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Agricultural Yield Responses to Climate Variabilities in West Africa: A Food Supply and Demand Analysis

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Abstract: Agricultural productivity is expected to decrease under changing climate conditions that correspond to the stability of West African food systems. Although numerous studies evaluated food production gaps or impacts of climate variability on crop yields, many uncertainties are associated with climate extremes, but also rapid population growth and the corresponding dietary lifestyle determine farming activities. Here, we present a food supply and demand analysis based on the relationship between climate change, crop production, as well as population growth in three experimental sites from southwestern Burkina Faso to southwestern Ghana. The method consists of a tiered approach that encompassed a statistical analysis of historical climate as well as agricultural time series using boxplots and a trend test by Mann-Kendall. Food balance sheets were calculated by estimating the demand using a population growth model linked to food supply with local consumption patterns. Results of the boxplot analysis revealed for the majority of climate time series light to strong right-skewed distributions with either a few heavy rainfall or hot temperature events. We found almost insignificant rainfall and temperature trends for both sites in the Sudano-Guinean savannah. The rainfall regime of southwestern Ghana indicated an insignificant upward or downward trend while the temperature significantly increased over time. Crop yield boxplots demonstrated mainly right-skewed distributions for cereals, legumes and tubers as well as cash crops such as cotton. Backed by the Mann-Kendall test, maize and sorghum significantly enhanced in both study areas of the Sudano-Guinean savannah. Southwestern Ghana depicted a different crop pattern where cassava and plantain showed a strong upward trend at a confidence level of 1%. The grouped food balances sheets across the regions illustrated a surplus for the Sudano-Guinean savannah ranging from 221.2 megatons (Mt) to 4,846.77 Mt while southwestern Ghana exhibited a deficit between -193.33 Mt and -16,188.82 Mt. Despite a growing yield of various crops, food demand outpaces the regional production. Hence, it is recommended to focus on a larger array of commodities, imports and marketing of farm products.

Keywords: agriculture; climate variability; crop yield; food supply and demand analysis; West Africa; Ghana; Burkina Faso

1. Introduction

Changes in climate patterns have fundamental impacts on agriculture that affect rural livelihood in West Africa. The increasing frequency of droughts, irregularities in onset and a shortening of the rainy period combined with a high reliance on rain-fed agriculture, weak institutional power or limited adaptive capacity make many regions less favorable for crop production [1–3]. A study by [4] projected for the Volta basin in West Africa a rising mean temperature of 1.2 °C to 1.3 °C while the precipitation rate will fluctuate from around -150 mm to +200 mm. To mitigate these impacts, the

2014 Malabo declaration, as the main instrument of the Comprehensive Africa Agriculture Development Programme, aims to allocate 10% of African public resources to enhance agricultural productivity [5]. Without any adaptation of farming practice, climate effects will cause a regional yield loss close to 11% by 2050 [6].

The deep connection between climate variability, crop yield and management turns the area of West Africa into a hotspot with severe land degradation processes as well as socio-economic challenges [7]. However, the agricultural sector remains the backbone of most economies in Sub-Saharan Africa and employs roughly 60% of the workforce [8]. Smallholder farmers produce the majority of staple food with a dominance of cereals such as maize, millet, rice, sorghum and wheat [9]. A study in Burkina Faso revealed a strong total crop production of maize, millet and sorghum enhanced by 116.78% from 1990 to 2014 [10]. [11,12] reported for the country that the growing yield resulted from land expansion and not from any farming improvements such as fertilization or irrigation practices.

Non-climatic factors such as population growth, changes in the dietary pattern and food demand will accelerate the human-induced transition to agricultural land [13,14]. The population growth rate for West Africa is forecasted to increase approximately three-fold by 2050 with high expected values for Niger, Nigeria and Burkina Faso [15]. This will influence the availability of food and generate a structural imbalance between crop yield and demand. In West Africa, the number of undernourished people rose from 32 to 56 million between 2009 and 2018, which renders the region quite vulnerable to food insecurity [16].

Many governments of West Africa have confronted the food consumption gap through a variety of measures such as banning crop exports or procuring subsidized inputs. With regard to these threats, sub-regional bodies adopted the common agricultural policy (ECOWAP) in 2005 as a basis for improving crop yield productivity and sub-regional collaborations for technology sharing [17]. In tandem with the West African Alliance for Climate Smart Agriculture, both initiatives intended to promote research on farming practices that will contribute to sustainable agro-ecosystems and welfare of farmers [7].

In this study, we aim to investigate the food supply-demand relation based on the nexus between climate variability, agricultural production and population growth in Burkina Faso and Ghana. Many research studies connect climate change impacts on rural regions with food security. [18] analyzed the risk of climatic conditions on crop suitability and confirmed that savannah crops such as sorghum or groundnuts are most affected in northern Ghana. For the same region, [19] studied the nexus of flood disasters and food security with an emphasis that flooding events also have effects on socio-economic activities. Another host of recent studies revealed that food insecurity mostly occurred in rural areas due to an inappropriate infrastructure and food storage system, donor tensions or reduced incomes [20,21]. In a different view, [22] investigated the linkage between climate change and farming activities with an emphasis on the perception of local farmers to support the agricultural and nutritional requirements in Burkina Faso. In line with these studies, [23] concluded that the gap of agricultural yield shortfalls relative to demand will increase for starchy crops such as rice in West African countries.

Uncertainties exist in studying projected climate change impacts on crop yield and in the adaptation of agricultural systems to future climate conditions. For example, fixed climate emission scenarios such as the RCP8.5 projection only captures the impacts of average changes in climate without relevant temperature and rainfall features. Several studies neglect weather extremes but many crops have a narrow range of climate variations corresponding to an optimal growth [24]. In this regard, many approaches focus on cereals, groundnuts or some tubers without including other crops such as vegetables [25]. Additional constraints are associated with the projection of rapid population growth and the respective dietary lifestyle that determines the food demand within climate risk zones.

The objective of this study goes beyond existing uncertainties and literature on climate variability, yield data as well as food supply-demand in two ways. First, we practiced an empirical analysis of various weather and crop time series using boxplots as well as trend patterns to

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characterize the performance of the agricultural sector over time. Second, the statistical findings are balanced with regional population information to evaluate food supply and demand in three selected case study sites. Based on the relationship between harvested yield of cultivars, population growth and demand, we were able to assess consumption deficits as well as surpluses. The results are then compared with management practices, agricultural policies and climate trends.

2. Materials and Methods

In this section, we introduce the research sites situated along different agro-ecological zones and the design of the methodological approach including a brief description of time series data to perform this work. The framework aims at bringing together local food consumption patterns and the quantification of temporal changes in climate variables as well as crop yield with household census information to understand the interplay of food supply-demand across both countries.

2.1. Study areas

The study was carried out in three experimental regions from southwestern Burkina Faso to two areas in Ghana (Figure 1). The Dano site, as one of the research catchments of the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), is positioned in the Ioba province of Burkina Faso. The Bolgatanga/ Bongo districts are located in the Upper East Region (UER) of Ghana, while the administrative units Nzema East/ Ellembelle/ Jomoro are parts of the Western Region. Corresponding to the Köppen-Geiger classification, the areas are dominated by a tropical-savannah or tropical-monsoon zone [26]. Dano as well as Bolgatanga/ Bongo share a similar unimodal distinct rainy season from late April or early May to October and a dry period for the remaining months [27–29]. The mean rainfall ranges between 900 mm to 1200 mm and reaches its peak in July or August [30,31]. Annual temperatures of the Sudano-Guinean savannah, where both research sites are placed, oscillate between 20.1 °C to 38.4 °C [32]. The rainfall pattern for the three districts in southwestern Ghana consists of two wet seasons from March or April to July and a shorter rainy period from September to November with a dryer spell in August. From the coastal line to inland, precipitation lies within 1200 mm to 1400 mm while the air temperature ranges between 25 °C to 29 °C [33].

