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Advances in Quantifying Impact and Extent of Water-Land-Food Nexus for Food Security in Africa

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Abstract

Food systems have the potential to promote human health and enhance environmental sustainability; yet most African countries have decadal starvation and malnourishment due to unstable food systems lacking basic nutritional profiles. To understand the key questions of the African food production and food security crisis, it is important to evaluate the past and the present balance of food production and consumption quantitatively and comprehensively and identify resource constraints. This continental study analyzed water-land-food (WLF) nexus in recent decades (1997-2017) and accessed whether these resources cope with different population growth projections, dietary changes and agricultural water management. The findings revealed that in 2017, total production in Africa for the four major crops was 83.3, 34.1, 21.0 and 26.7 million tons for, respectively, maize, rice, sorghum and wheat. Together with the imported food, 38 countries experienced an increase in kcal by food supply, while 7 countries encountered a decrease. However, only 6 countries were above the 1500 kcal·capita^{-1}·day^{-1}—the global average food consumption from the four major crops. The study also found that in the context of food production and out of the total African population, 268 million (21.6%) have enough land and water, 310 million (25.0%) is without enough land and water, further 279 million (22.5%) have enough water but not enough land, and 381 million (30.8%) encounter enough land but not enough water. This is the first WLF nexus study for the African continent and emphasizes the need for efficient and rapid changes in the food systems of the African population, both in production and consumption, in order to provide sustainable and secure food systems, and ultimately approach the first three Sustainable Development Goals.

Keywords

Basic Dietary Requirements, Cereal Import Dependency Ration, Constraint, Import, Production, Shortages, Resource

1. Introduction

Food security impacts human health by numerous paths and particularly for children and women and their overall well-being, with lack of food and poor diets contributing to deteriorated health, increased malnutrition and mortality. The majority of the African nations are affected by food deficit and malnutrition, with many citizens having no access to adequate resources and basic food supplies [1]. Rapid population increase, slow or diminishing economic growth with disproportionate economic development, high poverty and frequency of famines altogether limit the adaptation capacities for solutions and improvements [2]. Yet, resources availability in terms of net primary production and socio-economic vulnerabilities are being paradoxically at their height in Africa [3] [4]. There is an urgent need to identify the linkages across key natural resource sectors in Africa.

In 2019, 135 million African people of 54 nations and territories have already suffered food emergency crisis; another 183 million people in 47 countries and territories are classified as being in “food stress” [5]. The international community is largely involved by monetary and enterprise means in the African countries and discuss the issue of food security for few decades [6]. It has been recognized that all resources required for food production and security are under strain and will soon be stressed to a critical level, with large and concurrent increase in the demand for water, land, and food in the near future [7]. The demand in Africa’s Sub-Saharan region will be particularly large as countries face a challenge to meet the ever-increasing need for resources sustainability [8]. The agricultural production in this vast part of Africa, which is mostly rainfed, is negatively affected by rainfall irregularity in space and time, growing water demand amid limited availability due to multi-sectoral overuse and climate change.

Previous studies showed that erratic rainfalls threaten > 90% of the productivity in the African rainfed agriculture in a short period between 2005 and 2010 (e.g., [6]). Agricultural production in Sub-Saharan Africa remains the lowest in the world and some studies attribute this to factors inherent and imposed to Africa and its people, such as tropical climate and associated communicable and non-communicable diseases, pedogenically old and leached soils, colonial history and modern-day social exhaustion [2] [9]. The loss of agricultural land *per se* is due to land expansion and especially degradation, such as agricultural land abandonment, erosion, wastelands and desertification [10], as well as conversion of agricultural land to substandard urban land uses with impervious surfaces, including road infrastructure, residential areas and industrial facilities [11]. Altogether with the temperature rise and the variable/declining rainfall, the current land situation implies negative consequences for food production and a surge in demand for food imports in both North- and especially Sub-Saharan Africa. Durodola *et al.* [12] pointed out that by year 2050 food production is likely to grow by 60% to feed an estimated 9 billion world population, the largest growth occurring precisely in Sub-Saharan Africa. Food demand factors, such as the number of people and their consumption patterns, are closely linked to the amount of land and water required [13]. These factors vary greatly across the world and the African continent, reacting to socio-economic and cultural influences in diverse ways [14]. Land and water are resources necessary to produce food in the most local context [15], as opposed to energy and other assets such as fertilizers and fuel that can be transported across distances [16]. Moreover, consumption and production both influence the area's capacity to fulfill its own food needs [17]. Due to the interdependence of the water, the food and the land sectors, designing water and food link without considering land will result in land stress [18]. The variances in agriculture, particularly crop yields, food per capita cropland and water use are high and the African countries are dependent on international trade, being dramatically increased in the past two decades [19]. Amid uneven rainfall, assessments of only water and land provide insufficient information on food security extent, severity and impact on the region. Therefore, it is necessary to integrate methodological approaches for water, land [20], and food [21] on a broad scale in a nexus.

Africa currently encounters a triple threat of overcrowded regions, climate change and the COVID-19 pandemic, which in short time appear to have increased the rate of water scarcity, food insecurity and poverty in the continent [22]. The 2020 World Water Development report suggested water-climate-food-environment nexus adaptations and mitigations [11] and models. Numerous nexus studies have been conducted for regions and countries coupling water and climate [23], land and food [24] and other sectors to assess the effects of climate change on water and nutrition [11] [25]. However, cross-sectoral interconnections between water, land and food (WLF) in nexus for the entire African continent, as well as their implications and consequences for food security, remain unknown and understudied [26]. Among the many, two *key questions* relevant for the research and the policy remain to be answered. 1) Are national water and land resources sufficient to meet future domestic demand for food in Africa? 2) What proportion of Africans will live in land- and water-restricted conditions for food production? In order to answer these questions, it is necessary to construct a WLF nexus for recent decades and study whether resources will be sufficient with different population growth projections, dietary changes and agricultural expansion. It is also essential to evaluate the current balance of production and consumption based on the degree of undernourishment in Africa, to comprehend the main concerns of the African food security crisis.

This paper collected continental data on crop production, water resources, farmland area and irrigation in all 54 countries in Africa for 1997 and 2017 (a 20-year time span) and conducted a systematic WLF nexus analysis aiming to inform readers about the food dynamics in Africa. We also studied the trends of food intake expressed in kilocalories (kcal) per person per day. Hence, comparison between availability of land and water to population demand for food production is tackled by building a nexus for WLF for the African countries, with farmland and water available per capita being linked to the need of each country. This study provides important information for researchers, policymakers and WLF managers to increase awareness of the prevalence and seriousness of the food insecurity in Africa.

