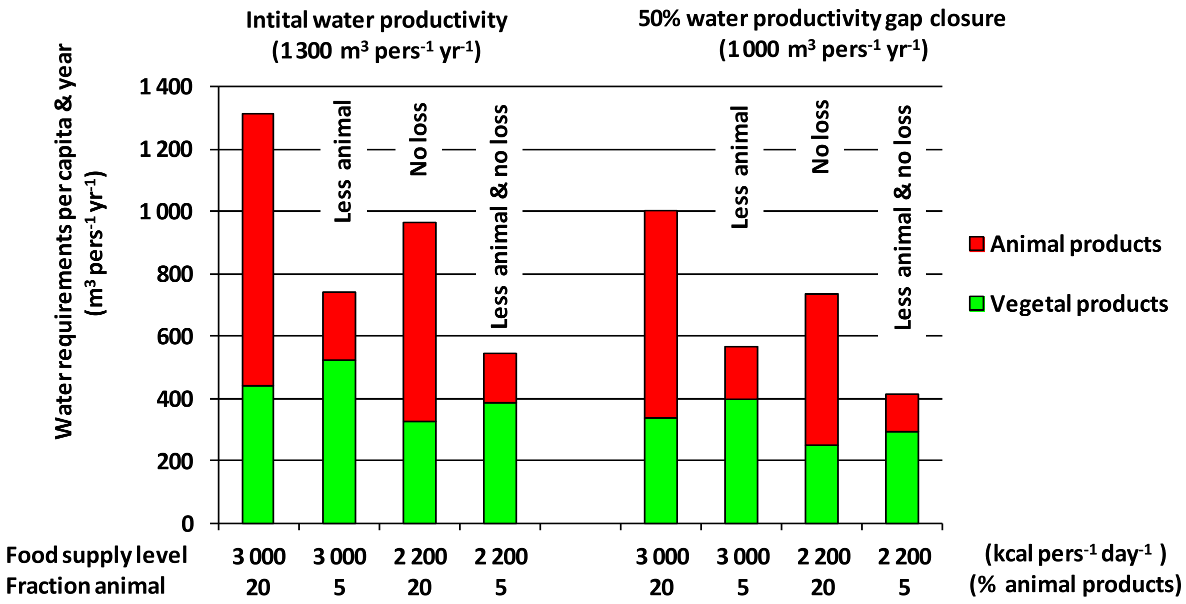


Figure 11 | Bringing down food water requirements – comparing a per capita food water requirement of 1,300 m^3 pers^{-1} yr^{-1} and a future level of 1,000 m^3 pers^{-1} yr^{-1}. Considering full standard food supply, no losses, less animal products, and combined loss-free and less animal foods.[30]

4.3.2. SSA food water requirements 2050 – water scarcity or trade

To feed the sub-Saharan population by 2050 two challenges have to be faced, as mentioned above. Food production must be amplified to cater to the expected population increase of 900 million, and the Millennium Development and World Food Summit goals must be reached with enhanced per capita food supply to assure an acceptable diet level for the present under-nourished 220 million.

In **Figure 12** the extracted results for sub-Saharan Africa from a global food water requirement analysis[28] are visualized. The research study explores how availability of water resources by 2050 correlates to global food demand, analyzed on country level for food self-sufficiency. The results show whether a country has surplus water that can be used for food export or whether it is water-deficit and needs to import, or to find other solutions.

For any country with too little water available for self-sufficient food production import is a solution to balance food deficits. However, this is only possible for countries with necessary purchasing power. In the analysis, the economic situation in 2050 is assumed to follow a recent World Bank income country group categorisation.[31] Countries are grouped according to 2009 gross national income (GNI) per capita, calculated using the World Bank Atlas method, giving four groups: Low Income; Lower Middle Income; Upper Middle Income; and High Income. For

2050 it is assumed that the three upper groups will have purchasing power to import food to compensate for water deficits. However, the poorest country group, i.e. Low Income, is assumed to lack this option. In **Figure 12** only SSA is included and most countries thus fall into the two lowest categories, Low Income and Lower Middle Income. In the left column of **Figure 12** the water deficits and water surpluses for the different economic income groups are visualized. In the right column the summarized populations for the different surplus and deficit categories are shown.

