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Evaluation of the Effects of Climate Variability on Water Resources and Agriculture: Insights from Regional Climate Models

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Climate variability and change present significant challenges to global food and water security, particularly in vulnerable regions like East and Southern Africa. This review synthesizes current research on the impact of climate drivers such as temperature and precipitation variability—on water resources and agricultural productivity in this region. Analyzing over four decades of data and recent findings, this paper discusses the complex interactions between climate phenomena, including El Niño Southern Oscillation (ENSO), and their effects on regional agriculture and water systems. The review highlights the limitations of Regional Climate Models (RCMs) in accurately

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predicting climate patterns and emphasizes the need for improved modeling techniques. Recommendations for future research and policy interventions are provided to enhance climate resilience in these critical sectors.

Keywords: Climate variability; water resources; agriculture; precipitation; regional climate models (RCMs).

1. INTRODUCTION

Climate variability and change present formidable global challenges, particularly concerning food and water security. With the increasing frequency and severity of extreme weather events, public concern has grown, driving an urgent need to understand and predict these evolving patterns in the coming decades. The study of historical shifts in climate patterns is essential for optimizing water resource management and enhancing food production, as these insights guide critical applications such as hydrological modeling, climate variability assessment, and water resources planning [1,2].

Precipitation and temperature are two of the most crucial variables in climate science and hydrology, serving as key indicators of climate change and variability. Precipitation, a vital component of the hydrological cycle, directly influences regional water resources. Changes in rainfall patterns affect stream flows, runoff distribution, soil moisture, and groundwater reserves, necessitating adjustments in reservoir operations and water management strategies [3]. Similarly, temperature, which reflects energy exchange processes over the earth's surface, plays a significant role in understanding climate dynamics. Analyzing the temporal variability of these factors is essential for predicting and managing extreme events such as droughts and floods, which are critical for agriculture, hydropower, and domestic water supply [2].

Numerous studies have explored trends in temperature and rainfall over time, revealing significant regional changes. For example, research in North-Eastern Cuttack District, Orissa, and the Tana River Basin in Kenya, identified considerable shifts in precipitation patterns [4,2]. The impact of climate variability is particularly pronounced in regions like East and Southern Africa, where seasonal changes significantly influence water resources, agriculture, and the socio-economic well-being of rural communities dependent on rain-fed systems of production [2].

Ethiopia, with its highly variable seasonal rainfall, is a case in point. Phenomena such as the El-Nino Southern Oscillation (ENSO) significantly influence agricultural productivity and water resources, with droughts often exacerbated by ENSO episodes and anomalies in sea surface temperature. The complex interaction between these global climate drivers and local weather patterns underscores the need for a detailed understanding, particularly given the critical importance of the main rainy season (kiremt) for agricultural productivity and water reservoir levels [5,6]. Despite extensive research, gaps exist in RCMs' simulation of climate variability in East and Southern Africa. This study assesses RCM performance in modeling rainfall and temperature, providing insights for strategies to mitigate climate impacts on water and agriculture.

2. CLIMATE CHANGE

Climate is described in terms of the variability of relevant atmospheric variables such as temperature, precipitation, wind, snowfall, humidity, clouds, including extreme or occasional ones over a long period in a particular region. Basically, the term climate derived from ancient Greek “klima”, meaning “inclination” is commonly defined as the weather averaged over a long period of time. Different scholars explained the concept of climate in different perspectives in this regard [7] defined Climate generally as “average weather”. It is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time. The same source further elucidated that global observations of temperature increases and changes in other climate variables provide unequivocal evidence that the climate is warming.

Şensoy et al. [8] conceive climate in a narrow sense defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years whereas climate in a wider sense is the state, including a statistical description, of the climate system. Consistently, the same study noted that climate is defined as the collective state of the atmosphere for a given place over a specified interval of time. On the same source it is indicated that there are three parts to this definition; the first deals with the state of the atmosphere. The collective state is classified based on some set of statistics. The most common statistic is the mean, or average. Climate descriptions are made from observations of the atmosphere and are described in terms of averages (or norms) and extremes of a variety of weather parameters, including temperature, precipitation, pressure and winds.

