

Original Research Article

Agro-climatic characterization of potato production areas in Rwanda: meteorological data analysis and farmer perceptions

ABSTRACT

From years ago, many climate change effects are happening in different areas of the world, including Rwanda. Potato as one of main commodities grown mainly in the cooler and wetter highlands of Rwanda, its production could be facing the global warming. The purpose of this study is to carry out weather change dynamics in the potato growing zones of Rwanda by analyzing rainfall and temperature evolution trend over the last thirty years. Temperature and rainfall daily data were collected from three weather stations, at- Kawangire for low elevation (1581 masl), at Gikongoro mid elevation (1910 masl), -and at Kora high elevation (2500 masl), respectively. Farmers were interviewed to know their perceptions on weather conditions during past thirty years. Temperature and rainfall data were analyzed by ombrothermic diagram, Nickolson Index and graphing with generated trend equation methods. Interview data were analyzed with Chi-square test at P-Value significance <5%. Results have shown as dry June, July and August months in low elevation; June, July and August in medium elevation and June and July in high elevation depending on decade.

Rainfall was increasing (evolution trend was positive) in low and medium elevations, while it was decreasing (evolution trend was negative) in high elevation. Temperature was decreasing in low elevation area and it was increasing in medium and high elevation areas. All interviewed farmers confirmed long term-shift in temperature and precipitations. A total of 95%, 54% and

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43% of farmers from respectively low, medium and high elevations reported that weather was becoming wetter during last years. As conclusion, potato growing cooler and wetter conditions of high elevation are shifting to low elevation in Rwanda. For climate change mitigation, Rwanda needs to promote potato in its Eastern part, the low elevation region, in order to increase the crop production in the future.

Key words: Agro-climatic characterization, Climate change, Farmer perceptions, Potato production, Rwanda.

1. Introduction

Potato is the fourth most important food crop worldwide after maize, rice and wheat [21]. It is grown in 140 countries [8]. Rwanda is among five African countries producing potato and third producer in Sub-Saharan Africa [29]. Potato is grown in all parts of country, mainly above 1800 masl. Yields vary from 9 to 10 tons per hectare. Climate change will affect global human feeding by 2050 [3]. Global temperature would increase to between 1.9 and 4°C during century, and this will affect global agriculture in general [27]. -In East Africa, temperature will likely exceed 2°C until mid-21st century and more than 4°C at the end of century. During this period, potato yield is predicted to be affected by global warming at -15 to +10% level [1]. Rwanda is recognized by its tropical climate moderate and hilly topography [4]. Climate change affects Rwanda depending on its regions variabilities [11]. Precipitations are predicted to be reduced in this country [7]. It is predicted rainfall variations between -100 mm and + 400 mm from 2000 to 2050 [26] and temperature variations between +1.3°C and -1.9°C up to 2050 [26]. Some consequences could result from these increases or variations like floods, storms, landslides, crop losses and diseases, including potato. Despite information above, climate change evolution is uncertain in Rwanda.

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Temperature or rainfall can increase or decrease, because there is no sufficient climate data which could help to predict well the situation [12]. This study will contribute to carry out climate change situation in Rwanda. This study aimed to assess climate characteristics change over the past years in Rwanda. Specifically, the study determined dry months, inter-year variability of precipitations, temperature trends, dry, wet, cold and hot years, all of them in last 30 years in Rwandan potato production areas. The study has also assessed how farmers from the study areas perceive climate change.

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2. Materials and methods

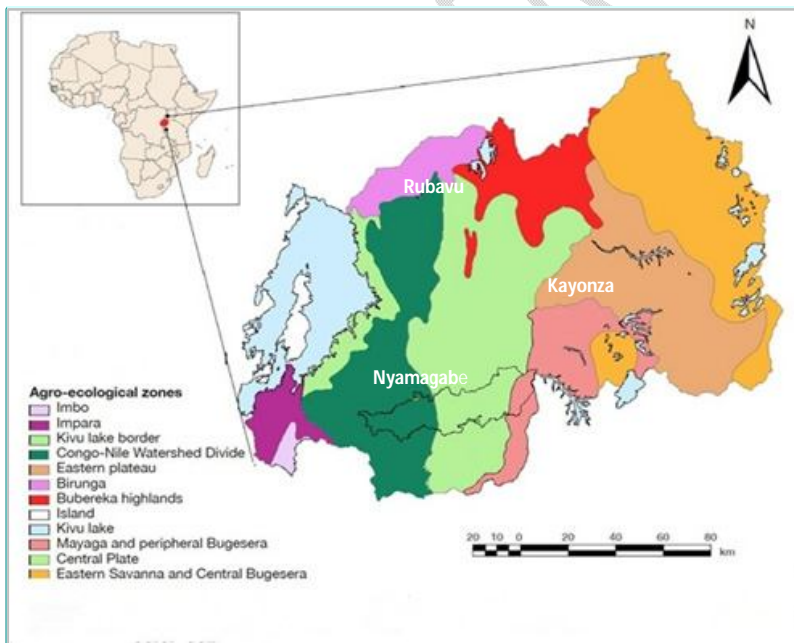
2.1 Study area

Rwanda is an East Africa country of 26,338 km² square at -1° 56'37.34" S and 29° 52'50.08" E, predicting a population of between 15.4 – 16.9 million in 2032 [17]. It is characterized by moist highland tropical climate, with temperature and rainfall ranging between 16-20°C and 1,000-1,600 mm, respectively. The country has a highland part of North-West with altitude, which exceeds 2,300 masl, and the eastern, south and central parts where altitudes vary between 1,500 and 1,900 masl. [2].