Country-level water values are generated from the process-based vegetation and hydrology model LPJmL including both green and blue water resources.[32] Modeling is done for different crops on current croplands and combined and correlated to FAO statistics for yields, etc. to produce estimates at the national level. The underlying approach builds on calories, both regarding water productivity and demand. The base year is 2000, and scenarios are developed for the year 2050. Country-level food production on current croplands is analyzed for different per capita food supply combinations at the national level, considering several parameters. Population numbers are given by the UN medium population forecast. In all cases, climate change impacts on crops are included in the LPJmL modeling.

Statistics show that prevalence of under-nourishment tends to decrease towards zero only when the national per capita food supply approaches 3,000 kcal cap^{-1} day^{-1}.[33] To reach full nourishment in the analysis 3,000 kcal cap^{-1} day^{-1} and 20% from animal products (as in China or Brazil today) are thus the first level of three compared food supply combinations. The second represents minimal animal foods with a 5% fraction, still at the 3,000 kcal pers^{-1} day^{-1} level. The third is the loss-free level of 2,200 kcal pers^{-1} day^{-1} and 5% from animal products. Baseline water productivity is compared to a 25% WP-gap closure. In **Figure 11** above, a 50% gap closure is exemplified. However, a 25% closure is a more realistic achievement and thus used here. In the three latter examples irrigation expansion is assumed to have been achieved, i.e. potentially available blue water is used to meet crop water deficits.

Figures 12 a and **b** visualize the situation in 2050 with the medium population projection and an average per capita food supply of 3,000 kcal pers^{-1} day^{-1} and 20% from animal products, and with the baseline water productivity. In fact, when viewed in the global context the water deficits in SSA stand for 96% of the global deficits and are so large that export from surplus countries, like USA or Brazil, would simply not be large enough. After taking differences in water productivity between importing and exporting countries, the demand from water-deficit countries would be seven times larger than the possible export.[28]

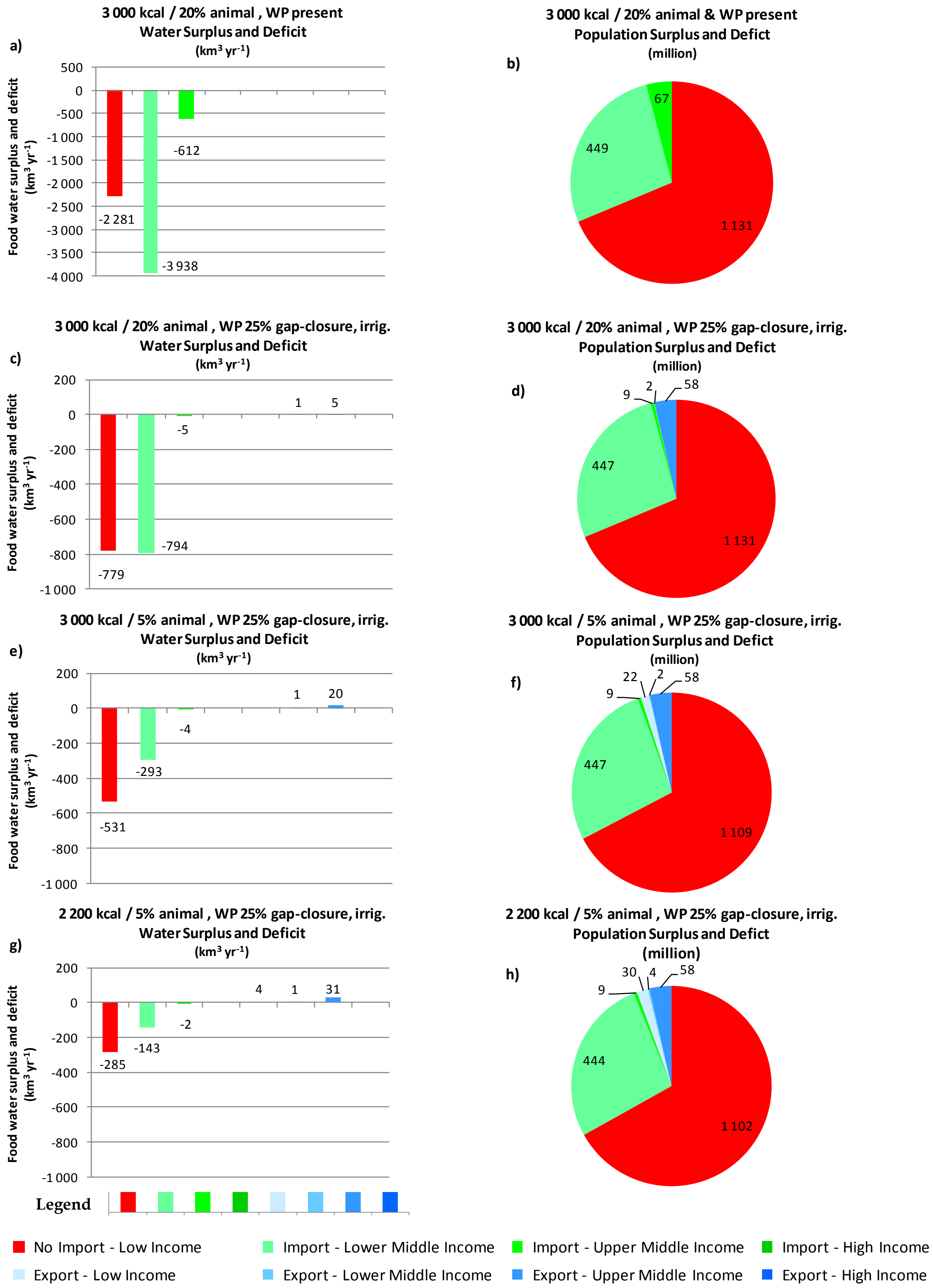
Figures 12 c and **d** show how the situation changes if the water productivity gap is closed by 25% and modeled possible irrigation expansion increases the blue water availability on current croplands. Deficits dramatically decrease, from 6,800 to 1,600 km^3 yr^{-1}. Globally, deficits can, in principle, be met by food export from water-surplus countries. With improved agricultural output a few SSA countries shift from being deficit to surplus countries, like South Africa. This can be seen when comparing **Figures 12b** and **d** where 58 million in the Upper Middle income population move from import to export. More worrying is the fact that 1.1 billion people will still live in sub-Saharan countries where part of the food supply cannot be imported, due to lack of purchasing power.

