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Agro-climatic Characterization of Potato Production Areas in Rwanda: Meteorological Data Analysis and Farmer Perceptions

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Authors' contributions

This work was carried out in collaboration among all authors. The draft was conceived and wrote by author ANN under supervision of author KKD. Authors KD and CM learned drafts of proposal. Author ATN help to perfume the laboratories analyses. All authors read and approved the final manuscript.

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ABSTRACT

From years ago, 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 (temperature and rainfall) change dynamics in the potato growing zones of Rwanda over the last thirty years. Weather daily data from 1987 to 2016 were collected from three weather stations, at Kawangire for low elevation, at Gikongoro mid elevation, and at Kora high elevation,

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respectively. Farmers were interviewed to know their perceptions on weather conditions during past thirty years. Weather 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* =.05. 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 in low and medium elevations, while it was decreasing 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 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.

Keywords: 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 [1]. It is grown in 140 countries [2]. Rwanda is among five African countries producing potato and third producer in Sub-Saharan Africa [3]. 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 [4]. Global temperature would increase to between 1.9 and 4°C during century, and this will affect global agriculture in general [5]. 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 [6]. Rwanda is recognized by its tropical climate moderate and hilly topography [7]. Climate change affects Rwanda depending on its regions variability [8]. Precipitations are predicted to be reduced in this country [9]. It is predicted rainfall variations between -100 mm and + 400 mm from 2000 to 2050 and temperature variations between +1.3˚C and -1.9°C up to 2050 [10]. 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. Temperature or rainfall can increase or decrease, because there is no sufficient climate data which could help to predict well the situation [11]. Up to now, no study was done with the purpose of showing climate variability over last years in this country. This study will contribute to carry out climate change situation in Rwanda. This study aimed at assessing the 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 30 passed years (from 1987 to 2016) in Rwandan potato production areas. The study has also assessed how farmers from the study areas perceive climate change.

2. MATERIALS AND METHODS

2.1 Study Area

Rwanda is an East Africa country of 26,338 km^2 square at -1^o 56'37.34" S and 29^o 52'50.08" E, predicting a population of between 15.4–16.9 million in 2032 [12]. 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. [13].

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) [14,15,16,10]. Three locations, Kayonza, Nyamagabe and Nyabihu, were chosen for this study. The study area locations were chosen because they different in terms of agro-ecological conditions and are potato growing zones. Therefore, can give information about to promote potato in the future. 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. Nyabihu is localized in northern part of Western Province, in Birunga agro-ecological zone (volcanic zone) and low temperature [16,17,18]. Kayonza, Nyamagabe and Nyabihu were chosen as study area representing low, medium and high elevations, respectively (Fig. 1). Three weather stations such as Kawangire from Kayonza, Gikongoro from Nyamagabe and Kora from 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.

2.2 Data Collection and Analysis

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) 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:

1. Ombrothermic diagram to determine dry and wet moths. 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.

2. Nicholson Index method to carry out interannual variabilities of rainfall was used following formula [19].

$$\mathrm{I}i = \frac{Xi - \overline{X}}{\sigma}$$

Where I*i* is pluviometry index, *Xi is* Rainfall height of the year (mm), $\overline{X}$ is average of rainfall height for the study period and σ is Standard deviation of rainfall height during study period.