In Rwanda, potato is grown over 2 or even 3 seasons during a year, often on the same land. The first starts in February for ending in June (season B) and from September to December as second annual season (Season A) [5,10, 14 & 26]. Three locations, Kayonza, Nyamagabe and cross parts of Rubavu-Nyabihu, were chosen for this study. Chosen locations belong to different agro-ecological zones. Kayonza is located is Eastern Rwanda, characterized by rainfall between 740 and 1130 mm, temperature which some time reach 30°C. Nyamagabe is located in Southern Province, Crete Congo Nile watershed with elevation average of 1800 m, temperatures varying

between 15-17°C, abundant rainfall. Rubavu-Nyabihu part is localized in northern part of Western Province, in Birunga agro-ecological zone (volcanic zone) and low temperature [14, 22 & 24].

Kayonza, Nyamagabe and Rubavu-Nyabihu parts were chosen as study area representing low, medium and high elevations, respectively. Three weather stations such as Kawangire from Kayonza, Gikongoro from Nyamagabe and Kora from Rubavu-Nyabihu were considered. Kawangire weather station is hold by Mukarange sector at 1581m altitude, 30.5°C longitude and -1.9°C latitude; Gikongoro weather station is localized in Gasaka sector, 1910 m altitude, at 29.56°C longitude and -2.46°C latitude. Kora weather station is located in Bigogwe sector, at 2500 m altitude, 29.45°C longitude and -1.6°C latitude.



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Figure 1: Map showing three locations of study area. Adapted map [22].

2.2 Data collection and analysis methods

Two approaches were used: collection of meteorological data and field survey, interviewing potato farmers by designed and structured questionnaire. Daily rainfall and temperature for thirty years (from 1987 to 2016) were collected from [Rwanda Meteorological Agency RMA](#) (~~RMA Rwanda Meteorological Agency~~) primary data. For constituting analysis baseline, excel calculations were done for having monthly and annual data. Then data were organized for analysis using following graphical tools:

- Ombrothermic diagram to determine dry and wet months [28]. Graph in rainfall histograms and temperature in transversal line was done after calculating of same month averages from thirty considered years. Graphs were generated in terms three decades (1987-1996, 1997-2006 and 2007-2016) for each elevation level.
- Nicholson Index method to carry out interannual variabilities of rainfall was used following formula [31].

$$I_i = \frac{X_i - \bar{X}}{\sigma}$$

I_i : pluviometry index

X_i : Rainfall height of the year (mm)

\bar{X} : Average of rainfall height for the study period

σ : Standard deviation of rainfall height during study period

Formula application was followed by results excel graphing with generated trend equation demonstrating precipitations' positive or negative evolution for each elevation level [18].

- Excel graphing with generated trend equation demonstrating evolution was used for temperature averages in three elevations in terms of years (from 1987 to 2016). Graphics with generated trend equations will carry out the cold and hot years.

Interview face-to-face was done through 148 questionnaires distributed to men and women, in terms of 43, 55 and 50 questionnaires in low, medium and high elevations, respectively. Questionnaire number was fixed according to total potato farmers' number owned by study area districts [15]. Asked questions were focusing on rainfall and temperature during thirty last years. Statistical data analysis was done by Chi-square test at P-value significance <5%.

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3. Results and discussion

3.1 Determination of dry and wet months

3.1.1 Low elevation

The analysis showed that June, July and August are dry months in three elevation levels (figure 2). The three decades showed two rainfall periods during the year, which lasted from January to May as the first period and from September to December as the second period. Rainfall peak quantities are in April, with 145.5 mm, 153.0 mm and 140.4 mm averages, respectively for the first, second and third decades. The lowest rainfall quantities are in July months in terms of 0.9 mm and 5.1 mm respectively for the first and third decades, while it is 12.7 mm for the second one.