2. Materials and Methods

2.1. Study Area

Africa has 1.1 billion ha classified as agricultural land out of its 3 billion ha of land area, of which only 252 million ha (20%) is arable [27]. More than 60% of the world's arable land is in Africa, but the continent's share of global agriculture production is small [28]. The vast majority of farmland in Sub-Saharan Africa is rainfed (**Figure 1(a)**), as opposed to 75% irrigated farmland in the Middle East and North Africa [29]. From 1990 to 2013, the total value of agricultural production in Sub-Saharan Africa increased by 130%, with total farm production dominated by the crop sector.

The continent features wide range of elevation (**Figure 1(b)**) with eastern and southern regions being generally higher, while elevation declines north and west. Annual precipitation is estimated at 20,360 km^3 [30], but the majority of the continent is semi-arid and therefore susceptible to large annual rainfall changes

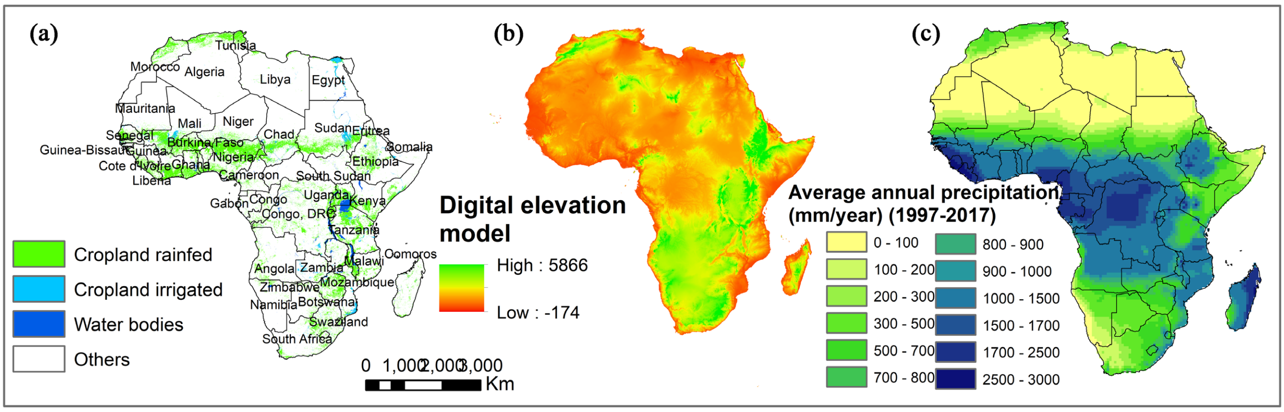

Figure 1. The African continent with (a) agricultural land use, (b) digital elevation model and (c) precipitation.

[31]. The islands have the largest rainfall (1700 mm a year), followed by the countries of Central Africa (1430 mm) and the Gulf of Guinea (1407 mm; **Figure 1(c)**). The lowest rainfall is in the largely desert north (<70 mm) [32]. Similarly to the world average, 85% of the total amount of freshwater is used in agriculture, 9% for communal water supply and 6% for industry [32]. Africa, with 2.2 billion people predicted in 2050 and more than 4 billion in 2100, is the fastest-growing continent of the world [33].

2.2. Methodology

2.2.1. Data Collection and Analysis

We compiled country-level data for 54 countries on the African continent for the years 1997 and 2017 from the database of the Food and Agricultural Organization (FAO) of the UN. The first data included demographic and economic records, *i.e.*, population and Gross Domestic Product (GDP; 2020 US$) per capita [34]. Land constraints have decreased dramatically during the study period as arable land was available in most countries in 1997 and in 2017 many countries had values closer or lower than 2000 m^2 $capita^{-1}$. Further, we considered the four majors crops in Africa, *i.e.*, maize, rice, sorghum and wheat and production data collected were from 1997 to 2017 and contained harvested area (m^2) and yield, domestic production and consumption, import and export, all in tons $year^{-1}$ [35]. The thematic maps were digitized, integrated, and analyzed in ArcGIS and the Mann-Kendall nonparametric test [36] was used to assess trend, magnitude, and change in these time series variables.

2.2.2. Analysis of Africa's Current Potential Food Demand

The FAO's definition of food security includes four pillars: 1) availability, 2) access, 3) use and 4) stability of food [37]. The analysis was conducted by highlighting the change and their impact on the livelihoods in countries from 1997 to 2017, followed by calculating the cereal import dependency ratio. The cereal import dependency ratio shows domestic food supply of cereals versus imported supply and indicates a country's or region's dependence on cereal imports, being calculated as [38]:

$$\text{Cereal import dependency ratio} = \frac{(\text{cereal import} - \text{cereal export})}{(\text{cereal production} + \text{cereal imports} - \text{cereal export})} \times 100\% \quad (1)$$

Negative values imply the country exports more cereals than it imports, whereas high values show large dependence on imports.

Land data were collected for 1997 and 2017 from FAO [39] and included % of irrigated land, agricultural water withdrawal (%), per capita agriculture land area (m^2 $capita^{-1}$) and water resources (m^3 $capita^{-1}$). The analysis of current land and water resources was conducted by highlighting the link between land and water as their impact on the livelihoods in host countries from 1997 to 2017, then quantifying the change based on different drivers of food insecurity.

2.2.3. Linking Resources Availability to Demand Food in Water-Land-Food Nexus

In order to determine the capacity to meet national food demand, we contrasted the supply of available farmland and water with the population's demand for food production. We have thus established the land-water-food nexus for each country as available farmland and water per capita are related to the demand for land and water per capita of each country: this demand depends on the form of diet. We used the data from [40] [41] to describe the per capita demand for land and water for every country. The average use of land and water for each type of diet in 2017 (*Avg*) was estimated using the formula from [16]:

$$\text{Avg} = \frac{\sum A_i P_i}{A_i} \quad (2)$$

where *i* is the diet category of countries based on the per capita GDP in 2017, *i.e.*, basic (lower than \$2000 GDP per capita), transition (\$2000 - \$10,000 GDP per capita), or affluent diet (above \$10,000), *Ai* is the per capita demand for land or water from each country, *Pi* is the population of each country in 2017. For all estimates, many countries would have less than the food required for the typical global diet, *i.e.*, *less than* 2000 *m^2 of arable land per capita* [40]. The countries with the sharp drop in per capita land available were the ones with increased food demand due to population growth and dietary changes, and the amount of resources required to produce a person's food depends on how the food is produced, *i.e.*, agricultural technology and type of diet people consume.

