UNIVERSITY OF NAIROBI

ASSESSING EFFECTS OF CLIMATE VARIABILITY AND CHANGE ON THE ONSET AND CESSATION DATES OF SEASONAL RAINFALL IN KENYA

BY

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DECLARATION

I declare that this dissertation is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work, or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements

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DEDICATION

I dedicate this dissertation to my family members.

ACKNOWLEDGEMENT

I would like to thank the Almighty God for the great gift of life He has bestowed on me so as to complete writing my dissertation. He has showered His Blessings upon me and without His Grace I surely would not have made it this far.

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ABSTRACT

Climate change has great impact on various sectors that are dependent on rainfall. As a result of increased global warming due to continuous emission of greenhouse gases into the atmosphere, the influence of climate change on human activities is great especially those dependent on rainfall for agriculture production. The IPCC fifth assessment report indicated that increase in the frequency and/or magnitude of climate related disasters such as flood and droughts could be linked to some of the impacts that climate change impose on human activities around the world. This study has therefore focused on assessing effects of climate change on the onset and cessation dates of seasonal rainfall over Kenya. To achieve this, the study aimed at determining the current climate variability and trend of onset and cessation dates based on gauged observations, evaluating the skill of CORDEX RCA4 models in simulating onset and cessation dates and determining the future climate variability and trends of onset and cessation dates from CORDEX model projections for the RCP4.5 and RCP8.5. Onset date was defined as 1st day from 1st March and 1st October for long and short rains respectively with at least a total rainfall of 20 mm while cessation was defined as the date after 1st May for MAM and 1st December for OND when the supply of water to the soil becomes null and after which there is no rainfall for the next ten days.

The study used CHIRPS and CORDEX data sets to determine the past and future variability and trends of onset and cessation dates for seasonal rainfall over Kenya. The CHIRPS data period was from 1981-2010 and CORDEX data was from 1976-2005 for baseline and 2021-2050 for projections. The CORDEX data used were from CNRM, ICHEC, MPI and their ensemble. Future variability and trends onset and cessation dates were determined based on RCP4.5 and RCP8.5 scenarios for the period 2021-2050. Mean and standard deviation were calculated to determine both current and future variability of onset and cessation dates. Mann Kendall was used to determine the trends of onset and cessation dates. Root Mean Square Error (RMSE) and Pearson correlation coefficient methods were used to assess the skills of the models.

The results showed high variability of onset dates (ranging from 5-17 days) compared to cessation dates (ranging from 4-15 days) for both MAM and OND seasons for the period 1981-2010. The results further showed high variability in MAM season compared to OND season for both onset and cessation dates for the period 1981-2010. Skill assessment results using RMSE method showed low RMSE values for ensemble model compared to individual CNRM, ICHEC and MPI model in simulating onset and cessation dates of seasonal rainfall. The performance of ensemble model based on Pearson correlation showed varying correlation coefficients values compared to other three GCM models. Going into the future, the results showed that the onset dates have higher variability than the cessation dates for both MAM and OND seasonal rainfall based on both RCP4.5 and RCP8.5. Results also showed that based on the RCP4.5 projections, more regions will experience insignificant negative trends for both MAM and OND onset dates compared to RCP8.5 projects that showed that more regions will experience insignificant positive trend for the MAM and OND onset dates. Therefore, with these kind of results, there is need for climate users like farmers to work closely with the climate producers through consultation in order to have a clear information on when seasonal rainfall will begin and end.

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ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Land
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Couple Model Inter-comparison Project Phase 5
CNRM	Center National de Recherches Meteorologiques
CORDEX	Coordinated Regional Downscaling Experiment
ECHAM 4.5	European Centre Hamburg Model Version 4.5
ECMWF	European Centre for Medium-Range Weather Forecasts
GCM	Global Climate Model
GHA	Greater Horn of Africa
GMet	Ghana Meteorological Agency
ICHEC	Irish Center for High-End Computing
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institute Pierre Simon Laplace
ITCZ	Inter Tropical Convergence Zone
KNBS	Kenya National Bureau of Statistics
MAM	March-April-May
MIROC	Model for Interdisciplinary Research on Climate
MPI	Max Planck Institute for Meteorology
NN	Nearest Neighbor
OND	October-November-December
RCA4	Rossby Centre Regional Climate Model Version 4
RCP	Representative Concentration Pathway
RMSE	Root Mean Square Error
SSA	Sub-Saharan Africa

CHAPTER ONE: INTRODUCTION

1.0 Background Information

The influence of climate change on human activities is great especially those that are dependent on rainfall such as agricultural production and this is anticipated to increase with continuous rise in global warming. The increase in the frequency and/or magnitude of climate related disasters like flood and droughts could be linked to some of the effects that change in climate imposes on human activities around the world (IPCC, 2013). Climate change is understood as the change in the long-term average of climate elements over a longer duration of time. Over the past several years, human activities have interfered with global climatic system characteristic through increased emission and this has led to great interference with the precipitation amount in many regions (Diaconescu *et al*., 2015). However, it's significant to take into consideration that water is a major element for crops and therefore, this means that many plants or crops uses water for nutrient transportation within their system.

Among the different climate elements, rainfall is one of the parameters that has a great or significant impacts on socio-economic wellbeing among the larger population that are dependent on rain-fed agriculture (Recha *et al*., 2012). In East Africa, two rainy season are being experienced. These are the long rain that occurs from March to May and the short rain that occurs from October to December. The two rainy periods are linked with the shift of the Inter Tropical Convergence Zone to the south as well as to the north of the equator. The two rainy season are important for farmers who fully rely on rainfall for their agricultural activities. According to Camberlin *et al.*, (2009), the long and short rain seasons display substantial inter-annual variation of onset which has been attributed to the pressure gradient that exist between Atlantic Ocean and Indian Ocean. The rainfall experience during the long rains depends mostly on the onset dates as compared to cessation dates (Camberlin and Okoola, 2003).

The shift of the Inter Tropical Convergence Zone (ITCZ) either to the north or south of the equator affects the onset of the precipitation in during the two rainfall seasons. According Nicholson (2018), delay in the ITCZ shift from the south to the north due to the low pressure in the southern hemisphere will results in delayed onset for long rains while delayed shift of ITCZ from north to south would influence the rainfall onset for the short rain season. The movement of the ITCZ to the north and south of the equator is linked to the sun's position on the northern and southern hemisphere.

In Kenya, there are different sectors that depend of rainfall such as the agricultural sector. This means that precipitation timing and seasonality is of great significance to many stakeholders/sectors in Kenya and Africa at large who rely on seasonal rains for domestic and agricultural purposes (Diaconescu *et al.*, 2015). According to Vizy *et al.* (2015) delays in seasonal rains could results to socio-economic impacts especially among people who have their livelihoods dependent on the seasonal rainfall. Future effects of climate change will not only be evident on the changes in mean rainfall, but it will also result into alteration of seasonal rainfall in terms of early or late onset and cessation dates of rainfall season. This would lead to great impacts on the crop yield as well as growing seasonal length. Besides, the future changes in climate will also have impact on the length or duration of malaria transmission, surface water supply and hydroelectric power supply (van Vilet *et al.*, 2016).

It is essential to understand the need to predict the start of the seasonal rainfall effectively and also to understand forthcoming climate change influences on the cessation and onset dates of rainfall for effective planning particularly for activities that are reliant on the onset and cessation of seasonal rainfall (Mugalavai *et al.,* 2008). The dates for onset and cessation of seasonal rainfall are significant especially to farmers who depend on rainfall. According to Vizy *et al.* (2015), climate change has triggered great impact on the distribution of rainfall across Sub-Saharan Africa (SSA) and this is evident through more or less precipitation than what farmers have been used to. Besides, there other sectors that also rely on rainfall and therefore, there is need to comprehend the future effects of climate change on the cessation and onset of rainfall since this help in determine the growing season length.

1.1 Statement of the Problem

According to the IPCC (2013), climate change will have influence on the precipitation within the East Africa and this include having an increased rainfall intensity and variation in the duration of the seasonal rainfall. Many sectors in Kenya rely on rainfall such as the agricultural sector. Close to 60% of Kenya’s economy is greatly reliant on rain-fed agriculture (Bryan *et al.*, 2013). With impacts of climate change are becoming more evident, it will be essential to understand how future onset and cessation dates will behave given that most activities are rainfall dependent. Also, there is not adequate information in relation to how climate change would influence the onset and cessation dates of seasonal rainfall.

1.2 Objective of the study

The main study objective was to assess the effects of climate change on the onset and cessation dates of seasonal rainfall in Kenya. To attain this main objective, the subsequent specific objectives were formulated;

i. To determine the current climate variability and trend of onset and cessation dates of seasonal rainfall over Kenya based on gauged observations
ii. To evaluate the skill of Coordinated Regional Downscaling Experiment using Rossby Centre Regional Climate Model (CORDEX RCA4) models in simulating onset and cessation dates of seasonal rainfall over Kenya
iii. To determine the future climate variability and trends of onset and cessation dates of seasonal rainfall over Kenya derived from Coordinated Regional Downscaling Experiment model projections for the RCP4.5 and RCP8.5

1.3 Justification of the study

IPCC fifth assessment report (2013) indicates that by the year 2050 there will be a decline in the yield of crops in numerous parts of the Sub-Saharan Africa (SSA). This is expected to push a huge number of people who are poor into deeper vulnerability and poverty since they rely on agriculture as the basis of livelihood (Diaconescu *et al.*, 2015).

Bryan *et al.* (2013) indicated that about 60% of the economy of Kenya depends on the rain-fed agriculture. The yield of crops such as maize which is mainly grown in the rainy season depends on onset timing and end of the seasonal rains and its distribution. Besides agricultural sector, there are other sectors such as tourism that need to understand the onset and cessation dates of seasonal rainfall for the purpose of planning outdoor activities. Also, the hydropower generation firms need the information on onset and cessation dates in order to plan on dam management in terms of releasing water back to the rivers. Therefore, as a country, it is essential to evaluate the effect of climate change on the onset and cessation of rainfall for the purpose of planning in the sector of agriculture and other sectors that depend on rainfall (Dunning *et al.*, 2016). Besides, it will be important for the farmers to have knowledge on how change in climate will have effect on the rainfall onset and cessation for the purpose of making valuable decisions on when to start planting and other farm activities. Therefore, Kenya being a country that depends rainfall for agricultural production and other socio-economic activities, early/late onset coupled with early/late cessation will determine the food production and also economic growth of other sectors dependent on rainfall. The study will help in assessing the effect that climate change will have on the dates of seasonal precipitation onset and cessation in Kenya.

1.4 Study area

The area of current study is Kenya and it is about 586, 646 km^2. Kenya is positioned on the eastern side of Africa within the latitudes 5.5^{o}N to 5^{o}S and longitude 34^{o}E to 42^{o}E. Kenya has a population of 49.7 million (KNBS, 2019). Kenya has large lakes like Lake Victoria and Great Rift Valley and also has complex topography stretching from Coastal lowlands to snow-capped mountains, Elgon (4321 m) and Kenya (5199 m).

Kenya has about 80% of its landmass categorized as arid and semi-arid (ASAL) (Recha *et al.*, 2012). There are two rainfall seasons experience in Kenya namely the long rains (March-April-May) and short rains (October-November-December). Also, Indian Ocean borders Kenya to the southeast as indicated in the Figure 1. To the west Kenya boarders Uganda, to the south it boarder Tanzania, to the east it boarder Somalia and to the north it boarder Ethiopia.

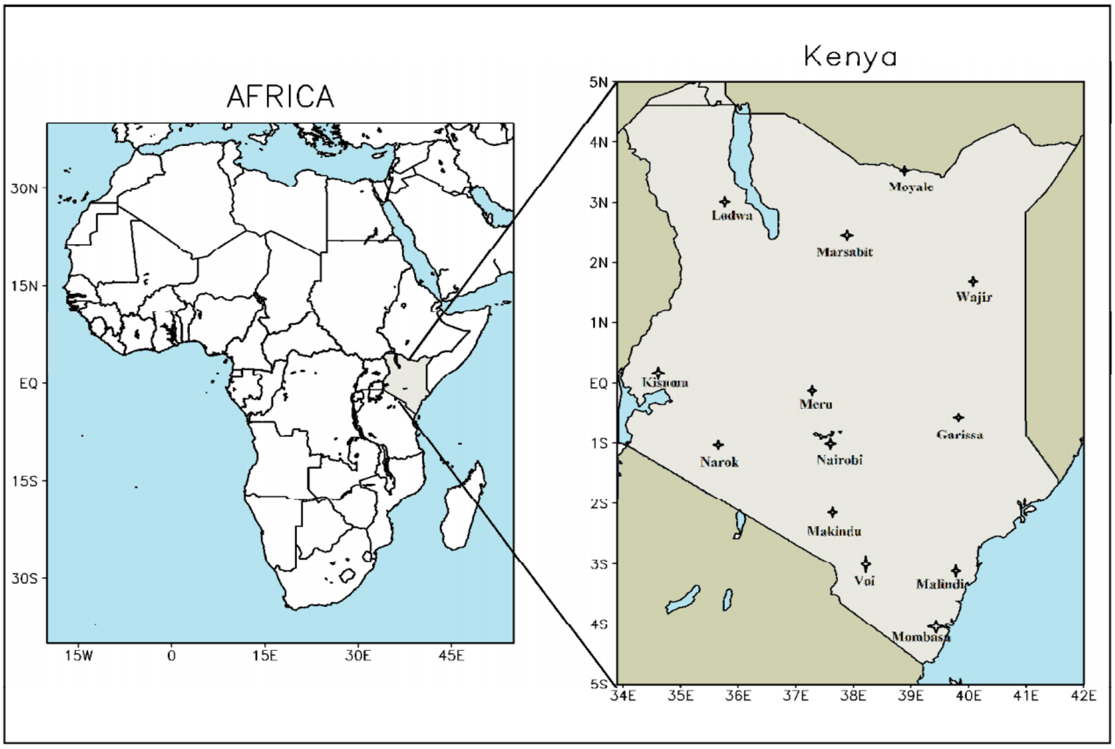

Figure 1: Study area showing the location of Kenya in Africa continent (source: Ayugi et. al., 2016)

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The chapter reviews the relevant literature regarding cessation and onset dates of seasonal rainfall. The chapter similarly examines the various studies carried out over different regions that focuses on the future onset and cessation dates of seasonal rainfall.