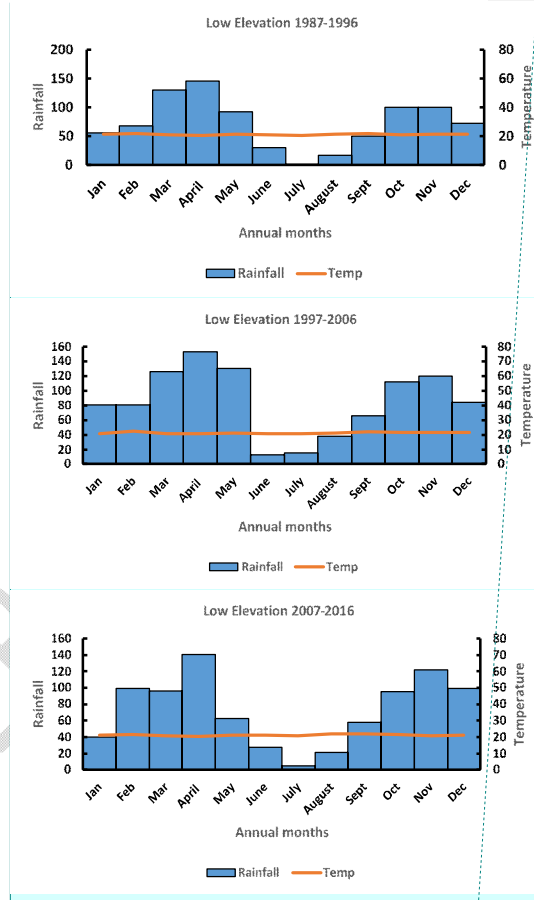


Figure 2: Demonstration of dry months for three decades in low elevation area

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3.1.2 Medium elevation

In medium elevation, two months were found dry depending on decade (Figure 3).

In medium elevation, June and July are noted as dry months in first and second decades, while July and August are dry in the third decade. Peak Rainfall is in April month in the first and second decades, with respectively 197.3mm and 216.3mm. The peak rainfall month for the third decade is December with 174.3mm. July months were characterized by lowest rainfall quantities of 7.1mm, 36.6mm and 12.3mm respectively in the first, second and third decades.

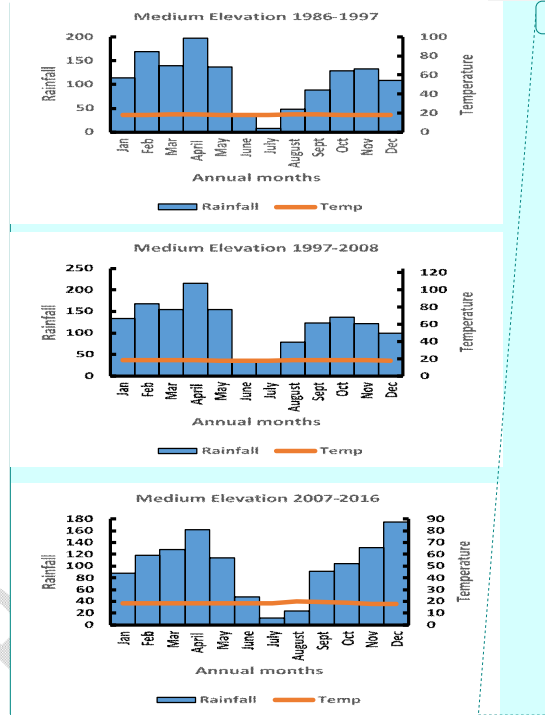


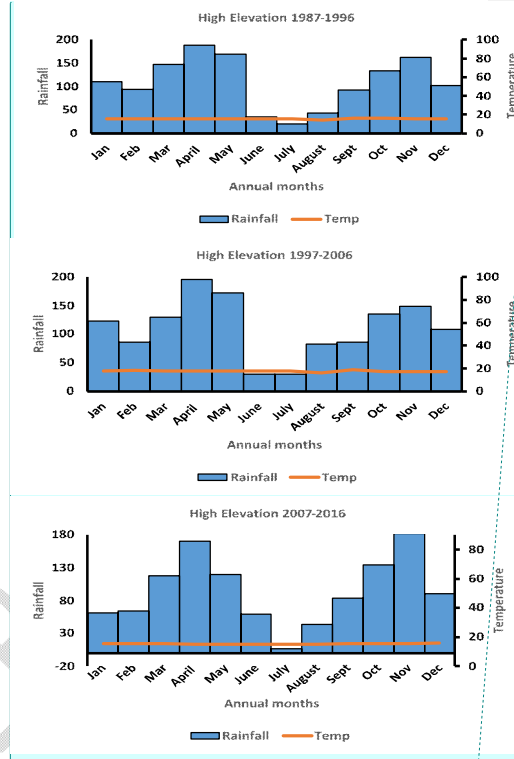
Figure 3: Demonstration of dry months for three decades in medium elevation area

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3.1.3 High Elevation

Two months are dry in second decade (1997-2006) of high elevation and its first and third decades were characterized by one dry month (July) (Figure 4). The reading tour across figures above shows deep drought of July month of first and third decades and a light drought of June and July of second decade. Peak rainy months is April in first and second decades, respectively with 187.5mm and 195.3mm, and November as peak rain month with 182.2mm for third decade. Lowest rainfall month is July, with 19.3mm, 30.0mm and 6.0 mm respectively in first, second and third decades.