3. Results and Discussion

3.1. Food and Energy per Capita Condition in Africa

Increased cereal food consumption per capita was observed in 36 countries, while 9 experienced a decrease (**Figure 2(a)**). The average cereal food consumption per capita in Sub-Saharan Africa increased from 132 $kg \cdot capita^{-1} \cdot year^{-1}$ in

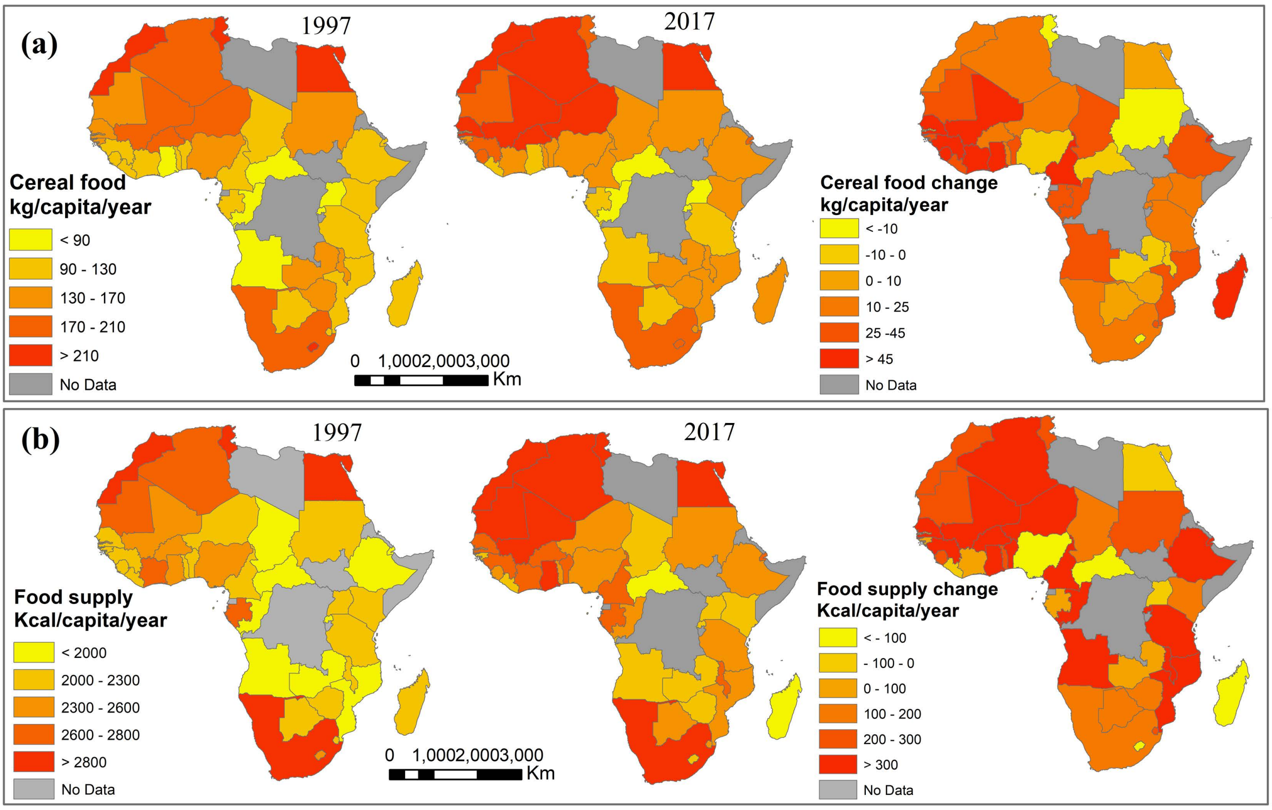

Figure 2. (a) Cereal food quantity supply per capita and (b) food supply kcal per capita.

1997 to 156 kg·capita^{-1}·year^{-1} in 2017, with Sierra Leone and Guinea having largest positive changes in cereal food consumption 1997 vs. 2017 of, respectively, 85 and 77 kg·capita^{-1}·year^{-1}. The largest declines in cereal food consumption were in Lesotho and Namibia with, respectively, −38 and −12 kg·capita^{-1}·year^{-1}, although Sudan was in the same category. Key variable for measurement and evaluation of the evolution of global and regional foods is consumption of food expressed in kcal·capita^{-1}·year^{-1}.

In most countries, per capita cereal consumption remained stable for 20 years (Figure 2(b)). The average food supply per capita in Sub-Saharan Africa increased from 818 in 1997 to 937 kcal·capita^{-1}·year^{-1} in 2017, and largest positive changes of about 510 kcal·capita^{-1}·year^{-1} in Sao Tome, Principe and Djibouti. The largest declines were in Egypt, Lesotho, and Sudan, with −90, −230, and −109 kcal·capita^{-1}·year^{-1}, respectively. Overall, 38 countries experienced an increase, while 7 countries experienced a decrease in annual kcal food supply per capita. In Sub-Saharan Africa, the per capita calorie supply has remained almost stable and recently declined in the economic transition countries. From 1883 kcal·capita^{-1}·day^{-1} in 1997 to 2110 kcal·capita^{-1}·day^{-1} in 2017, Africa's energy supply rose by 11%, though this number was largely affected by rapid change in Tunisia and Egypt, showing the most by far drastic variations. Sub-Saharan Africa's poor regions saw only small rises in its prevailing low levels of available food, especially Central Africa experiencing a marked decline. It is obvious that

Africa production of cereals has been increasing more slowly than population growth and food per capita consumption in most countries could decline and remains to rely on import. During the study period, sorghum had no increase as grown mostly in rainfed agriculture, especially in Central and Western Africa (rainfall of 2000 - 3000 mm·year^{-1}). Dietary energy has been growing a little, but not consistently or rapidly enough, according to the results. The observed food production and consumption patterns illustrate the urgency of pursuing a deep transformation of the agricultural sector in Sub-Saharan Africa if incomes are to be increased and food security issues mitigated.

3.2. Trends of Food Production in Africa

Figure 3 shows the dynamics of production and yield of the four major crops in Africa for the past 20 years. Increasing trend was seen for production, attributed to land expansions as yields of all crops showed moderately increasing trends, with large variations for wheat and sorghum. Average, minimum and maximum production values for rice were 17,386, 10,261 and 36,836 Mt respectively, with corresponding values for maize of 55,586, 38,586 and 83,282 Mt and for sorghum of 22,026, 18,079 and 26,511. Average annual wheat production in Africa from 1997 to 2017 was 21,235 Mt, flanked by 13,900 and 28,956 M minimum and maximum production values, respectively.