In **Figures 12e** and **f** the fraction of the calories from animal products has been reduced to 5% and in **Figures 12g** and **h** the overall calorie level has been reduced to only 2,200 kcal $pers^{-1}$ day^{-1}, the loss-free level and the current level in eastern Africa. For every change in the food combination the deficits decreases, but there is still a deficit that needs to be met. The results highlight the critical situation for the countries that are harboring 1.1 billion by 2050 and lacking water for food production, even at the lowest average calorie level.

Availability of food and water will be a critical issue in the coming decades. As mentioned, the analysis above builds on potential water availability on current croplands and a horizontal expansion of croplands can thus be one solution. However, such an expansion of current croplands to appropriate more green water implies that current vegetation and ecosystems will be replaced, endangering the resilience of the important SSA wildlife ecosystems and pastures. Any potential horizontal expansion also requires that the rainfall is sufficient and the lands are suitable for crop cultivation. Each country thus has to be analyzed individually.

Any country lacking the potential of full expansion of croplands to meet food demands will be in the most precarious situation, and might have to rely on food aid. A more constructive option would be international support to these countries to enable an economic development that opens up for food import to ensure national food security.

In summary, from a food water requirement and agricultural water availability perspective, **Figure 12** shows four different scenarios for the sub-Saharan region by 2050. To ensure food security and provide food for all will accordingly be a major endeavor.



Figures 12a-f | Food water surplus and deficit in SSA in 2050 for four income country groups, three food supply combinations, for current water productivity (WP), and for 25% WP-gap closure and irrigation expansion. Blue indicates a food water surplus and food export possibilities, green indicates deficit with an income level permitting import, red indicates deficit countries assumed too poor to afford import. All cases include climate change (CC) impacts. NB: the scale of the vertical axis in a differ c, e and g.

5. Research issues – water and nutrition

The linkages between water availability and accessibility and nutrition are manifold and a number of research questions can be formulated to address future challenges.

5.1.1. Water availability across sub-Saharan Africa

Water resources availability in sub-Saharan Africa is characterized by a large variability across both temporal and spatial scales. With water being a prerequisite for nutrition, it is crucial to understand where, when and how much water will be available for different uses.