2.1 Variability and trends of onset and cessation dates of seasonal rainfall

According to Lima and Lall (2009), the rainfall onset, peak and cessation in Brazil was determined using hierarchical Bayesian modeling of day-to-day rainfall occurrence from multisite. The onset of rainfall was determined by identifying the year's first day through which the approximated rainfall likelihood is larger than stated number such as 0.5. The same procedure was applied establish the end of rainfall season.

Edao *et. al.*, (2018) carried out a study in the Ethiopian semi-arid central rift valley to analyze the start, end and growing season length. The study used three rainfall stations (Mieso, Melkassa, and Adami Tulu) in the region and the result findings showed a high variability for the rainy days. This called for the need for more attention to be given to crop variety genetic management and different agronomic practice.

A study by Mbogah (2015) in Tanzania emphasized on the need to take into consideration the different variability values of onsets when looking at different farming practices in various regions. Different variability values will be critical towards understanding which regions fall on high, moderate or less variability and thereby informing valuable decision making in terms different farming practices.

According to MacLeod (2018), there is limited attention by the scientific community or scholars on onset and cessation over the East Africa and this means that further studies should be undertaken in order address the knowledge gap. Over Kenya and Tanzania, the onset and cessation is well correlated throughout the short rains (October-November-December) as compared to long rains (March-April-May).

Camberlin and Okoola (2003) undertook a study on the long rains onset and cessation in eastern Africa and its inter-annual variability. The study found out that on average over the years 1958-1987, onset occurred on March 25th and the cessation on 21st May (for the long rains) which gave duration of no more than 57 days. They also found out that for the period 1958 to 1987, there was a small increase in trend signifying a late rainfall onset. The study considered only long rains season.

In Kenya alone, approximately 300 mm is received by 72% part of country for the period March-May rainfall season (Kisaka *et al.*, 2015). In relation to this, variations in total rainfall amount, onset/cessation or intra-seasonal rainfall distribution may pose a difficult coping mechanism for the farmers in the East Africa (Mapfumo *et al.*, 2013). Apart from the seasonal amount of rainfall, the rainfall timing has strong effects on yield of crops and other agricultural activities.

Ngetich *et. al.*, (2014) carried out a study in the Kenyan highland to determine the rainfall pattern and this focused on onset, cessation, rainfall distribution and length of growing season in the semi-arid and tropical sub-humid region in the central highlands of Kenya. In this study, the seasonal onset was late for low altitude regions compared to regions in the highlands. However, for OND rainfall season the temporal and spatial variability were narrow compared to the long rain season.

Therefore, despite different studies looking at rainfall onset and cessation variability and trends for different seasons separately, this study focused on looking at the past trend and variability of onset and cessation dates for both MAM and OND seasons for a period of 1981-2010 for different rainfall homogenous zones over Kenya.

2.2 Model comparison in simulating variability and trends of onset and cessation dates of seasonal rainfall

In a study to assess the skills of three model in simulating temperature and rainfall over Murray-Darling basin in Australia, Maxino *et al.* (2008) used the probability density function to undertake the exercise. The results showed that the three models which include MIROC-M, CSIRO and IPSL has a good match with the observed data for the temperature, both minimum and maximum, and rainfall parameters.

Odongo and Mugume (2019) used the RMSE and Pearson Correlation Coefficient to assess the simulation skill of Weather Research and Forecasting (WRF) model in Uganda. Using the Pearson correlation, the model showed a mixture of positive and negative correlation coefficients and this implied that the WRF model was simulating either early or late onset dates for September to December rainfall period.

In a study to assess the CODEX model capability in simulating onset dates over West Africa, Mounkaila *et al.* (2015) in their study used nine RCMs that were used in CORDEX-Africa experiment. The results indicated that the nine RCMs gives simulation of onset dates that are realistic over West Africa when compared to the observed data.

In a study with a focus on comparing various approaches to evaluate climate models, Schaller *et al.*, (2011) found a positive correlation between observed data and 7 CMIP3 models. The results further revealed that six out seven models had a significant agreement with the observed data. This informed that the CMIP3 models can be effectively used to project the future rainfall.

Nikulin *et al.* (2012) in their study focusing on regional climate simulation using CORDEX-Africa ensemble found that the RCMs have a tendency of overestimation of precipitation during the onset and thus showing too early start of seasonal rainfall. Also, various RCMs indicated early onset for the West Africa Monsoon rainfall.

Validation of the model data is essential towards determining the performance of the data in relation to the observed data. A study by Mensah *et. al.*, (2016) in Ghana focused on comparing the rainfall onset and cessation from GMet and RegCM4 datasets. In this study, RMSE and Pearson correlation were used to compare the GMet and RegCM4 datasets and the study results showed the seasonal rainfall onset and cessation from GMet and RegCM4 datasets had positive correlation using Pearson correlation coefficient and RMSE. The Pearson correlation values from the study ranged between 0.4 to 0.8, however, there was a record of both positive and negative correlation values within the coastal region of Ghana. In addition, a good agreement between GMet and RegCM4 datasets especially for the seasonal rainfall cessation dates was found.

Mwangi (2010) used Pearson correlation coefficient and RMSE to assess the ECHAM 4.5 skills in simulation seasonal rainfall over the Greater Horn of Africa (GHA) location. The study looked that period from 1961 to 2008 and the results indicated that there were smaller RMSE values and larger coefficient of correlation for regions around equatorial sector. Also, the results further revealed that model matched well for OND season than the MAM season.

In a study to assess the predictability of seasonal rainfall onset and cessation over the east Africa region, MacLeod, 2018 used Pearson correlation to compared observed and forecasted onset and cessation anomalies. The study results showed a statistical significance level of 95 percent for a small domain section during the long rains while for over large part of the region they are significant for short rains onset and cessation. For the short rains, early onset detection is better around the coast, and detection of late onset is better over northwestern Kenya. Therefore, this means that the use Pearson correlation coefficient can be effectively used to compare the model and observed onset and cessation dates for seasonal rainfall.

2.3 Variability and trends of onset and cessation dates of seasonal rainfall projections

A study by Sylla *et al.* (2015), suggested changes on seasonal rainfall onset/cessation dates by analyzing variations in the amount of precipitation in the transition months at the beginning and end of wet season. Park *et. al.* (2016) carried out analysis on the future growing season projection in Africa. This was done using a solo regional climate model with the boundary conditions determined using a nine climate model simulation output from the models' generation from phase 3 of the Coupled Model Inter-comparison Project (CMIP3). The study found out that there is longer growing season in eastern and central Sahel. Also, the study found that there is reduction growing season length over parts of western Sahel and southern Africa.

According to Feng *et. al.* (2013), future changes in the patterns of tropical circulation could have an alteration in rainfall seasonality and hence, this may lead to greater uncertainty in the rainfall timing in Greater Horn of Africa and to the larger Africa continent. Dunning *et. al.* (2016) indicates that it is important to clearly understand the change and variability in order to critically interpret the recent changes in the onset and cessation of seasonal rainfall in Africa.

Dunning *et. al.* (2018) found out that there is an earlier projection for cessation for long rains and late onset for short rains over the Horn of Africa. However, some of these changes are significant statistically over smaller areas and also on average they are less than a week. The analysis was carried out based on RCP4.5 and RCP8.5. Based on CMIP5 projection, there is variation timing for seasonal rainfall in various parts of the Africa. For instance, in the Horn of Africa, there is an increases rainfall during the short rains and this is accompanied by late cessation dates for the season.

Variation in onset and cessation has great influence on crop production over East Africa. A study by Msongaleli *et al.*, (2017) showed a mixture of significant and insignificant trends rainfall onset, cessation and growing season length over central Tanzania. This had a significant effects of sorghum yields in the region. Further analysis showed that future sorghum yields in central Tanzania will be overridden and this will be attributed to increased rainfall variability which is directly linked to rainfall onset and cessation variability. In this study, it was recommended that farmers and other key stakeholders pay great attention to advanced warning of either late or early onset and cessation dates for seasonal rainfall in the region.

MacLeod, (2018) carried out a study focusing on assessing the seasonal predictability of onset and cessation dates over the East Africa region. In this study, MacLeod used European Centre for Medium-Range Weather Forecasts (ECMWF) model which showed a significant skill in forecasting failure of long rain season over the northwest part of Kenya and failure in short rain season in northeast Kenya and Somalia. Study finding also showed that late cessation dates is correlated with westerly anomaly for the short rains and easterly anomaly for the long rains. However, the spatial pattern and strength of relationship is not well taken into consideration in the model. On the other hand, early cessation dates for the short and long rain season was correlated with easterly anomaly within the east Africa region.

In Kenya, studies that have been carried out focused on looking at past variability of seasonal rainfall onset and cessation dates. However, from the literature review, no study has focused future climate change impacts on seasonal rainfall onset and cessation dates. Therefore, this will focus on providing more information on how climate change will affect onset and cessation dates of seasonal rainfall which is very critical for different sectors that relies on rainfall for planning purposes.

CHAPTER THREE: DATA AND METHODOLOGY

3.0 Introduction

This chapter focuses on the data and various methodologies that have been used to attain results for main and specific objectives in the study.

3.1 Data

The study used daily rainfall data to achieve the study objectives. The datasets used were from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) daily rainfall and Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa.

3.1.1 CHIRPS Daily Data

Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) has rainfall data for a period of over 30 years. The dataset has a coverage from 50°S-50°N and all longitudes. The dataset starts from the year 1981 all the way to the near present. CHIRPS datasets are at 0.05° resolution satellite imagery that incorporates in-situ station data to generate gridded rainfall time series for analysis of trend as well as monitoring of seasonal drought. CHIRPS datasets provides essential information for regions in the tropics and also areas that are poorly monitored as alternative to gauge-based products (Funk *et al*., 2015).

The daily rainfall was extracted for station representing different rainfall homogenous stations as shown in Figure 2. According to Paredes-Trejo *et al.* (2020), CHIRPS data can be extracted using the nearest neighbor (NN) method. The method is preferred since there is less uncertainties due to inadequate coverage of gauge-based stations in a given region or study areas. The CHIRPS data was used to determine the onset and cessation dates in the past and analyze trend and variability for the onset and cessations during MAM and OND rainfall season. The study used CHIRPS daily rainfall data for a period of 30 years from 1981 to 2010.

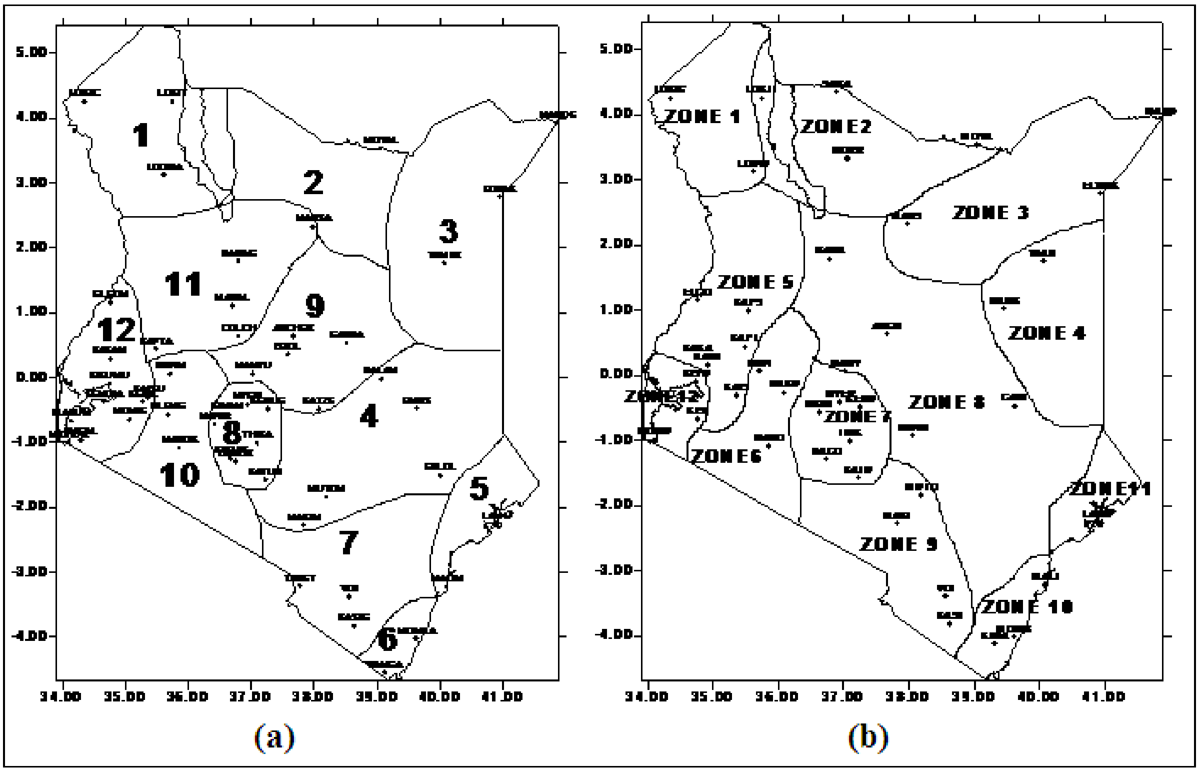

Figure 2: Homogenous zones for rainfall over Kenya for MAM (a) and OND (b) rainfall seasons (Source: Kenya Meteorological Department Rainfall Atlas 2004)

3.1.2 CORDEX datasets

The baseline period for the model data used was extracted for the period 1976 to 2005. The projected daily rainfall data was also extracted from Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa for a period from 2021 to 2050. Three GCM models were used and these were Max Planck Institute for Meteorology (MPI), Irish Center for High-End Computing (ICHEC) and Center National de Recherches Meteorologiques (CNRM). CORDEX is a project that coordinates the dynamical downscaling of Global Climate Model (GCM) datasets to regional scales using specified domains over the entire globe. The data from the three GCMs MPI, ICHEC and CNRM were downscaled using Rossby Centre Regional Climate Model (RCA4) (Shongwe *et al*., 2015). A baseline data for the period 1976-2005 from the CORDEX was also used to assess the past onset and cessation for the seasonal rainfall by comparing with observed data. Daily rainfall data from CORDEX was used to assess the future effects of climate change on the onset and cessation seasonal rainfall in Kenya for the period 2021-2050. Couple Model Inter-comparison Project Phase 5 (CMIP5) has 8 GCMs and three of them were used in the study. CNRM model was developed by Centre National de Recherches Météorologiques for simulation of climate variables. The CNRM is able to simulate current climate on timescale ranging from daily to centuries. MPI model was developed by Max-Planck-Institute for simulating both historical and future climatic conditions. ICHEC model was developed by Irish Centre for High-End Computing in collaboration with other partners. The model was useful in the projection future climate scenarios. The ICHEC model has standard calendar and this implies that all dates are taken into consideration respective of the leap year.