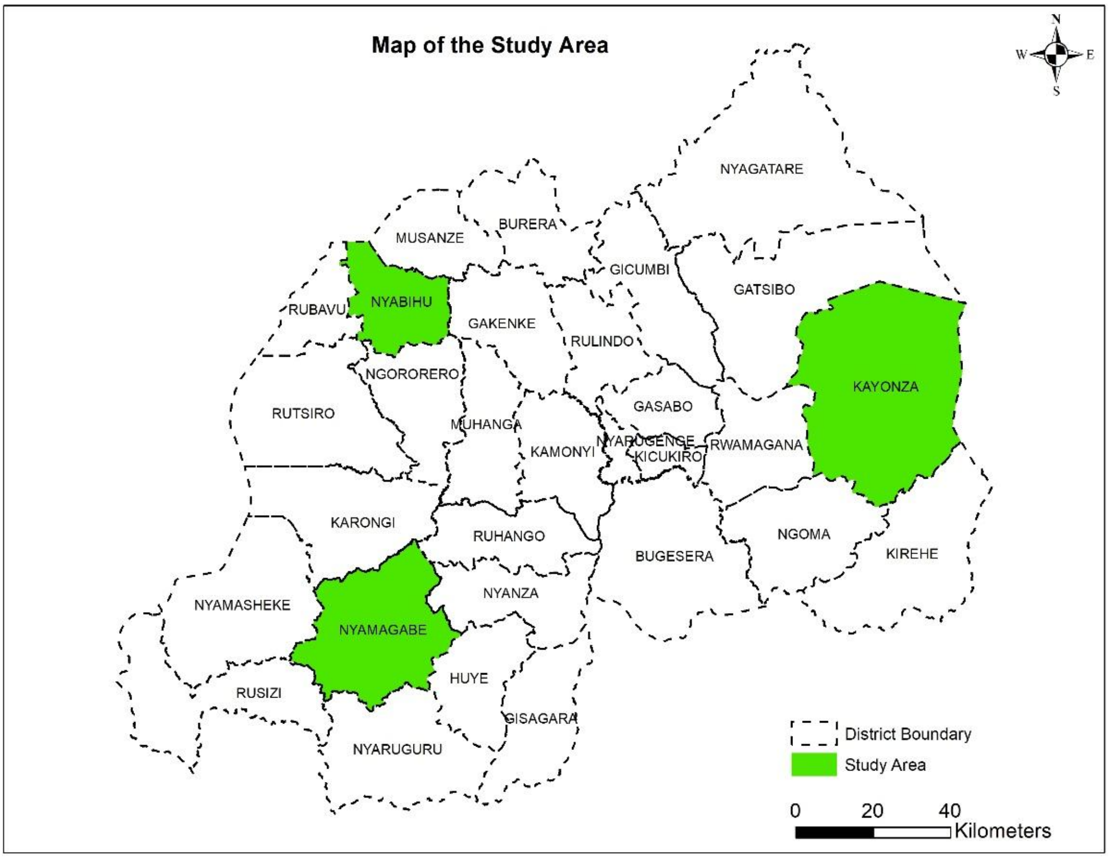

Fig. 1. Map showing three locations of study area

Formula application was followed by results excel graphing with generated trend equation demonstrating precipitations' positive or negative evolution for each elevation level [20].

3. 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.

4. 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 estimated according to total potato farmers' number owned by study area location and calculated through the following binomial distribution equation:

$$\tilde{N} = 1.96^2 * (P)\ (1- P)/d^2$$

Where Ñ is number of samples, 1.96 is Z value for 95% confidence limits, P is estimated prevalence (for instance 0,3 for 30%), (P) (1-P) is deviation for a binary variable (binomial) and d = 1/2 of the desired confidence interval (for instance 0,025 for ± 5%) [21]. Asked questions were focusing on rainfall and temperature during thirty last years. Statistical data analysis was done by Chi-square test at *P* =.05.

3. RESULTS

3.1 Determination of Dry and Wet Months

In low elevation, the analysis showed that June, July and August are dry months in three elevation levels (Fig. 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 145.5mm, 153.0 mm and 140.4mm averages, respectively for the first, second and third decades. The lowest rainfall quantities are in Julies months in terms of 0.9mm and 5,1mm respectively for the first and third decades, while it is 12.7mm for the second one. In medium elevation, two months were found dry depending on decade (Fig. 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. In 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) (Fig. 4). The reading tour across figures 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.

Comparing 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 months and from second and first decade, respectively, and 182.2mm 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 0.9mm 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.