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Figure 4: Demonstration of dry months for three decades in high elevation area

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3.1.4 Comparison of decades and Elevations

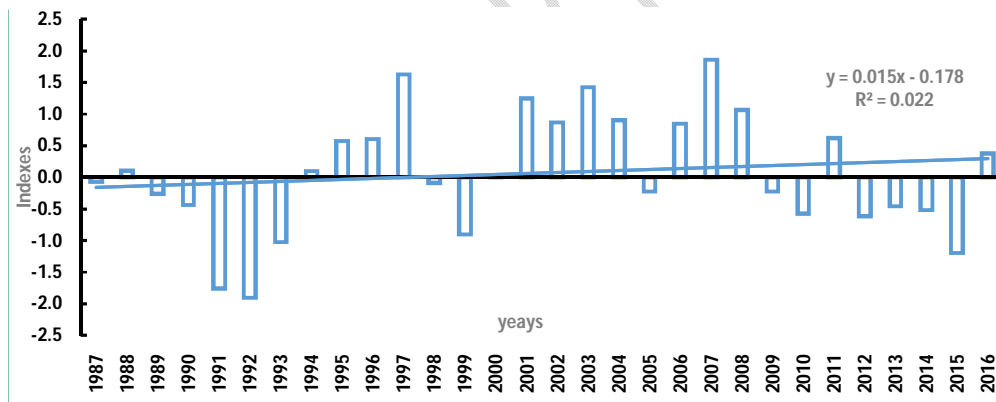
Within each elevation, peak rain months were found in the second decade followed by the first one in general. Therefore, in low elevation, the all decades were characterized by peak rainfall in April months, with 153_mm, 145.5_mm and 140.4_mm concomitantly in second, first and third decades. -In medium elevation, high rainfall was met in Aprils in second and first decades in terms of 216.3_mm and 197.3_mm, respectively, and 174.3_mm in Decembers of third decade. The high elevation showed high rainfall of 195.3_mm followed by 187.5_mm both for Aprils mMonths and from second and first decade, respectively, and 182.2_mm in Novembers of third decade. Within decades of all elevation study areas, the dry month with high precipitations is June of the second decade with 30.5_mm and the dry month with low precipitations is 0.9_mm of July in first decade of low elevation. April months are always peak rainfall months and Julies months have always lowest rainfall quantities in the all decades and all in all elevations. Observations above demonstrate high rainfall quantity in second decades followed by the first ones, while the third decades were recognized as lowest one in precipitations. Thus, July months are always dry in study area. Observation of ombrothermic diagrams showed decrease of dry months' number from low to high elevation. This is illustrated by three dry months' notable in three low elevation decades and one dry month seen in first and third decades of high elevation study area. Indeed, this shows decreasing trend of rainfall from 1987 to 2016.

3.2 Evaluation of inter-annual variabilities of precipitations

After thirty years (from 1987 to 2016), precipitation analysis by Nicholson Index, it showed that there was rainfall generally increasing in low and medium elevations, and decreasing in high elevation (figure 11). Precipitation variabilities are different depending on decades. The second decade (from 1997 to 2006) was characterized by high number of wet years.

3.2.1 Low elevation

Comparing precipitations of low elevation, the trend equation ($Y=0.0159X-0.1786$) generated with the graphic below shows positive evolution with meaning of precipitation increasing for the last 30 years (Figure 5). –The second decade (1997-2006) was more characterized by low variability and was wetter than others with high rainfall of 1232 mm in 2007. Precipitations variabilities were accentuated in third decade, and its 2015 year was the driest with 716mm of rainfall. Number of dry years shifted from three (1998, 1999 and 2005) in second decade to six years (2009, 2010, 2012, 2013, 2014 and 2015) in third decade. In the first decade, three years (1988, 1995 and 1996) are wet and the two years (1991 and 1992) are the driest of the study thirty years. The total of wet years is fifteen (15).



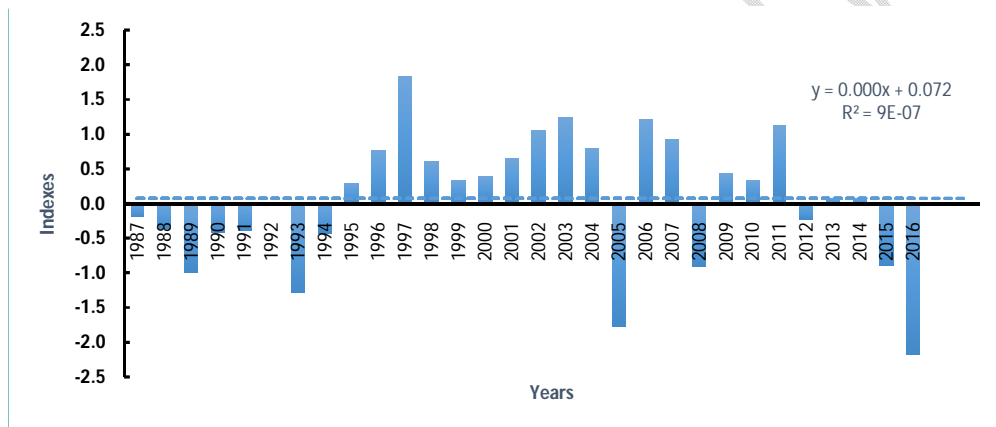
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Figure 5: Inter-annual variabilities of precipitations in low elevation, from 1987 to 2016.