RQ 1: How can data about hydro-climatic conditions (as precipitation, ET demand, temperature) and hydrological conditions (as run-off formation, river flow and groundwater levels) be more efficiently collected and shared across SSA?

RQ 2: How can these data be used to generate reliable water availability analyses? How much water is, and will be, available - including water storage to build redundancy – for both domestic and agricultural uses?

RQ 3: How can these data be transformed into information about water availability and accessibility to managers across different water-related fields to increase the understanding of water challenges and to encourage required actions? How can it be assured that this crucial information is shared?

5.1.2. Domestic water availability and accessibility, and nutrition

By 2050, the urban population in SSA will have tripled and the rural population will have increased by one-third. In the urban areas, the domestic water demand might increase by 650-1,300%. Domestic water is necessary as drinking water, for food preparation, and for personal hygiene, all three of which are prerequisites to secure the nutritional status of any person.

RQ 4: How can adequacy and continuity of domestic water supply be assured in the decades to come? Where should the water come from? Which sources can, and should, be used?

RQ 5: It is unlikely that optimal access to water can be mobilized for all (**Table 2**). How can the standard of drinking water be improved and how can personal hygiene be maintained, also for those still living under water-scarce conditions? How can research find pathways to educate and motivate people without a reliable improved water supply to improve hygiene?

RQ 6: Water quantities must be matched by water quality. How can a minimum standard of sanitation be implemented to assure that water resources and water supply are not contaminated by waterborne human diseases?

RQ 7: Poor and resource-weak people are particularly vulnerable. How can these groups be assured of affordability, continuity and quality of domestic water supply?

RQ 8: Technological development is moving fast, e.g. wastewater can viably be treated and reused as drinking water, and information technology can improve monitoring of water supply and water quality. How can new technical options be used to improve and optimize domestic water supply?

5.1.3. Agricultural water availability and accessibility, and nutrition

In four decades the sub-Saharan African population will increase by 900 million. Already 220 million are under-nourished. Food supply for all will be a huge undertaking, and translated to agricultural water demands more water will be required than appear to be available. Improved agricultural water productivity and irrigation expansion will assure food self-sufficiency in some SSA countries. Other water-scarce countries, which have economic capacity, rely on food import. However, the majority will face major difficulties in both producing and importing the necessary food quantities.

RQ 9: The static analysis presented in this paper shows national food production self-sufficiency in a water perspective. More research can reveal to what degree food production in each local site is water-constrained. How should water-scarce countries act to assure food self-sufficiency? A plethora of options and alternatives must be developed. What are they?

RQ 10: A static analysis presents a baseline. However, today's world is characterized by dynamic cross-scale linkages, including biophysical and socio-economic dimensions. For example, climate change might alter fundamental agricultural preconditions as climate seasonality and storm frequency, and social or economic turmoil in another part of the world can suddenly propel food prices and agricultural input costs rupturing both national food production and the global food trade system, potentially blocking imports. How can SSA countries build redundancy in their food production system to increase the resilience to such rapid changes? How can different buffers regarding water storage and food supply be increased to build coping capacity?

RQ 11: Any losses along the food production chain represent a wasted water quantity. How can food losses be minimized in SSA to save water for additional food production and thus improved nutrition?

RQ 12: More than 50% of the losses in the livestock sector in SSA take place in the animal production step (**Figure 8b**). Why is it so? How can these losses be reduced to both save water and increase the amount of animal proteins available for consumption?

RQ 13: Rain-fed smallholder farmers are the pillars of future SSA food production. With successful water-harvesting techniques, over 50% of lost water can be recovered at relatively little cost. How can farmers be inspired to utilize and manage precious green and blue water resources better?

RQ 14: Mixed livestock and crop cultivation systems offer a number of synergies, as to assure diets with high nutrition value and to minimize food water requirements, as biomass residues from crops can be used as fodder. How can these synergies be further promoted and optimized?

