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Effect of Climate Change on Crop Production in Rwanda

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Abstract: For Africa's developing countries the agricultural system is among the most vulnerable due to extensive use of rainfed crop production, presence of droughts and floods that affect crops as well as initial poverty of population that limits the capacity to adapt. In this study were realized the analysis of long-term rainfall data and its impact on main crop products in Rwanda. Some rainfall data was infilled for the period of 1926-2013. It was done using the monitoring data of a neighbor weather station with relatively the same elevation above sea level and with a monitoring record of no less than 40 years. The neighboring station with the best correlation was selected for the infilling. The missing rainfall data was infilled for all the stations with resulting regression coefficients ranging from 0.55 to 0.80. This indicates the acceptability of the performed regression. Also were constructed different-cumulative curves of rainfall and sort out cycles of decline and increment of rainfall. Similar different-cumulative curves were constructed for main crops in Rwanda. Correlation and regression analysis were used to determine the relationship between rainfall, arable land expansion, fertilizer use and crop yield. Particularly for Rwandan conditions, the rainfall variations are determinant for the crop yield increment. The intensification of extreme flood's and, as rule, flooding of agricultural lands in connection with rainfall augmentation was also allocated.

Keywords: Rainfall Data Reconstruction, Different-Cumulative Curves, Rainfall Augmentation, Crop Production

1. Introduction

Agriculture contributes to development as an economic activity, as a livelihood, and as a provider of environmental services, making the sector a unique instrument for growth and poverty reduction. In Rwanda, over 80% of employment is based in rural areas. Agriculture is the main sector making up 32% of GDP. Agriculture in Rwanda faces multiple challenges. Land is scarce and population densities high, which means the median land size is approximately 0.3 ha per household. Smallholder farmers dominate production, with complex extension needs. The country is also landlocked, which creates higher energy and transport costs than regional neighbors. Rwanda's unique topography means that farm activity depends on a diverse range of geographical landscapes and micro-climates [11].

The climate variability of Rwanda is one of the most significant factors influencing year to year crop production. Even in high-technology agricultural areas [21] that factor remains one of the most important. In recent years, more and more attention has been paid to the risks associated with climate change, and the increase uncertainty with respect to food production [21]. In Rwanda water regime of fields and wetlands is closely linked to rainfall. It could be one of the limiting constraints for crop production and food security. The leguminous production sensibly went down in 2004 due to heavy rains registered in high altitude regions, which are generally more productive [3]. In addition, the intensity and frequency of climate hazards and their harmful effects, are emphasized by the topographical structure proper to Rwandan territory, a country particularly characterized by a very accident relief and consequently very sensitive to erosion and landslides. Also other factors which influencing the crop production are discussed. Among them are air temperature, sunlight, CO_2 variations, soil aeration and structure, biotechnology use, fertilizer application, use of machinery, and etc. This study, therefore, examines the rate of climate change in terms of rainfall and its impact on crop production in Rwanda. Additionally the impacts of several factors (climatic or non-climatic) on crop production are allocated.

2. Materials and Methods

2.1. Description of the Study Area

Rwanda is located in the central-eastern part of Africa. It shares boarders with Uganda in the North, Tanzania in the East and South East, Burundi in the South and Democratic Republic of Congo in the West (fig. 1). The territory of Rwanda is 26,338 km^2 with a population of over 9 million people as estimated in 2007. Rwanda receives about 1250 mm average annual rainfall.

2.2. Relief

The Rwandan relief is hilly and mountainous with an altitude varying between 900 m and 4507 m. The components of that relief are:

Congo Nil Ridge overlaying Lake Kivu with an altitude between 2500 m and 3000 m. It is dominated in the NorthWest by the volcanic ranges consisting of five volcanic massifs of which the highest is Karisimbi itch 4507 m.

The central plateau presents a relief of hills with an altitude ranging between 1500 m and 2000 m.

The lowlands of the East are dominated by a depression characterized by hills with a more or less round top and 1000 to 1500 m in altitude.

The lowlands of the South-West in Bugarama plain with an altitude of 900 m are part of the tectonic depression of the African Rift Valley.