3.2.2 Medium elevation site

Just like in low elevation, the trend equation ($Y=0.0001X+0.072$) generated with graphic demonstrates precipitations' increasing for the last 30 years in medium elevation (figure 6).

Second decade is the wettest among others with few precipitations inter-annual variability which are more visible in third decade. Therefore, many years of second decade were wet. The year 2016, the last of the 30_years included in our study, was the driest with 682_mm. Dry years' number shifted from one (2005) in second decade to four (2008, 2012, 2015 and 2016) in third decade, while only two years of the first decade (1995 and 1996) were wet. The driest years were 2005 and 2016 of the third decade. Fifteen years were found wet.



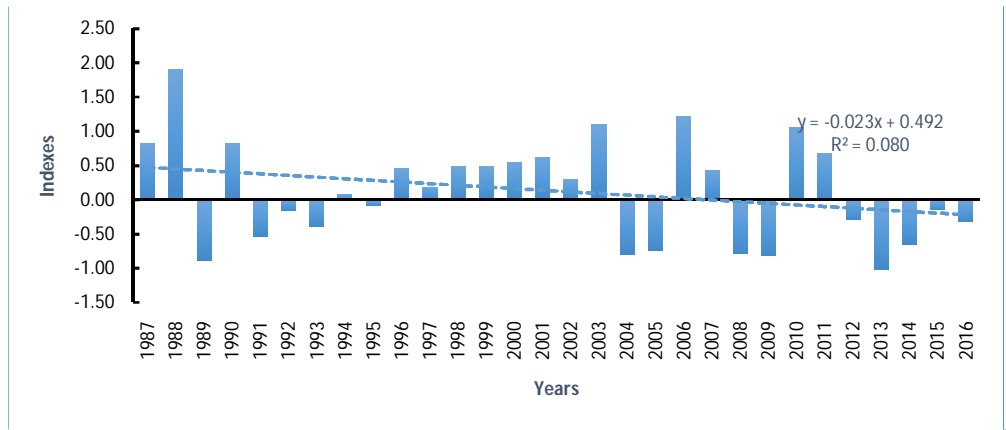
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Figure 6: Inter-annual variabilities of precipitations from 1987 to 2016 for medium elevation.

3.2.3 High elevation site

In this level, results were very different from previously described sites: trend equation ($Y = -0.0238X + 0.4926$) generated with graphic shows negative evolution meaning precipitation decreasing (figure 7). Likely previously, second decade is the wettest and 2013 of third decade is the driest within thirty years with 1052mm of rainfall. First and third decades showed more precipitation inter-annual variability. Dry years' number changed from two (2004 and 2005) in second decade to seven years (2008, 2009, 2012, 2013, 2014, 2015 and 2016) in third decade. The wettest year is 1988 of the first decade with 1622mm of rainfall. Sixteen years (1987, 1988,

1990, 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2006, 2007, 2010 and 2011) were wet.



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Figure 7: Inter-annual variabilities of precipitations from 1987 to 2016 for high elevation

3.2.4 Comparison of three elevation levels

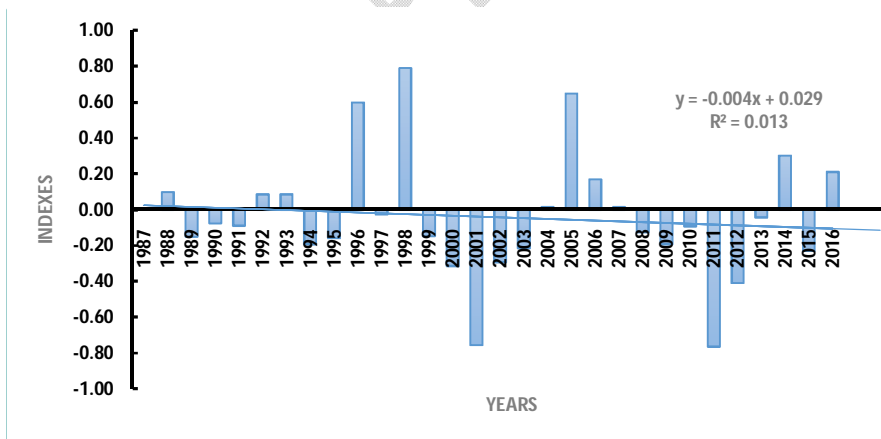
Regarding tour across three elevation levels during 30 years, medium elevation was the wettest with rainfall average of 1324.1 mm, followed by high elevation with rainfall average of 1273.2 mm and low elevation was the driest with rainfall average of 929.3 mm. During thirty years, rainfall increased in low and medium elevations, and it was decreasing in high elevation. First and third decades in all elevation levels were characterized by remarkable variability of annual precipitations.