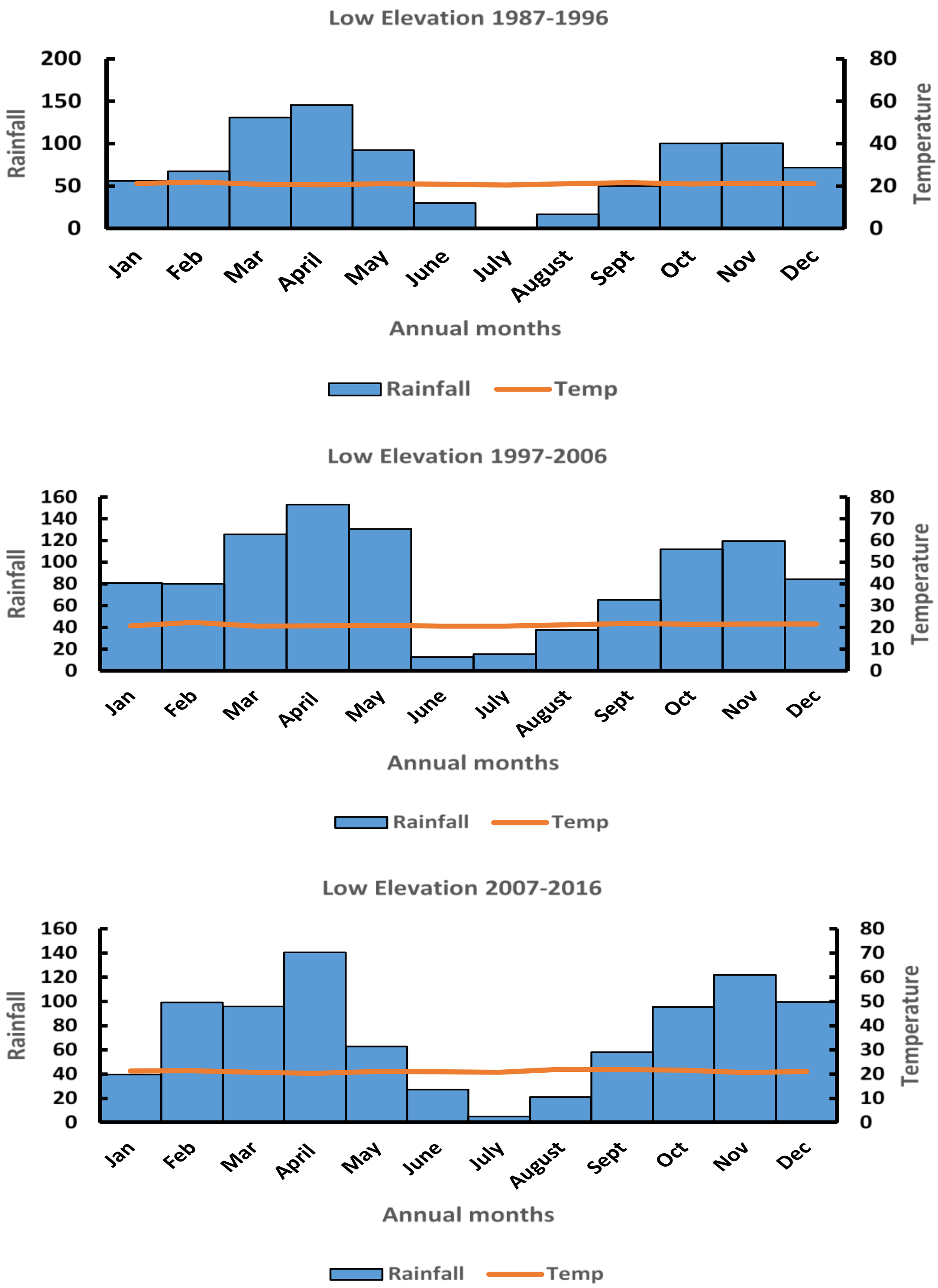

Fig. 2. Demonstration of dry months for three decades in low elevation area

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 (Fig. 11). Precipitation variabilities are different depending on decades. The second decade (from 1997 to 2006) was characterized by high number of wet years.

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 (Fig. 5). The second decade (1997-2006) was more characterized by low variability and was wetter than others with high rainfall of 1232mm 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).