Livelihood activities in the Sudano-Guinean belt are mainly determined by rain-fed agriculture with a low level of mechanization. Over recent decades, farmland has massively increased to meet the demand of a rising population with annual growth of around 3% [34–36]. At the same time, intensification practices such as modern water and soil conservation practices enhanced the crop production. Principle crops are millet, sorghum, maize, rice and legumes, for example groundnut or cowpea. Apart from food production, cotton cultivation, as the main cash crop in Dano, is central to the local livelihood of rural population [37].

The humid regions in southwestern Ghana are predominated by tubers such as cassava, yam or cocoyam as well as cash crops such as rubber, palm oil or cocoa. Commercial production of rubber is the largest and most economically viable cultivar in the Western Region [38]. Despite an intensive expansion of agricultural land, food demand outpaces crop production. Key issues are a rapid population growth mixed with a changing urban diet [39].

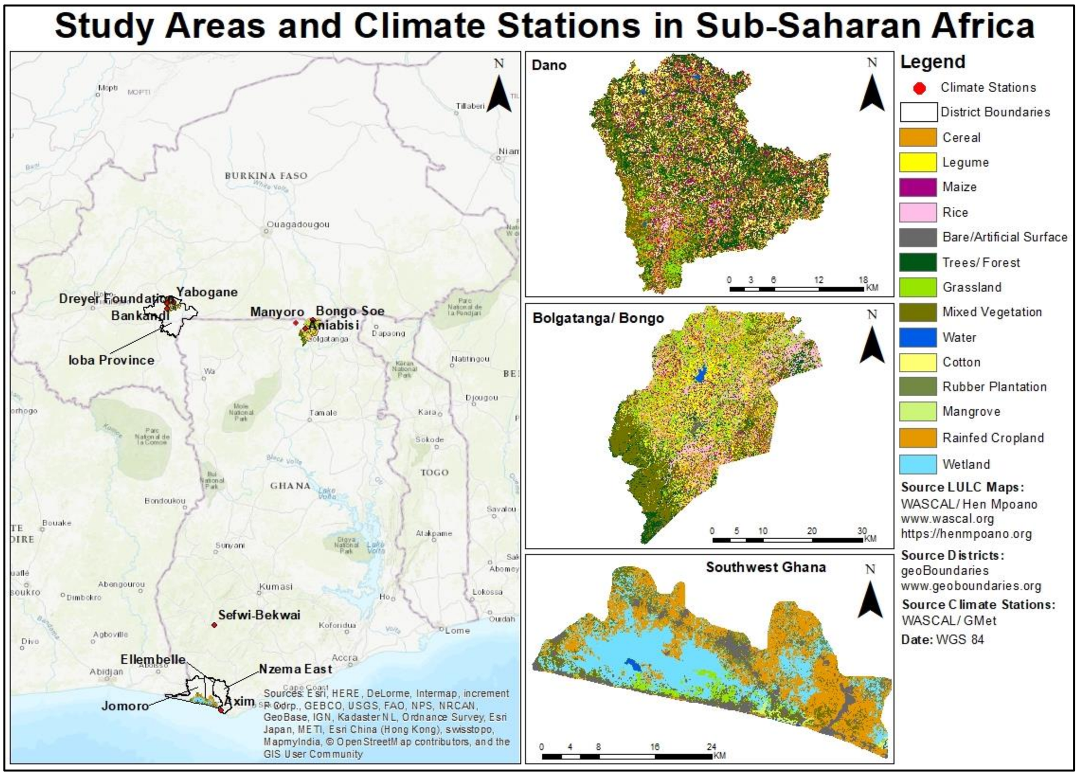

Figure 1. Study sites and climate stations.

2.2. Method

The developed methodology consists of a three-tiered framework to investigate food balance sheets that encompass (I) a data quality check as well as statistical analysis of climate and crop yield time series followed by (II) an estimation of annual population changes (III) to evaluate the food supply-demand nexus (Figure 2). As a pre-processing step, we visually evaluated the suitability of all datasets with regard to missing values. A further screening of the climate time series comprised both the location of meteorological stations and the covered time periods. We used boxplots as an explanatory tool to understand the skewness, its data sub-structures and extremes based on input time series. Corresponding to [40], values outside the range of the Tukey's method of 1.5-time the interquartile range (IQR) are considered as outliers. Crop yield extreme values were kept to avoid any bias from correction. Suspicious climate records are reconstructed from adjacent stations utilizing a linear regression technique.

The Mann-Kendall test is a commonly used method to detect the presence of a monotonic upward or downward trend over time. The method does not make any assumptions about the data distribution and the rank-based measure is not influenced by outliers [41]. For given time series, the method provides information on the Kendall rank correlation to assess the monotony of a slope, varying between -1 that represents a decreasing trend and 1 indicating a rising trend. The significance, as an additional source of information, distinguishes between the null hypothesis assuming an independent data distribution and an alternative hypothesis describing an existing monotonic trend [42].

Subsequently, we balanced the food supply with local consumption patterns and census data to evaluate consumer surpluses or deficits. A simplistic growth model allows ascertainment of the yearly alteration in the population rate to project the food demand.

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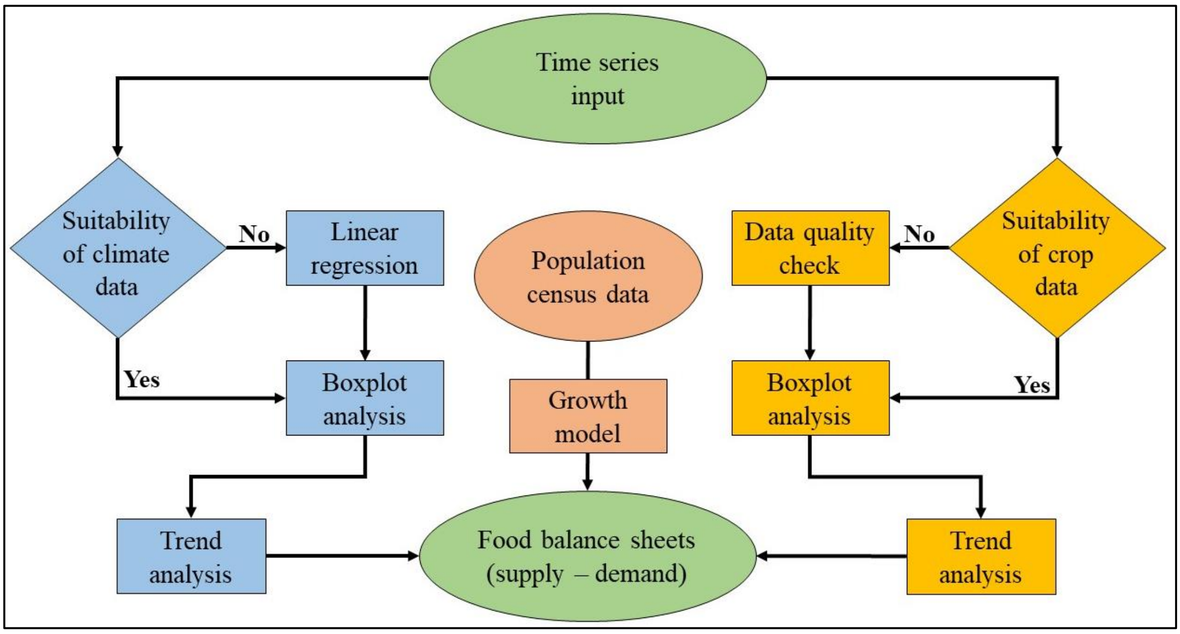

Figure 2. Analytical framework.