A study by Alemseged and Tom (2015) in Upper Blue Nile basin focusing on regional model evaluation of rainfall recommended the use of MPI and MOHC models for rainfall analysis. Gabiri et al. (2020) in their study focusing on land use and climate change effects on water resources in Uganda used CNRM model to understand future climate change impacts on water resource. In their study, CNRM model was found to be suitable for rainfall analysis over the East Africa region. Muhati et al. (2018) also used CNRM model in understanding projected temperature and rainfall trend in sub-humid Montane Forest in Northern Kenya. Gadissa et al. (2018) further recommended the use of ICHEC model over the East Africa regions.

The study used RCP4.5 and RCP8.5 to assess future effects of climate change on onset and cessation of seasonal rainfall in Kenya. According to Gadissa *et al.* (2018) and Alemseged and Tom (2015), RCP4.5 and RCP8.5 scenarios are used since CORDEX-Africa prioritized them. RCP4.5 is critical in understanding the climate scenario taking into considerations the different measures put in place to reduce emission of greenhouse gases into the atmosphere (IPCC, 2013). RCP8.5 is based on a scenario that limited or no measures are put in place to reduce emission of greenhouse gases into the atmosphere. Therefore, this informs the need to assess the effects of climate change on onset and cessation dates of seasonal rainfall using the two RCPs.

3.2 Methodology

This section shows the methodology that was used to address each specific objective of the study.

3.2.1 Determining the variability and trends onset and cessation dates of seasonal rainfall over Kenya based on based on gauged observations and projections

This section shows the criteria used to define onset and cessation dates and also methodology for determining the variability and trends of onset and cessation dates of seasonal rainfall over Kenya.

3.2.1.1 Criteria for determining onset and cessation dates of seasonal rainfall

According to Adelekan and Adegebo (2014) and Mensah *et. al.* (2016) the seasonal rainfall onset date was defined as 1^{st} day from 1^{st} March and 1^{st} October for long and short rains respectively with at least a total rainfall of 20 mm. The onset criteria are as follow,

i. At least rainfall total of 20 mm recorded in the five consecutive days of observation
ii. At least three days in five received rainfalls not less than 1 mm
iii. The thirty days following the start day must not have a dry period of seven days or more

The long and short seasonal rainfall cessation date was defined in relation to the following criteria;

According to Kasei and Afuakwa (1991) and Tadross *et al.* (2009), the cessation date was defined as the date after 1^{st} May for MAM and 1^{st} December for OND when the supply of water to the soil becomes null and after which there is no rainfall for the next ten days. The holding capacity of soil water was fixed at 60 mm. Bosire *et. al.*, (2019) in their study adopted the definition of cessation dates to analyze climate trends, variability and its implication on crop production over Machakos County.

3.2.1.2 Determination of Mean and Standard Deviation – variability

In order to understand the variability of seasonal rainfall onset and cessation dates through number of deviation days, the standard deviation and mean were calculated as shown in Equation 1 and 2. A study by Camberlin *et. al.* (2009) determined the onset and cessation dates variability through determining the standard deviation of the seasonal onset and cessation dates. This enabled understanding of number of deviation days for seasonal rainfall onset and cessation dates.

$$Standard\ deviation\ (s) = \sqrt{\frac{\sum(X_i - \bar{X})^2}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where;

- s is the standard deviation
- X_i is the onset/cessation dates
- $\bar{X}$ is the mean onset/cessation dates

- n is the length of the sample

$$Mean = \frac{\sum X_i}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where;

- X_i is the onset/cessation dates
- n is the length of the sample

3.2.1.3 Mann Kendall

Mann-Kendall is a non-parametric statistical approach for testing the increasing and decreasing trends of a given parameter. Mann-Kendall test is normally used for monotonic trend detection in environmental data series, hydrological and climate data (Macharia and Raude, (2017). Mann Kendall method has two advantages when used and first is that it is a nonparametric test and does not need a normally distributed data. Secondly, it has low sensitivity to sudden breaks because of inhomogeneous time series. Therefore, Mann Kendall was used to detect the trends of the onset and cessation dates of both MAM and OND rainfall as shown in Equation 3. The Mann Kendall results show either positive or negative trend of the onset and cessation of seasonal rainfall.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(X_j + X_k\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

Where **S** equals Mann-Kendall test value; X_k and X_j are the progressive data values; k, j and n are data length. When S is positive, it implies that trend is increasing and when S is negative, it signifies that trend is decreasing.

Also, the standard normal statistic test Z_s was calculated as indicated in Equation 4;

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & if\ S < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. 4$$

According to Arslan *et al.* (2017), negative Z_s values signifies a decreasing trend and positive Z_s values signifies increasing trend. The study used a significance level of $\alpha = 0.05$ to effectively test the trend and therefore, null hypothesis of no trend in onset and cessation dates was rejected and a significant trend was in existence in the time series for $|Z_s| > Z_{1-\alpha/2}$

3.2.2 Evaluation of the CORDEX RCA4 models skill in simulating variability and trends of onset and cessation dates of seasonal rainfall in Kenya

In order to effectively evaluate the skills of the CORDEX models, the CHIPRS data was re-gridded. The CHIRPS data were re-gridded from finer resolution to coarse resolution of the CORDEX model in order to allow effective comparison of observed data and model data under the same resolution. The study used the kriging method to grid the data. According to Jamaludin and Suhaimi (2013), kriging technique is preferable because most of the researchers identified that kriging can give a more accurate results for interpolation of daily rainfall data. The method provides some measures of precision of the predictions data, and also be able to produce a prediction surface.

Therefore, to achieve this specific objective, the study used Root Mean Square Error (RMSE) and Pearson correlation coefficient to assess the skill of CORDEX to simulate onset and cessation dates of seasonal rainfall over Kenya. The evaluation of the models skill was done for the period 1981-2005.

3.2.2.1 Root Mean Square Error (RMSE)

The root mean square error is always used to determine the difference between actual observed values and simulated values (MacLean, 2005). The RMSE values ranges from zero to infinity and the perfect score is always at zero (0). According to Colston *et al.* (2018), zero value implies that there is perfect lack of error, however, values closer to zero indicate that the model predicts closely with observed values. Therefore, the lower values of RMSE show that the simulated values are closely matching with the observed values. The RMSE Equation is as shown in Equation 5;

$$RMSE = \sqrt{\frac{1}{n}\sum_{i}^{n}(S_i - O_i)^2} \quad \ldots\ldots\ldots 5$$

In Equation 5 O_i and S_i are the i^{th} observed value and i^{th} simulated value respectively and on the other hand, n is number of simulated-observed pairs.

3.2.2.2 Pearson Coefficient of Correlation

The Pearson correlation coefficient measures the relationship strength between the observations and the simulation of the model and there is a limit of -1 and 1 (Gebrechorkos *et al.,* 2018). A correlation coefficient of -1 indicates that perfect yet negative association between the observed and model data, while the coefficient of 1 indicate perfect positive association between observed data and model data. According to Ruigar and Golian (2015), zero correlation values signifies that there is no linear relationship between the observed and model data. Also, the P-values with significance level of 0.05, were calculated to determine whether the correlation between observed and model data was statistically significant or insignificant.

The Pearson coefficient of correlation was calculated as shown in Equation 6;

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \, (y_i - \bar{y})^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where, x is the observed onset and cessation dates and y is the model values for onset and cessation dates

3.3 Conceptual Framework

The conceptual framework explores the various variables and their relationship in relation to attaining the study objectives. The study focused on assessing the effect of climate change on seasonal rainfall onset and cessation dates over Kenya. Observed daily rainfall was used to determine the past trends and variability of seasonal rainfall onset and cessation dates. A comparison of observed and historical model data was carried in order to determine how close the model data and observed data was. Future trends and variability of seasonal rainfall onset and cessation dates were determined under projection RCP4.5 and RCP8.5 as shown in the Figure 3 below

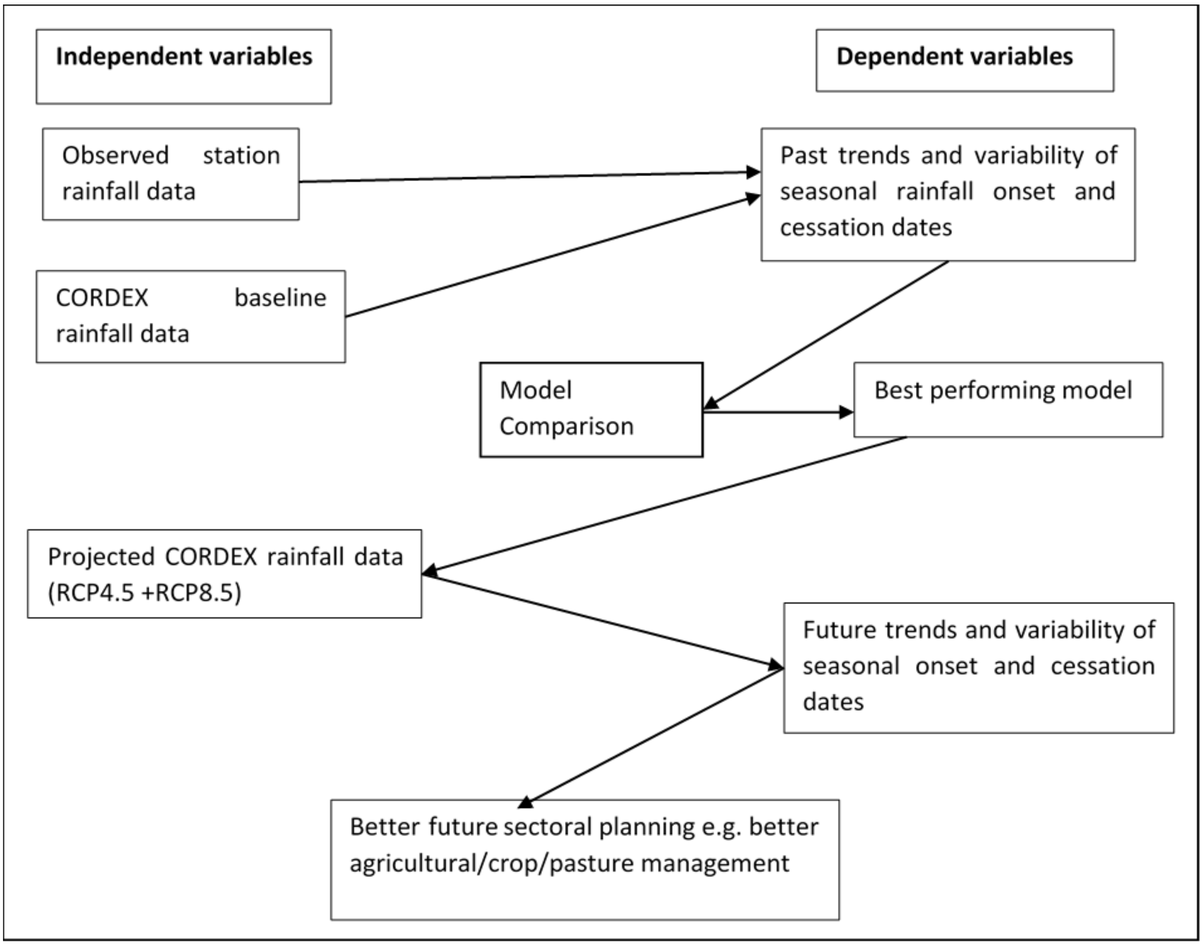

Figure 3: Study Conceptual Framework

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter addresses the analysis and the discussion of results based on three specific objectives. The study results were used to understand the effect that climate change will have on the seasonal rainfall onset and cessation dates over Kenya.

4.1 Determination of onset and cessation dates of seasonal rainfall based on based on gauged observations

This section shows the results for variability and trends of onset and cessation dates of seasonal rainfall for the period 1981 to 2010.