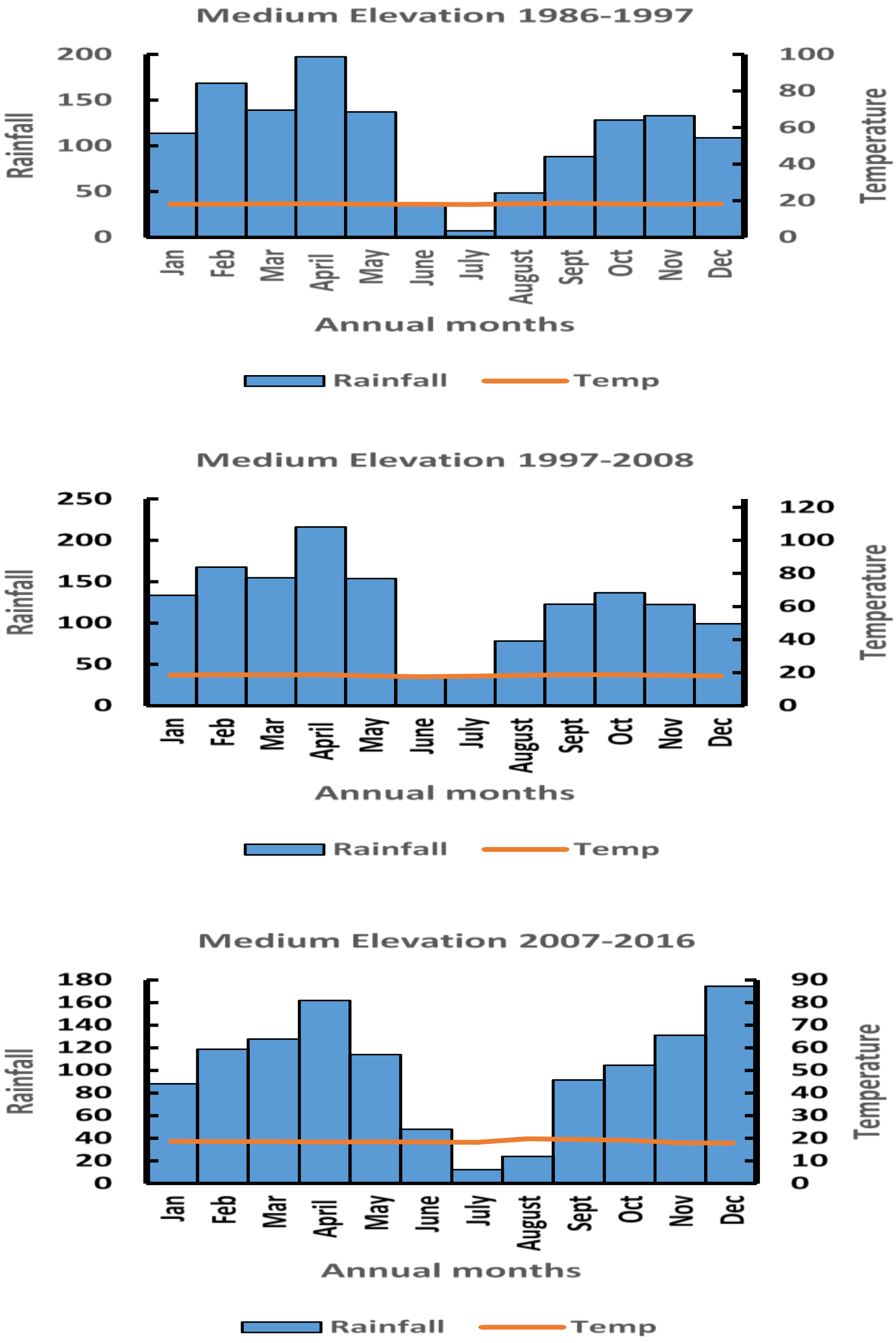

Fig. 3. Demonstration of dry months for three decades in medium elevation area

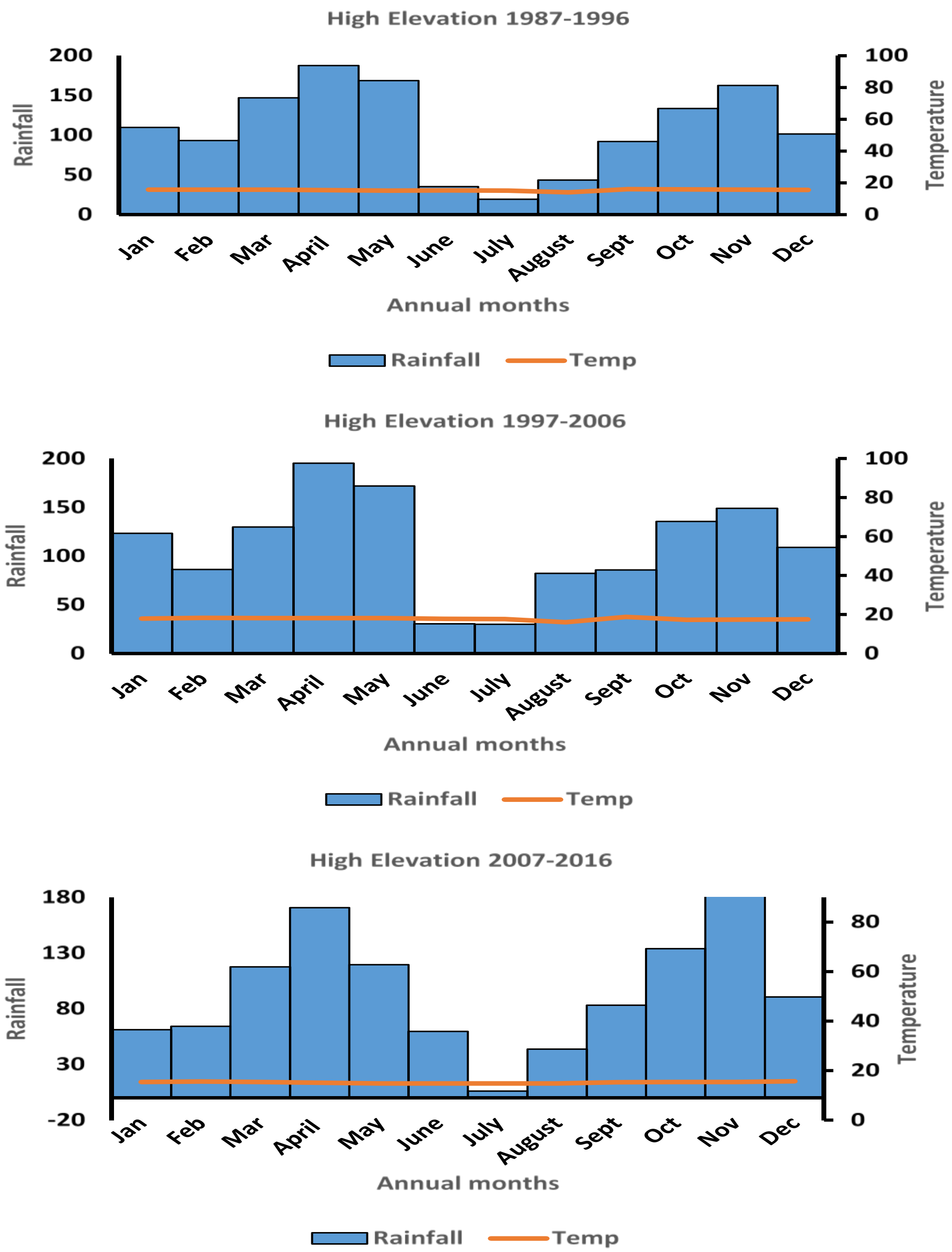

Fig. 4. Demonstration of dry months for three decades in high elevation area

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 (Fig. 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.

In high elevation, results were very different from previously described sites: trend equation (Y= -0.0238X + 0.4926) generated with graphic shows negative evolution meaning precipitation decreasing (Fig. 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, 1010 and 2011) were wet.