As drawn from [9] the second part of the climate definition deals with a location. It could be a climate the size of a cave, the Great Lakes region, or the world. In weather and climate studies we are most interested in micro-scale, regional, and global climates. The climate of a given place should be defined in terms of your purpose. Time is the final aspect of the definition of climate. A time span is crucial to the description of a climate. Weather and climate both vary with time. Weather changes from day to day. Climate changes over much longer periods of time. Variations in climate are related to shifts in the energy budget and resulting changes in atmospheric circulation patterns.

Climate change is the sever problem that the whole world facing today. It is now widely accepted that climate change is already happening and further change is inevitable; over the last century (between 1906 and 2005), the average global temperature rose by about 0.74 ºC. This has occurred in two phases, from 1910s to 1940s and more strongly from the 1970s to the present [10]. Many researchers into the detection and attribution of climate change have reported that most of the increase in average global surface temperature over the last 50 years is attributable to human activities [11]. It is estimated that, for the 20th Century, the total global mean sea level has risen 12-22 cm, this rise has been caused by the melting of snow cover and mountain glaciers (both of which have decline on average in both hemispheres [10]. The IPCC also notes that observations over the past century shows, changes are occurring in the amount, intensity, frequency and types of precipitation globally [10].

At this point it is worth mentioning the role and remit of the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme, and its role is to “assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human induced climate change, its potential impacts and options for adaptation and mitigation”. Among the different assessment that are carried out by the IPCC, the most recent which published in 2007, states the projected global surface warming lies within the range 0.6 to 4.0oC, whilst the projected see level rise lies within the range 0.18 to 0.59 m at the end of next century [10,11].

Today, climate change and its consequences receive much attention in the public debate. It is the most complex and cross-cutting environmental problem which afflicts every corner of the world its impact is diverse and globally witnessed. In relation with this [12] in its report stated about the prominence of climate is that it is a key natural resource on which the others depend. It influences food production, water management and energy availability. It also sets the stage for the establishment of habitats, affects the pace of primary productivity, and influences species density and distribution.

In general, climate is the average state of the atmosphere and the underlying land or water, on time scales of seasons and longer. Climate is typically described by the statistics of a set of atmospheric and surface variables, such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice. The statistics may be in terms of the long-term average, as well as other measures such as daily minimum temperature, length of the growing season, or frequency of floods. Although climate and climate change are usually presented in global mean terms, there may be large local and regional departures from these global means. These can either lessen or exaggerate the impact of climate change in different parts of the world.

3. MAJOR ATTRIBUTES OF CLIMATE CHANGE

3.1 Precipitation

Rainfall variability receives high attention among other climatic elements especially in relation with agriculture. As stated by Huffman et al. [13] the variability in rainfall can be explained either temporally or specially or both depending on the purpose needed. Africa is one of the most vulnerable continents to rainfall variability, a situation aggravated by the interaction of multiple stress occurring at various levels, and low adaptive capacity. Africa's vulnerability to climate variability and its inability to adopt to these changes may be devastating to the agriculture sector, the main source of livelihood to the majority of the population.

Precipitation is a key component of the hydrological cycle and one of the most important parameters for various natural and socio-economic systems: Water resources management, 2556 agriculture and forestry, tourism, flood protection, to name just a few [14]. The study of consequences of global climate change on these systems requires scenarios of future precipitation change as input to hydrologic cycle. Hydrological and meteorological data show no random behavior. Then they can be analyzing by some statistical methods based on frequency analyses of precipitation and flood data. Therefore, statistical distributions can be employed for the studies such as the design of water structure, the management of water resource and watershed, and the determination of effective factors about hydrologic cycle.

However, it is necessary to determine the best-fitted distribution to studied data. As referred from [15] the primary aim of frequency analysis is to relate the magnitude of extreme events to their frequency of occurrence using the probability of distributions. Rainfall variability receives high attention among other climatic elements especially in relation with agriculture. The variability in rainfall can be explained either temporally or specially or both depending on the purpose needed.