4.1.1 Determination of MAM onset and cessation dates and variability of seasonal rainfall based on based on gauged observations

Figure 4 shows the trends for the onset and cessation dates during the MAM rainfall season for Kisumu from the period 1981 to 2010. The Figure shows a continuous negative trend for the MAM seasonal onset dates and a continuous positive trend for the MAM seasonal cessation dates for the period 1981 to 2010. The continuous negative trend for the onset dates implies that since the year 1981, the onset dates have been coming early continuously while the cessation dates have been coming late continuously for Kisumu region. Figure 4 also shows that there has been a continuous steady increase in the length of the season and this evident based on the growing gap between the onset and cessation dates. The trends for the onset dates was significant while the trends for cessation dates was insignificant at 95% confidence level as shown in Table 3.

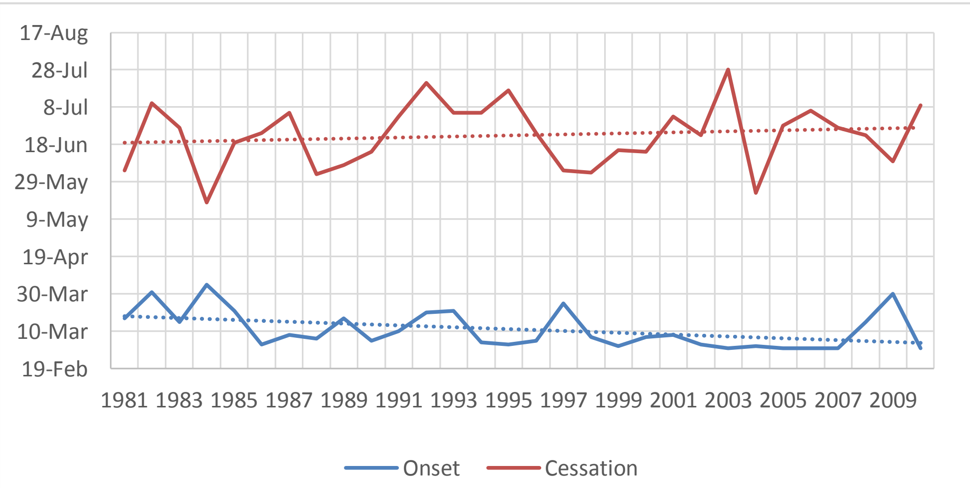

Figure 4: Variation of the Kisumu MAM Onset and cessation Dates from 1981-2010

Table 1 shows varying results of standard deviation and mean onset and cessation dates of MAM seasonal rainfall for different homogenous zones. The results show that the western part of Kenya had their onset coming earlier as showed by Kisumu station which has a mean onset of 10th March and a standard deviation about 12 days. Areas in the coast which is represented by Lamu, Mombasa and Voi have their mean onset dates coming between 21st March and 2nd April and standard deviation ranging from 11 to 16 days. On the other hand, the northern parts of the country have their mean onset dates between 25th March and 7th April and deviation ranging from 11 to 14 days as indicated in Table 1.

The cessation dates for the MAM rainfall season were also varying for different homogenous zones in Kenya. Areas in the northern part of Kenya had their cessation dates between 2nd May to 6th May and a standard deviation of 2 to 5 days compared to other regions such as coastal, central and western part of Kenya which had cessation dates from 10th May to 21st May and deviation 5 to 15 days. The regions in the northern part of Kenya had their cessation dates early compared to western, central and coastal part of the country. By looking at the number of deviation days between the MAM onset and cessation dates, there is high variability in the determining the MAM onset dates compared to the MAM cessation dates as shown in Table 1. The results are in line with a study carried out by Camberlin and Okoola (2003) that found that onset dates have larger variability compared to the cessation dates. Also, a study carried out by Mugalavai *et. al.* (2008) indicated a high variability for onset dates and low variability for cessation dates for both MAM and OND seasonal rainfall.

Table 1: Mean and standard deviation of onset and cessation dates for the MAM seasonal rainfall for the period 1981-2010 over Kenya

Stations	**Onset dates**		**Cessation dates**	
	Mean Date	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**
Dagoretti	27-Mar	14	11-May	12
Garissa	27-Mar	12	2-May	3
Kisumu	10-Mar	12	20-May	10
Lamu	2-Apr	11	18-May	10
Lodwar	7-Apr	12	2-May	4
Mombasa	24-Mar	15	10-May	12
Moyale	29-Mar	12	14-May	10
Voi	21-Mar	16	5-May	6
Wajir	31-Mar	11	6-May	6
Nanyuki	26-Mar	13	11-May	12
Narok	24-Mar	17	21-May	15
Marsabit	25-Mar	15	5-May	6

4.1.2 Determination of OND onset and cessation dates and variability of seasonal rainfall based on based on gauged observations

Table 2 show results of standard deviation and mean onset and cessation dates of OND seasonal rainfall for different homogenous zones over Kenya. Regions in the western part of Kenya represented by Kisumu and Kakamega have onset dates around 6th October while regions in the northern Kenya represented by Garissa, Wajir, Lodwar and Mandera have onset dates on 30th October, 27th, 23rd and 12th October respectively. Coastal region represented by Mombasa, Lamu and Voi have onset dates between 18th and 28th October. Region represented by Nakuru had OND onset date around 12th October. Homogenous zones in the western Kenya had early onset dates followed by some zones in the northern Kenya such as Mandera and Lodwar and central highlands including Nairobi area.

The cessation dates also varied across different regions over Kenya. However, station in the northern Kenya, represented by Garisa, Wajir, Lodwar and Mandera, had early cessation dates that came between 1st to 5th December. However, the deviation ranges from 1 to 7 days. Kisumu and Kakamega, that are in the western region, had cessation dates around 7th and 8th December. The coastal region represented by Mombasa, Voi and Lamu had cessation dates between 7th to 10th December. Central highlands including Nairobi area represented by Dagoretti station had cessation date around 4th December and a deviation of 7 days as indicated in Table 2. A comparison between the OND onset and cessation dates shows that the onset dates were more variable compared to the cessation dates. This could imply that it is more certain to understand when the cessation date will be as compared to the OND onset dates. The results resonate with finding from Mugalavai *et al* (2008) and Camberlin *et. al.* (2009) study that observed a low variability and high variability for onsets and cessation dates respectively for the two rainfall seasons. A comparison between the MAM onset dates and OND onset dates clearly indicate that the MAM onset dates have high variability following the high number of deviation days for the onset dates. The results depict the outcome of Recha *et. al.* (2012) in their study that found out by comparing both MAM and OND seasons, there is high variability of onsets within the season for the MAM seasonal rainfall.

In conclusion, the MAM onset dates showed high variability compared to the OND onset dates for the period 1981-2010. Also, for the cessation dates, more stations representing different homogenous zones showed high variability for the MAM cessation dates compared to the OND cessation dates.

Table 2: Mean and standard deviation of onset and cessation dates for the OND seasonal rainfall for the period 1981-2010 over Kenya

Stations	**Onset dates**		**Cessation dates**	
	Mean Date	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**
Dagoretti	31-Oct	13	4-Dec	7
Garissa	30-Oct	12	5-Dec	7
Kisumu	6-Oct	10	7-Dec	9
Lamu	28-Oct	13	7-Dec	9
Lodwar	23-Oct	15	1-Dec	2
Mombasa	18-Oct	16	10-Dec	11
Moyale	25-Oct	14	3-Dec	4
Voi	28-Oct	12	10-Dec	11
Wajir	27-Oct	11	5-Dec	8
Mandera	12-Oct	5	2-Dec	4
Nakuru	12-Oct	10	2-Dec	4
Kakamega	6-Oct	10	8-Dec	9

4.1.3 Trends onset and cessation of seasonal dates rainfall over Kenya based on based on gauged observations

The Table 3 shows the trends for onset and cessation dates for seasonal rainfall in Kenya for period of 1981 to 2010. The values in bold shows positive and significant trends while bold and italic values mean negative and significant trends for onset and cessation dates. The results show that for MAM seasonal rainfall, most homogenous zones indicated negative trend for seasonal rainfall onset dates except Dagoretti, Garissa, Lamu Moyale and Lodwar. Kisumu and Lodwar shows significant trends which is negative and positive respectively for the MAM seasonal rainfall onset dates. This means that for the period 1981-2010, Kisumu and Lodwar had early and late onset dates respectively for the MAM rainfall season. On the other hand, the cessation dates for MAM seasonal rainfall, most zones indicated a negative and insignificant trends except for Voi region that recorded negative and significant trends during the MAM seasonal rainfall cessation dates. Only Kisumu and Lodwar recorded a positive and insignificant trend for the MAM rainfall cessation dates. The negative trends signify early onset or cessation dates while positive trends signify late onset or cessation dates. In conclusion, the results indicate a mixture of positive and negative trends which are either significant or insignificant at 95% confidence level. The results closely depict the results by Kansiime *et. al.* (2013) that found a mixture of positive and negative trends for rainfall onset and cessation dates. Also, the results show both significant and insignificant onset and cessation trends and this is in line with a study carried out by Msongaleli *et al.* (2017) that recorded both significant and insignificant trends

Table 3: Trends of onset and cessation dates of MAM seasonal rainfall over Kenya from 1981 to 2010. The symbol star (*) and bold means significant at 95% confidence level

Stations	MAM	
	Onset	Cessation
Dagoretti	0.204	-0.227
Garissa	0.093	-0.192
Kisumu	***-0.412****	0.088
Lodwar	**0.564***	0.071
Mombasa	-0.040	-0.195
Moyale	0.274	-0.061
Voi	-0.236	***-0.424****
Wajir	-0.142	-0.204
Lamu	0.100	-0.209
Marsabit	-0.245	-0.287
Nanyuki	-0.038	-0.238
Narok	-0.205	-0.232

4.1.4 Trends onset and cessation date of OND seasonal dates rainfall over Kenya based on based on gauged observations

Table 4 show trend results for OND onset and cessation dates for the period 1981-2010 over Kenya. The results indicate that OND rainfall onset and cessation dates had a mixture positive and negative trends, however, almost all station representing the homogenous zones showed insignificant trend for the OND seasonal rainfall onset and cessation dates except for Mandera station that indicated a sportive and significant trend for onset dates. This implies that for the period 1981 to 2010, changes in the trends of the onset and cessation for the OND season were not consistence in terms of having early and/or late onset and cessation. In conclusion, the results indicate that there is a mixture of positive and negative trends for the trends of OND onset and cessation dates across different homogenous zones in Kenya. This is also in line with Kansiime *et. al.* (2013) study that found a mixture of positive and negative trends for rainfall onset and cessation dates.

Table 4: Trends of onset and cessation date of OND seasonal rainfall over Kenya from 1981 to 2010. The symbol star (*) and bold means significant at 95% confidence level

Stations	OND	
	Onset	Cessation
Dagoretti	0.219	0.147
Garissa	0.262	-0.011
Kisumu	-0.016	-0.202
Lodwar	0.062	0.062
Mombasa	-0.102	-0.020
Moyale	-0.179	0.028
Voi	-0.008	-0.177
Wajir	-0.303	-0.092
Lamu	-0.059	0.030
Nakuru	0.063	0.020
Kakamega	-0.016	-0.202
Mandera	**0.488***	0.114

4.2 Determination of onset and cessation dates of seasonal rainfall over Kenya using CORDEX Model

This section describes the plots for onset and cessation dates of seasonal rainfall for CORDEX baseline period of 1976 to 2005. The plots show the trends of onset and cessation dates for MPI, ICHEC, CNRM and ensemble models.

4.2.1 Determination of onset and cessation dates of MAM seasonal rainfall over Kenya using CORDEX Model

Figure 5 shows a plot for Kisumu MAM onset dates for the MPI, ICHEC, CNRM and ensemble models for the period 1976 to 2005. The CNRM model shows a continuous decreasing trend in the MAM onset dates from 1976 to 2005. This means that the MAM seasonal rainfall has steadily and continuously come early based on the CNRM model. ICHEC, MPI and ensemble model shows a positive trend for the onset dates for the period 1976 to 2005. This signifies that for the period 1976 to 2005, the onset dates have continuously and steadily come late. The results similar to Mugalavai et al. (2008) that analyzed onset and cessation dates for both MAM and OND seasonal rainfall and found varying trends in seasonal onset and cessation dates for the western part of Kenya.

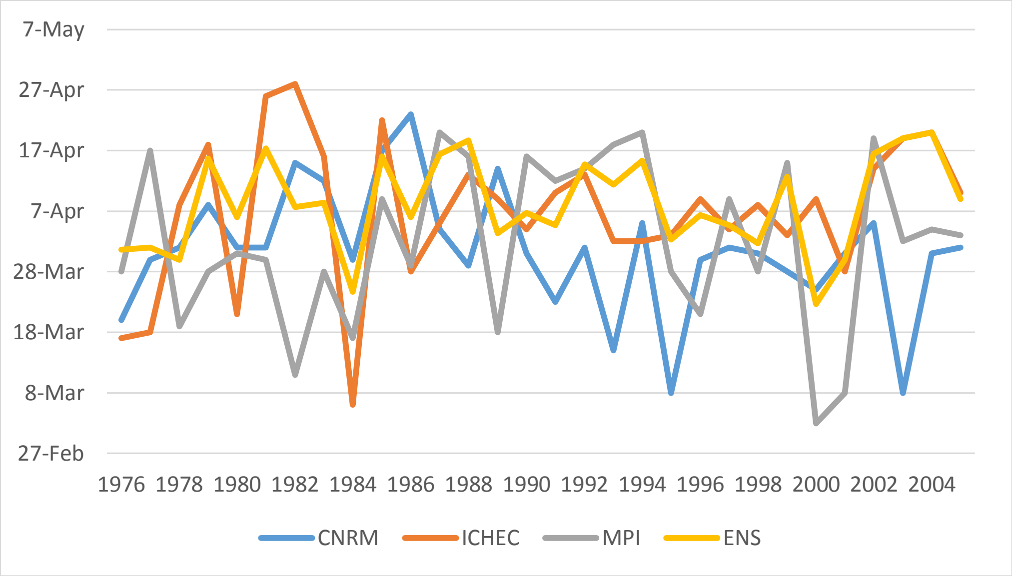

Figure 5: Variation of the Kisumu Onset Dates from 1976-2005 for CORDEX model

Figure 6 shows results for trends of MAM seasonal cessation dates for the period 1976 to 2005 over Kisumu based on different CORDEX models. From the Figure the MPI, ICHEC and ensemble models indicate a positive trend for the cessation dates of MAM seasonal rainfall from 1976-2005. The positive trends imply a late cessation dates based on the three models. CNRM models shows a negative trend of cessation dates and this means that for the period 1976 to 2005, the cessation dates of MAM seasonal rainfall have been continuously coming early for the Kisumu region. Therefore, by comparing results from Figure 5 and Figure 6, trends of onset and cessation dates based on ICHEC, MPI and ensemble models signifies that late onset and cessation dates for the period 1976 to 2005. On the other hand, the onset and cessation dates trends based on CNRM models signifies an early onset and cessation dates of MAM seasonal rainfall for the period 1976 to 2005. In conclusion, the results similar to Mugalavai *et al.* (2008) study that analyzed onset and cessation dates for both MAM and OND seasonal rainfall and found varying trends in seasonal onset and cessation dates for the western part of Kenya.