2.2.1. Climate time series

Meteorological datasets such as rainfall, minimum (Tmin) as well as maximum (Tmax) temperature were provided by WASCAL and the Ghana Meteorological Agency (GMA) with a temporal resolution from 5 min. to daily intervals (Table 1). The geographical location of used climate stations is shown in Figure 1. All data were aggregated by day and contain missing values due to interruptions in observations such as a breakage or malfunctions of instruments. Station measurements of rainfall, Tmin and Tmax of the Dano catchment were adjusted from 10/ 2012 to 12/ 2018. Time series for the administrative units of Bolgatanga/ Bongo covered a modified period between 06/ 2014 and 07/ 2019. Temperature datasets are only available as an average value of Tmin and Tmax (Table 1). Both climate stations, namely Aniabisi and Manyoro comprised missing values for all variables with a majority of data gaps between 2014 and 2017. The time series of Aniabisi encompassed many suspect mean temperature data lower than 10 °C from 05/ 2015 to 06/ 2019. However, the daytime and nighttime temperature in the UER ranges between 26.10 °C and 41.10 °C as well as 13.25 °C and 29.10 °C [43]. Bongo Soe did not encompass any data gap.

In total, GMA offered datasets of 14 climate stations for southwestern Ghana. We selected Axim and Sefwi-Bekwai as most suitable because of their long-term coverage of climate variables with few data gaps. The time series of both weather stations involves similar missing values from the late 1970s to mid-1980s and from 2010 to 2015, while incorrect values were detected on 06/ 1976. This possibly indicates measurement failures of precipitation, Tmin and Tmax observations.

A linear regression approach was used to reconstruct such incomplete meteorological variables from nearby stations. The coefficient of determination (R^2), as a validation criterion, helped to understand the relationship between two datasets to identify most qualified time series to fill the gaps.

Table 1. Climate time series.

<table>
<tr><th rowspan="2">Station</th><th rowspan="2">Rainfall [mm]</th><th colspan="3">Temperature [°C]</th></tr>
<tr><th>Min.</th><th>Max.</th><th>Mean</th></tr>
<tr><td colspan="5">Dano [10/ 2012 - 12/ 2018]</td></tr>
<tr><td>Bankandi</td><td>09/ 2012 - 12/ 2019</td><td colspan="2">09/ 2012 - 08/ 2018</td><td rowspan="3"></td></tr>
<tr><td>Foundation</td><td colspan="3">09/ 2012 - 12/ 2018</td></tr>
<tr><td>Yabogane</td><td colspan="3">10/ 2012 - 12/ 2018</td></tr>
</table>

Bolgatanga/ Bongo [06/ 2014 - 07/ 2019]			
Aniabisi	05/ 2014 to 11/ 2019		05/ 2014 to 11/ 2019
Bongo Soe	09/ 2012 to 11/ 2019		09/ 2012 to 11/ 2019
Manyoro	06/ 2014 to 09/ 2019		06/ 2014 to 09/ 2019
Southwestern Ghana [01/ 1970 - 07/ 2015]			
Axim	01/ 1960 to 10/ 2016	01/ 1960 - 07/ 2015	
Sefwi-Bekwai	01/ 1964 to 07/ 2016	01/ 1964 - 08/ 2015	

2.2.2. Agricultural time series and food consumption

Agricultural area, production and yield data were sourced from Ministry of Food and Agriculture (MOFA) in Ghana between 1991/ 93 to 2016, while the Direction des Statistiques Agricoles/ DGPSA/ MAHRH in Burkina Faso provided primary information from 2001 to 2019 (Table 2). Time series for the Dano catchment were only available on the administrative level of the Ioba province and consisted of two different datasets from 2001 to 2006 and from 2009 to 2019 with a merging gap between 2007 and 2008. Missing yield values were identified for potato from 2002 to 2003 and sesame from 2011 to 2012. White and red sorghum exhibited a gap between 2001 and 2002 at the beginning of the time series.

Agricultural statistics for Bolgatanga/ Bongo are provided for the majority of crops between the early 1990s and 2016. Only sweet potato, cowpea and soya bean cover a shorter period from 2003 to 2016. A bigger data gap for maize exists between 2000 and 2004 in Bongo. The districts in southwestern Ghana revealed a similar time series collection from 1991 to 2016 with an exception for yam. Yield data of Nzema East and Ellembelle involve a missing value for plantain in 2009.

Relevant consumption patterns were extracted from national reports as shown in Table 2. Most prominent food crops of the Sudano-Guinea savannah are cereals. The prevalent type of food in southwest Ghana was determined to be tubers such as cassava, yam and cocoyam.

Table 2. Per capita food consumption and time series data (southwestern Ghana [44]; Bolgatanga/ Bongo [45]; Ioba province [46]).

<table>
<tr><th>Crop</th><th colspan="2">Ioba province
[kg/ a] / time period</th><th colspan="2">Bolgatanga/ Bongo
[kg/ a] / time period</th><th colspan="2">Southwest Ghana
[kg/ a] / time period</th></tr>
<tr><td>Maize</td><td rowspan="5">218</td><td rowspan="3">2001 - 2019</td><td>20</td><td rowspan="3">1991/ 93 - 2016</td><td>45</td><td>1991 - 2016</td></tr>
<tr><td>Rice (milled)</td><td>30</td><td>32</td><td></td></tr>
<tr><td>Millet</td><td>54</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>White Sorghum</td><td rowspan="2">2003 - 2019</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Red Sorghum</td></tr>
<tr><td>Guinea Corn</td><td colspan="2" rowspan="3"></td><td>30</td><td>1991/ 93 - 2016</td></tr>
<tr><td>Cassava</td><td colspan="2"></td><td>152.9</td><td>1991 - 2016</td></tr>
<tr><td>Sweet Potato</td><td>10</td><td>2003 - 2016</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Potato</td><td rowspan="2">10</td><td rowspan="2">2001 - 2019</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Yam</td><td>125</td><td>1998/ 99 - 2016</td></tr>
<tr><td>Cocoyam</td><td colspan="2" rowspan="2"></td><td>40</td><td rowspan="2">1991 - 2016</td></tr>
<tr><td>Plantain</td><td>84.8</td></tr>
<tr><td>Groundnut (seed)</td><td rowspan="4">19</td><td rowspan="4">2001 - 2019</td><td rowspan="3">15</td><td>1991/ 93 - 2016</td><td colspan="2" rowspan="6"></td></tr>
<tr><td>Cowpea</td><td rowspan="2">2003 - 2016</td></tr>
<tr><td>Soya Bean</td></tr>
<tr><td>Bambara Bean</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Cotton</td><td></td><td>2001 - 2019</td></tr>
<tr><td>Sesame</td><td>16</td><td>2001 - 2019</td></tr>
</table>

2.2.3. Estimating population change rates

Population data were obtained from household census reports provided by the Ghana Statistical Service and the Ministère de l'Economie, des Finances et du Développement of Burkina Faso (Table 3). To be consistent with the agricultural statistics for the Dano catchment, we focused on the total population of the Ioba province where the population rate changed around 2.5% per year between both time steps [35,47]. Both administrative units namely UER and Western Region in Ghana estimated an annual population growth rate of 2% between 2010 and 2021 [36]. From 1960 to 2010, the UER recorded the lowest number of inhabitants due to outmigration activities [48]. Nowadays, dwellers of the UER are primarily living in rural or scattered settlements. Conversely, the majority of citizens, around 52%, in the Western Region dwell in urban areas. A comparison of the District Analytical Reports 2010 and the Population Housing Census 2021 revealed for Bolgatanga a yearly population change of 3% while the number of residents in Bongo increased with an annual rate of around 3.3% [36,49,50]. In 2018, the eastern part of the Bolgatanga municipality unit was split off to establish the Bolgatanga East district. To keep the consistency, we retained census information from both parts as one administrative unit. The yearly population growth over the three districts in the Western Region ranges from 4.2% (Nzema East) to -1.6% (Jomoro) [36,51–53].

We projected the population rate at each time step by using a growth model:

$$P(year) = P_{(0)} * (1 + p/ 100)^n \,, \qquad (1)$$

where P(year) is the estimation of population in year x, P(0) represents the population size as the base, p is the growth rate and n reflects the number of years [54] (Gleisberg-Gerber, 2012).

Table 3. Census data.