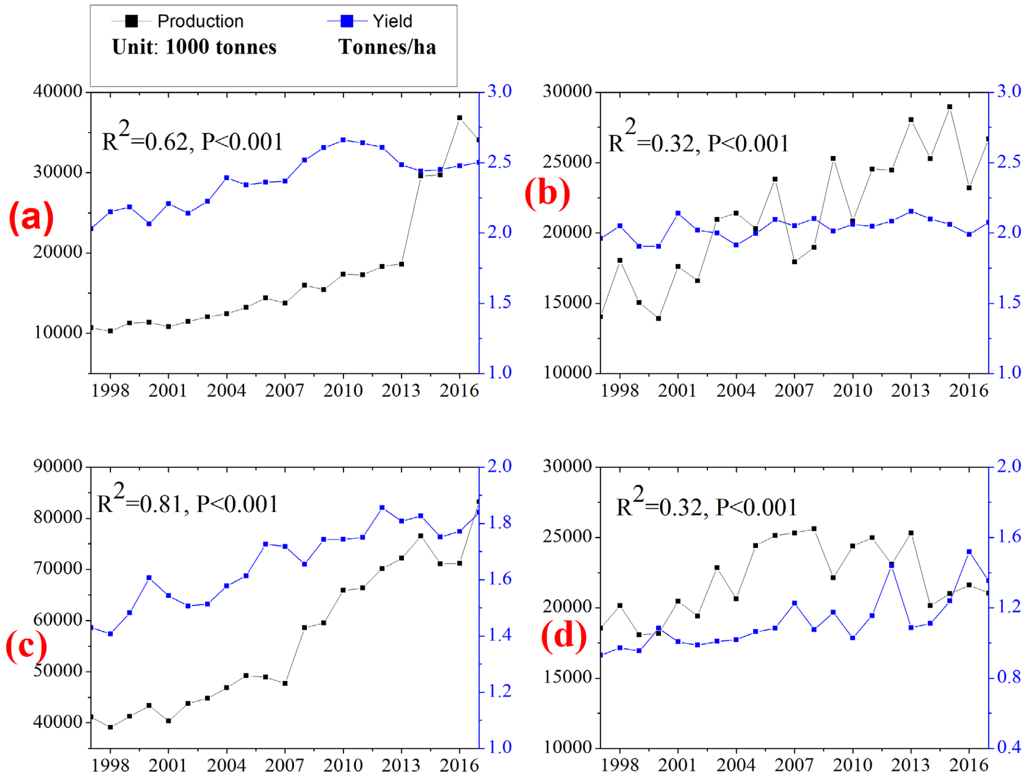

Figure 3. Linear trend (with equation) of cereal production and yield of (a) rice, (b) wheat, (c) maize, and (d) sorghum in Africa for the past 20 years. The coefficient of determination (R^2) and probability value (P) refer to the time series analysis of both production and yield with the Mann-Kendall test.

Substantial reliance on food import is only possible if economic development is sufficient to afford it, while low-income countries need a strong agricultural development to sustain such imports (**Figure 4**). Apart of sorghum, all other crops increased in imports in Africa, especially rice (**Table 1**). The increasing imports of maize are contrary to expectations, given the suitability of the Sub-Saharan region for maize cultivation in terms of climate, and the decadal breeding programs supported by foreign research and business entities. The increasing dependency of cereal imports was also shown in the increasing values of the cereal

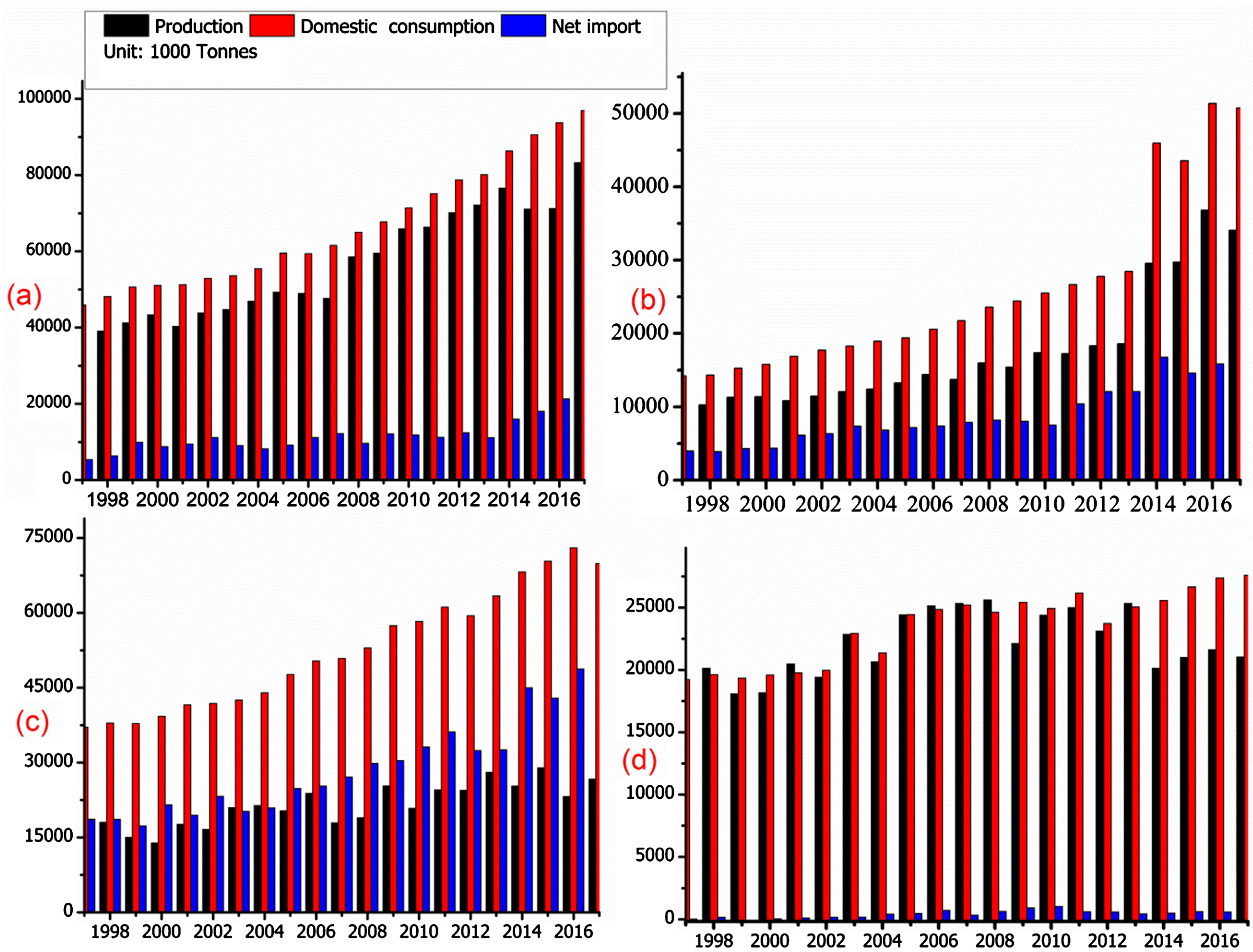

Figure 4. Africa's domestic consumption, production and net import (imports-exports) from 1997 to 2017 for (a) maize, (b) rice, (c) wheat, and (d) sorghum. Note the difference in y-axis between plots.

Table 1. Africa's domestic consumption, production and net import of the major crops from 1997 to 2017.