3.3 Temperature results

3.3.1 Temperature trends from 1987 to 2016

Regarding temperature trends, there is an increase from 1987 to 2016 in high and medium elevations while low elevation is characterized by temperature decrease. –In addition, there is decrease from low to high elevation areas, because for 30 years, averages temperatures are 21.2°C, 18.2°C and 16.1°C for low, medium and high elevation areas, respectively.

In low elevation, the graphic with generated equation ($Y = -0.0045X + 0.029$) rises temperature decreasing for thirty years (figure 8). The number of hot years moved from four (1988, 1992, 1993 and 1996) to three years (2007, 2014 and 2016) in the third decade. The coldest year is 2011 of third decade followed by 2001 of the second one. The two hottest years are 1998 and 2005 of the second decade. Calculated average temperature of low elevation for thirty years is 16.1°C. A total of 12 years was found hot.

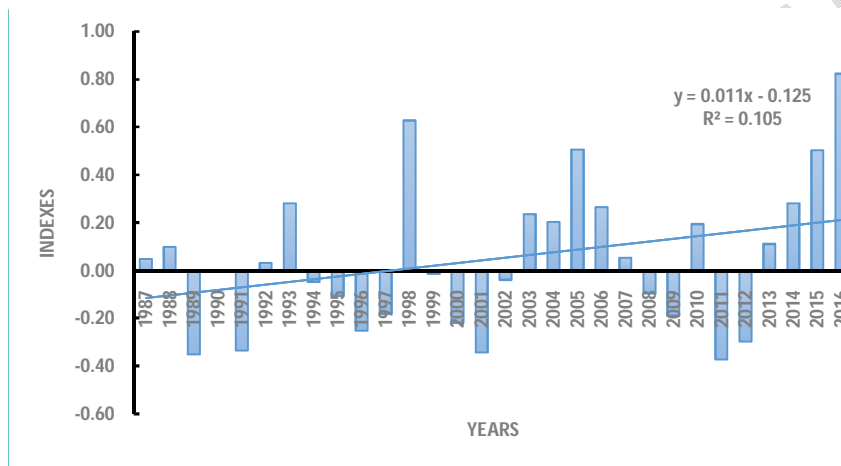


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Figure 8: Low elevation temperature evolution trend from 1987 to 2016: cold and hot years.

In medium elevation, the temperature was shown as increased as it is shown by the figure 9 below. The number of hot years change from four (1987, 1988, 1990, 1992 and 1993) in the first decade to six years (2007, 2010, 2013, 2014, 2015 and 2016) in the third decade. The hottest year is 2016 followed by 1998. Sixteen years (1987, 1988, 1990, 1992, 1993, 1998, 2003, 2004, 2005, 2006, 2007, 2010, 2013, 2014, 2015 and 2016) have been hot.

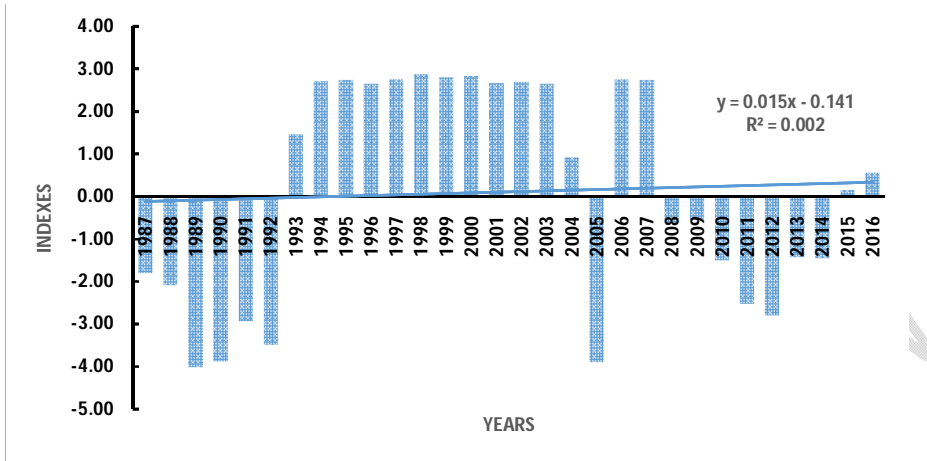
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Figure 9: Medium elevation temperature trend evolution for 30 years: cold and hot years.

For high elevation, as it is illustrated by figure 10, the temperature increased from 1987 to 2016. This increase was due to 16 years which were hot, such as from 1993 to 2004, 2006, 2007, 2015 and 2016. The second decade was characterized by the hotness. After the analysis, sixteen years were noted hot.