Comparing the 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 1273.2mm 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 Evaluation of Inter-annual Variabilities of Temperature

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 (Fig. 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.

In medium elevation, the temperature was shown as increased as it is shown be the Fig. 9. The number of hot years change from five (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.

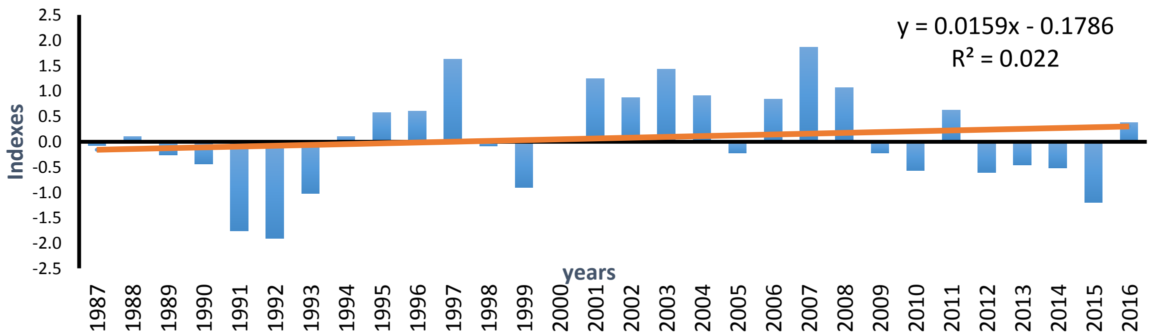

Fig. 5. Inter-annual variabilities of precipitations in low elevation, from 1987 to 2016