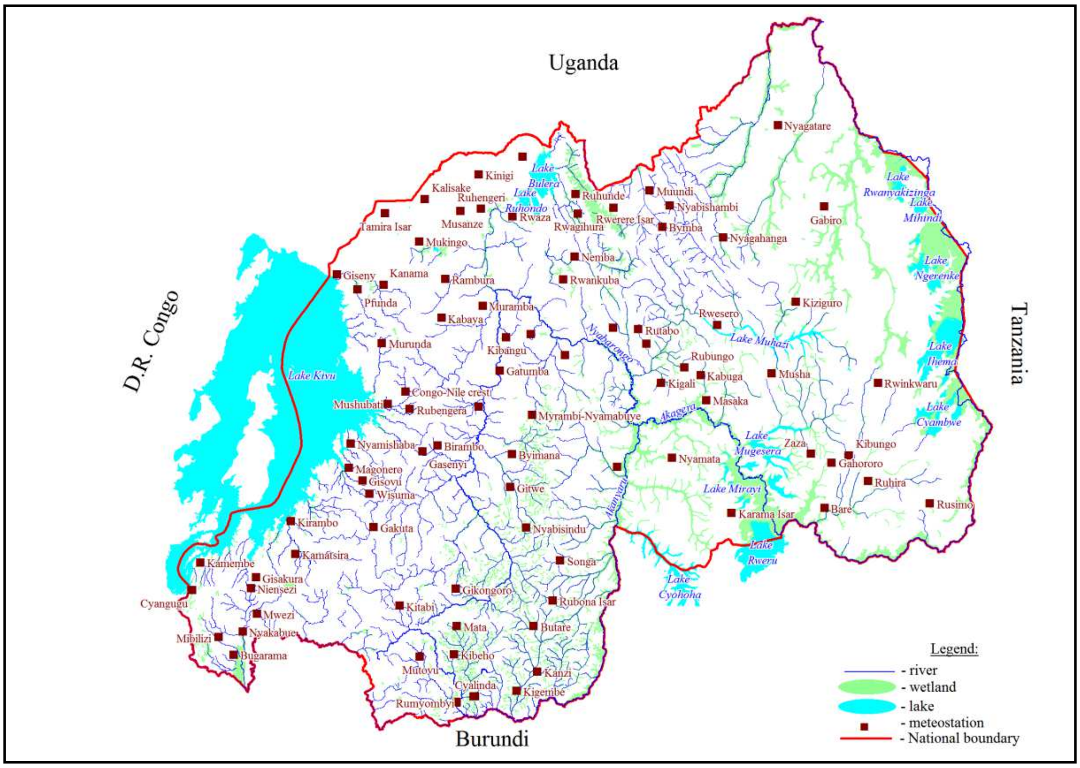


Figure 1. *Distributions of weather stations and water bodies in Rwanda [8].*

2.3. Climate

Rwanda is located in a tropical temperate climate due to its high altitude. The average annual temperature ranges between 16°C and 20°C, without significant variations. Rainfall is abundant although it has some irregularities. Winds are generally around 1-3 m/s. In the high regions of the Congo-Nile ridge, average temperatures ranges between 15°C and 17°C and the rainfall is abundant. The volcanic region has much lower temperatures that can go below 0°C in some places. In areas with intermediary altitude, average temperatures vary between 19°C and 21°C and the average rainfall is around 1000 mm/year. Rainfall is less irregular, and sometimes causes periods of drought. In the lowlands (East and Southeast), temperatures are higher and the extreme can go beyond 30°C in February and July-August. The absolute temperature of 32.8°C was recorded in the Southeast by Karama-Plateau station on September, 1980. Thermal constraints are more considerable there than in the remaining part of the country. Rainfall is also less abundant in that region with around 700-970 mm/year.

The main synoptic features scale system controlling rainfall is the ITCZ. Low pressures, the maximum of humidity and the convergence of winds characterize this one. It crosses Rwanda twice a year and determines two rainy periods: from mid-September to mid-December and from March to May. During the season from mid-September to December, the dominating winds are from the North-East and humidity comes from masses humidified by the Indian Ocean and Lake Victoria. The dry season that follows (mid-December to end February) is characterized by the penetration in East Africa by masses of dry and cold airs from the Arabian Dorsal. However, the moderating effect of Lake Victoria and the diversity of the Rwandans relief maintain some rainfalls in the country.

During the season from March to May, Rwanda is influenced by a front situated between the dry winds from Southeast and from Southwest, which carry the humidity from the South Atlantic passing through the Congolese Basin. Lastly, during the dry season from June to mid-September, the air masses of winds from the South–East which arrive in Rwanda are dried from the continental air crossing of Tanzania and present a divergence in the low layers. These conditions are unfavorable to precipitations [14].

Weather in Rwanda mostly is determined by the rainfall patterns. Thus, the climate of the country is characterized by an alternation of four seasons of which two are wet and the other two are dry. However, one can notice that rainfall is generally well distributed throughout the year, despite some irregularities. Eastern and South-Eastern regions (Umutara, Kibungo, Bugesera, Mayaga) are more affected by prolonged droughts while the northern and western regions (Ruhengeri, Gisenyi, Gikongoro and Byumba) experience abundant rainfall that usually causes erosion, flooding, and landslides.

2.4. Data Sources

Rainfall data, location of weather stations, crop production data and data about disastrous phenomena obtained from the National Meteorological Services, NUR-CGIS, the Ministry of Agriculture & Animal Resources, the World Bank, the Ministry of Lands, Environment, Forestry, Water & Mines, and also from the Ministry of Disaster Management & Refugee Affairs respectively.