The Horn of Africa has for a long time been an area neglected by climatologically studies. However, repeated drought badly affect the region, each time claiming the lives of several hundred thousands of people, e.g., 1973-1974 and 1982-1985 in Ethiopia [16]. The article states that the amount and temporal distribution of rainfall is the most important determinants of Ethiopia's crop production from year to year and rainfall in arid and semi-arid is often erratic and unreliable. Therefore, its necessary to study and analyze further in macro and micro scale of rainfall variability and temperature in the country, especially upper Gibe basin.

3.2 Temperature

Temperature is also considered a good indication of the state of climate because of its ability to represent the energy exchange process over the earth's surface with reasonable accuracy [17]. Temperature is also considered a good indication of the state of climate because of its ability to represent the energy exchange process over the earth's surface with reasonable accuracy [17]. The temporal variability analysis of rainfall and temperature at timescales help in determining the likelihood of extreme (drought or flood) event occurrences and management of water resources particularly for major consuming sectors; namely agriculture, hydropower and domestic water supply within basins [2].

3.3 Trend

Changes in hydrological series can take place in many different ways. A change may occur abruptly (step change) or gradually (trend) or may take more complex forms. Changes can be seen in mean values, in variability (variance, extremes, persistence) or within-year distribution. Abrupt changes can be expected because of a sudden alteration within the catchment. They can also inadvertently arise from changes to gauging structures, or to rating curves (stage-to-flow relationships), or to observation methods. Gradual hydrological changes typically accompany gradual causative changes such as urbanization, deforestation, climate variability, and other change. Although climate change is often thought of in terms of progressive trend, it is also possible for it to result in a step-like change because of complex dependencies on non-linear dynamic processes that feature cumulative effects and thresholds.

There is a huge variety of hydrological data that it is possible to analyses for trend and step change. These may be collected at a range of temporal intervals: continuous, hourly, daily, monthly, annually, or sampled irregularly. Data records contain either instantaneous values or totals for a time interval. Data may also pertain to different spatial scales, from point or experimental plot to large areas.

Studies of hydrological change are typically complicated by factors such as missing values, seasonal and other short-term fluctuations (climate variability) and by lack of homogeneity. In some cases, there are further problems because of censored data and data series that are not sufficiently long. The hydrological trends can be secular, periodic, and cyclical trend.

4. PARAMETRIC AND NON-PARAMETRIC TREND TEST METHODS

Many tests for trend detection have been used in studies of long time series of hydrological data. Yet, every test requires a number of assumptions to be satisfied. When underlying test assumptions are not fulfilled, acceptance and rejection regions of the test statistic cannot be rigorously determined. Therefore, such tests should be treated as methods of exploratory data analysis rather than as rigorous testing techniques. Many approaches can be used to detect trends and other forms of non-stationery data in hydrology. In deciding which approach to take it is necessary to be aware of which test procedures are valid (the data meets the required test assumptions) and which procedures are most useful (likely to correctly find change when it is present).

Parametric test is a test that involves estimation of parameters and it is not rank based. Parametric testing procedures are widely used in classical statistics. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution), and to make assumptions that data observations are independent of one another. For many hydrological series, these assumptions are not appropriate. Firstly, hydrological series rarely have a normal distribution. Secondly, there is often temporal dependence in hydrological series particularly if the time series interval is short. If parametric techniques are to be used, it may be necessary to (a) transform data so that its distribution is nearly normal and (b) restrict analyses to annual series, for which independence assumptions are acceptable, rather than using the more detailed monthly, daily or hourly flow series.

As stated by Elhakeem and Papanicolaou [18] a parametric test is based on theory or concepts that require specific conditions about the underlying population and/or its parameters from which sample information will be obtained. Non-parametric test is a test that does not involve estimation of parameters and it is rank-based tests. In non-parametric and distribution-free methods, fewer assumptions about the data need to be made. With such methods, it is not necessary to assume a distribution. However, many of these methods still rely on assumptions of independence. More advanced approaches must therefore be used for daily or hourly series. A very useful class of non- parametric tests is permutation tests. They are based on changing the order (shuffling) of data points, calculating statistics, and comparing these with the observed test statistics.