	Start year	Census [no. of residents]	End year	Census [no. of residents]
Ioba province	2006	192,321	2019	265,876
Bolgatanga	2010	131,550	2021	178,688
Bongo		84,545		120,254
Nzema East		60,828		94,621
Ellembelle		87,501		120,893
Jomoro		150,107		126,576

3. Results

The analysis of climate and crop yield dynamics focused on the rainy season to determine positive or negative changes on the supply side. Visualizing statistics as boxplots allows characterization of the quality of time series including outlier or skew detection. There are three cases to define whether a dataset is skewed either left or right related to the median and length of the whiskers. Firstly, the median position is close to the bottom or top of the interquartile box and the whiskers are equal. Secondly, the median is placed at the center while one whisker is longer than the other one. However, the majority shows a combination of both cases. The median position within the IQR box is located where the lower quartile range (25th), represented by one color and the upper quartile range (75th) represented by another color, meet. Subsequently, the Mann-Kendall test extends the boxplot analysis by investigating a two-sided trend at a confidence interval of three levels. Building on the agricultural yield data and population growth, we are able to figure out food balance sheets.

3.1. Climate

The R^2 score, as a goodness-of-fit approach, was used to select the most useful dataset for reconstructing missing climate information. The correlation among the rainfall time series ranged from 33% to 96% in Dano and Bolgatanga/ Bongo, respectively. Conversely, the rainfall data in southwestern Ghana are correlated less than 7%. Higher R2 coefficients were computed for the

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temperature values among all study sites. The (adjusted) datasets were resampled to a seasonal basis where the time series of Dano represented six discrete time steps, Bolgatanga/ Bongo encompassed four discrete time steps and the study site in the Western Region of Ghana contained forty-five samples.

The boxplots of the Dano catchment show a high rainfall variability, ranging from 670.4 mm to 1082.6 mm across the stations, with one negative outlier in 2017 (Figure 3a). The boxplot of Bankandi reveals a compact rainfall distribution, while both climate stations Foundation and Yabogane show greater oscillating rainfall rates. All temperature datasets of the Dano watershed encompassed a common gap for 01/ 2016 that was fixed by applying a forecast (linear regression) function implemented in Microsoft Excel. To ensure a similar temporal resolution over all data series, Tmin and Tmax of the Bankandi time series were extended from 09/ 2018 to 12/ 2018 using the same regression approach. As shown in Figure 3a, the temperature fluctuates between a minimum of 22.2 °C and a maximum of 35.2 °C. Both stations Bankandi and Foundation included one positive outlier for Tmax in 2015. The majority of time series illustrated right-skewed distributions with median positions close to the bottom of the IQR box. This indicates either few heavy rainfall or few hot temperature events.

Bolgatanga/ Bongo comprised two stations Aniabisi and Manyoro with one outlier below the whiskers for the years 2016 and 2017 (Figure 3b). The rainfall distribution with a mean value of 780.21 mm is mainly skewed left because of a large proportion of light rain events. Mean temperature boxplots demonstrate a high variability of all datasets ranging from 25.9 °C to 30.1 °C. Values of Aniabisi indicate a symmetric distribution, while both remaining datasets reveal a light-tailed skewness.

Both time series of southwestern Ghana were divided into two wet seasons with a dryer August (Figure 3c). Similar to Dano, we applied the forecast function of Microsoft Excel to project Tmin and Tmax for 06/ 2013 due to a common data gap. The mean rainfall rate of the major wet season ranges from 554.6 mm to 1509.5 mm, while the minor rainy period oscillates between 175.3 mm and 723.4 mm. The period in August and the minor rainy season comprised the bulk of outliers from the mid-1970s to early 2000s. Over the entire rainy period, Tmin and Tmax vary from 22.6 °C to 32.3 °C during the main season with a value span in August from 21.6 °C to 29.5 °C and during the minor season with a range of 22.4 °C to 31.2 °C. Few outlying scores of Tmin and Tmax were detected for the same period. Distributions of nearly all climate variables show a right skewness with a tendency of the median location towards the bottom of the interquartile box.

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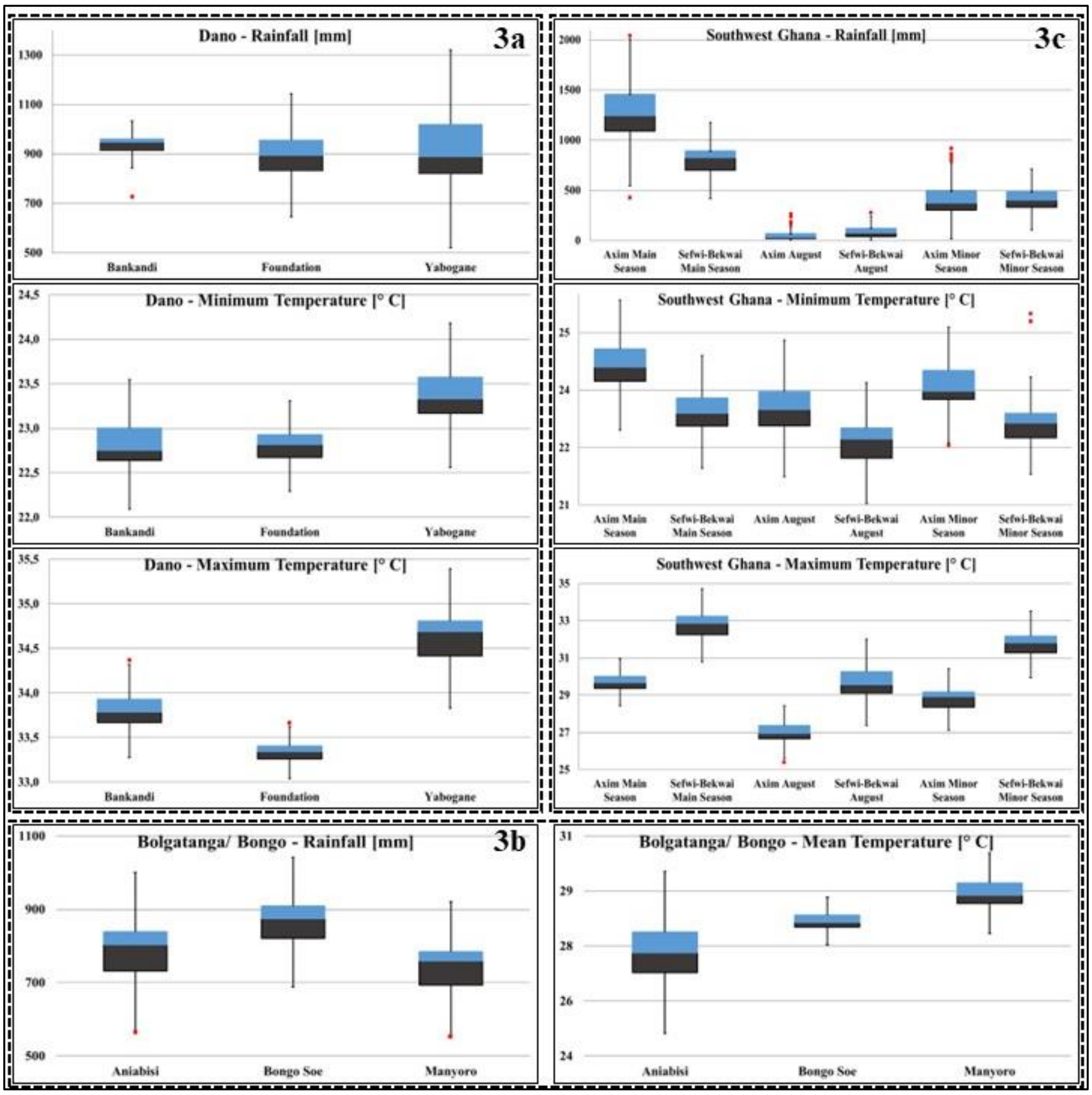

Figure 3. Boxplots of the seasonal climate analysis including outliers.

Table 4 presents an overview of climatic trends using the Mann-Kendall test. Rainfall statistics of Dano depict an insignificant and mostly downward directed tendency. Both stations Bankandi and Yabogane reveal a rising trend of Tmin, while the time series of Foundation does not include any direction because of independent and identically distributed values. The Tmax trend indicated either a growing or falling tendency.