Table 1. *Weather stations distributions according to number of years with observations.*

Interval of observations (years)	Number of stations	% of stations
1-20 years	184	100
21-30 years	153	83
31-40 years	115	63
41-50 years	70	38
51-60 years	52	28
61-70 years	42	23
71-80 years	24	13
More than 81 years	9	5

a. Monthly sums of rainfall data were collected for 184 weather stations (tab. 1). The majority of stations had a period less than 40 years (63%). For the analysis of rainfall data weather stations with long period of observations were used. Those weather stations covered the whole area. Research has a base on rainfall data analysis for 80 years and beyond (1926-2013). Detailed analysis of weather stations detected missing data. Statistical techniques were used for the reconstruction of initial data.

b. Total harvest of crops (tone/year) is available for period 2000-2013 (14 years) for following: sorghum, maize, wheat, rice, beans, pea, groundnuts, soya, banana, irish potato, sweet potato, yam &taro, cassava, vegetables and fruits.

c. Fertilizer consumption (kg/ha), agricultural machinery (tractors per 100 km^2 of arable land), arable land (ha) were accessed on World Bank web-site [24] and are available for period 2000-2013 (14 years).

d. Data about disastrous phenomena (floods, droughts) was collected from [13], [14], local publications and present for 1902-2013 years.

3. Results

3.1. Infilling Missing Rainfall Data

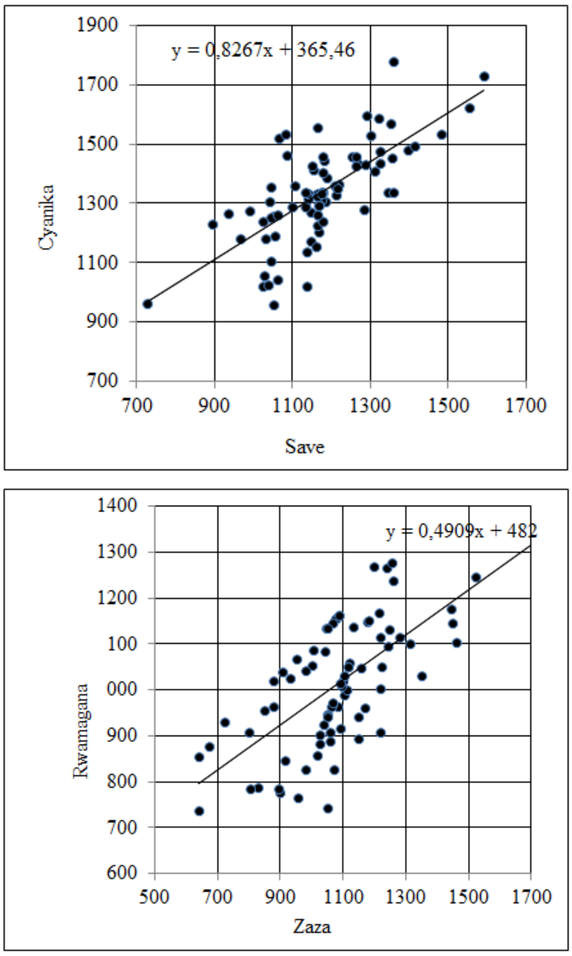


Figure 2. *Relations of the sum annual rainfall on weather stations for the period 1926-2013.*

The missing rainfall data was infilled using statistical linear regression methods. Graphs of the relationship between average monthly rainfall and time were constructed for 22 weather stations from 1926 to 2013. Zaza weather station was used as a foundation station because it has about a 69 year record within 1926 to 2013 with only 19 months of missing data. The neighbouring station with the best correlation was selected for the infilling. The best station is selected among the nearest possible and the two stations are correlated and the regression equation is then generated using Microsoft Excel Software (fig. 2). The obtained regression is then used to infill all the missing data. The acceptability of the regressions was tested using the ratio of standard error to the standard deviation and all the obtained values were within 0.55 to 0.80. This indicates the acceptability of the performed regression [15].

The infilled sums of the annual amount of rainfall for the 21 stations with more long-term records of observation within the territory of Rwanda for the period of 1926 – 2013 were used for this work. The listed weather stations cover the territory of Rwanda and have more long-term records of observations. The standardized Curves of sum of annual rainfall were constructed using the equation (1).

$$\frac{\sum(k-1)}{C_v} \qquad (1)$$

Where $k = \frac{x_i}{\bar{x}}$, x_i и $\bar{x}$ – sum of annual rainfall for a given year and average sum of rainfall for all the observation period, C_v – coefficient of variation.

The analysis of these curves shows the synchronicity in the change in sum of annual rainfall at weather stations of Byumba, Cyangugu, Kansi, Kibungo, Kirinda, Mugonero, Mubuga, Mibirizi, Rubona, Ruhengeri, Rulindo, Save and Zaza as well as for weather stations like Cyanika, Gisenyi, Kibeho, Muramba, Nyakibanda, Nyamiyaga and Rwamagana. From 1926 to 1958 rainfall declined. The rainfall increment began being registered in 1960. On average it was observed until 1988. Since that year rainfall has had no great change in its amount, mainly the intensity of the separate rains has changed.