Elhakeem and Papanicolaou [18] stated that, a non-parametric test is based on theory or concepts that have not required the sample data to be drawn from a certain population or have conditions placed on the parameters of the population. Even within the basic categories above it is necessary to choose tests that are appropriate for the situation. Some tests are very good at detecting a very specific type of change; other tests may be good at picking up any one of a broad range of possible changes. Since one does not know the pattern of variability beforehand, using a number of tests is sensible.

The primary difference between the assumptions made for the two classes of tests is that those made for non-parametric tests are not as restrictive as those made for parametric tests, such as complete specification of the underlying population [19]. The assumption of normality, needed in the case of parametric tests, may be an unacceptably simplifying one in the context of strongly positively skewed hydrological data. In the case of non-parametric, robust tests, one does not need to assume a distribution. Hirsch [20] found that non-parametric procedures offer large advantages when the data are strongly non-normal, and suffer only small disadvantages (in terms of efficiency of power) for normally distributed data. Even though no distribution needs be assumed, non-parametric tests still make assumptions.

Usually, an assumption of temporal independence must be made. When analyzing a time series of river flows, this assumption may be adequate for annual flow records. However, for shorter time intervals, such as months or days, it is not likely to hold. There are many parametric and non-parametric tests for change detection. These are, Mann’s test (non-parametric), Normal scores linear regression (non-parametric), Spearman’s rank correlation (non-parametric), Linear regression (parametric), Jump fitting to normal scores (non-parametric), Jump fit to ranks (non- parametric) and Jump fit (parametric). Some parametric tests can be applied in a non-

parametric way by testing either the ranks or the so-called “normal scores”, i.e. the series transformed in such a way that the marginal distribution becomes normal, while the relative ranks of the values are preserved [21].
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Two common types of non-parametric tests used for detecting monotonic trend in a time series are Mann-Kendall (MK) and Spearman's rho (SR) test. Both MK and SR methods are rank based non- parametric tests. However, the MK test has been popularly to applied assess the significance of trends in hydrometer-logical time series [22]. The simulation experiments they made have demonstrated that SR test provided results almost identical to those obtained by the MK test. However, the SR test is seldom used in hydro meteorological trend analysis.

5. NON-PARAMETRIC MANN-KENDALL TREND TEST

Mann-Kendall’s test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or non-linear [23]. The non-parametric Mann-Kendall test on the sample variable was first suggested by Yue, Pilon, and Cavadias [22] using the test for significance of Kendall's tau. The Mann- Kendall test is based on the null hypothesis that a sample of data is independent and identically distributed, which means that there is no serial correlation or trend among the data points.

According to Elhakeem and Papanicolaou [18] this test is designed to detect a monotonically increasing or decreasing trend in the data rather than an episodic or abrupt event. The Kendall test may detect watershed changes due to either gradual trends or abrupt events. However, it is more sensitive to changes that result from gradually changing trends. This test is non-parametric test, and has been widely used to test for randomness against trend in hydrology and climatology [24].

The problem in using Mann-Kendall test is that the result would be affected by serial correlation of the time series. If there is a positive serial correlation (persistence) in the time series, the test will suggest a significant trend in a time series, which is actually random more often than specified by the significance level [25]. To remove the effects of serial correlation [26] suggest that the series be “pre-whitened” before applying the Mann- Kendall test. Here assumption of normality is not needed, but there must be no serial correlation for the resulting p-values to be correct.

The Mann-Kendall test possesses the useful property of other nonparametric tests in that it is invariant to (monotonic) power transformations such as those of the ladder of powers. Since only the data or any power transformation of the data need be distributed similarly over time except for their central location in order to use the Mann-Kendall test, it is applicable in many situations [27].