Almost all climate trends in Bolgatanga/ Bongo are insignificant over time. An increasing rainfall trend exists for both datasets of Aniabisi and Manyoro with an exception for Bongo Soe. The mean temperature declined at all stations, while only the data series of Bongo Soe exhibits a decreasing trend at a confidence level of 10%. The rainfall regime in southwestern Ghana oscillates between insignificant upward or downward trends. Both Tmin and Tmax strongly increased at a confidence level of 1% over the entire wet season.

Table 4. Climate trend (z-statistic with confidence levels: -; 0.10: +; 0.05: ++; 0.01: +++).

Station name	Rainfall	Min. temperature	Max. temperature
		Mean temperature	
Bankandi	Decreasing/	Increasing/	Decreasing/

	-0.14 I -	0.07 I -	-0.14 I -
Foundation	Increasing/ 0.28 I -	No Trend	Decreasing/ -0.21 I -
Yabogane	Decreasing -0.07 I -	Increasing/ 0.21 I -	Increasing/ 0.28 I -
Aniabisi	Increasing/ 0.34 I -	Decreasing/ -1.02 I -	
Bongo Soe	No Trend	Decreasing/ -1.70 I +	
Manyoro	Increasing/ 0.34 I -	Decreasing/ -1.02 I -	
Axim (main season)	Decreasing/ -0.52 I -	Increasing/ 5.06 I +++	Increasing/ 4.53 I +++
Axim (August)	Decreasing/ -0.53 I -	Increasing/ 3.20 I +++	Increasing/ 2.40 I +++
Axim (minor season)	Increasing/ 1.58 I -	Increasing/ 5.23 I +++	Increasing/ 4.02 I +++
Sefwi-Bekwai (main season)	Increasing/ 0.03 I -	Increasing/ 4.12 I +++	Increasing/ 5.23 I +++
Sefwi-Bekwai (August)	Decreasing/ -0.71 I -	Increasing/ 2.94 I +++	Increasing/ 2.87 I +++
Sefwi-Bekwai (minor season)	Increasing/ 0.17 I -	Increasing/ 4.00 I +++	Increasing/ 6.02 I +++

3.2. Crop yield

Yield, production and area statistics presented a diverse agricultural pattern with much irregular data information. Biased production or area values do not often correspond to yield scores and vice versa. In addition to Tukey's boxplot rule, we focused on unreasonable production and area changes over time to pinpoint possible yield outliers. These yield values were masked as missing data and are represented as red dots in Figure 4. The remaining black dots were detected by using Tukey's outlier method. To avoid any distortion from outlier correction, we kept these suspicious values within the yield analysis.

The Ioba province indicated yield statistics for cereals, legumes, cotton and sesame between 0.08 ton/ ha and 3.62 ton/ ha, excluding extreme values (Figure 4a). The majority of biased information was identified from 2005 to 2006 and in 2019. With regard to cereal data, maize and rice have the highest average yield, ranging from 1.24 ton/ ha to 1.32 ton/ ha. The mean yield of legumes oscillates between 0.66 ton/ ha and around 0.76 ton/ ha, where cowpea reveals the greatest value span. The root crops demonstrate a large yield dispersion with average values of 6.40 ton/ ha for yam and 4.09 ton/ ha for potato. Cotton yield lies between 0.66 ton/ ha and 1.47 ton/ ha, while sesame performs from 0.08 ton/ ha to 0.79 ton/ ha. A right-skewed distribution is shown for the bulk of crops that indicates a growing yield over time. Yam and maize exhibit a fluctuating production with a median position close to the top of the interquartile box.

Similar rain-fed farming actions were characterized in Bolgatanga/ Bongo. Cereal time series illustrated for both administrative regions a high yield variation, where rice and maize range from 0.34 ton/ ha to 4 ton/ ha. The drought-resistant crops reveal mean yield scores for millet of 0.94 ton/ ha and 1.07 ton/ ha for guinea corn in Bolgatanga. Conversely, the average yields are slightly less with 0.81 ton/ ha for millet and 0.9 ton/ ha for guinea corn in Bongo. Tukey's extreme value analysis determined unreliable information for rice, millet and guinea corn. Both research sites pointing out analogical yield statistics for legumes, ranging from 0.47 ton/ ha to 1.43 ton/ ha for groundnuts, from 0.2 ton/ ha to 1.2 ton/ ha for cowpea and from 0.3 ton/ ha to 1.3 ton/ ha for soya bean. The time series of soya bean includes irregular production and area statistics that did not match the observed yield data. Sweet potato, as an important root crop in the UER, showed lower yields in Bolgatanga compared to Bongo. Dubious production and area data were uncovered for Bolgatanga in 2007 and 2008. An asymmetric distribution is given for almost all crops that signal a tendency of a right skewness. The equal length of the boxplot whiskers with a median position close to the first percentile underpins the findings for rice, millet, groundnut and sweet potato. The sharp right skewed distribution with long tails for cowpea and soya bean indicates a rapid yield growth over a short-term period (Figure 4b).

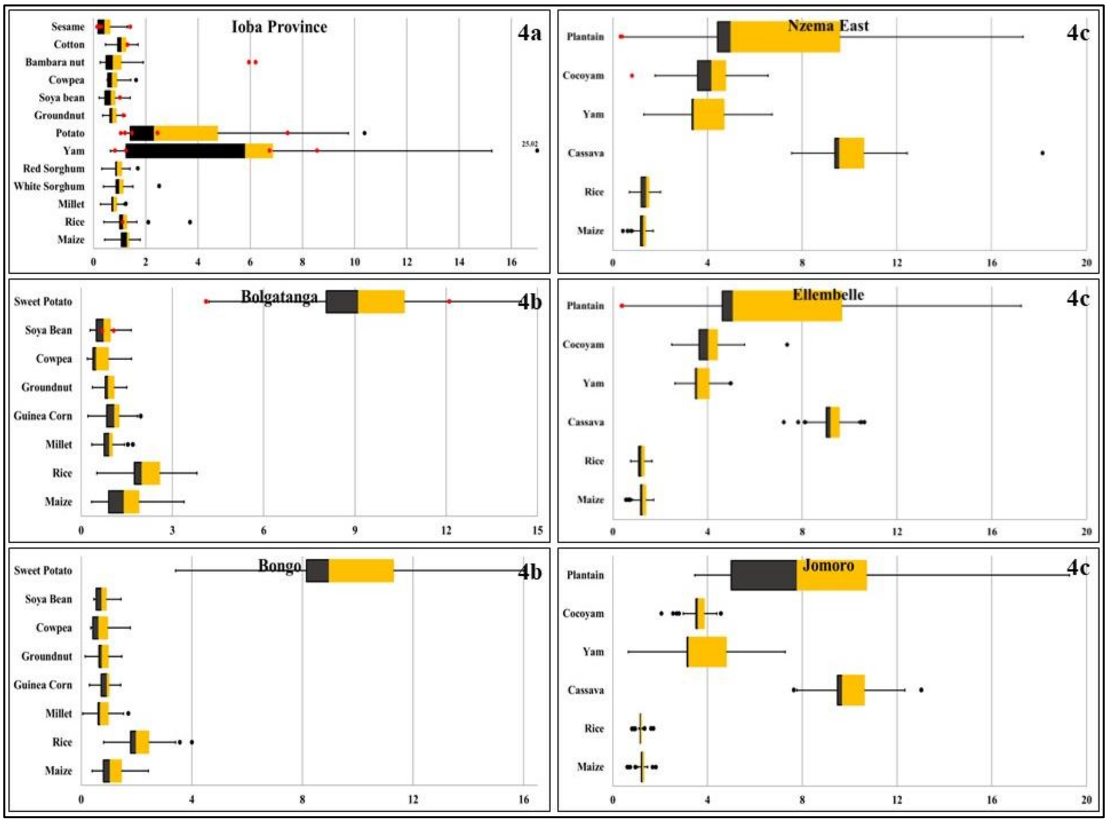

Figure 4. Crop yield boxplots (red dots: excluded from the analysis; black dots: suspicious outliers detected by Tukey's boxplot approach).