Crops	Production (metric tons)	Domestic consumption (metric tons)	Net import (metric tons)
Maize	83,282	96,941	18,163
Rice	34,057	50,730	18,524
Sorghum	21,044	27,584	358
Wheat	26,681	69,881	46,196

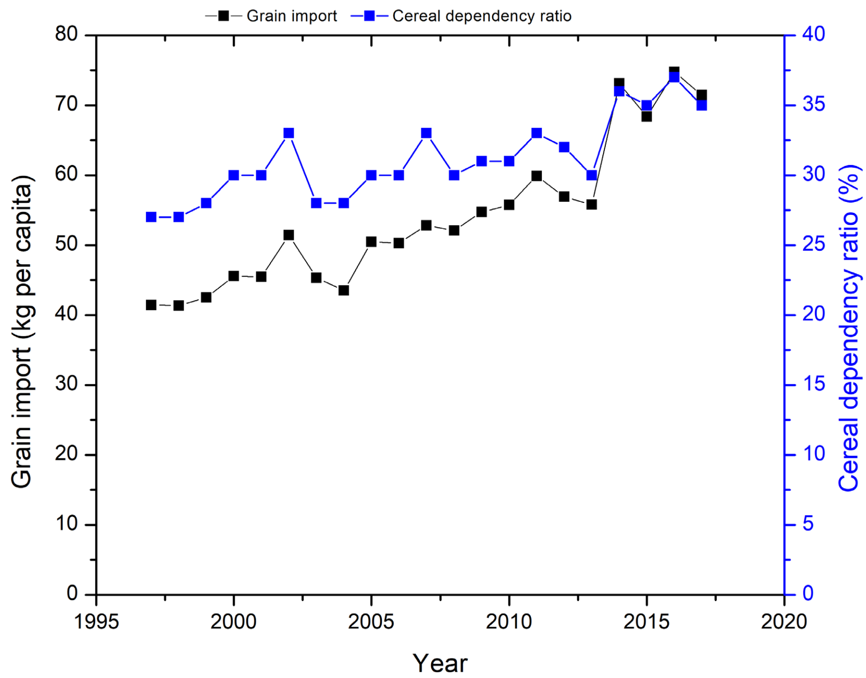

Figure 5. Comparing grain import levels and cereal dependency ratios.

import dependency ratio (Equation (1); **Figure 5**). The dependence on imports of cereals in Africa has increased from 29% to 34% between 1997 and 2017.

3.3. Past and Present Situation with Irrigated Land in Africa

The African continent is physically divided by the Sahara Desert to North Africa being arid compared to the Sub-Sahara which is much more humid, and this is very important for irrigation design and management. As expected, North Africa countries experienced an increase in irrigated land of >15% (e.g., Algeria-country mostly covered by desert), though some countries in the south such as South Africa also had an increase in irrigated land of 5% - 15% (**Figure 6**). For some countries with large areas, such as Sudan, South Sudan, Ethiopia, and the island of Madagascar, 1997 data were not available, hence it was not possible to assess the change in irrigated land, but it can be deduced from the 2017 data that certain developments in irrigation have been conducted.

3.4. Available Land and Water per Capita in Africa

The differences in population and land from 1997 to 2017 yielded large differences in both land area and water resources per capita, as depicted in **Figure 7** and **Figure 8**, respectively. **Figure 7** shows that for the past 20 years, land area per capita decreased in the vast majority of Africa (49 countries), reflecting the global trend. The average land area per capita in Sub-Saharan Africa declined from 3027 m^2 in 1997 to 2581 m^2 in 2017. Sierra Leone and Gambia witnessed a major positive change with, respectively, 1045 and 340 m^2 land area per capita increase, whereas the largest declines were seen in Niger and the Central Africa Republic, with corresponding −5659 and −1722 m^2 per capita.

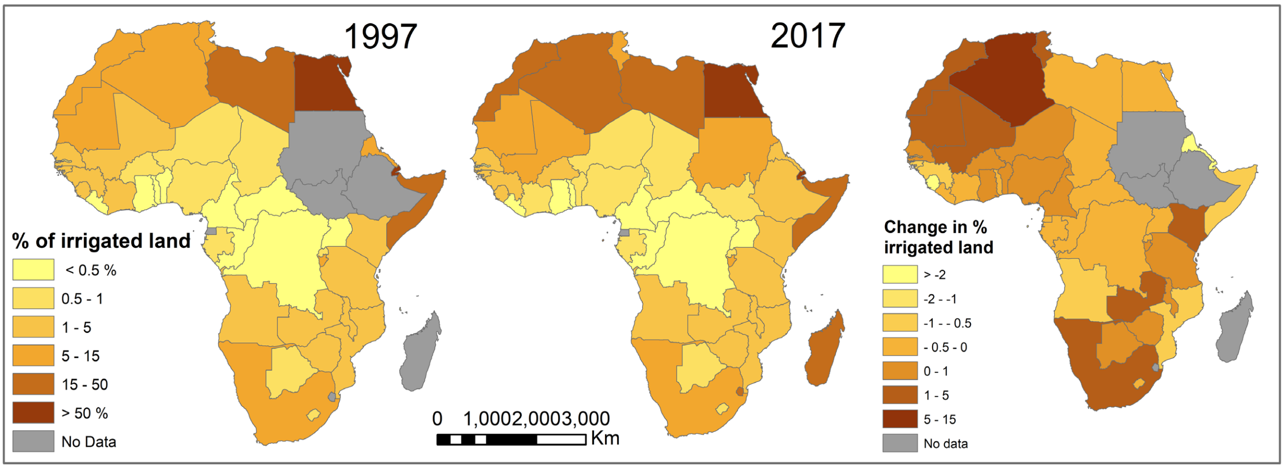

Figure 6. Percent (%) of irrigated land in Africa in 1997 and 2017 and its change between the two years. Countries with no data in 1997 have no change calculated.