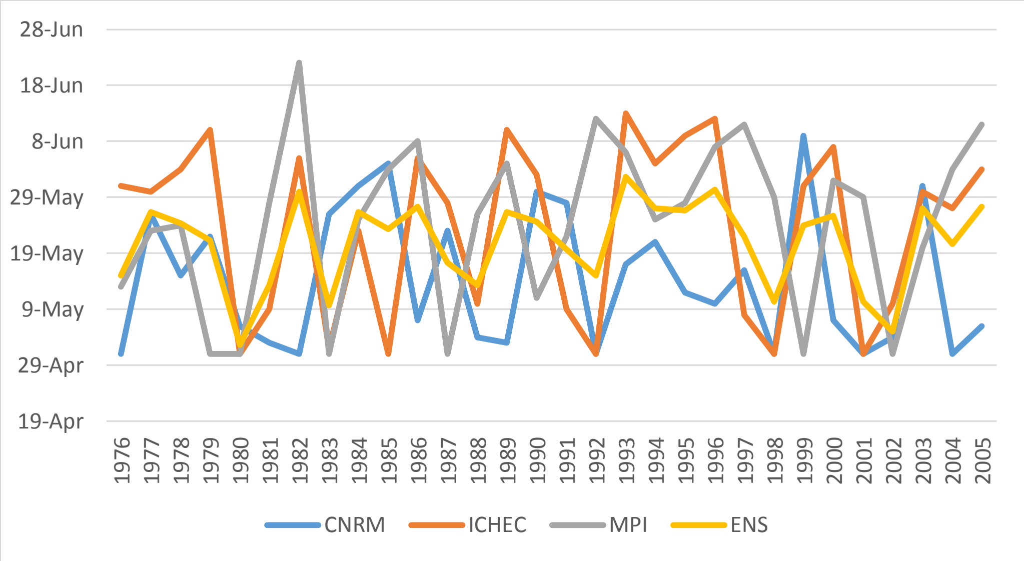

Figure 6: Variation of the Kisumu Cessation Dates from 1976-2005 for CORDEX model

4.2.2 Determination of mean, standard deviation and variability of MAM onset and cessation dates using CORDEX model

Table 5 shows the mean and standard deviation for MAM onset dates for the CNRM, MPI, ICHEC and ensemble model. Different models show varying mean onset dates and the standard deviation. The result in Table 5 indicate that most stations in the northern part of Kenya have onset dates coming from 7th April to 21st April. The deviation of onset dates also varies for different models and for different homogenous zones. For instance, the regions in the northern part represented by Garissa, Wajir, Marsabit and Lodwar have their onset dates deviating by 5 days to 13 days across different models. The coastal regions represented by Lamu, Mombasa and Voi have mean onset ranging from 27th March to 10th April and a deviation of 8 days to 16 days. This means that regions in the coastal area are more variable onset dates during the MAM seasonal rainfall compared to the regions in the northern part of Kenya. For the zone represented by Kisumu station shows a mean onset date of 9th April, 15th April, 4th April and 11th April based on ensemble model, CNRM, ICHEC and MPI models. The deviation of the onset dates ranges from 8 to 13 days across the models. A comparison across the different models show that the ensemble model has the less deviation days compared to the CNRM, ICHEC and MPI models. This mean that the onset dates are less variable when the ensemble model is used compared to the individual CNRM, ICHEC and MPI models. The results resonate with Olatunde and Love (2018) study that found that varying onset and cessation dates variability for different GCM models. However, in their study, the ensemble mode used indicated low variability in the onset and cessation dates of seasonal rainfall in Nigeria.

Table 5: Mean and standard deviation for onset dates for the MAM seasonal rainfall for CORDEX Models and their ensemble over Kenya during the 1976 to 2005 period

Stations	Ensemble Onset		CNRM Onset		ICHEC Onset		MPI Onset	
	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)
Dagoretti	9-Apr	9	9-Apr	12	9-Apr	12	9-Apr	12
Garissa	9-Apr	7	15-Apr	13	4-Apr	13	11-Apr	12
Kisumu	8-Apr	8	1-Apr	12	11-Apr	14	3-Apr	15
Lamu	9-Apr	9	14-Apr	10	3-Apr	17	10-Apr	10
Lodwar	21-Apr	5	19-Apr	11	22-Apr	7	18-Apr	12
Mombasa	3-Apr	8	8-Apr	8	29-Mar	14	3-Apr	9
Moyale	13-Apr	7	12-Apr	10	11-Apr	12	14-Apr	13
Voi	27-Mar	13	5-Apr	11	28-Mar	15	25-Mar	16
Wajir	14-Apr	8	15-Apr	10	12-Apr	13	15-Apr	11
Nanyuki	2-Apr	13	10-Apr	13	31-Mar	15	31-Mar	17
Narok	5-Apr	8	6-Apr	12	3-Apr	13	1-Apr	17
Marsabit	7-Apr	10	11-Apr	10	9-Apr	15	28-Apr	12

Table 6 show the results of mean and standard deviation for the MAM cessation dates for the CORDEX model baseline period. The results show that the homogenous zones in the coastal and northern part of Kenya had early cessation dates based on the ensemble model outputs which occurred between 1st May to 20th May. The deviation of cessation dates for the ensemble model ranges from 2 days to 10 days. The zone represented by Kisumu have a mean cessation date of 20th May based on the ensemble model and 14th May, 23rd May and 24th May based on CNRM, ICHEC and MPI models respectively. However, the ensemble model shows lesser days (8 days) for deviation of cessation as compared to CNRM, ICHEC and MPI that shows 12 days, 15 days and 14 days respectively. This implies that based on the different models, the ensemble model has low variability for cessation dates compared to CNRM, MPI and ICHEC model.

In conclusion, a comparison of MAM onset and cessation dates for different zones show that for most zones, the onset dates have more deviation dates as compared to cessation dates and hence, this signifies that MAM onset dates are more variable than the MAM cessation dates for most zones in Kenya. The study shows similar results to the Olatunde and Love (2018) study that found out that the onset dates had slightly higher variability compared to the cessation dates of seasonal rainfall.

Table 6: Mean and standard deviation for cessation dates for the MAM seasonal rainfall for CORDEX Models and their ensemble over Kenya during the 1976 to 2005 period

Stations	Ensemble Cessation		CNRM Cessation		ICHEC Cessation		MPI Cessation	
	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)
Dagoretti	17-May	14	17-May	14	17-May	14	17-May	14
Garissa	4-May	3	2-May	3	6-May	8	5-May	6
Kisumu	20-May	8	14-May	12	23-May	15	24-May	15
Lamu	18-May	10	7-May	8	16-May	15	23-May	18
Lodwar	7-May	8	4-May	9	4-May	12	8-May	13
Mombasa	8-May	6	3-May	4	8-May	10	12-May	13
Moyale	24-May	9	16-May	14	1-Jun	20	19-May	14
Voi	5-May	4	3-May	5	5-May	7	6-May	7
Wajir	6-May	5	3-May	4	9-May	10	7-May	8
Nanyuki	5-Jun	18	23-May	22	22-May	25	30-May	24
Narok	2-Jun	10	9-Jun	15	28-May	18	1-Jun	15
Marsabit	1-May	2	1-May	2	1-May	2	2-May	4

4.2.3 Determination of mean, standard deviation and variability of OND onset and cessation dates using CORDEX Model

Table 7 show mean and standard deviation for the onset dates for OND seasonal rainfall for different zones and for different GCM model using CORDEX. Result shows that early OND onset dates are observed in regions represented by Lodwar, Moyale, Wajir and Mandera which ranges between 5th and 17th October for ensemble model, 5th to 18th October for CNRM model, 8th to 21st October for ICHEC model and 7th to 20th October for MPI model. For zones in the coastal region represented by Lamu, Mombasa and Voi, the onset dates varying based on different models. However, the ensemble model indicates that different regions had their onset coming a bit earlier as compared to CNRM, ICHEC and MPI models. Also, the deviation days of onset dates are lower for ensemble model compared to the CNRM, ICHEC and MPI models. This implies that the prediction of OND onset dates based ensemble model were more certain compared to other models and this is as a result of less number of deviation days as shown in Table 7. The results are similar to Fuwape and Ogunjo (2018) study results that showed varying mean onset dates for different zones and also varying deviation day for the seasonal onsets when modelling seasonal rainfall onset and cessation dates.

Table 7: Mean and standard deviation for onset dates for the OND seasonal rainfall for CORDEX Models and their ensemble over Kenya during the 1976 to 2005 period

Stations	Ensemble Onset		CNRM Onset		ICHEC Onset		MPI Onset	
	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)
Dagoretti	16-Oct	18	17-Oct	17	10-Oct	8	10-Oct	8
Garissa	25-Oct	9	24-Oct	15	23-Oct	9	20-Oct	12
Kisumu	7-Oct	4	6-Oct	6	5-Oct	5	10-Oct	8
Lamu	15-Oct	8	11-Oct	13	21-Oct	16	14-Oct	11
Lodwar	10-Oct	9	28-Oct	7	6-Oct	10	9-Oct	6
Mombasa	20-Oct	9	17-Oct	13	23-Oct	14	20-Oct	15
Moyale	5-Oct	5	5-Oct	7	4-Oct	7	7-Oct	7
Voi	19-Oct	7	18-Oct	12	21-Oct	11	18-Oct	12
Wajir	13-Oct	8	13-Oct	11	16-Oct	11	14-Oct	9
Mandera	7-Oct	4	5-Oct	5	8-Oct	9	10-Oct	9
Nakuru	12-Oct	8	23-Oct	9	10-Oct	9	10-Oct	8
Kakamega	15-Oct	8	26-Oct	16	5-Oct	5	10-Oct	8

Table 8 show results for the mean and standard deviation for the OND cessation dates. Early cessation dates were observed for regions represented by Lodwar, Nakuru, Moyale, Dagoretti, Kisumu, Wajir, Mandera and Kakamega since their dates were between 1st December and 4th December based on different models. However, the deviation days were less for the ensemble model and this could signify that despite the zones having close cessation dates, the variability based on ensemble model is low than other models. On the other hand, the zones represented by Garissa, Lamu, Mombasa, Voi had cessation dates from 10th December to 15th December across different models. The deviation day are less for ensemble model than CNRM, ICHEC and MPI models. This implies that variability of cessation dates based on ensemble model is lower compared to CNRM, ICHEC and MPI models.

In conclusion, the deviation days for the OND onset dates are much higher compared to deviation days for OND cessation dates for the different GCM models including the ensemble model. Also, there are varying onset and cessation dates for different regions and this is similar to results from Adelekan and Adegebo (2014) study that showed the variances in mean onset and cessation dates for the seasonal rainfall in various homogenous zones.

Table 8: Mean and standard deviation for cessation dates for the OND seasonal rainfall for CORDEX Models and their ensemble over Kenya during the 1976 to 2005 period

Stations	Ensemble Cessation		CNRM Cessation		ICHEC Cessation		MPI Cessation	
	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)
Dagoretti	4-Dec	5	4-Dec	5	4-Dec	5	4-Dec	5
Garissa	8-Dec	5	5-Dec	6	9-Dec	8	10-Dec	8
Kisumu	3-Dec	3	3-Dec	5	3-Dec	5	2-Dec	5
Lamu	10-Dec	5	7-Dec	7	10-Dec	9	15-Dec	10
Lodwar	1-Dec	1	1-Dec	2	2-Dec	3	1-Dec	3
Mombasa	11-Dec	7	7-Dec	8	10-Dec	8	19-Dec	9
Moyale	1-Dec	1	1-Dec	1	1-Dec	2	1-Dec	3
Voi	10-Dec	5	5-Dec	7	12-Dec	9	15-Dec	9
Wajir	3-Dec	2	3-Dec	4	3-Dec	5	2-Dec	3
Mandera	2-Dec	2	2-Dec	3	1-Dec	2	2-Dec	4
Nakuru	1-Dec	2	1-Dec	3	2-Dec	3	1-Dec	1
Kakamega	3-Dec	3	3-Dec	5	3-Dec	5	2-Dec	5

4.3 Comparison of the observed and CORDEX models onset and cessation dates of seasonal rainfall over Kenya

The section show results for comparison of observed and CORDEX model onset and cessation dates of seasonal rainfall for different regions using RMSE and Pearson Correlation Coefficient.