The agricultural pattern in Nzema East, Ellembelle or Jomoro is mainly characterized by cereals, tubers and plantain. Mean maize yield values vary over all three districts from 1.23 ton/ ha to 1.25 ton/ ha, while rice yield fluctuates between 1.19 ton/ ha and 1.35 ton/ ha. Tukey's boxplot method detected common outliers for maize from 1991 to 1993 for the selected datasets. Cassava, as the main root crop, illustrates a close yield range from 9.28 ton/ ha to 10.06 ton/ ha within the administrative regions. The remaining tubers, yam and cocoyam, depict a similar oscillating yield between 3.79 ton/ ha and 4.31 ton/ ha in Nzema East as well as Ellembelle. A lower production with a mean yield for yam of 3.75 ton/ ha and for cocoyam of 3.57 ton/ ha is shown in Jomoro. This cocoyam time series demonstrated unreliable data between 2002 and 2004. The same district had the highest mean plantain yield of 7.85 ton/ ha compared to Nzema East with a value of 7.57 ton/ ha or Ellembelle with a less yield of 6.83 ton/ ha. All three datasets of plantain showed an analogical characteristic where the first period between 1991 and 2003 signaled lower yields between 3.21 ton/ ha to 5.25 ton/ ha followed by a sharp increase ranging from 4.71 ton/ ha to 13.43 ton/ ha. Nzema East and Ellembelle encompassed suspicious production data that affected plantain yield observations in 2002 or 2003. The cereal boxplots across all districts represents a similar yield tendency based on the median location close to the middle of the IQR box with equal tails. An exception is given for rice time series in Jomoro where the median is directed towards the IQR bottom, while the majority of values are located in the third percentile. All datasets of cassava and yam are mainly right-skewed with equal whiskers and a median break at the IQR bottom. While Nzema East and Jomoro pose widely distributed values within the time series, Ellembelle presents a dense IQR box (Figure 4c). Plantain exhibits for both datasets of Nzema East and Ellembelle a right-skewed distribution that confirms the rising yield over time. The time series of Jomoro indicates a similar result. Yet, the median is located close to middle of the IQR box with a longer right tail.

Most crops in the Ioba province illustrate an increasing yield at varying confidence intervals (Table 5). Few yield time series grown at a significant level such as red sorghum at the 1% level, cotton and maize at the 10% level while yam decreased significantly at a 5% level. Bolgatanga/ Bongo experienced a high crop yield in both regions for maize at the 1% level, closely followed by rice and guinea corn. Bolgatanga exhibits a slightly, non-significant, grown yield trend for millet and groundnut. Yield of the remaining crop types decreased, whereas sweet potato shows a yield loss trend at the 1% level. A significant upward trend is given for cowpea and soya bean at a level of 1% with a stagnation pattern for all other crops in Bongo. The districts located in southwestern Ghana indicate an increasing yield trend for almost all crops with a declining exception of rice in Jomoro. Cassava and plantain show a significant upward trend at a 1% confidence level in contrast to an insignificant trend for rice or yam in Nzema East and Ellembelle.

Table 5. Crop trends (z-statistic with confidence levels: 0.10: +; 0.05: ++; 0.01: +++).

<table>
<tr><th>Crop</th><th>Nzema East</th><th>Ellembelle</th><th>Jomoro</th><th>Bolgatanga</th><th>Bongo</th><th>Dano</th></tr>
<tr><td>Maize</td><td>Increasing 2.09 | ++</td><td>Increasing 1.56 | -</td><td>Increasing 1.83 | +</td><td>Increasing 2.98 | +++</td><td>Increasing 2.94 | +++</td><td>Increasing 1.77 | +</td></tr>
<tr><td>Rice</td><td>Increasing 0.04 | -</td><td>Increasing 0.31 | -</td><td>Decreasing -0.48 | -</td><td>Increasing 1.37 | -</td><td>Increasing 1.93 | +</td><td>Increasing 1.22 | -</td></tr>
<tr><td>Millet</td><td></td><td></td><td></td><td>Increasing 0.35 | -</td><td>Decreasing -1.07 | -</td><td>Increasing 1.15 | -</td></tr>
<tr><td>White Sorghum</td><td></td><td></td><td></td><td></td><td></td><td>Increasing 0.89 | -</td></tr>
<tr><td>Red Sorghum</td><td></td><td></td><td></td><td></td><td></td><td>Increasing 2.47 | +++</td></tr>
<tr><td>Guinea Corn</td><td></td><td></td><td></td><td>Increasing 1.70 | +</td><td>Increasing 0.99 | -</td><td></td></tr>
<tr><td>Cassava</td><td>Increasing 3.73 | +++</td><td>Increasing 3.20 | +++</td><td>Increasing 3.59 | +++</td><td></td><td></td><td></td></tr>
<tr><td>Sweet Potato</td><td></td><td></td><td></td><td>Decreasing -1.70 | +</td><td>Decreasing -1.19 | -</td><td></td></tr>
<tr><td>Potato</td><td></td><td></td><td></td><td></td><td></td><td>Increasing 1.15 | -</td></tr>
<tr><td>Yam</td><td>Increasing 1.61 | -</td><td>Increasing 0.49 | -</td><td>Increasing 2.50 | +++</td><td></td><td></td><td>Decreasing -2.26 | ++</td></tr>
<tr><td>Cocoyam</td><td>Increasing</td><td>Increasing</td><td>Increasing</td><td></td><td></td><td></td></tr>
</table>

	4.65 | +++	3.44 | +++	0.93 | -			
Plantain	Increasing 3.86 | +++	Increasing 2.69 | +++	Increasing 4.19 | +++			
Groundnut				Increasing 0.11 | -	Decreasing -0.67 | -	Increasing 0.50 | -
Cowpea				Decreasing -0.76 | -	Increasing 3.25 | +++	Increasing 1.52 | -
Soya Bean				Decreasing -0.67 | -	Increasing 2.18 | ++	Increasing 1.17 | -
Cotton						Increasing 1.67 | +
Sesame						Increasing 1.07 | -
Bambara Bean						Increasing 1.34 | -

3.3. Food balance sheets

The analysis of food balance sheets based on a comparison of agricultural production to census data. An unpublished report by [45] recommended to take into account a post-harvest loss of 20% for rice and 30% for all remaining crops. Thus, we decreased the yield statistics according to the supposed post-harvest loss values to quantify the net production. For example, indigenous storage facilities such as mud silos, barns or drums are often used for storing grain or fodder. However, such storages are inefficient to protect crop products from biological, physical or environmental hazards [55]. Subsequently, the yearly projected population growth was multiplied by the per capita consumption to project the demand. The mean values of both net production and estimated consumption were compared to identify a food surplus or deficit (Table 6). Cash crops such as cotton or sesame were excluded from the food balance analysis.

Cereals, especially rice and maize, are the main consumed staples. The aggregated food balance sheet of the Ioba province displays a surplus of 4,113.3 Mt. Both cereals and legumes indicate for almost all years a surplus with an exception in 2018. Tubers reveal permanently negative values over the whole period. The overall food balance sheet of Bolgatanga demonstrates a surplus of 221.2 Mt. While cereals and legumes indicate a strong deficit for the period between 2014 and 2017, there was a high surplus of sweet potato for all these years. Maize, millet and guinea corn represent for the majority of crop years a massive food shortage. On the other hand, almost all crop years exhibit positive rice values. Cowpea and soya bean reported a consumption deficit compared to a huge groundnut surplus. A similar diet pattern is given for Bongo with an overproduction of 4,846.77 Mt due to a giant surplus of sweet potato. The deficit in available cereals and legumes for consumption is less than that of Bolgatanga. A food gap exists for maize or millet for the whole period and guinea corn exhibits a deficit from 2015 to 2017. Conversely, a surplus of rice subsists for all years. Food consumption compared to crop yield is mainly negative for cowpea and soya bean, whereas groundnut indicates a vast surplus.