6. REGIONAL CLIMATE MODEL (RCM)

Regional Climate Models (RCMs) are developed based on the same representations of atmospheric dynamical and physical processes as GCMs. They have higher spatial resolution in the order of 10-50km that can cover a sub-global domain. As a result of the higher spatial domain, RCMs provide a better description of orographic effects, land-sea surface contrast and land-surface characteristics [28]. Moreover, they enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales which shows their improved ability to reproduce present day climate [29]. However, there is still some limitations (Res et al. 2014) such as: (i) the inheritance of systematic errors in the driving fields provided by global models, (ii) lack of two-way interactions between regional and global climate (iii) the algorithmic limitations of the lateral boundary interface (iv) computationally demanding, and (v) further downscaling requirement for impact studies.

There are many different RCMs currently available, for various regions, developed at different modeling centers of the world. However, the uncertainty issues remain another drawback in use of RCM. Due to this fact, several international efforts have been taken to quantify uncertainties through model inter-comparison. More recently, a new project called CORDEX (Coordinated Regional Climate Downscaling Experiment) has been initiated by the world climate research program simulations at 50km resolution for multiple regions.

Due to the availability of numerous numbers of such RCMs a number of studies have been conducted in the past. Teutschbein and Seibert [30] provided a recent review on the use of RCMs for hydrological models. They recommend that a bias correction is necessary for using the outputs in any hydrological models as RCMs are susceptible to systematic model errors caused by imperfect conceptualization, discretization and spatial averaging within grid cells. These biases are typically due to the occurrence of too many wet days with low-intensity rain or incorrect estimation of extreme temperature in RCM simulations.

7. COSMO-CLM MODEL

An ensemble of climate change projections has been created by downscaling the results of four GCMs from the CMIP5 climate projections, namely: The Max Plank Institute MPI-ESM-LR, Hadley centers HadGEM2-ES and the National Centre for Meteorological Research CNRM-CM5 and EC-Earth, i.e., the Earth System Model of the EC-Earth Consortium (http://ecearth.knmi.nl/) indicated on Table 1. The historical runs, forced by observed natural and anthropogenic atmospheric composition, cover from the period 1950 until 2005, whereas the projections (2006–2100) are forced by two Representative Concentration Pathways (RCPs), [31], namely, RCP4.5 and RCP8.5. The numerical domain common to all groups participating to the CORDEX Africa initiatives covers the entire Africa continent at a special horizontal resolution of 0.44o and the model grid uses 194 points from West to East and 201 points from South to North. CORDEX-Africa domains (source: http://cordex.dmi.dk/)

In this work we analyze the climate change projections as simulated by the regional climate model COSMO-CLM (CCLM).

8. CORDEX PROJECT

In 2009, World climate Research program (WCRP) has initiated Global Coordinated Regional Downscaling Experiment (CORDEX: http://wcrp-cordex.ipsl.jussieu.fr/) with the intention of producing an ensemble of high-resolution climate change projections by downscaling GCM simulations from Coupled Model Inter-comparison Project Phase 5 (CMIP5) data archive (Taylor et al., 2012) on 25Km and 50Km grid spacing for 14regions of the Globe. Africa was selected as the first target region for the World Climate Research programmes (WCRPs) in CORDEX (Coordinated regional downscaling Experiment). CORDEX consists of two phases: in the first phase downscaling centers are asked to downscale a reference /verification period using Interim European Center for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-Interim) data (Dee et al., 2011) and in the second phase they use data from the Coupled model Intercomparison Project phase 5(CMIP5) GCMs from the period 195-2100.

Hernández et al. [32] evaluates the ability of ten RCMs over Africa and concludes that all RCMs simulate the seasonal mean and annual cycle quite accurately. Likewise, it is verified that the mean of multi-model outputs do better than individual simulation. They successfully reproduce the overall features of geographical and seasonal distribution over most Africa. In their report, CORDEX simulations succeed in reproducing the average distribution of precipitation and its large geographical differences.