4.3.1 Comparison of the observed and CORDEX models onset and cessation dates of seasonal rainfall over Kenya using RMSE

Table 9 show results for a comparison of the RMSE statistics for observed and model data for MAM seasonal rainfall onset and cessation dates for different homogenous zones over Kenya for the period 1981-2005. Generally, from the Table 9 the RMSE values for ensemble model has lower values as compared to most regions for each GCM model. This implies that the simulated MAM seasonal onset and cessation values from the ensemble model closely match that of observed MAM seasonal onset and cessation values. However, the cessation dates had the lowest RMSE values compared to the onset dates and this means that prediction of MAM cessation dates using ensemble model is closer to the observed than the MAM onset dates. The results resonate with the Schaller *et al.* (2011) study which indicated lower RMSE values for the ensemble models when comparing the observed data and 7 CMIP3 models.

Table 9: Results of RMSE for Observed and Model Comparison of MAM Onset and Cessation dates over Kenya

Stations	CNRM		ICHEC		MPI		Ensemble model	
	Onset	Cessation	Onset	Cessation	Onset	Cessation	Onset	Cessation
Dagoretti	22	20	21	20	24	20	21	20
Garissa	28	4	16	8	24	7	19	5
Kisumu	32	40	36	38	29	35	30	34
Lamu	21	23	19	26	19	36	18	22
Lodwar	19	10	23	19	23	14	21	9
Marsabit	17	7	45	6	28	7	20	7
Mombasa	22	15	19	17	20	16	18	14
Moyale	22	18	20	33	24	16	20	17
Nanyuki	24	28	22	42	23	50	22	19
Narok	25	29	22	27	24	24	20	24
Voi	19	9	19	11	18	8	19	8
Wajir	21	9	21	11	19	9	20	7
Mean	**23**	**18**	**24**	**22**	**23**	**20**	**21**	**15**

Table 10 shows comparison results for observed and model for OND seasonal rainfall onset and cessation dates using RMSE for the period 1981-2005. The Table shows varying RMSE values for CNRM, ICHEC, MPI and their ensemble. The RMSE values for ensemble model are lower for both OND seasonal onset and cessation dates values for most regions as compared to other models. This means that the model simulation based on ensemble model give onset and cessation dates that are close to observed onset and cessation dates. However, the results show that RMSE values for onset dates are high as compared to cessation dates. This means that for period 1981-2005, the forecast of OND onset dates were more uncertain as compared to OND cessation dates. A comparison between MAM and OND variability from Tables 9 and 10 shows that the simulated onset RMSE values are much higher compared to cessation dates for each values. However, the RMSE values are slightly higher for the MAM onset and cessation dates as compared to OND onset and cessation dates. Hence, determining OND onset and cessation dates are more certain as compared to MAM onset and cessation dates. The results clearly resonate with Mensah *et. al.*, (2016) that found out a good agreement between GMet and RegCM4 datasets especially for the seasonal rainfall onset and cessation dates.

Results from Tables 9 and 10 show that simulation of seasonal onset and cessation dates using ensemble model data gives lower RMSE values and this signifies that onset and cessation dates simulated are close to observed onset and cessation dates. Therefore, based on these results, the study as adopted ensemble model values for further analysis of future trends and variability of onset and cessation for the period 2021-2050.

Table 10: Results of RMSE for Observed and Model comparison of OND Onset and Cessation dates over Kenya.

Stations	CNRM		ICHEC		MPI		Ensemble model	
	Onset	Cessation	Onset	Cessation	Onset	Cessation	Onset	Cessation
Dagoretti	22	7	24	7	24	7	21	7
Garissa	24	9	13	13	19	11	13	9
Kisumu	10	12	10	11	16	11	10	11
Lamu	25	9	18	12	25	16	19	10
Lodwar	14	10	23	14	21	14	19	8
Kakamega	27	12	10	11	16	12	16	11
Mombasa	22	15	19	13	22	16	18	12
Moyale	27	4	33	21	24	4	18	4
Mandera	8	4	10	18	11	5	5	3
Nakuru	25	4	12	5	14	5	13	4
Voi	19	15	16	14	18	14	15	12
Wajir	18	7	20	7	19	9	17	7
Mean	**20**	**9**	**17**	**12**	**19**	**10**	**15**	**8**

4.3.2 Comparison of the observed and CORDEX model onset and cessation dates of seasonal rainfall over Kenya using Pearson Correlation Coefficient

Table 11 shows the Pearson correlation coefficients of the onset and cessation dates from observed and model data during the MAM season for the period 1981-2005. The results show varying Pearson coefficient values for different models as shown in Table 11. Comparison using the CNRM model shows that Garissa and Voi had negative and significant correlation for MAM cessation dates, hence, the determination of cessation dates using the CNRM model underperformed in comparison with observed values. Determination of onset dates showed positive and significant trends for Garissa and Marsabit using ICHEC model while determination of cessation dates using ICHEC model shows negative and significant correlation for Voi and positive and significant trend for Lodwar. The determination of onset dates using ensemble model shows negative and significant correlation onset dates for Nanyuki and on the other hand, determination of onset and cessation dates using MPI model showed a mixture of positive and negative insignificant trends for different stations as indicated in Table 11. This results depicts the study by MacLeod, (2018) that assessed the predictability of seasonal rainfall onset and cessation over the east Africa region and found out a mixture of positive and negative correlation coefficient for both onset and cessation dates at confidence level of 95% over northwestern Kenya.

Table 11: Results of Pearson coefficient correlation for Observed and Model comparison of MAM Onset and Cessation dates over Kenya. The symbol star (*) and bold values means significant at 95% confidence level

Stations	CNRM		ICHEC		MPI		Ensemble model	
	Onset	**Cessation**	**Onset**	**Cessation**	**Onset**	**Cessation**	**Onset**	**Cessation**
Dagoretti	-0.010	-0.158	0.074	-0.158	-0.330	-0.158	-0.107	-0.158
Garissa	-0.031	**-0.400***	**0.392***	0.048	-0.299	-0.046	-0.021	-0.089
Kisumu	0.040	-0.218	-0.210	-0.055	0.312	0.233	0.226	-0.034
Lamu	-0.181	0.059	0.085	-0.212	-0.229	0.086	-0.358	-0.095
Lodwar	**0.399***	-0.163	0.259	**0.751***	0.043	0.042	0.040	0.208
Marsabit	0.001	0.003	**0.374***	0.288	0.254	-0.068	-0.004	0.069
Mombasa	-0.003	-0.148	0.107	-0.227	-0.016	0.126	0.195	-0.070
Moyale	-0.097	-0.099	0.151	-0.195	-0.015	0.071	0.049	-0.253
Nanyuki	-0.093	-0.102	-0.288	0.193	-0.202	0.059	**-0.376***	0.230
Narok	0.047	-0.182	0.029	-0.332	0.033	-0.064	0.138	-0.191
Voi	0.102	**-0.376***	0.320	**-0.390***	0.266	0.205	0.106	-0.288
Wajir	-0.065	-0.194	-0.202	0.223	0.128	0.221	-0.197	0.239

Table 12 shows the Pearson correlation coefficient results for onset and cessation dates for both observed and model data during the OND season for the period 1981-2005. The Table 12 show a mixture of positive and negative correlation results for CNRM, ICHEC, MPI and ensemble models. The results show more positive and significant correlations OND cessation dates from the models as compared to OND onset dates. Positive and significant correlation for cessation dates are evident at Mandera, Nakuru and Wajir using CNRM model, Lodwar, Moyale and Mandera using ICHEC model and Mandera using ensemble model. This means that determining the onset and cessation dates for those regions were in line with observed data. On the other hand, negative and significant correlation of onset dates were evident in Garissa using CNRM model and positive and significant trend for Garissa and Mandera using ICHEC model as shown in Table 12. The results are in line with a study by Mensah *et. al.*, (2016) in Ghana that focused on comparing the rainfall onset and cessation from GMet and RegCM4 datasets. The study results showed both positive and negative correlation using Pearson correlation coefficient for seasonal onset and cessation dates.

Table 12: Results of Pearson coefficient correlation for Observed and Model comparison of OND Onset and Cessation dates over Kenya. The symbol star (*) and bold values means significant at 95% confidence level

Stations	CNRM		ICHEC		MPI		Ensemble model	
	Onset	**Cessation**	**Onset**	**Cessation**	**Onset**	**Cessation**	**Onset**	**Cessation**
Dagoretti	-0.005	0.255	0.208	0.261	0.032	0.261	-0.267	0.259
Garissa	**-0.655***	0.024	**0.365***	-0.167	0.184	0.188	0.019	0.035
Kisumu	0.326	-0.317	0.126	-0.088	-0.328	-0.208	-0.046	-0.353
Lamu	0.019	0.359	0.259	0.071	-0.343	-0.086	0.022	0.128
Lodwar	-0.147	-0.034	-0.095	**0.430***	-0.264	0.024	-0.025	0.272
Kakamega	0.068	-0.317	0.126	-0.088	-0.328	-0.208	-0.065	-0.353
Mombasa	-0.226	-0.135	0.233	0.002	-0.027	0.052	0.021	-0.033
Moyale	-0.193	0.054	0.243	**0.425***	-0.223	0.199	-0.068	0.357
Mandera	0.131	**0.369***	**0.368***	**0.408***	-0.270	0.113	0.127	**0.464***
Nakuru	-0.105	**0.476***	0.237	0.059	0.006	-0.072	0.001	0.299
Voi	0.048	-0.195	0.138	0.002	0.176	0.047	0.189	-0.066
Wajir	0.099	**0.372***	-0.166	0.347	0.046	-0.254	-0.012	0.337

In conclusion, the model comparison using RMSE indicated that lower values for ensemble model for both MAM and OND onset and cessation dates compared to other three GCM models. This implies that the ensemble model performs better in determining both MAM and OND seasonal rainfall onset and cessation dates. On the other hand, the performance of ensemble model based on Pearson correlation showed varying correlation coefficients values compared to other three GCM models. However, study by Parker (2013) indicated that the use of ensemble model in simulation of future provides a more comprehensive estimate of uncertainty about future conditions than the spread found when individual model is used. Wang et. al. (2018) further indicated that the use of ensemble GCM models is critical in reducing the uncertainty of future projections for climate parameters. Therefore, the analysis of future onset and cessation dates of seasonal rainfall for the period 2021-2050 used the ensemble model.

4.4 Future variability and trends of onset and cessation dates of seasonal rainfall over Kenya as projected under RCP4.5 and RCP8.5

This section gives results of future variability and trends of onset and cessation dates of seasonal rainfall over Kenya using ensemble model as projected under RCP4.5 and RCP8.5. The results show projection for the period 2021 to 2050.

4.4.1 Determination of MAM onset and cessation dates of seasonal rainfall for projection scenarios

Figure 7 shows results for Kisumu MAM onset and cessation dates for both baseline and projected period. The baseline period is from 1976-2005 and projections runs from 2021-2050. The result shows that the varying deviation for the MAM onset dates under RCP4.5 and RCP8.5 is evident from around the year 2030 moving forward. For the cessation dates, there is slight variation in the patterns since both RCP4.5 and RCP8.5 lines depicts similar pattern.

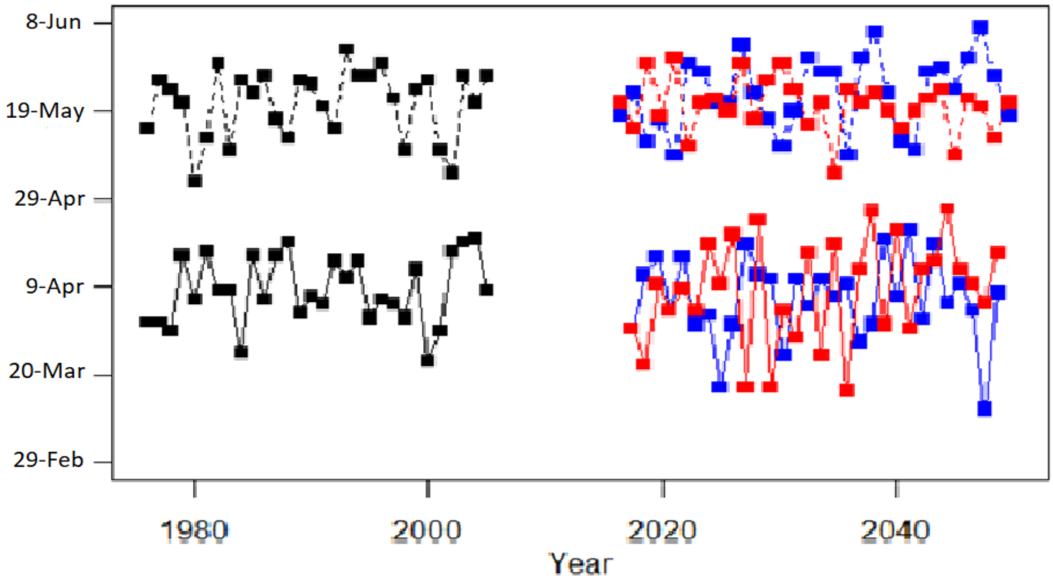

Figure 7: Baseline and Projected Kisumu MAM seasonal rainfall onsets and Cessation dates *(Solid line = onsets dates, Dotted lines = cessation; Black lines = baselines, Blue lines=RCP4.5, Red lines = RCP8.5)*

4.4.2 Future mean, standard deviation and variability of MAM onset and cessation dates over Kenya as projected under RCP4.5 and RCP8.5

Table 13 shows the mean and standard deviation for MAM seasonal onset dates for the period 2021-2050 and this is based on RCP4.5 and RCP8.5 scenarios. The projected mean onset and standard deviation were compared against the model baseline and observed mean and standard deviation vales. The results show that the central highlands including Nairobi area which is represented by Dagoretti will have onset around 4th April and 7th April as projected under RCP4.5 and RCP8.5 respectively. The deviation days of the onset will be 9 days for RCP4.5 and 18 days for RCP8.5. The large deviation days signifies high variability of MAM onset dates under RCP8.5 compared to RCP4.5.