3.2. Assessment of the Rainfall Dynamic in 20-40 Years

The general tendency of rainfall for 22 weather stations shows increments of precipitations. Some weather stations like Byumba, Kansi, Kibeho, Kibungo, Kirinda, Mubuga, Mugonero, Muramba, Nyakibanda, Rubona, Ruhengeri, Rulindo, Rwaza, and Zaza have a high tendency of rainfall growth (tab. 2). The weather station Cyanika shows the tendency of constant rainfall, and also some weather stations show the tendency of a slight increase of rainfall, these are; Cyangugu, Gisenyi, Mibirizi, Nyamiyaga, Rwamagana, and Save.

The probabilistic forecast of rainfall dynamic in Rwanda was done for the period of 1926-2013. According to table 2, the general average of rainfall increase of the 21 weather stations for the period of 2013-2033 is 4.5% and for the period of 2033-2053 is 6% meaning that rainfall from 2033 to 2053 will grow by 1.5%.

Table 2. *Probabilistic forecast of rainfall dynamic in Rwanda for 2033 and 2053 years.*

Weather station	a	X_{aver}	2033			2053		
			X_1, mm	Δx_1, mm	Δx_1, %	X_2, mm	Δx_2, mm	Δx_2, %
Byumba	+0.89*	1293	1350	57	4	1368	75	6
Cyangugu	+0,65*	1378	1419	41	3	1432	54	4
Cyanika	+0,003	1329	1329	0	0	1329	0	0
Gisenyi	+0,53*	1139	1173	34	3	1183	44	4
Kansi	+1,11*	1156	1226	70	6	1249	93	8
Kibeho	+1,68*	1339	1446	107	8	1480	141	10
Kibungo	+1,12*	999	1070	71	7	1093	94	9
Kirinda	+1,77*	1310	1422	112	9	1457	147	11
Mibirizi	+0,23	1502	1517	15	1	1522	20	1
Mubuga	+0,71*	1366	1411	45	3	1425	59	4
Mugonero	+1,32*	1352	1436	84	6	1462	110	8
Muramba	+1,47*	1294	1387	93	7	1416	122	9
Nyakibanda	+0,76*	1231	1279	48	4	1294	63	5
Nyamiyaga	+0,31	1129	1149	20	2	1155	26	2
Rubona	+1,16*	1172	1246	74	6	1269	97	8
Ruhengeri	+1,89*	1330	1450	120	9	1487	157	12
Rulindo	+0,84*	1240	1293	53	4	1310	70	6
Rwamagana	+0,52*	1007	1040	33	3	1051	44	4
Rwaza	+1,19*	1318	1394	76	6	1418	100	8
Save	+0,23	1164	1179	15	1	1184	20	2
Zaza	+1,79*	1093	1207	114	10	1242	149	14
Average		1249	1306	56	4,5	1323	74	5,9

Where a – parameter of tendency estimation; X_{aver} – average precipitations for period 1926-2013; X_1, X_2 – probabilistic forecast for 2033 and 2053; Δx_1, Δx_2 – forecast dynamic for 2033 and 2053 in millimeters (mm) and percentage (%); * – significant trend.

Some weather stations like Zaza, Rwaza, Rulindo, Ruhengeri, Rubona, Nyakibanda, Muramba, Mugonero, Mubuga, Kirinda, Kibungo, Kibeho, Kansi, Byumba, Rwamagana and Cyangugu have a significant trend of rainfall grow for the 2013 to 2053. Ruhengeri weather station has had a higher significant increase (12%) in 40 years coming. Also some weather stations like Cyanika and Mibirizi have a low increase of rainfall (less than 1%) for the period of 2013-2053. For the Cyanika, Mibirizi, Nyamiyaga, and Save weather stations show no significant increase of rainfall.

3.3. Impact of Climate Change on Environment

Climate change can intensify different disastrous phenomena such as floods and droughts. Analysis of present data shows that in Rwanda since 1991-1997 the periods between disastrous events of the one order was receded in two times (table 3).

Table 3. *Drought's and flood's events in Rwanda.*

Years	Period*, years	Years	Period*, years
Droughts		Floods	
1902/03		1974	
1916/1918	14	1988	14
1924/25	8	1997/98	9
1943/44	19	2001	4
1963	20	2002	1
1982/83	19	2006	4
1991/92	9	2007	1
1999/2000	8	2008	1
2005/2006	6	2011	3
2008	3	2012	1
2009	1		