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Figure 10: High elevation temperature trend evolution for 30 years

3.4 Farmers’ perceptions on climate change

3.4.1 Temperatures

About 82%, 76% and 54% of respondents from low, medium and high elevations respectively reported have noticed some long-term shift in temperature in their farms (figure 15). Furthermore, 100%, 95% and 58% of respondents from low, medium and high elevations respectively stated that the weather became warmer (figure 11).

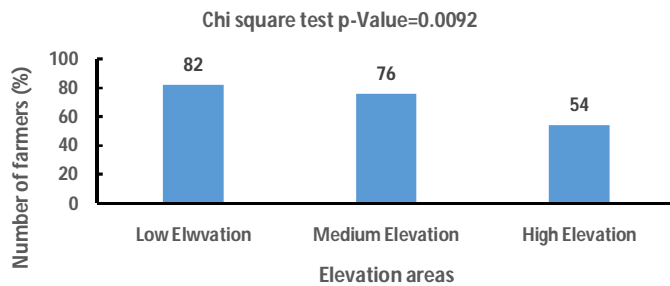


Figure 11: Graph showing how farmers noted long-term shift in temperature in their farms.

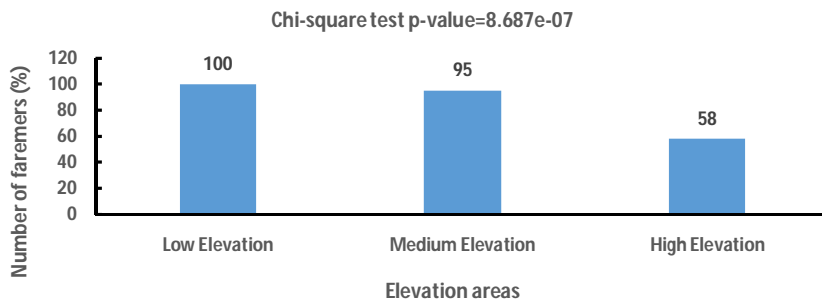


Figure 12: Number of farmers noted if shifting of weather from cooler to warmer

3.4.2 Precipitations

Similarly, around 88%, 98% and 74% of respondents from low, medium and high elevation areas respectively reported have noticed some long-term shift in precipitations in their farms (Figure 13). Moreover, 95%, 54% and 43% of respondents from Low, Medium and high elevations respectively stated that the weather became wetter (Figure 14).

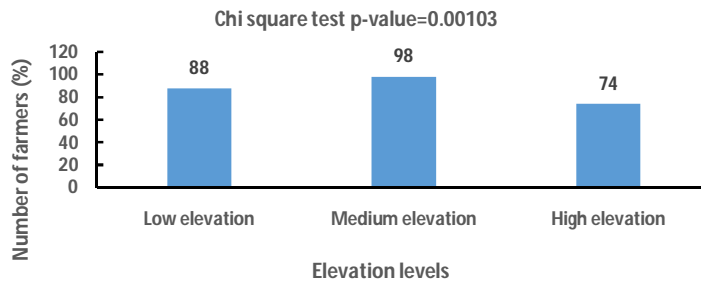


Figure 13: Number of farmers confirming long shift-terms in precipitations during years ago.

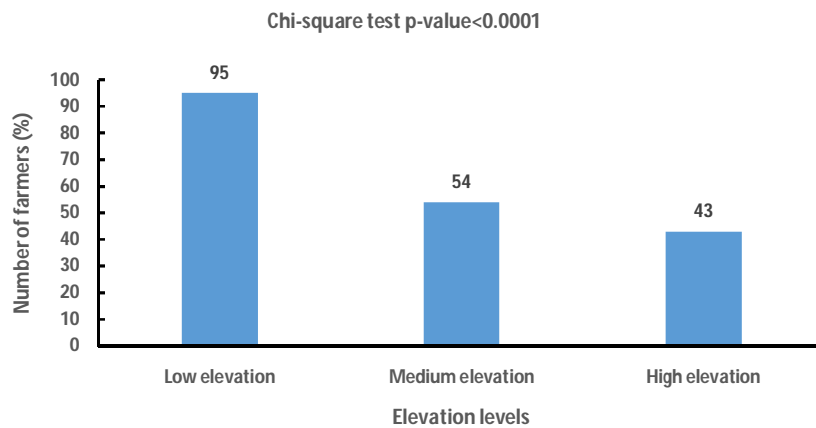


Figure 14: Number of farmers having reported that weather was becoming wetter during last years

3. 4. Results discussion

Many studies predicted climate variability impact on different crops including potato [16]. Climate change has an impact on incidence magnitude and frequency of potato pests and diseases [20]. Rwanda topography is dominated by steep slopes and hill relief, which is among factors influencing climate [14]. Because of rainfall variability, season A (normally from September to December) will extend to January in mid-century [7]. Precipitation variability was predicted to be between -100 up to +400_{mm} between 2000 and 2050 [26].