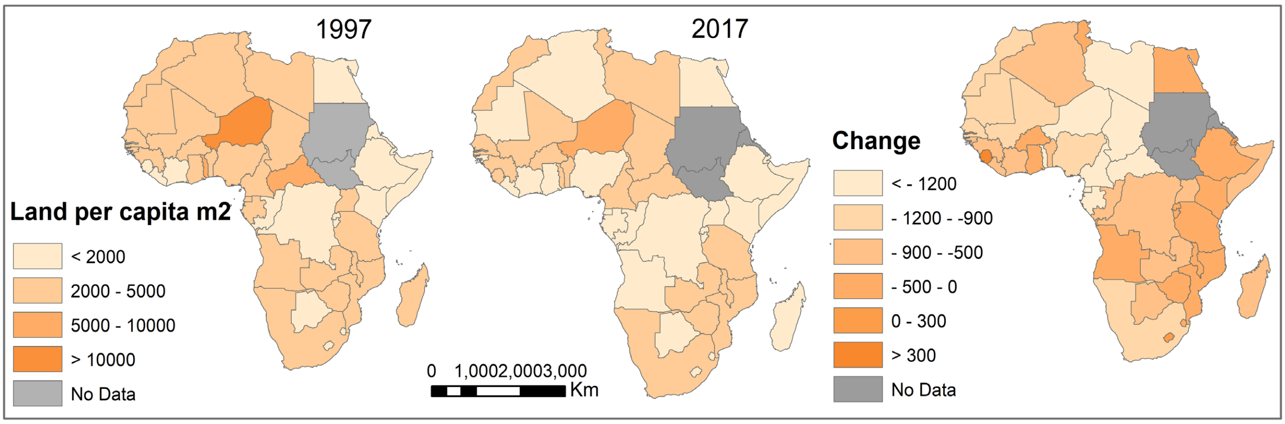

Figure 7. Land per capita in Africa in 1997 and 2017 and its change between the two years. Countries with no data in 1997 have no change calculated.

The majority of the countries, particularly North Africa, but also the entire East Africa have water constraints similar to or lower than the average global footprint of 1500 $m^3 \cdot capita^{-1}$ (Figure 7). North Africa is vulnerable to climate change to a limited extend since most of the environment in the region is desert and there already is little precipitation. Agriculture and growing population might impose additional demands for water supply, but political, economic, and institutional factors can and often lead to water deprivation even if resources are generally large. There were large differences between countries in per capita availability of water resources, in addition to temporal variation of three orders of magnitude for some countries from 1997 to 2017 and overall, the water availability per capita decreased dramatically, reflecting population growth (Figure 8). Some countries, such as DR Congo had more than 100,000 $m^3 \cdot capita^{-1} \cdot yr^{-1}$ without noticeable reflection of population increase, whereas Libya was the sole country with positive annual difference from 17 to 109 m^3 per capita between 1997 and 2017.

3.5. Agricultural Water Withdrawal in Africa

Water withdrawal for agriculture in Africa between 1997 and 2017 overall increased (Figure 9), reflecting the declining water resource per capita. The largest increase (>25%) was observed in the arid North Africa. In Sub-Saharan Africa, the agricultural water withdrawal overall increased from 20% in 1997 to 24% in 2017, with the largest change (13% - 25%) in the east countries of Ethiopia, Somalia, Kenya, but also on South Africa and Namibia on the very south.

3.6. Land and Water Required for Food Production

Countries with rapid decrease in per capita land available are typically those with increased food demand due to population growth and dietary changes, with per capita agricultural land high in water-scarce regions and low in water-rich regions. In Africa, however, the supply of land and water per capita is somewhat different and changed differently due to variations in population growth. We

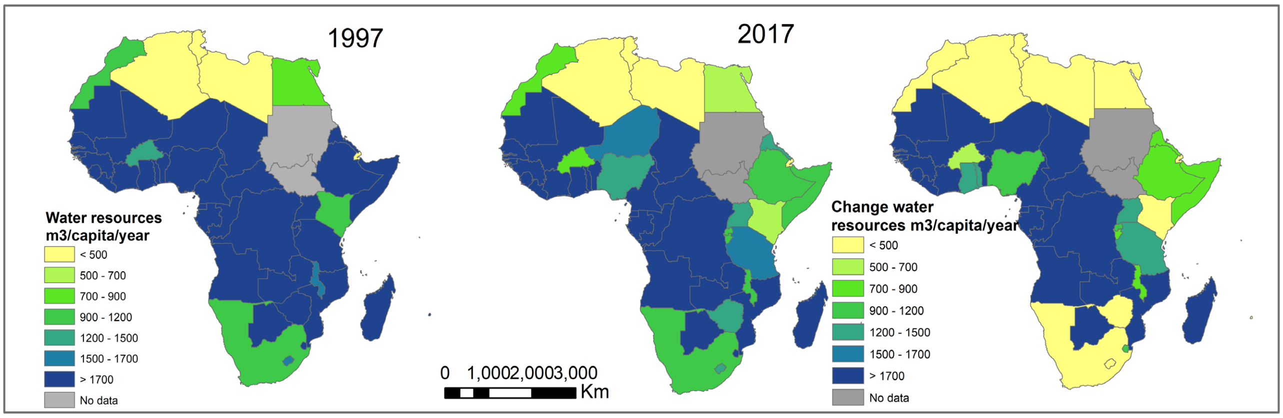

Figure 8. Water resources per capita in Africa in 1997 and 2017 and its change between the two years. Countries with no data in 1997 have no change calculated.

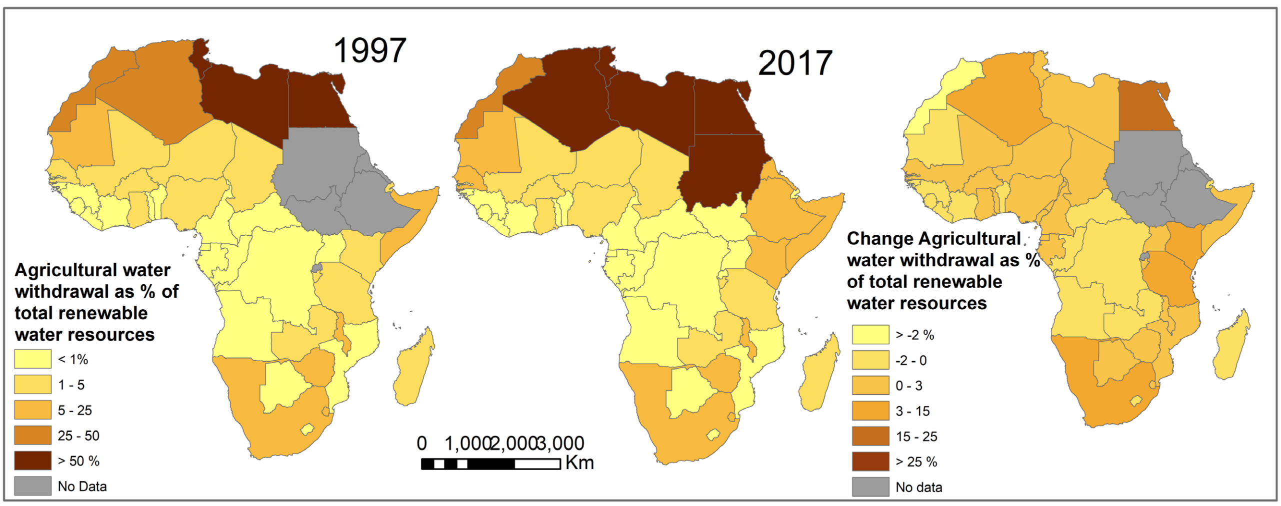

Figure 9. Agricultural water withdrawal in Africa in 1997 and 2017 and its change between the two years. Countries with no data in 1997 have no change calculated.

discuss this by data on the amount of land and water needed per person to produce food for a certain diet (Table 2). Land constraints have decreased dramatically during the study period 1997-2017, arable land was widely available in most countries in 1997 and in 2017 many countries had values closer or lower than 2000 $m^2 \cdot capita^{-1}$ mainly in developing countries. During the study period and for countries with <$2000 GDP per capita, population growth was the primary driver of the sharp decline in available land, whereas or countries between $2000 - $10,000 GDP per capita it was dietary shift, whereas food demand has been constant in countries with >$10,000 GDP per capita.