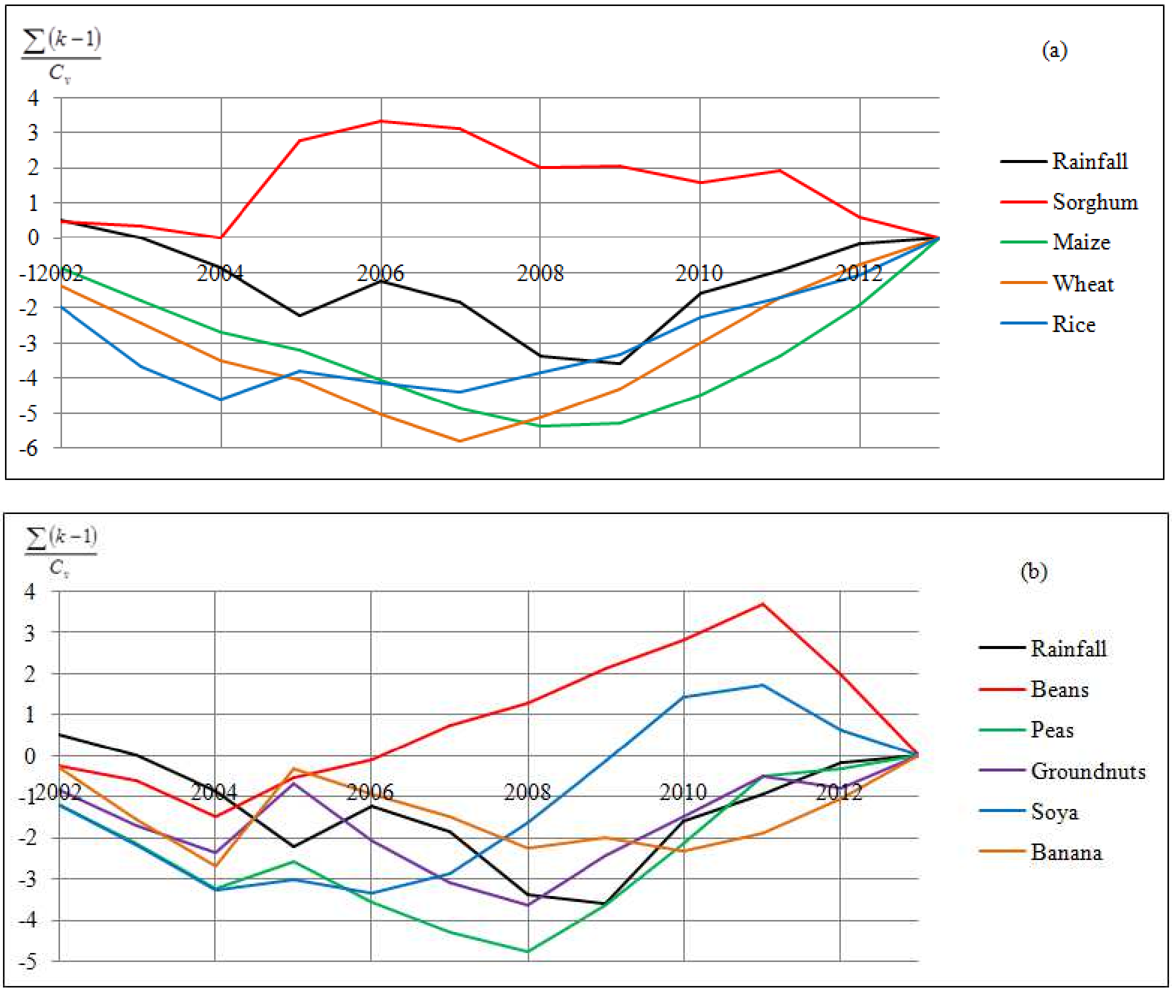
* Period is a difference between current event and previous one.

Since 2007-2008 these events have been registered every 1-3 years. One of the latest floods in 2012 was especially destructive. It affected Musanze (Northern Province), and Nyabihu and Rubavu districts (Western Province). About 2,200 households or 11,000 people were affected by the floods. Almost 1,000 hectares of potatoes, maize, bananas, tea and sugar, were inundated, 348 houses were destroyed and 446 were partially damaged.

3.4. Impact of Climate Change on Crop Production

Several recent studies [2, 3, 7] indicate that climate change in Africa will have variable impacts on crops, with both production losses and gains possible. On a base of the combined different-cumulative curves of rainfall and crops was allocated rainfall effect on crops production in Rwanda. Maize, wheat, rice, peas, groundnuts, banana, irish potato, and cassava, were positive to the rainfall growth and follows its dynamic (fig. 3 a, b, c).

While sorghum and yam have an opposite movement to rainfall change (fig. 3 a, c). Data analysis from both agricultural seasons (A and B) indicates that there have been production gains due to forced cropping changes. While sweet potato production increased in both seasons, other staple crops including sorghum, maize and wheat were volatile. This could illustrate the continued need for infrastructure development including irrigation, mechanization and training for farmers for seasonal preparedness. The low performance of food production from 2002 is the result of irregular rainfalls and a dislocation of rainy seasons which took place. This weakening of agricultural production linked to climate hazards is to be seriously considered knowing that food needs in the country are ever growing.