Found rainfall averages are 1324.1_{mm}, 1273.2_{mm} and 929.3_{mm} respectively in medium, high and low elevations. Annual rainfall on all Rwandan territory is around 1250_{mm} [14 & 26]. South-Eastern part (low elevation area) of the Country where is located low elevation study area is characterized by drought and rainfall between 700 and 970_{mm} per year. North-Western

part (high elevation area) holding high elevation study area is recognized by abundant rainfall [14].

Eastern province, including low elevation study area (Kayonza district) receives between 740-1130 mm annually [24]. High precipitations are found in Congo-Nile region including medium elevation study area and Birunga region holding high elevation study area [3].

Rainfall was decreasing from 1987 to 2016, and the second decade (1997-2006) was found wetter in all study areas. In mid-century (between 2040-2069) precipitations are predicted to decrease 6% (from 1139 mm to 1066 mm) in all Rwandan provinces [7]. Severe drought was reported in 2000 and floods were noted in 1997, 2006, 2007, 2008 and 2009 through Nicholson index [26]. Wetness of most of these years is confirmed by this study. In western Province, previous studies reported 1993, 1995, 2002 and 2016 as dry, while the period of 2006-2010 and 2014 were wetter likely confirmed in this study [24]. These results are likely similar to our study findings. The study of 1961-2016 found rainfall decline from 1960, and 2000-2009 period was the driest in Rwandan Northern part. In West, 1998-2005 period was the driest and one of 200-2014 was wettest [4]. This confirms the research findings above. However, despite reported decrease, some reports pretend precipitation increase in Rwanda. This increase would be 20% and 30% respectively in 2050 and 2080 [13] and between 10-20% in mid-century [3].

The study revealed three dry months (June, July and August) with increasing in number from high to low elevation study areas. From July to September is a season C between two rainy seasons (A&B) for crops which supplement diet [3]. The three months constitute an off- short and dry season between two rainy seasons which are suitable for potato production in the country [26]. Given that potato yield depends on weather conditions, Western Province, holding high and

medium elevation study areas, is among Rwandan parts producing most its production (potato production) because it is cooler and moisture content region [10].

Rainfall determine potato productivity; the study done in Ethiopia showed bilateral decreasing of rainfall and potato yield from 2000 to 2019 [30]. In Kenya, there were increasing trends of annual rainfall and potato yield from 1999 to 2009 [9].

The study resulted with 21.2°C, 18.2°C and 16.1°C temperature averages in low, medium and high elevations respectively. The country is characterized by temperate climate with temperature average between 16 and 20°C [14]. Congo-Nile and Birunga regions where are located respectively medium and high elevations study areas are indicated by 18.1° C and 15.4°C [3]. The same author reports that South-Eastern part of the country is warmer and drier with temperature varying between 21.7-22°C. Elevated temperatures (20-30°C) reduce potato tuber numbers and photosynthesis up to 20%, and shift biomass from tubers to leaves [6].

Study raised temperature increase for thirty years ago especially in high elevation study area. Previous researches reported temperature increase in Rwanda. From 1971 to 2010, temperature increase of 0.35°C was predicted. Temperature increase of 2.5°C and 4°C are predicted respectively in 2050 and 2080 [13]. Between 2040-2069, temperature is pretended to 1.7°C increase on all Rwandan territory [7] or to between 1.3-1.9°C [3]. Months of August, September, October, November and December will have between 1.7-2.1°C temperature increase [7].

It is predicted that temperature amplitudes will increase in the future and will have effect on plant pathogens. Previous studies demonstrated that temperature amplitude impacts positively potato late blight disease [25]. Potato need temperature for tuber formation, general at 20°C as optimum. In India, warming is predicted to reduce potato yield up to 40% in the future due to diseases, animal pests and weeds, including 21% due only to diseases, especially late blight [23].

4. Conclusion and recommendations

This study proved that from 1987 to 2016 climate was changed in Rwanda. Annual precipitations were reducing at high elevation site and increasing in medium and low elevation sites, with annual variability. Temperatures were increasing in low and medium elevation sites while decreasing in low elevation site. Annual precipitations and temperature variabilities were raised by the study. Above results found by different analytical methods were confirmed by interviewed farmers except for temperature decrease found in low elevation that was not noted by farmers. Indeed, rainy periods' length is variable depending on elevation area. High elevation areas are wetter and cooler, and they becoming drier and warmer. The low elevations are drier and warmer and they are becoming wetter and cooler. Generally, potato growth cooler and wetter conditions are shifting from high to low elevations. As strategy for climate change mitigation, Rwanda needs to promote potato is East, the lower elevation region, in order to increase the crop production in the future.

Consent for publication

Not applicable

Ethic approval and consent to participate

The research proposal was approved by University Felix (U-FHB) as part of PhD studies. Field work was facilitated by Rwanda Agriculture and Animal Resources Development Board (RAB). Interviews were done after farmer consent.

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