All administrative areas in the Western Region of Ghana exhibit food insecurity with a common diet pattern over time. The grouped deficit of Nzema East amounts to -193.33 Mt which represents the lowest value. Both neighboring districts demonstrate a deficit of -13,617.47 Mt in Ellembelle and -16,188.82 Mt in Jomoro. Maize, rice and plantain depict a lack of consistent access to enough food from 2011 to 2017 at all sites. With respect to tubers, the results indicate inconsistent food balance sheets across the regions. Root crops of Nzema East illustrate a positive relationship between consumption and agricultural yield with a shortage in 2012. Conversely, the adjacent districts Ellembelle and Jomoro present a deficit. Only cassava indicates an excellent agri-food situation over the analyzed period for all areas. Yam and cocoyam represent an imbalance between demand and food production.

Table 6. Food balance sheets of rain-fed crops [in Mt; per capita consumption in kg].

Crops	Total production	Net production	Per capita consumption	Estimated consumption	Surplus/ deficit
Ioba province [2009 – 2020] I ∑ 4,113.3 Mt					
Cereals	19576.8	13703.76	218	10704.64	2999.12
Legumes	5619.41	3933.59	19	1228.79	2704.80
Tubers	95.19	66.63	10	1657.25	-1590.62
Bolgatanga [2011 – 2017] I ∑ 221.2 Mt					
Cereals	5321.25	3937.79	134	4968.70	-1030.91
Legumes	2637.14	1846	45	2224.79	-378.79
Sweet Potato	4448.71	3114.10	10	1483.20	1630.90
Bongo [2011 - 2017] I ∑ 4,846.77 Mt					
Cereals	3966.16	2961.56	134	3231.84	-270.28
Legumes	2015.67	1410.97	45	1447.09	-36.12
Sweet Potato	8739.86	6117.90	10	964.73	5153.17
Nzema East [2011 - 2017] I ∑ -193.33 Mt					
Cereals	1086.44	779.42	77	2770.16	-1990.73
Tubers	19610.77	13727.54	317.90	7878.99	5848.55
Plantain	2929.12	2050.39	84.80	6101.54	-4051.15
Ellembelle [2011 - 2017] I ∑ -13,617.47 Mt					
Cereals	839.58	630.39	77	3798.23	-3167.84
Tubers	10209.12	7146.38	317.90	10454.18	-3307.79
Plantain	1748.76	1224.13	84.80	8365.97	-7141.84
Jomoro [2011 - 2017] I ∑ -16,188.82 Mt					
Cereals	1224.57	924.69	77	5420.86	-4496.17
Tubers	18171.64	12720.15	317.90	14920.27	-2200.12
Plantain	3496.34	2447.44	84.80	11939.97	-9492.53

4. Discussion

This section presents a discussion on the magnitude and consequences of climate variation as well as socio-economic challenges on agriculture. Evidence suggests that analyzed rainfall and temperature changes of recent years are affecting food supply. We will focus on crops with significant trends to understand temporal yield changes. To take this further, fluctuations in crop production will be related to agricultural policies or subsidy programs and how this will support a positive food balance.

4.1. Climate variability

Climate results of the Sudano-Guinean savannah revealed a growing variability over the rainy periods. Rainfall time series demonstrated almost insignificant upward or downward trends. The rainfall rate of the Dano catchment agrees with the findings by [56], while [57] identified a slight increase during the recent years. The latter study characterized three rainfall clusters in Burkina Faso starting with the first cycle in 1970 to 1990. This period is marked by various years of droughts in 1982, 1983 and 1987. The following phase is classified as an intermediate circle ranging from dry conditions to wet years until 2008. The third trend from 2008 to 2013 is determined by a return to more positive rainfall patterns. However, begin and end of the rainy season is impacted by the movement of the Inter-Tropical Front that results in a shift of the wet period towards north [58]. In this regard, [59] reported that annual temperatures of coolest and hottest days rose in Burkina Faso from 1950 to 2013. Mean values of Tmin with 22.9 °C and Tmax with 33.96 °C exhibited a non-significant and contrary tendency in Dano. The majority of values of the Tmin time series increased, while the Tmax datasets showed a declining trend.

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With a focus on Bolgatanga/ Bongo, the rainfall rate is lower than the findings by [60], who reported a yearly precipitation of 901.9 mm with similar trend results. In addition, the warming of the North Atlantic Ocean has causes a rising oscillation in the amount of rainfall over recent years [61]. The mean temperature of Bolgatanga/ Bongo decreased at all stations and only the Bongo Soe time series exhibited a significant downtrend at a confidence level of 10%. This result is in line with the outcomes by [60], who identified for the neighboring Bawku municipality a slightly decreasing trend. Zooming out to the regional climate system leads to a diverse view where natural processes such as solar variability, waterbodies, vegetation and fast-moving squall lines with larger convective complexes determine the local temperature of Dano as well as Bolgatanga/ Bongo [62].

The climate regime in southwest Ghana indicated a fluctuating and insignificant rainfall trend. Results on rainfall mean values of the major wet season of 1028.64 mm and the minor rainy period of 413.44 mm are inconsistent with the outcomes by [63]. Findings of their study detected a precipitation range from 2074.5 mm to 2863.8 mm during the main spell, while observations of the minor season ranged between 650.5 mm and 1446.8 mm. Reasons can be linked to non-linear interactions with factors such as urban sprawl, distance to ocean or atmospheric drivers. According to [64], the variability of the major season is strongly affected by atmospheric moisture that may result in upward humidity trends over the minor period. A recent study by [65] determined a growing rainfall tendency during the minor cycle that agrees with the Mann-Kendall trend results. Also, the greening of the rain forest causes higher surface moisture which is most likely enhancing the amount of precipitation. This temperature analysis has implied a strong rising mean Tmin of 23.05 °C and Tmax of 29.92 °C throughout the inter-seasonal periods at a confidence level of 1%. The results are in line with the statistical findings by [63] who detected a yearly temperature range from 26.9 °C to 27.9 °C.

4.2. Effects on agricultural yield

The investigation of rain-fed agriculture indicated a clear dominance of maize and rice across all study sites. Both crops have been extended from southern regions in West Africa to the Sudanian zone because of breeding efforts that meet yield responses to the low availability of fertilizer [66,67]. Despite similar farming patterns in the Sudano-Guinean savannah, yield trends vary greatly between the countries. Studies by [68,69] highlighted that climate variabilities associated with low soil fertility, floods and management practices have serious impacts on agricultural production. These driving forces can be connected to significant growing yields of red sorghum, maize and cotton, while only yam declined at a confidence level of 5% in the Ioba province. According to [70], yam requires precipitation greater than 800 mm and high soil fertility to maintain productivity. The calculated mean yield of 6.4 ton/ ha for yam was not consistent with a recent study by [71] who identified a range from 6.75 ton/ ha to 26.8 ton/ ha for northwestern Burkina Faso. Thus, red sorghum and/ or maize represent an alternative to nutrient-poor soils or heavy drought events in the Sudano-Guinea area [54]. The priority of farmers to cultivate red sorghum is intended for commercialization that probably accounts for the strong upward yield tendency. In the case of maize, yield trend rose significantly, while intensification practices are mainly limited by the availability of farm inputs or subsidy programs [34]. At the same time, maize farmers who also grow cotton are eligible to receive subsidized fertilizers from their cooperatives. A national fertilizer program was initiated after the crop price shock in 2008 and has led to a great expansion of maize-cotton rotation systems [72]. Cotton, as the main cash crop, increased remarkably at a 10% confidence level that is in conformity with the findings of [73]. The study reported that cotton production increased nearly fourfold from 1995 to 2005 and forms one of the economic backbones in Burkina Faso.