Table 1. List of Regional Climate Model and Driving GCMs

GCM-1 Name	Institution aacronym, country	GCMs Horizontal Resolution	RCM	Institutions and country of Origin
MPI-ESM-LR	MPI-M,Germany	$1.9^0 * 1.9^0$	COSMO-CLM	Max plank institute, Germany
CNRM-CM5	CNRM-CERFACS, France	$1.4^0 * 1.4^0$	COSMO-CLM	National center for Meteorological research, France
EC-EARTH	EC-EARTH, European consortium	$1.125^0 * 1.12^0$	COSMO-CLM	Earth System Model of the European Consortium
HadGEM2-ES	Hadley Ceneter, Uk	$1.875^0 * 1.25^0$	COSMO-CLM	The Hadley center, MOHC(Met Office Hadley Center and Institution, Uk

9. HISTORICAL DEVELOPMENT OF FUTURE EMISSIONS SCENARIO

9.1 Representative Concentration Pathway (RCP's)

The potential future evolution of anthropogenic emission of greenhouse gases and other radioactive forcing substances are depicted according to a set of scenarios spanning alternative future development. Past generation of climate projections, in particular experiments issued from the CMIP3 and integrated in the IPCC Fourth Assessment Report (AR4, IPCC 2007), were based on the family of green gas emission storylines (Sutton et al. 2011).

In particular, medium to high range emissions according to the SRES A1B scenarios were the focus of the discussions and climate impact research. Deferent types of emission scenarios are used in climate research to assess the long-term impact of atmospheric greenhouse gases and pollutants based on the assumptions of population growth, economic development level, etc. Scenarios previously approved by the IPCC included in Table 2.

A new generation of scenarios was developed and later used within CMIP5 of the intergovernmental Panel on climate change (IPCC) Fifth assessment Report (RR5) published on 2013-2014. The new scenarios are called Representative concentrations pathways (RCPs) have been defined as a basis for long term and near-term climate modeling experiments in the climate modeling community [31].

There are four RCPs as in Table 3 defined by their level of the total radiative forcing pathway in the year 2100, and are representative for the existing literature about emission scenarios. The definitions of the RCPs allows for a parallel development of new socioeconomic, technical, and policy scenarios that provide insights into the impact of policy decisions on the future climate [31].

9.2 RCPs Primary Characteristics and their Development

RCP 8.5(High Emission) was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels [33].

Table 2. List of emission scenarios used in IPCC reports

Year	Name	Use in
1990	SA90	First assessment Report
1992	IS92	Second assessment report
2000	SRES-specail Report on Emission and Scenarios	Third and Fourth assessment report
2009	RCP-Representative Concentration Pathways	Fifth Assessment report

Table 3. Description of the four Representative concentration pathways (RCPs)

	Description	Publication-IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5W/m^2 (~1370ppm CO_2 eq) by 2100	(Riah et al.2007)-MESSAGE
RCP6	Stabilization without overshoot pathway to 4.5 W/m^2 (~850ppm CO_2 eq) at stabilization after 2100	(Fujino et al.2006; Hijiola et al. 2008)- AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650ppm CO_2 eq) at stabilization after 2100	(Clarle et al. 2007; Smith and Wgley 2006; Wise et al. 2009)-GCAM
RCP2.6	Peak in radiative forcing at ~3W/m^2 (~490ppm CO_2 eq) before 2100 and the decline (the selected pathway declines to 2.6 W/m^2 by 2100	(Van Vuurent et al., 2007a; Van Vuurent et al. 2006)-IMAGE

Note; IA Model = Integrated Assessment model; MEASSAGE= Model for Energy Supply strategy Alternatives and their General Environmental Impact; International Institutes for applied Systems, Austria; AIM = Asia-pacific Integrated Model, National Institute for Environmental studies, Japan; GCAM= Global change Assessment Model, Pacific North West National Laboratory, USA(Previously referred to as MiniCAM); IMAGE= Integrated Model to Assess the Global Environment; Netherlands Environmental assessment Agency, The Netherlands.

RCP6 was developed by the AIM modeling team at the National Institute for Environmental Studies (NIES) in Japan. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions [34].

RCP 4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory 's Joint Global Change Research Institute (JGCRI) in the United States. It is a scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level [35].