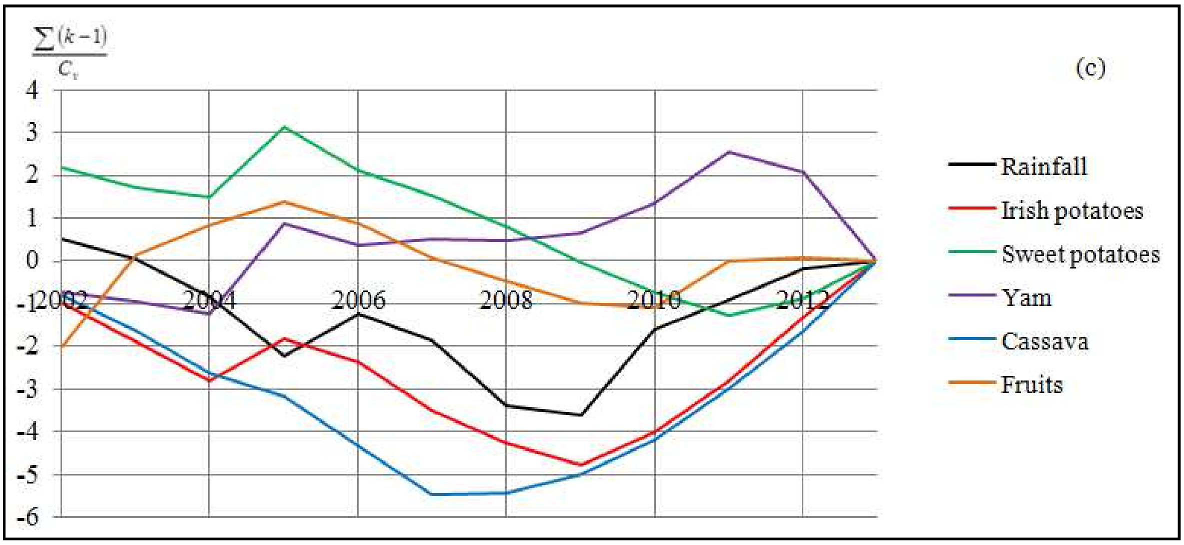


Figure 3. *Standardize curves of sums of rainfall and crops production for 2002-2013 (a-c).*

3.5. Other Factors Influencing Crop Production

Factors which are influencing crop production are subdivided into climatic (rainfall, air temperature, sunlight, CO_2 variations) and non-climatic (soil aeration and structure, seed quality, fertilizer application, use of modern technologies, and etc).

It is obvious that the trend of the crop yield reflects crop response to rainfall variability in a case if other factors (climatic or non-climatic), that influence crop production does not vary or vary very little. As an example the annual increase of atmospheric CO_2 (less than 2 ppm) which is vary very negligible from one year to another [4]. In such case factor could be not considered. Additionally other studies [1, 22] have detected that the mean and high temperatures are not the main factors to decide the crop yield, but extreme temperature has a negative effect on crop yield. Crop yield is more sensitive to precipitation than temperature.

In the cases where climate conditions do not vary, the crop production reflects the effect of non-climatic factors (land expansion, fertilizer application, plant breeding, technology, and etc). Those factors could influence crop yield significantly but it becomes difficult to distinguish the contribution of each factor to crop yield due to the composite interactions between growing conditions and the crop response to these interactions. Hereafter, we are addressing contributions of non-climatic factors to crop production dynamics.

Arable land expansion. About 80 percent of the projected growth in crop production in developing countries will come from intensification in the form of yield increases. Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa, Latin America and some countries in East Asia, although much less so than in the past [7].

In Rwanda the growth rate for arable land is 1.6%, while crop production has risen by 7% annually. In several years arable land remains stable while crop production has grown significantly by 13%. Most likely the land expansion leads to impact on yield growth but it is not a determinant factor due to the low rate of it (table 4).

Table 4. *Coefficient of variation (C_v) for period 2000-2014.*

Crop yield (tons)	Rainfall (mm)	Arable land (ha)	Fertilizer (kg/ha)
0,21	0,11	0,02	0,83

Fertilizer application. Commercial fertilizer is necessary to maintain crop productivity. Fertilizer is still critical to avoid depletion of soil nutrients and ensure soil quality. In many African countries fertilization is inadequate and unbalanced, which limits the expression of yield potential and negatively impacts crop quality. It is difficult to determine exactly how much crop yield is due to the use of commercial fertilizer because of inherent soil fertility, climatic conditions, crop rotations, management, and the crops itself [18].

Fertilizer consumption in Rwanda has always been extremely low in both relative and absolute terms. Aggregate national consumption from 1980 to 2007 rarely exceeded 5,000 tons per year [20]. Application of fertilizers vary significantly 0.1-9.4 kg/ha (table 4) in different years. An average consumption is estimated at 3.3 kg per hectare of arable land. It remains one of the countries with the lowest fertilizer consumption in the World. A wide list of crops are cultivated within a country but fertilizers are applied mostly to maize, irish potato, wheat, rice, coffee and tea.

Table 5. *Parameters of relation between $\frac{\Sigma(k-1)}{C_v}$ of crop yield and $\frac{\Sigma(k-1)}{C_v}$ of rainfall (x_1), land expansion (x_2) and fertilizer application (x_3) for period 2002-2013.*

Crop yield, tons	x_1	x_2	x_3
a	0,72	0,77	-0,87
r	0.84	0.67	0.77

Where a – parameter of tendency estimation; r – coefficient of correlation.