RQ 15: The ongoing nutrition transition towards higher consumption of more sugar, cereals like wheat and rice, and more animal foods often lead to more water-intensive agricultural production, like irrigated sugar cane or paddy and production of pigs and chickens. A diet based on traditional cereals, often better adjusted to water-scarce conditions and more nutritious, and animal foods from ruminants, feeding from pastures and crop residues, would decrease the water demand. How can nutrition researchers impact food consumption and food preferences to secure a sustainable and water-resource effective food production and a healthy diet for all?

5.1.4. The nexus of domestic and agricultural water use and nutrition

Peri-urban areas are characterized by informal settlements without property rights, lack of planning, and continued inflow of new settlers. The likelihood is high that the future SSA urban majority will live in these areas where human living conditions often imply poverty, under-nutrition and lack of both water supply and sanitation. Here the domestic and agricultural water use overlap and thus open up for both options and challenges.

RQ 16: Peri-urban agriculture links urban water use and food production as untreated waste water is often used for cultivation of perishables, e.g. fresh vegetables and salad, at a short distance from urban consumers. On the one hand, this food production generates income and nutritious foods and, on the other, the health risks are considerable. How can the health aspects be addressed to safeguard the nutritional value of the produce, and the health of the farmers using such water sources?

RQ 17: The peri-urban areas are the transition zone between the urban core and the surrounding rural landscape. Often, the uncontrolled settlements spread into catchment areas polluting the water resource for the cities. At the same time, untreated waste water from the urban core often spreads into the peri-urban areas. How can management of scarce water resources be improved to both ensure uncontaminated water sources for the cities and waste water treatment to protect downstream users?

RQ 18: It is virtually impossible to live anywhere without water. Planning of settlements in relation to water resource availability is crucial. How can urban planners gain momentum to manoeuvre the ongoing urbanization in relation to future demand of water resources, sanitation and protection of the environment?

RQ 19: With increased demand for food and increased demand for domestic water supply, the competition for scarce water resources rises. How can multiple uses of water, as for example, drinking water, irrigation, industry, the environment and hydropower, be recognized and optimized to balance competing demands? What trade-offs have to be made?

6. Conclusion

Water and nutrition constitute a multi-dimensional issue stretching from local issues, such as the supply and quality of water from a neighborhood tap shared among a few households, to global World Trade Organization food trade agreements, setting the rules for any water-scarce country reliant on food imports. The overall complexity to secure nutrition in sub-Saharan Africa in the coming decades calls for interdisciplinary approaches. Current, often sectoral ways of thinking must be combined to broaden the perspectives. This is also the case regarding water. Too often, water is separated into individual compartments as water supply, irrigation, or ecosystem considerations without considering the wider interlinkages.

Water is the bloodstream of the biosphere and the base for all socio-economic development, and it is thus the key to almost every aspect of nutrition. The most important and overarching future objective must be to assure that water resources are sustainably used. With over-exploitation of blue water resources, leading to depleted aquifers, rivers running dry and heavy pollution, and mis-management of rain-fed agriculture, with water and nutrient losses and erosion, there is a risk of the base for sustainable water resource use and agricultural development being degraded.

The sub-Saharan region is at the cross-roads of future global water and food dynamics and it is important to find the best solutions. Sub-Saharan nutritional researchers with unique local knowledge have a key role to play when developing a research agenda to find successful avenues for the future.

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Appendix 1. FAOSTAT African country groups

Western Africa

Benin
Burkina Faso
Cape Verde #
Côte d'Ivoire
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
Saint Helena #
Senegal
Sierra Leone
Togo

Middle Africa

Angola
Cameroon
Central African Republic
Chad
Congo
Equatorial Guinea #
Gabon
Sao Tome and Principe #
Democratic Republic of the Congo

Southern Africa

Botswana
Lesotho
Namibia
South Africa
Swaziland #

Northern Africa

Algeria
Egypt
Libya
Morocco
Sudan*
Tunisia
Western Sahara

Eastern Africa

British Indian Ocean Territory
Burundi
Comoros #
Djibouti #
Eritrea
Ethiopia
Kenya
Madagascar
Malawi
Mauritius
Mayotte #
Mozambique
Réunion #
Rwanda
Seychelles #
Somalia #
Uganda
United Republic of Tanzania
Zambia
Zimbabwe

Regional classification according to the M49 UN classification.
Countries not included in the food water requirement analysis due to lack of data
*NB. Sudan here part of Northern Africa, and thus not part of sub-Saharan Africa.

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