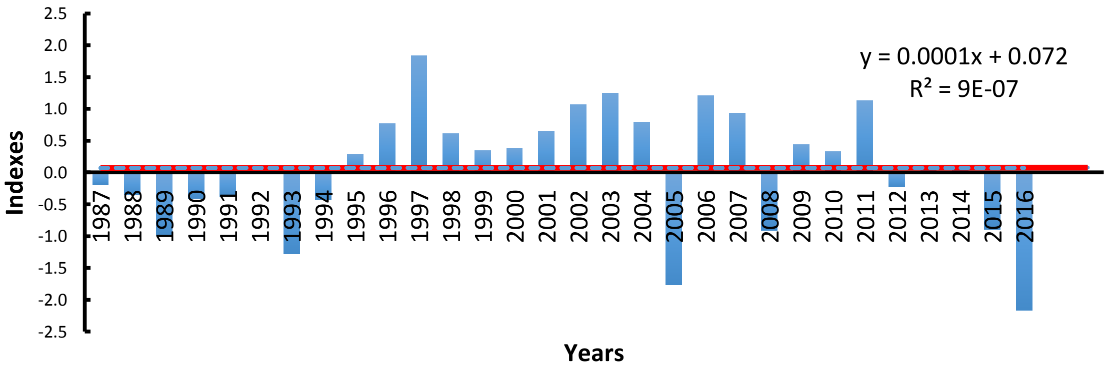

Fig. 6. Inter-annual variabilities of precipitations from 1987 to 2016 for medium elevation

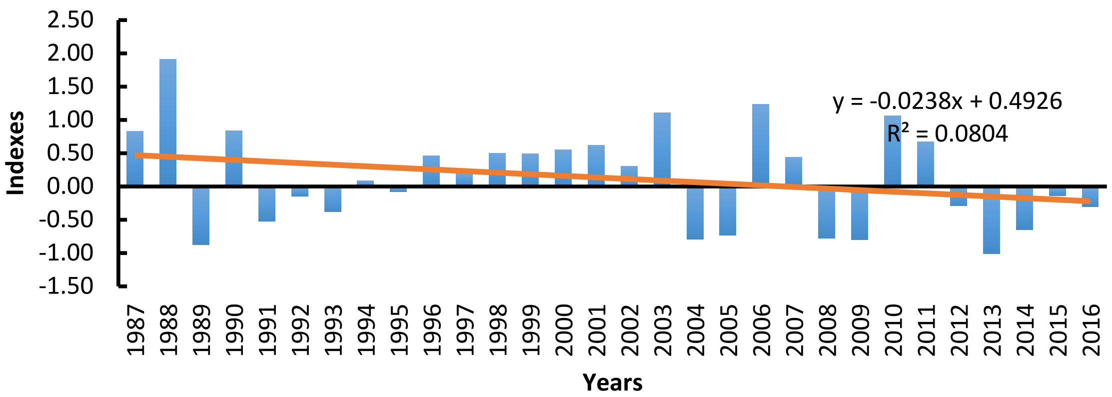

Fig. 7. Inter-annual variabilities of precipitations from 1987 to 2016 for high elevation

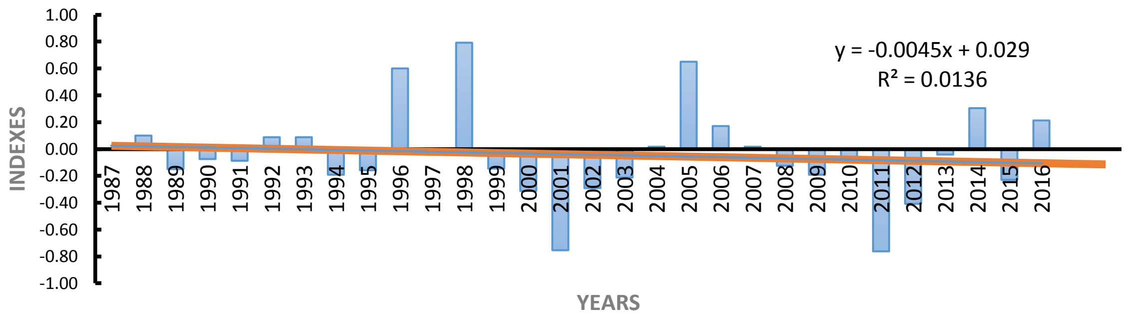

Fig. 8. Low elevation temperature evolution trend from 1987 to 2016: Cold and hot years