The analyzed maize yields of Bolgatanga/ Bongo are in conformity with the findings of [74], who reported a range from 0.8 ton/ ha (without fertilizer) to 1.8 ton/ ha (with fertilizer). To compensate a low crop yield, [75] suggested that a growing application of nitrogen will boost the maize production up to 3.6 ton/ ha. Both yield trends of guinea corn in Bolgatanga and rice in Bongo rose slightly significantly. [76] found out that many farmers in northern Ghana prefer to cultivate guinea corn due to lower risks of crop failures in case of droughts or insufficient soil fertility. Although rice yield variability is mainly related to climate adverse conditions, harvested areas have been widely

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extended in Bolgatanga/ Bongo. The significant trends of cowpea with an average of 0.71 ton/ ha and soya bean with a mean of 0.78 ton/ ha recorded in Bongo remained low compared to a potential yield over 2 ton/ ha for cowpea [77] or an estimated production of 2.5 ton/ ha for soya bean [78]. Intercropping legumes with guinea corn, millet or maize will raise soil fertility by fixing atmospheric nitrogen that conserves nutrients for higher productivity of cereals [79]. While guinea corn, millet and cowpea are well-known as climate-resilient crops in the Sudano-Sahelian savannah, tubers such as sweet potato attain high prominence in the Guinean zone because of its short-term growth cycle [80]. However, our findings indicated a decreasing yield trend for sweet potato in Bolgatanga. A study by [81] classified various socio-economic impacts, such as a lack of access to markets or a high perishability rate of sweet potato, which limit growers' ability to expand production.

Significant yield trends of maize, cassava, cocoyam and plantain are almost similar across the districts in southwestern Ghana. Farmers in this site enjoy the advantage that rainfed maize can be cultivated twice in a year. The growing periods follow the rainfall pattern with a major planting season from April to August, while the second cultivation phase starts in September and ends in December [82]. Yet, mean maize yield of around 1.25 ton/ ha remains low compared to other African countries such as South Africa with 4.9 ton/ ha or Ethiopia with 4.2 ton/ ha [83]. Results on cassava revealed a strong rising trend at a confidence level of 1% with a ranging yield from 9.28 ton/ ha to 10.06 ton/ ha in this region. This trend is mostly related to a massive expansion of cropland that fits with findings by [84] who identified an extensification of framing practices between 1990 and 2010. Many interventions have been made to improve the productivity by providing extension services to introduce new technologies, offer climate data or other farming related information [85]. The further assessment of cocoyam revealed significant trends with mean yields from 4.21 ton/ ha to 4.31 ton/ ha in Ellembelle and Nzema East. These findings agree with a report by [86] where cocoyam ranges from 4 ton/ ha to 6.5 ton/ ha. However, the productivity per area is much lower compared to high yield potentials up to 120 ton/ ha in small areas in Zimbabwe [87]. In particular, proper water management and affordable farm inputs are key to maximizing crop outcomes. The yield trend of yam showed an analogical strong tendency of 3.75 ton/ ha in Jomoro, while similar environmental and socio-economic impacts are associated with low yields. Moreover, plantain is often cultivated under cocoa farms or in combination with other crops such as cassava, cocoyam or yam [88]. All three districts classified a significant rising yield trend at a level of 1% that is congruent with results of [89], who attributed growing yields to improved research and extension activities.

4.3. Demand and food production

Our findings obtained from the analysis highlighted how climate change and a growing population impact the food balance. Both countries depend primarily on cereals as their primary source of calories. The Ioba province produced a total surplus of 4,113.3 Mt that made it possible to cover the regional demand. The cereal and legume yield statistics indicated sufficient quantities, while tubers revealed a deficit. A report by [90] highlighted rising consumption of maize and rice due to a changing urban diet. However, domestic cultivated rice is often not very competitive because of large household size or low incomes steering consumers to commodities with the lowest price. Thus, rice imports will possibly increase as a growing population outpaces current production. The proportion of rice consumption covered by domestic farming declined from 70% in the mid-1990s to around 30% in the early years of the last decade [91]. It is projected that the population of Burkina Faso will reach 26 million by 2030 and approximately 41 million by 2050 [92]. Against this backdrop, millet and sorghum are known as crops for vulnerable households, while maize is consumed by the majority of people. Yet, the crop results revealed relatively small quantities for millet, white and red sorghum because the three staple crops are traditional subsistence cultivars. Legumes as companion crops with cereals play an essential role in the diets of locals. Cowpea, groundnuts, soya beans and Bambara beans are grown for on-farm consumption, domestic marketing outside households, as well as for export to neighboring countries such as Ghana or Ivory Coast [93]. On the other hand, consumption of tubers has increased even faster than the agricultural production. [94] emphasized the importance of potato as foodstuff, but the cultivar is still acknowledged as a minor crop.

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All districts of both Ghanaian research sites demonstrated low cereal output which fails to respond to local demand. As in Burkina Faso, rice is mainly related to urban diets that account for about 76% of total consumption [95]. In this regard, Ghana depends largely on rice imports with shares remaining above 50% to stabilize domestic markets. To reduce the dependency on imports, the central government initiated campaigns such as the Fertilizer Subsidy Program or Block Farms Program with a key focus on raising farm productivity. These interventions have been rolled into the flagship initiative Planting for Food and Jobs to provide subsidized seeds and fertilizer for prioritized crops [96]. However, the productivity of the agricultural sector does not determine individual food consumption preferences. For example, per capita consumption of maize is highest in northern Ghana, while the same region contributes 20.7% to the national production. By contrast, southern Ghana is not traditionally a maize-growing area, yet its inhabitants claim 32% of demand. In conformity with MOFA-IFPRI Market Brief No. 1 [97], Bolgatanga/ Bongo showed a lower cereal balance deficit compared to southwestern Ghana. The total surplus in Bolgatanga of 221.20 Mt and Bongo of 4,846.77 Mt was decisively achieved through cultivating sweet potato. Despite declining yield trends, the production of sweet potato remained higher than the need. Reasons are related to socio-economic constraints such as lack of awareness, high perishability or inclusion in daily diets [81]. In southwestern Ghana, the majority of tubers indicated negative root crop balances sheets with the exception of Nzema East. The massive surplus in the tuber food balance might result from historical land transitions to agriculture, while Ellembelle and Jomoro are more covered by forest reserves or protected natural areas. Cassava, yam and cocoyam are primarily cultivated for home consumption to improve food security or as cash crops to generate income. The rising local and international demand for cassava allows the enhancement of marketing and export activities which increase the farmer's livelihood [98]. Ranked after cassava and yam, plantain is the third valuable starchy staple with considerable socio-economic significance which creates jobs [97]. Yet, the marketing is often disturbed by a lack of value chains or limited communication between producers and urban consumption centers. Also, plantain is highly perishable and prone to post-harvest losses that affect both quality and quantity [89].

5. Conclusions

This study investigated the food supply and demand as an interplay between climate change impacts, crop production as well as population growth along three study sites from southwestern Burkina Faso to southwestern Ghana. The empirical analysis of rainfall and temperature time series demonstrated a high variability with light to strong tailed skewed data as well as various outliers. These results were backed by a trend test in which both study regions in the Sudano-Guinean savannah mostly revealed an insignificant tendency in all climate variables. Conversely, the research area in southwestern Ghana illustrated erratic downward and upward tendencies in rainfall changes while the temperature increased for all sub-seasons at a confidence level of 1%. The yield statistics of Dano and Bolgatanga/ Bongo are predominated by a huge variety of drought-resistance cereals as well as legumes. Calculated boxplots identified mostly a right-skewed distribution for the majority of crops over time. Significant trend results confirmed the underpinned direction of crop production. Towards southwestern Ghana, a strong yield growth was characterized for almost all tubers. Trends depicted a similar sharp rise in cassava, cocoyam and plantain yield. It was found that the rising agricultural production had not resulted in a balanced surplus supply and demand for all sites. Only the research site in Dano exhibited a positive food balance for the primary cereal and legume crops while the tuber cultivation does not meet the regional demand. On the other hand, both study regions in Ghana represented a consumption pattern for cereals, legumes or tubers that outpace the recent on-farm supply. Bridging the supply and demand gap will remain an ongoing challenge that needs further policies in both countries to focus on a larger array of commodities, imports or marketing of food products.

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