RCP2.6 was developed by the IMAGE modeling team of the PBL Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a ―peak-and-decline‖ scenario; its radiative forcing level first reaches a value of around 3.1 W/m2 by mid-century, and returns to 2.6 W/m2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially, over time [31].

Bias-Correction Methods: Often, outputs of regional climate models cannot be directly used for impact assessment as the computed variables may differ systematically from the observed ones. Bias correction is therefore applied to compensate for any tendency to overestimate or underestimate the mean of downscaled variables. Bias correction factors are computed from the statistics of observed and simulated variables. Bias correction methods are assumed to be stationary, i.e. the correction algorithm and its parameterization for current climate conditions are assumed to be valid for future conditions as well. However, a good performance during the evaluation period does not guarantee a good performance under changed future conditions. Teutschbein and Seibert [30] provide a detailed discussion and state that a method that performs well for current conditions is likely to perform better for changed conditions than a method that already performs poorly for current conditions. The correction method used in the study was the power transformation. The method uses the exponential form Xb that is used to adjust the statistical variance standard deviation and coefficient of variation of precipitation time series. The temperature was bias corrected by variance scaling method.

Previous Related Studies in Analysis of Rainfall and Temperature Trends at Watershed Level: Study of different time series data have proved that trend is either decreasing or increasing, both in case of temperature and rainfall. Mondal, Kundu, and Mukhopadhyay [4] investigated in rainfall trend analysis by Mann-Kendall test in North-Eastern part of Cuttack District, Orissa observed that there is evidence of some change in the trend of precipitation of the region in these 40 years in different month. In Kenya, [2] studied temporal variability and trends of rainfall and streamflow in Tana river basin and reported Annual rainfall trend analysis showed negative monotonic trend in seven rainfall stations and positive trends in three stations, indicating an increasing rainfall in high elevation areas, and more drying conditions for low areas within the basin.

In Maharashtra, [36] investigate in trend analysis of drought events over upper Krishna and detected that there is negative trend of pre-monsoon rainfall at over 63 percent of the area. Villani [37] studied Trend analysis of annual and seasonal rainfall time series in the Mediterranean area using 81 years' datasets from 221 gauge stations and detected overall significant changes in the area.

Also, from the review of literature, it is evident that several studies have been undertaken to characterize trends in rainfall and temperature at various locations across the country, Ethiopia. A study by Asfaw et al. [3] in Northcentral of Ethiopia pointed out that there is declining trend for annual and kiremt rainfall was found to be statistically significant while that of belg was not significant and the rate of change of temperature was found to be 0.046, 0.067 and 0.026 C per decade for mean, minimum and maximum respectively.

In Blue Nile [38] had reported that there is neither consistent increasing nor decreasing trend in rainfall and flow extremes of recent years. In Tekeze river [39] revealed that Trend in mean monthly rainfall data shows increasing trends in the Eastern part of the Basin whereas decreasing trend for Western part of the basin. In Omo-Gibe river [40] reported that the results show complex spatial patterns on the frequency and magnitude of drought events across the study area for all timescales and intensity classes [41-44]. Therefore, in-depth knowledge and analysis of rainfall and temperature regimes on different time scales are increasingly becoming necessary for enhancing the management of water resources, planning and designing of hydraulic structures, agriculture production and to mitigate the negative effects of floods and droughts [45-48].

10. CONCLUSION

This review underlines the crucial need to understand the effects of climate variability on water resources and agriculture through insights generated from Regional Climate Models (RCMs). This review finds significant shifts in rainfall and temperature patterns, demonstrating the heightened vulnerability of places like East and Southern Africa to climate variability and related extreme events, such as droughts aggravated by phenomena like ENSO. These findings underline the importance for adaptive management solutions in water resources and agricultural activities to prevent harmful impacts. Through offering a complete evaluation of RCM performance and its predictive capacities, this research contributes to the creation of more effective methods for mitigating the effects of climate change. Future research should focus on boosting RCM accuracy, addressing research gaps, and refining predictive models to better anticipate and respond to changing climate circumstances, thereby enabling enhanced food and water security.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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