Additionally the relationship between crop yield and fertilizer application (table 5) with respect to rate of its variation (C_v) shows inverse relationship. It has become inappropriate due to the main aim of fertilizer use. The reasons of that could be due to the initial data quality or improper management and application of fertilizers within a country. Based on first, it is impossible to detect the impact of fertilizer application on crop yield.

Plant biotechnology. Crop yields also could benefit from genetic improvements through plant breeding. Extensive evidence suggests that crop yields have benefited the most from plant breeding, which includes the use of improved hybrids and varieties. Studies of the determinants of increased crop yields for maize, soybeans, and wheat conclude that 50 percent or more of the overall yield gain for each crop can be attributed to genetic improvements of plant varieties [25].

In Rwanda, little or no work has been done on plant breeding after the genocide (1994), and publication of research results has not been effective from 1994 to 2006 [16]. Plant biotechnology is in its infancy, and limited to plant tissue culture. The development and application of modern biotechnology in Rwanda is just emerging, and faces enormous challenges. There is a very low human resource and infrastructure capacity coupled with lack of biotechnology facilities [6]. Due to this plant breeding can't impact on studied crop yield in Rwanda.

Agricultural technology improvement. Agricultural mechanization has many benefits. It contributes to improving productivity of cultivated land and facilitates expansion of cropping areas as well as improving crop yield [12]. Unfortunately application of agricultural technologies in general, remains infrequent in Rwanda. In 2000-2002 just around 0.6 tractors (per 100 sq km of arable land) were available and this number gradually decreasing, thus in 2009 just 0.5 tractors (per 100 sq km of arable land) were available. In accordance with this, technology improvement can't have a significant impact on crop yield in the studied period.

4. Discussions

4.1. Infilling Missing Rainfall Data

The obtained acceptability coefficient of this regression modeling shows using regression for infilling missing rainfall data is acceptable. Quality information about spatial and temporal distribution of rainfall is necessary for the construction of thematic maps of rainfall distribution which can be used for classifying wet and dry years and also for the solving of problems related to forecasting changes in the water regime of rivers and lakes. However, availability of an infilled rainfall record can facilitate water resources assessment through various modeling techniques. Standardized curves for sum of annual rainfall have not been constructed for Rwanda and therefore their cycle has not been identified.

4.2. Analysis of Rainfall Dynamic

The general average of rainfall increase of 20 weather stations for the period 2013-2033 is 4.5% and for the period of 2033-2053 is 6%. Some weather stations have a significant growth of rainfall and others have no significant rainfall increment. Analysis of rainfall trends show that rainfall is tending to grow but the rainy period might be shorter with higher intensity. This tendency will affect agricultural products and lead to events such as droughts in dry areas (Eastern and Southeast Provinces); and floods or landslides in areas with heavy rains (Western and Northern Provinces). Results comparison of reconstructed data by other models rainfall change demonstrates data comparability. Recent studies [9] indicate truncated boreal spring rains in the mid-21st century over eastern Ethiopia, Somalia, Tanzania, and southern Kenya while the boreal fall season has lengthened in southern Kenya and Tanzania [19]. Recent authors suggest that over eastern Africa by the end of the 21st century there will be a wetter climate with more intense wet seasons and less severe droughts during October-November-December as well as March-April-May [19].

4.3. Impact of Climate Change on Environment

During the flood's episodes the annual amount of rainfall did not exceed its average values. Climate change impact caused by growth of separate rain intensity but not total amount of rainfall in Rwanda. The provinces which receive high amount rainfall are Western, Northern and South-West. Those areas have aggravated the impacts of floods on people, agriculture and the physical infrastructure as results of human activities (poor farming practices, deforestation and environmental degradation). The 'flood and landslide risk zones' derived from the analysis of frequencies of daily rainfall exceeding 50 mm, are located in the Southern, Northern and Western Province. Cases of floods and landslides are often associated with outbreaks of water-borne and water-related diseases like malaria, diarrhea, cholera and viral infections mainly through the contamination of wells and boreholes. Cities located in low-land areas are also at great risk of floods. In Kigali City people have begun occupy the Nyabugogo River's flood plains, raising the issue of flood exposure [14].

According to table 3, Rwanda has experienced long droughts in many different years. The eastern province has been experiencing rainfall deficits over the last few decades. Prolonged droughts are frequent in the east and southeast such as Bugesera, Mayaga and Umutara. They tend to be cyclical and can be persistent. Droughts are often responsible for famine, food shortages, a reduction in plant and animal species and displacement of people in fetching of food and pasture. At times this has led to conflicts over different land uses such as with protected areas. For instance drought has on several instances forced herders to move their herds from Mutara closer to or into the Akagera National Park during the dry season. Bugesera experienced severe droughts in 1999, 2006 and more recently in November 2008. The livelihoods of people in Bugesera are dependent on agriculture. These long dry spells have great impacts on their livelihoods and welfare. Crop failure during the 2000 drought meant that the entire region had to depend on external food supplies. The length and intensity of land degradation have also weakened the lands' resilience. When combined with overgrazing and poor cultivation practices, drought has led to deterioration in pasture and arable land to the point where they have been abandoned. Changing climatic conditions have been associated with declining food crop production due to low moisture content. Cassava, the main food and income-generating crop is now a rare commodity; and the production of beans has also been negatively affected by the low soil moisture. Little effort has been made to mitigate the problems of rainfall unpredictability. There is an emergence of pests and diseases, possibly because of changing environmental conditions. Crop pests were reported to have increased [17, 23].