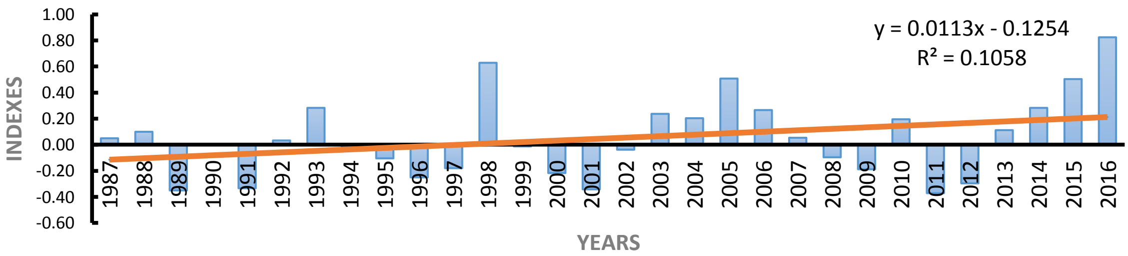

Fig. 9. Medium elevation temperature trend evolution for 30 years: Cold and hot years

For high elevation, as it is illustrated by Fig. 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.

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 (Fig. 11). Furthermore, 100%, 95% and 58% of respondents from low, medium and high elevations respectively stated that the weather became warmer (Fig. 12).

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 (Fig. 13). Moreover, 95%, 54% and 43% of respondents from Low, Medium and high elevations respectively stated that the weather became wetter (Fig. 14).

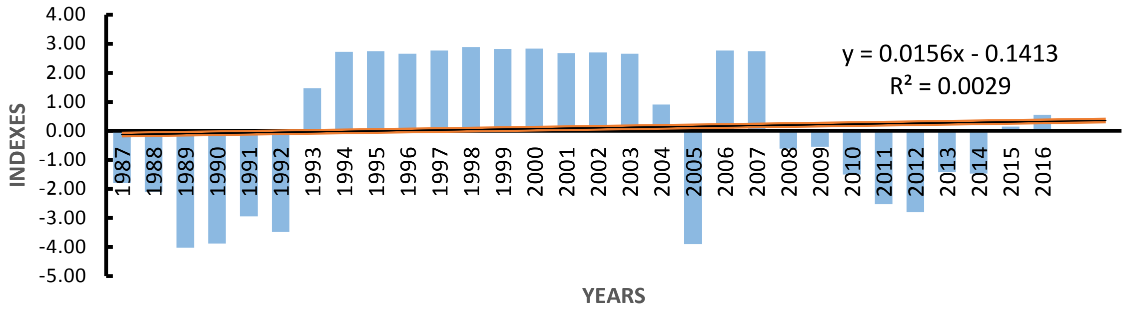

Fig. 10. High elevation temperature trend evolution for 30 years

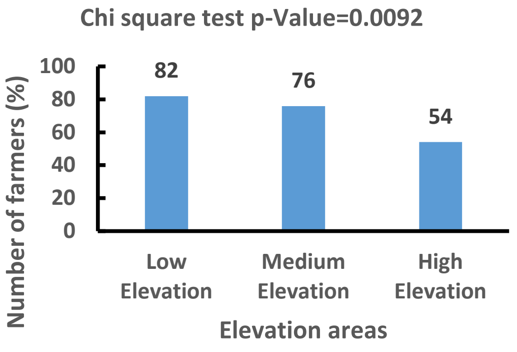

Fig. 11. Graph showing how farmers noted long-term shift in temperature in their farms

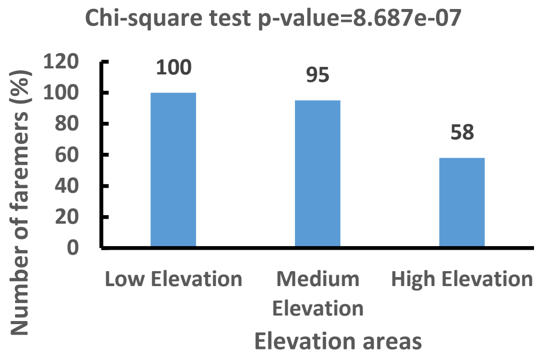

Fig. 12. Number of farmers noted if shifting of weather from cooler to warmer

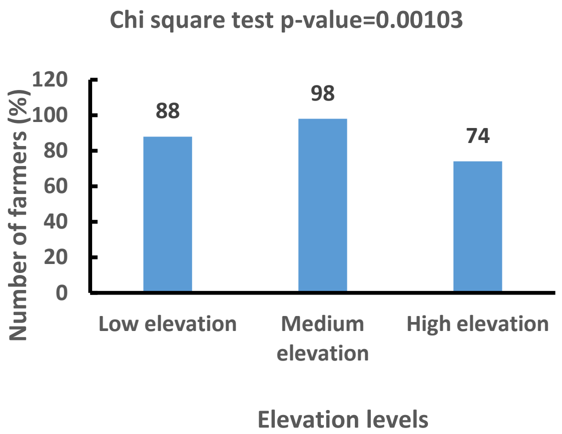

Fig. 13. Number of farmers confirming long that shift-terms in precipitations during years ago last