The zones in the coastal regions represented by Voi, Mombasa and Lamu have mean onset dates between 27th March to 12th April under RCP4.5 projections and 26th March to 12th April under RCP8.5 projections. However, the deviation days for the onset dates is between 8 to 11 days for RCP4.5 and 10 to 12 days for RCP8.5. This shows a slight variability increase based on RCP8.5 projection compared to the RCP4.5. The zones in the northern and northeastern part of Kenya, which are represented by Garissa, Wajir, Lodwar, Moyale and Marsabit have a projected mean onset dates between 4th April to 19th April under RCP4.5 and between 3rd April to 22nd April under RCP8.5. The deviation days are between 8 to 11 days under RCP4.5 and between 7 to 14 days for RCP8.5. Based on the analysis results, projection under RCP8.5 shows more number of deviation days for MAM onset compared to RCP4.5 and implies variability is slightly high under RCP8.5 for the period 2021-2050. The results match Park *et al.* (2016) study that pointed out the high variability of onset dates for different regions. This was linked to the likelihood of having more uncertain seasonal rainfall onset dates.

Table 13 Mean and standard deviation for future MAM onset dates for the period 2021-2050 over Kenya

Stations	**Observed**		**Ensemble baseline**		**Ensemble RCP4.5**		**Ensemble RCP8.5**	
	Mean Date	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**
Dagoretti	27-Mar	14	9-Apr	9	4-Apr	10	7-Apr	18
Garissa	27-Mar	12	9-Apr	7	4-Apr	11	3-Apr	14
Kisumu	10-Mar	10	8-Apr	8	7-Apr	9	9-Apr	12
Lamu	2-Apr	11	9-Apr	9	12-Apr	10	12-Apr	10
Lodwar	7-Apr	12	21-Apr	5	18-Apr	9	19-Apr	8
Mombasa	24-Mar	15	3-Apr	8	1-Apr	11	2-Apr	13
Moyale	29-Mar	12	13-Apr	7	13-Apr	8	12-Apr	10
Voi	21-Mar	16	27-Mar	13	27-Mar	8	26-Mar	11
Wajir	31-Mar	11	14-Apr	8	11-Apr	10	10-Apr	9
Nanyuki	26-Mar	13	2-Apr	13	2-Apr	10	6-Apr	10
Narok	24-Mar	17	5-Apr	8	3-Apr	11	3-Apr	10
Marsabit	25-Mar	15	7-Apr	10	19-Apr	8	22-Apr	11

The results in Table 14 show the projected mean and standard deviation for the MAM cessation dates for the period 2021-2050 under the RCP4.5 and RCP8.5 scenarios. The results indicate varying mean cessation dates and deviation day for different zones. For the zones in the northern and northeastern part of Kenya, represented by Garissa, Wajir, Lodwar and Marsabit, tend to have early cessation dates followed by the coastal, western and central part of Kenya under both RCP4.5 and RCP8.5. However, the deviation days for cessation dates are slight higher under RCP4.5 compared to RCP8.5 for almost all homogenous zones. This implies that based on projections, RCP4.5 project a slight higher variability of MAM cessation dates than RCP8.5 scenarios.

A comparison of MAM seasonal onset and cessation date variability based on the number of deviation days indicates that MAM onset dates are more variable compared to the cessation dates. Therefore, the implication is that, going into the future the determination of MAM onset dates will be less certain compared to MAM cessation dates based on both RCP4.5 and RCP8.5 projections for the period 2021-2050. These results match the findings by Asfaw *et al.* (2018) that also found out that the onset dates were more variable compared to the cessation dates. It means that MAM onset dates would be more uncertain compared to the cessation dates of the MAM seasonal rainfall.

Table 14: Mean and standard deviation for future MAM cessation dates for the period 2021-2050 over Kenya

Stations	**Observed**		**Ensemble baseline**		**Ensemble RCP4.5**		**Ensemble RCP8.5**	
	Mean Date	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**
Dagoretti	11-May	12	17-May	14	17-May	8	17-May	7
Garissa	2-May	3	4-May	3	5-May	4	5-May	3
Kisumu	20-Jun	15	20-May	8	22-May	8	20-May	6
Lamu	18-May	19	18-May	10	17-May	9	13-May	10
Lodwar	2-May	4	7-May	8	4-May	7	5-May	5
Mombasa	10-May	12	8-May	6	8-May	5	6-May	5
Moyale	14-May	10	24-May	9	19-May	10	19-May	9
Voi	5-May	6	5-May	4	5-May	4	4-May	4
Wajir	6-May	6	6-May	5	6-May	6	7-May	4
Nanyuki	11-May	12	5-Jun	18	24-May	14	25-May	12
Narok	21-May	15	2-Jun	10	1-Jun	9	2-Jun	8
Marsabit	5-May	6	1-May	2	1-May	2	1-May	2

4.4.3 Future mean, standard deviation and variability of OND onset and cessation dates over Kenya as projected under RCP4.5 and RCP8.5

The results in Table 15 shows the future mean and standard deviation for the OND onset dates for the period 2021-2050 as projected under RCP4.5 and RCP8.5 scenarios. The results show varying mean and deviation days of onset dates for different zones. However, based on projection there is slight early onset dates based on RCP4.5 compared to RCP8.5 for the period 2021-2050. For instance, the zone represented by Garissa station shows mean onset date on 20th October and deviation of 6 days under RCP4.5 and a mean onset date of 22nd

October and deviation of 10 days under RCP8.5. This indicate that there are more deviation days for Garissa onset dates based on RCP8.5 and hence, this implies that the prediction of Garissa onset date is more variable under RCP8.5 compared to RCP4.5.

Generally, the OND onset dates projection is slightly more variable under RCP8.5 compared to RCP4.5 scenarios. However, a comparison with the model baseline, the projected deviation days is slight higher for most homogenous based on RCP8.5 projections compared to RCP4.5 projections. A comparison of MAM and OND onset dates as indicated in Tables 13 and 15 shows that there are more deviation days for MAM onset dates compared to the OND onset dates. The findings are in line with Kisaka *et al.* (2015) that indicated high variability of onset dates of seasonal rainfall for different stations. Dunning *et al.* (2018) in their study also found varying onset and cessation dates variability for seasonal rainfall.

Table 15: Mean and standard deviation for future OND onset dates for the period 2021-2050 over Kenya

Stations	Observed		Ensemble baseline		Ensemble RCP4.5		Ensemble RCP8.5	
	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)	Mean Date	Standard Deviation (Days)
Dagoretti	31-Oct	13	16-Oct	18	12-Oct	4	13-Oct	6
Garissa	30-Oct	12	25-Oct	9	20-Oct	6	22-Oct	10
Kisumu	6-Oct	10	7-Oct	4	9-Oct	6	8-Oct	6
Lamu	28-Oct	13	15-Oct	8	15-Oct	9	17-Oct	11
Lodwar	23-Oct	15	10-Oct	9	11-Oct	9	18-Oct	11
Mombasa	18-Oct	16	20-Oct	9	22-Oct	7	23-Oct	9
Moyale	25-Oct	14	5-Oct	5	7-Oct	5	6-Oct	3
Voi	28-Oct	12	19-Oct	7	21-Oct	7	21-Oct	9
Wajir	27-Oct	11	13-Oct	8	15-Oct	7	16-Oct	9
Mandera	12-Oct	5	7-Oct	4	8-Oct	4	19-Oct	8
Nakuru	12-Oct	10	12-Oct	8	9-Oct	8	18-Oct	10
Kakamega	6-Oct	10	15-Oct	8	9-Oct	6	8-Oct	6

Table 16 show results of mean and standard deviation of OND cessation dates for the period 2021-2050 under RCP4.5 and RCP8.5 projections. A comparison of past and future mean onset indicates that most homogenous zones reveal that there are slight late cessation dates based on both RCP4.5 and RCP8.5 projections. For instance, the past mean cessation date for Dagoretti was 4th December and the future mean cessation date is 9th and 7th December under RCP4.5 and RCP8.5 respectively. Both RCP4.5 and RCP8.5 projections indicate that early cessation dates will be observed over zones represented by Nakuru, Mandera, Wajir, Kisumu, Lodwar, Kakamega and Moyale and late cessation dates is projected in zones represented by

Dagoretti, Mombasa, Voi and Lamu. This means that the zones in the coastal regions will tend to have late cessation dates compared to other regions. In comparison with the OND onset in Table 15, the cessation dates have less deviation days than the onset dates. It implies that the onset dates are more variable compared to the cessation dates and hence, it would be more certain to determine the OND cessation dates in future that the OND onsets dates. The results are similar to Kisaka *et al.* (2015) that found out that the variability of onset dates are slightly higher that cessation dates of seasonal rainfall and further indicated that this will be case going into the future.

Table 16: Mean and standard deviation for future OND cessation dates for the period 2021-2050 over Kenya

Stations	**Observed**		**Ensemble baseline**		**Ensemble RCP4.5**		**Ensemble RCP8.5**	
	Mean Date	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**	**Mean Date**	**Standard Deviation (Days)**
Dagoretti	4-Dec	7	4-Dec	5	9-Dec	6	7-Dec	4
Garissa	5-Dec	7	8-Dec	5	7-Dec	5	10-Dec	5
Kisumu	7-Dec	9	3-Dec	3	3-Dec	3	3-Dec	3
Lamu	7-Dec	9	10-Dec	5	12-Dec	6	12-Dec	6
Lodwar	1-Dec	1	1-Dec	1	1-Dec	2	1-Dec	2
Mombasa	10-Dec	11	11-Dec	7	15-Dec	8	14-Dec	6
Moyale	3-Dec	4	1-Dec	2	1-Dec	1	1-Dec	3
Voi	10-Dec	11	10-Dec	5	12-Dec	7	11-Dec	6
Wajir	5-Dec	8	3-Dec	2	3-Dec	3	4-Dec	3
Mandera	2-Dec	4	2-Dec	2	1-Dec	2	1-Dec	1
Nakuru	2-Dec	4	1-Dec	2	1-Dec	1	1-Dec	1
Kakamega	7-Dec	9	3-Dec	3	3-Dec	3	3-Dec	3

4.4.4 Future trends of MAM seasonal onset and cessation over Kenya as projected under RCP4.5 and RCP8.5 for the period 2021-2050

Table 17 show the trends on MAM seasonal rainfall onset under RCP4.5 and RCP8.5 projections in comparison with observed and ensemble model baseline MAM seasonal rainfall onset dates. The negative, bold and italic values signify negative and significant onset trends while bold and positive values signify positive and significant trends of onset dates.

The results show that more regions in the north and north eastern part of Kenya represented by Moyale, Lodwar, Wajir and Marsabit are projected to have negative trends of onset dates under RCP4.5 compared to RCP8.5 which are showing positive trend. This implies early onset dates for those regions under RCP4.5 projection and late onset dates under RCP8.5 projections. Projection of MAM seasonal dates based on RCP4.5 shows that regions in the coastal part of Kenya represented by Lamu, Voi and Mombasa are having negative trends compared to RCP8.5 projections.

Regions represented by Kisumu and Lodwar shows negative and positive significant trends respectively based on observed data. However, going into the future, the regions are projected to have negative and insignificant trends MAM onset dates for RCP4.5 and positive and insignificant trends under RCP8.5. The zone represented by Marsabit station show a positive and significant onset trend based on ensemble model baseline data while going into the future, the projection shows a negative and significant trends under both RCP4.5 and RCP8.5. This implies that for the period 2021-2050, the zone represented by Marsabit station will continuously be encountering early onset dates as projected by RCP4.5 and RCP8.5.

Projection of onset dates based on RCP4.5 shows that more zones will be having negative and significant trends as compared to RCP8.5 projections. For example, zones represented by Dagoretti, Wajir, Marsabit and Narok indicate a negative and significant trends under RCP4.5 while only Marsabit shows a negative and significant trends under RCP8.5 for the period 2021-2050. Therefore, projections under RCP4.5 implies that more homogenous zones will experience early onset dates for MAM rainfall while projections under RCP8.5 implies that more zones will encounter late onset dates for the period, though this will not be consistence since more stations are indicating insignificant trends.

Based on both RCP4.5 and RCP8.5 projections, more homogenous zones will continue to have either late or early MAM onset dates since more stations representing the zones are showing an insignificant trend. This could imply that going into the future it is more uncertain whether climate change effect would result into early or late onsets for long rains. The results matches that study by Dunning *et al.* (2018) that also found that future projections displays either early or late onset dates for different regions/stations over the Horn of Africa.

Table 17: Results of observed, ensemble model baseline and future trends of MAM seasonal onset dates over Kenya as projected under RCP4.5 and RCP8.5 for period 2021-2050. The symbol star (*) and bold values means significant at 95% confidence level

Stations	**MAM Onset**			
	Observed	**Ensemble model baseline**	**Ensemble model RCP4.5**	**Ensemble model RCP8.5**
Dagoretti	0.204	-0.069	***-0.339****	0.242
Garissa	0.0926	0.000	0.093	0.118
Kisumu	***-0.412****	0.121	-0.002	0.191
Lodwar	**0.564***	0.260	-0.201	0.210
Mombasa	-0.040	0.052	-0.081	-0.048
Moyale	0.274	**0.385***	-0.097	0.092
Voi	-0.236	-0.167	-0.166	0.064
Wajir	-0.142	0.198	***-0.368****	0.253
Lamu	0.100	0.000	-0.114	0.058
Marsabit	-0.245	**0.503***	***-0.452****	***-0.416****
Nanyuki	-0.038	-0.074	0.002	-0.019
Narok	-0.205	0.111	***-0.299****	0.182

Table 18 shows future MAM rainfall cessation trends as projected under RCP4.5 and RCP8.5 for the period 2021-2050. The projection results are compared with both observed data and ensemble model baseline data. The results show varying results across different homogenous zones represented by different stations. More zones in the north and north eastern part of the show negative trends for the MAM cessation dates and this is same case for zones in the coastal regions and central represented stations like Mombasa and Nanyuki respectively based on observed data and both RCP4.5 and RCP8.5.