Table 2. Required land and water per capita for different dietary classes for the population in Africa. Basic, transitional and affluent diets reffer to country GDP per capita as, respectively, <$2000, $2000 - $10,000 and >$10,000.

Diet level	Average land $m^2 \cdot capita^{-1} \cdot year^{-1}$	Average water $m^3 \cdot capita^{-1} \cdot year^{-1}$
Basic diet	1806	1148
Transition diet	1307	1389
Affluent diet	1625	1942

3.7. Nexus of Land-Water-Food

In 2017 and country-wise, many had enough land and water for food production, whereas much of West Africa. Algeria, Nigeria and Lesotho (generally high population density in dryer climate) had neither ample land nor water (Figure 10).

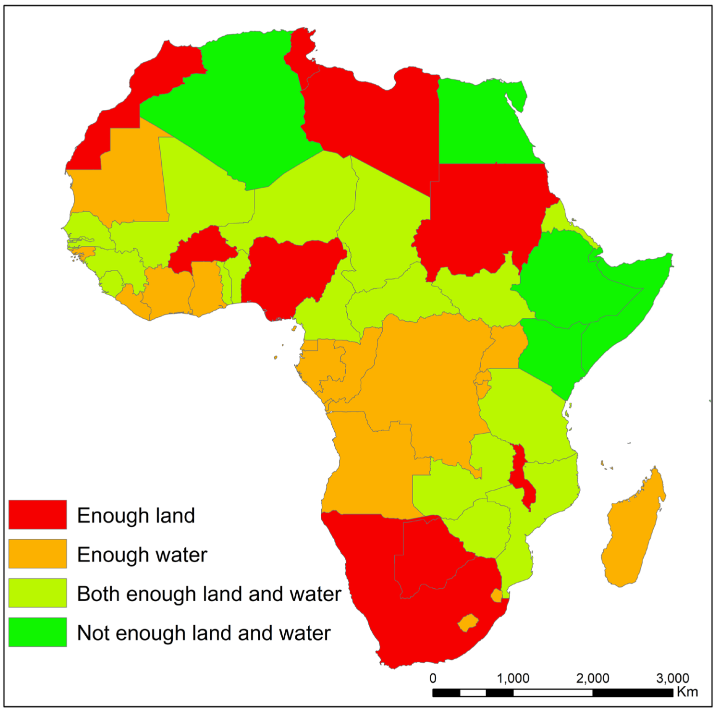

Figure 10. Water-Land-Food nexus for the African continent in 2017 based on data of per capita use of food, land and water.

The countries with insufficient land but enough water (dense populations and wet climates) were in central and western parts of the continent. In regions with dryer climates, the countries with ample land but lack of water were mainly in the north and few countries in the southern African tip.

Population-wise and considering the nexus results on **Figure 10**, in 2017 21.6% of Africa's population—268 million people had enough land and enough water, while one in four people, *i.e.*, 25% (310 million people) had neither enough land nor enough water. Enough land, but without enough water and *vice versa* experienced, respectively 31 (381 million people) and 22.5% (279 million people) of the African population.

4. Discussion

Global food security is expected to increase by all means, but with spatial disproportionality and by 2028 the Sub-Saharan Africa will still have the highest number of food-insecure people (ca. 300 million, or 24 % of the population) and the region is already highly dependent on imports of cereal products [42]. Progress in productivity and closing yield gaps have been studied [43] with identified significant constraints such as limited availability and supply of water and nutrients, insufficient or inadequate crop protection, mechanization and labor and a major gap in expertise [44]. In addition, Sub-Saharan Africa encounters large irrigation problems in terms of infrastructure, maintenance and water conflicts, but also the absence of effective policy and strategic framework and underutilization of productivity-boosting technology and inputs.

4.1. Limitation of Land and Water between 1997 and 2017 in Africa

According to the results, 38 countries experienced an increase in agricultural water withdrawal as % of total renewable water resources, against 15 countries with decrease (**Figure 6**). Overall solutions to lack of water are dams constructed to hold the water flows into the ocean without being utilized for irrigation and other purposes (*i.e.*, a true "water loss"). Projections show that by 2030, 14% more water will be required for irrigated agriculture in developing countries [45], *i.e.*, an additional storage of about 220 km^3 [46]. However, siltation of natural reservoirs reduces storage capacity and storage losses are currently measured at approximately 1% or 60 $km^3 \cdot year^{-1}$. Hence, more reservoirs should be built to meet the "Comprehensive Africa Agriculture Development Programme" target of 5 million ha irrigated land by 2025 while rehabilitating and sustaining the existing water infrastructure and considering biodiversity and ecosystems. Countries like Zimbabwe and South Africa with already large number of dams may require rehabilitation and be exempt from dam development [46]. In terms of proportion of farmers in areas with access and rights to securely owned land, statistics are difficult to find, but absence of ownership and security of land rights often hamper efforts to improving efficiency in agriculture [45].

The results show that Africa has large area suitable for irrigation that can help to increase food production. In the Near East/North Africa with untapped water resources, there will be a major irrigation expansion [47]. Overall, 6 countries experienced an increase in land area per capita, while 49 countries experienced a decrease. For most women, for example, lack of ownership and secure land rights impacts their ability to make successful investments and contribute to improved agriculture production and, by extension, improved food security for households. The allocation of crop-appropriate land is biased against those countries that most need to increase food production [48]. Thus, our study focused on the need for land for food production. There is a growing demand for land, some 90% are uncultivated in South- and Sub-Saharan Africa, while in North Africa almost no agricultural expansion land is available [49], with a few areas where both surplus arable land and freshwater resources remain for agriculture [50].

The large resource constraints addressed in this study point on difficulties in improving the concerned countries food security system. The choices for each region should be evaluated in detail, including agricultural intensification to avoid imports of food and meet dietary needs. Developing countries will face the greatest challenges as they reduce their per capita supply of land and water (through rapid population growth) and increase food demand by transitioning to a wealthy diet (due to rapid socio-economic growth). These modifications require a rapid shift in their food system. In conjunction with food security programs aimed at achieving an effective and rapid shift in agricultural production systems, policy implementation is necessary to increase production sustainably.