4.4. Impact of Climate Change on Crop Production

On a base of the relations of the $\frac{\Sigma(k-1)}{C_v}$ for rainfall and $\frac{\Sigma(k-1)}{C_v}$ for different crops constructed for the period 2002-2013 was allocated the degree of rainfall impact. Maize, wheat, rice, peas, groundnuts, banana, irish potato, and cassava have a direct relationship with rainfall (table 6).

Table 6. *Parameters of relation between rainfall and crops for period 2002-2013.*

Crops	a	r	Crops	a	r
Sorghum	-0,58	0,64	Peas	+0,90	0,74
Maize	+1,17	0,88	Groundnuts	+0,55	0,64
Wheat	+1,06	0,75	Soya	+0,13	0,09
Rice	+0,55	0,49	Banana	+0,30	0,44
Beans	-0,36	0,30	Irish Potato	+0,90	0,83
Sweet Potato	+0,01	0,00	Cassava	+1,19	0,86
Yam	-0,21	0,24	Fruits	-0,04	0,05

Where a – parameter of tendency estimation; r – regression coefficient.

Figure 4 shows a high rate of synchronous fluctuations between rainfall and maize. High amount of rainfall can significantly increase the above mentioned crop's yield. In the case of rainfall decline crops production recedes accordingly. While sorghum, beans, and yam have an inverse relationship to rainfall patterns (table 4).

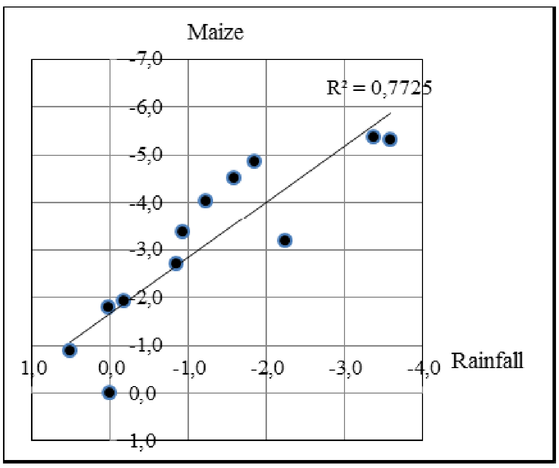


Figure 4. *Relation of the $\frac{\Sigma(k-1)}{C_v}$ rainfall and $\frac{\Sigma(k-1)}{C_v}$ maize for the period 2002-2013.*

4.5. Other Factors Influencing Crop Production

The trend of the crop yield reflects crop response to rainfall variability due to the fact that other factors (climatic and non-climatic), does not vary or vary very little. Rainfall has more synchronous fluctuations with crop yield (r=0,84) than land expansion or fertilization (0,67-0,77) (table 5). For Rwandan conditions, the rainfall variations are determinant for the crop yield change.

5. Conclusion

5.1. Infilling Missing Rainfall Data

After 1994 many weather stations stopped working and even before some of them had missing data so it is necessary to infill data before analysis. The coefficient of acceptability of the performed regression for the infilling of the sum of annual rainfall did not exceed 0.8. This gives ground for considering the infilling acceptable.

5.2. Analysis of Rainfall Dynamic

The rainfall tends to be augment. During a period 2013-2033 by 4.5% and for 2033-2053 by 6%. Obtained results of reconstructed data comparison by other models rainfall change set a data comparability.

5.3. Environmental Effects

Despite global climate change, flood events in Rwanda are also intensified by the nature of Rwandan relief characterized by steep slopes and the change in land cover as well as land use as a result of high population density. It is estimated that rainfall will be increasing in the next 40 years and the effect on environment will depend on the rate of environmental management.

5.4. Effects on Agriculture

Climate plays a central role in agriculture which is the main income item of the Rwandan economy and community livelihood. Some crops like maize, wheat, rice, peas, groundnuts, banana, irish potato, and cassava, are positive to the rainfall growth and follows its dynamic. While sorghum and yam has an opposite movement to rainfall variability. Irregular rainfalls and a dislocation of rainy seasons can lead to late planting and low harvest. The Rwandan government are working on programs to enable adaptation to some of the implications of climate change. At the same time it has set up mechanisms to reduce vulnerability to disasters. It should soon be in a position to monitor and forecast well in advance for adequate preparation and handling of disasters.

5.5. Impact of Other Factors

The analysis of most valuable non-climatic factors has identified that all factors can contribute to crop yield increment. But improper management, absence of experts and shortage of equipment lead to minimizations of overall impact of non-climatic factors.

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