Voi shows negative and significant trends for both observed and ensemble model baseline data, however, going into the future MAM cessation trends positive and insignificant trend for RCP4.5 and negative and insignificant trend for RCP8.5. This means that as results of the insignificancy in the trend, there will be uncertainty in terms of either having late or early cessation dates during the MAM season for the period 2021-2050. A comparison of MAM onset trends and MAM cessation trends for RCP8.5 implies that more regions will have late onset dates and early cessation dates, however, this will vary since many are showing insignificant trends.

Narok and Garissa are the only stations that show negative and significant trends for the period 2021-2050 under RCP4.5 and RCP8.5 projections respectively. Therefore, it implies that despite the continuous increase in global warming, there is insignificant changes in trends for MAM rainfall cessation dates. A study by Dunning *et al.* (2018) also found that future projections shows early cessation dates for the long rains over the Horn of Africa. This is clearly evident as shown in Table 18 where projections under RCP4.5 an RCP8.5 indicating that more stations have recorded negative trend for cessation dates which means early cessation dates for the MAM seasonal rainfall.

Table 18: Results of observed, ensemble model baseline and future trends of MAM seasonal cessation dates over Kenya as projected under RCP4.5 and RCP8.5 for period 2021-2050. The symbol star (*) and bold values means significant at 95% confidence level

Stations	MAM Cessation			
	Observed	Ensemble model baseline	Ensemble model RCP4.5	Ensemble model RCP8.5
Dagoretti	-0.229	-0.140	-0.106	-0.023
Garissa	-0.192	0.127	-0.091	***-0.326****
Kisumu	0.088	0.077	0.192	-0.132
Lodwar	0.071	**-0.312***	-0.180	-0.081
Mombasa	-0.195	0.120	-0.046	-0.126
Moyale	-0.061	-0.065	-0.053	-0.127
Voi	***-0.424****	***-0.336****	0.134	-0.101
Wajir	-0.204	-0.158	-0.019	-0.193
Lamu	-0.209	0.099	-0.025	-0.107
Marsabit	***-0.292****	0.023	-0.198	-0.174
Nanyuki	-0.238	-0.083	-0.009	-0.159
Narok	-0.232	0.169	***-0.247****	-0.180

4.4.5 Future trends of OND seasonal onset and cessation over Kenya as projected under RCP4.5 and RCP8.5

The results in Table 19 show the trends for OND seasonal rainfall onsets dates under RCP4.5 and RCP8.5 projections for the period 2021-2050 in comparison to both observed and ensemble model baseline data for OND rainfall onset dates. The results show varying trends of OND onset dates for both RCP4.5 and RCP8.5 and going into the future, different regions will experience a mixture of positive and negative insignificant trends for the OND onset dates based on both RCP4.5 and RCP8.5 projections.

Considering the ensemble model baseline, zone represented by Wajir show a negative and significant trends and thus implies that OND onset dates have been consistently coming early in the past as shown in Table 19. However, moving into the future, projections shows that OND onset trends for Wajir will be positive and insignificant trends for both RCP4.5 and

RCP8.5. This means that as climate is changing, the region will experience an insignificant late OND rainfall onset dates.

Also, a comparison of RCP4.5 and RCP8.5 reveals that more regions will experience an insignificant positive trends on OND onset dates under RCP8.5 compared to RCP4.5 projections. However, both projections show an insignificant trend of OND onset dates for the period 2021-2050 and thus means that even with climate change, there is no clear indication of consistently having either early or late OND rainfall onset dates. The projected results are also in line with a study carried out by Dunning *et. al.* (2018) which found out that future projections shows late onset dates for the short rains over the Horn of Africa.

Table 19: Results of observed, ensemble model baseline and future trends of OND seasonal onset dates over Kenya as projected under RCP4.5 and RCP8.5 for period 2021-2050. The symbol star (*) and bold values means significant at 95% confidence level

Stations	**OND Onset**			
	Observed	**Ensemble model baseline**	**Ensemble model RCP4.5**	**Ensemble model RCP8.5**
Dagoretti	0.219	0.106	-0.100	0.134
Garissa	0.262	-0.202	-0.049	0.167
Kisumu	-0.016	-0.167	-0.039	-0.128
Lodwar	0.062	-0.389	0.018	0.106
Mombasa	-0.102	-0.233	-0.079	0.072
Moyale	-0.179	0.105	-0.037	0.202
Voi	-0.008	-0.052	0.058	0.139
Wajir	-0.303	**-0.383***	0.146	0.177
Lamu	-0.059	-0.104	-0.014	0.162
Nakuru	0.063	-0.295	-0.100	-0.187
Kakamega	-0.016	0.213	-0.039	-0.128
Mandera	0.488	-0.331	0.045	0.051

Table 20 show results for OND rainfall trends for cessation dates for period 2021-2050 under RCP4.5 and RCP8.5 projections. A comparison of past and future cessation trends for the northern, north eastern, coastal and western regions shows more regions into the future indicate positive and insignificant trends for both RCP4.5 and RCP8.5 projections. The insignificant trends imply that there is less certainty in terms of the regions consistently having early or late cessation dates for the OND season during the 2021-2050 period.

The homogenous zone represented by Mombasa show a negative cessation trend based on both observed and ensemble model baseline data, however, the trends are significant for the ensemble model baseline. Going into the future, the RCP4.5 and RCP8.5 projections indicate that the regions will experience positive and insignificant trends. This means that cessation date will insignificantly come late and this could also imply that there will be period in which cessation dates will come late and other period when it will come early for the period 2021-2050. Therefore, change in climate due continuous global warming could either results into early or late OND rainfall cessation dates for the period 2021-2050.

Table 20: Results of observed, ensemble model baseline and future trends of OND seasonal cessation dates over Kenya as projected under RCP4.5 and RCP8.5 for period 2021-2050. The symbol star (*) and bold values means significant at 95% confidence level

Stations	**OND Cessation**			
	Observed	**Ensemble model baseline**	**Ensemble model RCP4.5**	**Ensemble model RCP8.5**
Dagoretti	0.147	**0.300**	0.127	0.019
Garissa	-0.011	-0.221	0.207	0.109
Kisumu	-0.202	-0.020	0.228	0.155
Lodwar	0.062	-0.025	0.021	0.133
Mombasa	-0.020	**-0.301***	0.131	0.123
Moyale	0.028	0.009	0.110	0.063
Voi	-0.177	-0.248	0.039	0.037
Wajir	-0.092	0.089	0.095	0.007
Lamu	0.030	-0.245	-0.063	0.021
Nakuru	0.020	-0.231	0.054	0.199
Kakamega	-0.202	-0.020	0.228	0.155
Mandera	0.114	0.063	-0.107	-0.143

In conclusion, the results have showed that by comparing onset and cessation dates based on both RCP4.5 and RCP8.5, the onset dates have higher variability than the cessation dates and this is the case for both MAM and OND seasonal rainfall. Also, a comparison of MAM and OND seasonal rainfall indicate that the onset and cessation dates during the MAM season have higher variability compared to the onset and cessation dates of OND season. A comparison of RCP4.5 and RCP8.5 scenarios also showed that there is higher variability of onset and cessation dates under RCP8.5 projection compared to RCP4.5 projections. This could be attributed to the continuous emission of greenhouse gases without mitigation measures as projected under RCP8.5 scenarios compared to RCP4.5 scenarios that indicate that despite the continuous emission, there are some mitigation measures being implemented to carb emission. The results further indicated that going into the future, the RCP4.5 projection show that more regions will experience insignificant negative trends for both

MAM and OND onset dates compared to RCP8.5 projects that shows that more regions will experience insignificant positive trend for the MAM and OND onset dates. On the other hand, the projections show that more regions will experience insignificant negative trends for MAM cessation dates based on both RCP4.5 and RCP8.5 while for the OND cessation dates, the positive and insignificant trends will be experienced based on both RCP4.5 and RCP8.5 for the period 2021-2050.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter gives the conclusions and recommendations from the results found based on three study objectives. The conclusions were used to understand the effect that climate change will have on the seasonal rainfall onset and cessation dates over Kenya. The recommendations to inform the use or incorporation of study results by different sectors who relies on onset and cessation dates of seasonal rainfall for their activities.

5.1 Conclusions

The study focused on assessing effects of climate change on the onset and cessation dates of seasonal rainfall over Kenya. To achieve the study objective, the trends and variability of onset and cessation dates of seasonal rainfall was carried with a focus on the past observed data and future climate projections. The results have shown that the MAM onset dates had high variability compared to the OND onset dates for the period 1981-2010. Also, for the cessation dates, more stations representing different homogenous zones showed high variability for the MAM cessation dates compared to the OND cessation dates. The results further indicated that there is a mixture of positive and negative trends for the trends of OND onset and cessation dates across different homogenous zones in Kenya.

A comparison results for the baseline models with the observed gauged data indicated that ensemble model simulate closely the onset and cessation dates of seasonal rainfall compared to the CNRM, ICHEC and MPI models. This implies that prediction of seasonal rainfall onset and cessation dates are well predicted using ensemble model compared to individual GCM models.

In comparison to the model baseline, the projection under RCP4.5 and RCP8.5 showed that there will be a slight increase in the variability of MAM onset dates for the period 2021-2050. However, there will be a slight decrease in the deviation days for MAM cessation days for the period 2021-2050 as compared to the model baseline data that showed that station will be having insignificant trends for the MAM seasonal rainfall onset and cessation dates. This implies that going into the future, the prediction of MAM onset dates will be more variable compared to the MAM cessation dates as a result of high variability observed. Projection under RCP4.5 and RCP8.5 indicates a mixture of early and late onset for different homogenous zones for the period 2021-2050.

In regards to OND seasonal rainfall, the projection based on RCP8.5 shows a slight high variability for the OND onset dates compared to RCP4.5. However, for the OND cessation dates, both RCP4.5 and RCP8.5 projections tend to give similar deviation days for the cessation dates. In general, the results have shown that MAM onsets and cessation dates for all the homogenous zones have more deviation days as compared to the OND onsets and cessation dates. This implies that going into the future, the prediction of MAM onset and cessation dates for the different homogenous zones in Kenya are more uncertain compared to OND onset and cessation dates under RCP4.5 and RCP8.5 for the period 2021-2050.

Projection of onset dates based on RCP4.5 shows that more zones will be having negative and significant trends as compared to RCP8.5 projections. For example, zones represented by Dagoretti, Wajir, Marsabit and Narok indicate a negative and significant trends under RCP4.5 while only Marsabit shows a negative and significant trends under RCP8.5 for the period 2021-2050. Therefore, based on both RCP4.5 and RCP8.5 projections, more homogenous zones will continue to have either late or early MAM onset dates since more stations representing the zones are showing an insignificant trend. This could imply that going into the future the climate change effect would either results into either early or late onsets dates for long rains. In addition, results show that projections under RCP4.5 an RCP8.5 indicate more stations have recorded negative trend for cessation dates which means early cessation dates for the MAM seasonal rainfall.

A comparison of RCP4.5 and RCP8.5 further reveals that more regions will experience an insignificant positive trends on OND onset dates under RCP8.5 compared to RCP4.5 projections. For OND cessation dates, going into the future, the RCP4.5 and RCP8.5 projections indicate that the regions will experience positive and insignificant trends. This means that cessation date will insignificantly come late and this could also imply that it will be a challenge to be certain on whether the cessation dates will be early or late for the period 2021-2050. In general, the RCP4.5 projection show that more regions will experience insignificant negative trends for both MAM and OND onset dates compared to RCP8.5 projects that shows that more regions will experience insignificant positive trend for the MAM and OND onset dates. In addition, the projections show that more regions will experience insignificant negative trends for MAM cessation dates based on both RCP4.5 and RCP8.5 while for the OND cessation dates, the positive and insignificant trends will be experienced based on both RCP4.5 and RCP8.5 for the period 2021-2050.

5.2 Recommendations

This section provides the essential recommendations to different sectors who relies on onset and cessation dates of seasonal rainfall for their activities. The following recommendation should be taken into considerations;

5.2.1 Recommendations to scientists and climate research institutions

Following the study results, scientist in the climate field should consider the use of other CORDEX models in assessing the effects of climate change on onsets and cessation dates of seasonal rainfall. This will help in understanding the performance of other CORDEX models in understanding future variability and trends of onset and cessation dates of seasonal rainfall over Kenya and East Africa at large

Besides understanding the onset and cessation dates, further studies should be done on identifying wet and dry periods within the seasons since this also influence crop production during the rainy seasons.

Following the high variability of MAM onset and cessation dates compared to the OND season, further studies should be done to assess the likelihood shift from MAM rainfall season to OND rainfall season as the main rainfall season.

5.2.2 Recommendation to users of climate information

To the users of climate information like farmers, there is need to incorporate the research findings for the purpose of effective planning going forward in terms of knowing when to undertake different farm activities such as land preparation and planting.

Users should work closely with the climate producers through consultation in order to have a clear information on when seasonal rainfall will begin and end. This is as a result of varying deviation days for both onset and cessation dates for different homogenous zones.

5.2.3 Recommendation to policy markers

Policy makers should work closely with Kenya Meteorological Department in order to facilitate it capacity on awareness creation in relation to seasonal rainfall onset and cessation dates. This is awareness creation will enhance effective planning for different sectors such as agricultural sectors in terms timely access to different farming inputs

Through policy development, more resources should be provided for carrying out more research geared towards enhancing capacity of scientist to address different research gaps such as identifying wet and dry periods within the rainy seasons.

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