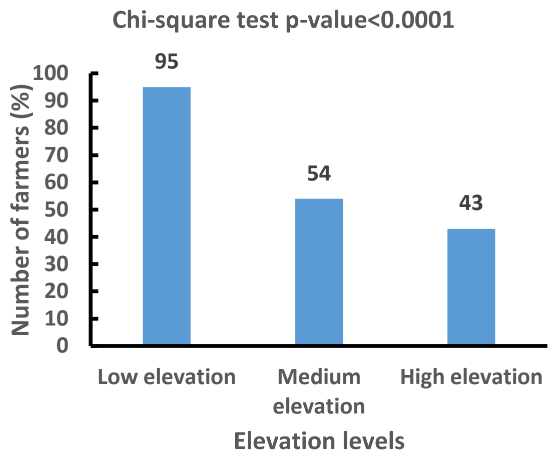

Fig. 14. Number of farmers having reported weather was becoming wetter during years

4. DISCUSSION AND CONCLUSIONS

This study proved that from 1987 to 2016 climate was changed in Rwanda. Rainy periods' length is variable (two or three dry months) depending on elevation area. Annual precipitations were reducing at high elevation site and increasing in medium and low elevation sites, with annual variability. Temperatures were increasing in high and medium elevation sites while decreasing in low elevation site. High elevation areas are wetter and cooler, and they are becoming drier and warmer. The low elevations are drier and warmer and they are becoming wetter and cooler. Therefore, annual precipitations and temperature variabilities were raised by the study. Above results found by different analytical methods were confirmed by interviewed farmers. This study is important to know climate conditions for potato productivity system in Rwanda. It is predicted that temperature amplitudes will increase in the future and will have effect on potato pests and pathogens [22]. Previous studies demonstrated that temperature amplitude impacts positively potato late blight disease [23]. Elevated temperatures (20-30°C) reduce potato tuber numbers and photosynthesis up to 20%, and shift biomass from tubers to leaves [24]. Potato need temperature for tuber formation, general at 20°C as optimum [25]. Many studies predicted climate variability impact on different crops including potato [26]. 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 [4]. The three months constitute an off- short and dry season between two rainy seasons which are suitable for potato production in the country [10] Found rainfall averages are 1324.1mm, 1273.2 mm and 929.3 mm respectively in medium, high and low elevations. Annual rainfall on all Rwandan territory in around 1250 mm [16,10]. South-Eastern part (low elevation area) of the Country is characterized by drought and rainfall between 700 and 970 mm per year and North-Western part (high elevation area) is recognized by abundant rainfall [16]. Eastern province, including low elevation study area (Kayonza district) receives between 740-1130 mm annually [18]. High precipitations are found in Congo-Nile region holding medium et high elevation study area [4]. The study found rainfall 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 1066mm) in all Rwandan provinces [9]. Severe drought was reported in 2000 and floods were noted in 1997, 2006, 2007, 2008 and 2009 through Nicholson index [10], the mostly yearly wetness 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 [18]. 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 [16]. 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 [4]. The same author reports that South-Eastern part of the country (low elevation) is warmer and drier with temperature varying between 21.7-22°C. 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 [27]. Between 2040-2069, temperature is pretended to 1.7°C increase on all Rwandan territory [9] or to between 1.3-1.9°C [4]. The temperature increasing in high elevation area could due deforestation of Gishwati and Virunga Park for agricultural activities extension. The decreasing of temperature in low elevation area could be due to afforestation national Program, aiming to increase agricultural productivity in that area. Through above findings, potato growth cooler and wetter conditions are shifting from high to low elevations. As strategy for climate change mitigation, Rwanda needs to promote potato in Est, the lower elevation region, in order to increase the crop production in the future. Father researches are recommended to know impact of weather factors (temperature and rainfall) on potato productions for supporting the suggested strategy in this study.

CONSENT AND ETHICAL APPROVAL

Interviews were done after farmer consent. 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).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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