4.2. Limitation of Food Supply in the African Continent

Agricultural potentials are enormous and not fully exploited in Sub-Saharan Africa, especially for cereal crops. Food shortages are partly offset by food imports (**Figure 3**) because some countries primarily import while others export and 10% of the global food supply comes from imports to cover the required per capita per day of food supply (**Figure 2(a)**). Lack of food typically increases food prices, but also smoothens demand and increases domestic production. Maize production remains focus in few East Africa countries, with more than 50% increase to 19 Mt in Sub-Sahara by 2025, with six countries contributing with over 60% [51]. Small-sized holdings and low crop yield prevent surpluses from being produced by farmers, who are therefore unable to invest in seeds of high-yielding varieties and irrigation needed to sustain these varieties. Land fragmentation causes farmers to rely on water vendors instead of investing in irrigation infrastructure, which would be economically inefficient due to poor use of the potential generated. Rice tends to be the most difficult crop to promote of the four major grains under an import substitution strategy since both supply and demand-side approaches are required to improve local competitiveness [52]. More food needs to be produced on home grounds in Africa amid the 212 million malnourished and one billion more predicted by 2050 [53]. However, the major constraints should be removed to the degree that almost doubles the production of food crops compared to the current levels to make the continent nearly self-sufficient for food (**Figure 11**).

Food import increased in recent years in Africa due to volatile food prices and political shifts, posing a threat to food security [54]. National food security policies must be strengthened [55]. The majority of the world's poorest countries are in Eastern Africa, *i.e.*, the Horn of Africa, despite many agricultural but low-yielding activities present there. In West Africa, agriculture is the key economy driver due to favourable and vast low-lying planes [56]. The failure to eliminate hunger in this region is linked to, among others, the rise in conflict and violence. Since 2011, the prevalence of undernourishment in conflict countries has increased from 23 to 26 %, staying constant at around 5% in non-conflict countries [57]. Sub-Saharan Africa, in particular, faces prospects of more cereal crop imports or expanding into previously uncultivated land. These strategies, however, question sustainability principles and closing yield gaps by sustainable intensification on existing croplands should be more in development programs, through promotion of rotations, irrigation expansion, and abandoning pastoralism.

4.3. Solution to Restrictions on Land and Water

In this study, the category "not enough" land or water does not directly indicate countries current or future food scarcity. Instead, it suggests that, depending on the available resources and the population needs based on the form of diet, these countries have or will have land and water *constraints*. Significant constraints

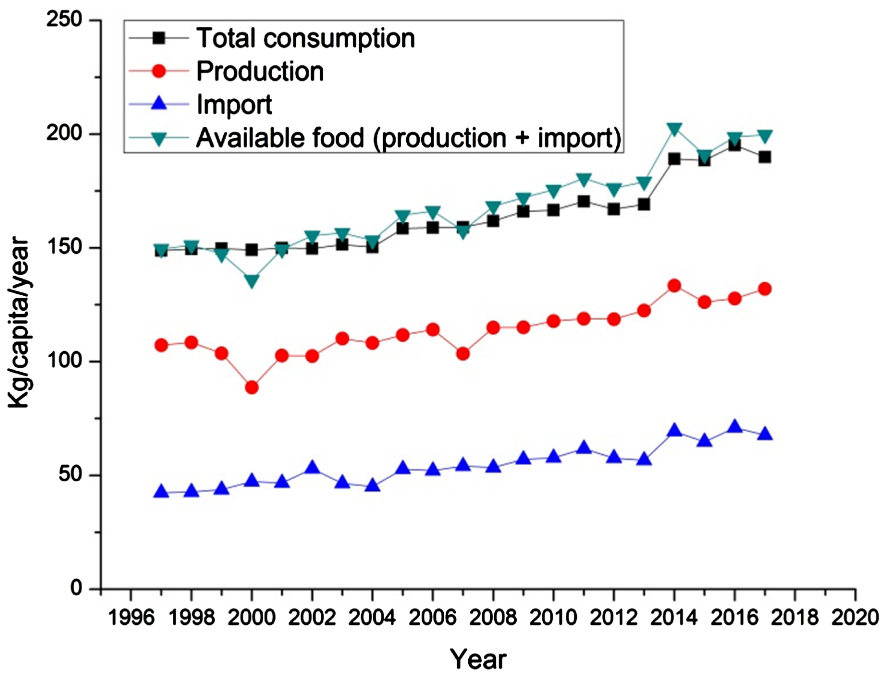

Figure 11. Cereal consumption versus available food for Africa.

include limited availability and/or supply of water and nutrients, insufficient or inadequate crop protection measures and use of mechanization, as well as deficient expertise. These constraints on land and water mean that food supplies are or will be met in part by food imports. Yet, the constraints addressed in this paper are large, but still do not necessarily imply inadequate food for the population in those countries, but rather that the countries face difficulties in making improvements in their food system. For each region, options for agricultural intensification (increasing crop yield), diversification, expansion, food imports, and dietary change should be analyzed in depth.

All sectors experience more pressure to reduce water utilization by considering more efficient water use and alternative value chains. Effects on land and water resources also need to determine how the scarcity value of the resources in the nexus can lead to changes in their usage and can jeopardize their accessibility to the poorer section of the population. The possibility of stabilizing population levels in the 21 centuries could also indicate more stable trends of global land use in the future. While some positive progress has been made, significant work remains to be done to make water security a reality by 2030, the Sustainable Development Goals target date.

5. Conclusion

Population growth reduces available resources per capita, while dietary shift from basic to affluent diet increases demands for resources per capita. These two key drivers of food demand have a significant impact on the capacity to supply food. Even though food production has the greatest impact on African self-sufficiency across all regions, the recent increase in food supply should not be overlooked. With revenue rising, consumption and diets are diversified, although consumption levels in Africa are significantly lower than the global average. Foreign food security in the future will be further pressured by the increasing demand for food because of the growing population. An analysis of the main factors which affect yields must be carried out and the main restrictions to improving yields must be understood. The impact of climate change and declining rainfall are some of the constraints for improved technology and also should to be examined.

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Food quantity supply and kcal per capita, total production and consumption: https://www.fao.org/faostat/en/#data/FBSH

Cereal production: https://www.fao.org/faostat/en/#data/QCL

Irrigated land:
https://www.fao.org/aquastat/statistics/query/index.html;jsessionid=BC9202E73416BAA383BE80027940D7CE

Total land per capita:
https://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC?locations=ZG

Water resource per capita water:
https://www.fao.org/aquastat/statistics/query/index.html;jsessionid=BC9202E73416BAA383BE80027940D7CE

Water withdrawal per capita:
https://www.fao.org/aquastat/statistics/query/index.html;jsessionid=BC9202E73416BAA383BE80027940D7CE

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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