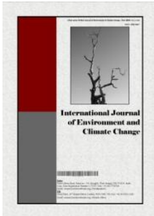

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Evidence of Climate Changes in a Tropical Rainforest: Case Study Kakamega Tropical Rainforest

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To assess trends in rainfall and temperature as evidence of climate change in the Kakamega tropical forest ecosystem over the last 30 years (1980-2010).
Study Design: Secondary data on temperature, rainfall and other climate related phenomena that have occurred within the Kakamega forest ecosystem over the last 30 years were obtained from the Kenya Metrological Department (KMD), Kenya Agriculture and Livestock Research Organization (KALRO), and local metrological stations and analysed to assess trends. This data was supplemented with data from questionnaires and structured interviews.
Place and Duration of Study: The study was carried out among forest adjacent communities in the Kakamega tropical forest ecosystem between April and December 2020.
Methodology: Data on awareness and preparedness for climate change was collected using structured questionnaires, focused group discussions (FGD) and structured interviews. Three villages in the east, west, north and south of the forest that are within a 2km radius of the forest

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were randomly selected for sampling. From the 52,729 households, 397 households were randomly chosen from each of the three selected villages. Questionnaires targeted family heads in all the selected households. The questionnaire sought first-hand information on climate change awareness and impacts of climate change among the forest-adjacent communities. Each questionnaire comprised of open and closed-ended questions. Focused Group Discussion involved specialized groups of women, village elders, local administrators, CBOs working in the ecosystem, among others. Further information was obtained using key informants. A total of forty-eight (48) key informants were randomly selected for discussion. The interview method involved key personnel working within the forest ecosystem which included staff from KWS, County environmental officers, National Environment Officers, Agriculture officers at the national and county levels. The interviews focused on preparedness, mitigative and adaptive capacity to climate change by the forest adjacent communities.

Results: Analysis of the mean rainfall trends over the last 30 years (1980-2018) reveal that, mean monthly rainfall ranged from a monthly minimum 36mm (2012) to a maximum mean of 402.30mm (2018). Similarly, analyses of the mean monthly rainfall reveal dissimilarities in amounts of rainfall in each year over the last 30 years. The mean monthly rainfall fluctuations appear to increase overtime. Analysis of temperature records for the last 30 years (1990-2018) revealed a maximum mean daily temperature of 27.72^{0}C, a minimum temperature of 25.35^{0}C and a maximum of 31.96^{0}C with a range of 25^{0}C - 30^{0}C. From 2005 to 2018, higher temperatures (above 30^{0}C) are evident. When a moving cumulative mean, using data on the minimum temperature over the last 30 years (1982 – 2018) was calculated, a forecasted trend gave a mean minimum temperature of 14.41^{0}C, a minimum temperature of 12.33^{0}C and a maximum temperature of 18.67^{0}C. In the year 1990, the minimum temperature rose from 15^{0}C to 18^{0}C. The forecasted temperature for 2019 also follows the same trend, with temperatures now stabilizing above 30^{0}C. Majority of the respondents (96.7%, n=290) were aware of changes in climatic conditions now, compared to previous years. Most of the respondents had moderate (53%, n=159) to high (30.7%, n=92) knowledge about changes in climate. Majority of the respondents (57.7%, n=173) affirmed that information on climate change was obtained from broadcast media. Majority of the respondents were very concerned about climate change 91.7% (n=275) suggesting that they understood the seriousness of the changing climate. Further analyses of the data revealed that many of the respondents were aware that natural causes (31%, n=93), human activities (34.3%, n=103) and a combination of both (34.7%, n=104) were the main causes of climate change, while many of the respondents (58%, n=174) had experienced some extreme weather events in the last five years.

Conclusion: There is a clear evidence of climate changes in the Kakamega forest ecosystem as observed from the rising temperatures and variability in precipitation. Most people adjacent to the forests are aware of climate changes and its effects. The main sources of information are the electronic media. The increase in temperature may be due to deforestation, urbanization and agricultural activities.

Keywords: Climate change; rainfall changes; temperature changes; Kakamega forest; tropical forest; Kenyan forests.

1. INTRODUCTION

The current climate change is a threat not only to biodiversity but also to the entire human economic fabric [1,2]. Of greater concern are the effects of climate change on food security [3]. Worldwide, hunger has been on the rise since in the recent past [4]. The prevailing climate variability coupled with extremes are the key drivers of global hunger [4,5], through their effects on all components of food security.

Manifestations of Climate change include, the rise in sea levels, abnormal rainfall, changing of river flows, increase in atmospheric carbon dioxide, heat waves and longer duration of droughts, and emerging and epidemic diseases [6,7,8,9]. The role of increasing carbon dioxide alongside temperature, are likely to change plant function [10]. Moreover, the role of the environment in emerging and re-emerging infectious diseases is increasingly recognized [11]. A report by [12] reveals that the earth's climate has shown tremendous changes at regional and global scales when observed from the pre-industrial era; and human society has been a major player in influencing these observed changes [13]. The changing climate is primarily driven by increases in concentrations of atmospheric greenhouse gases as a result of anthropogenic activities, which have led to an increase in global temperature of approximately 1°C since the pre-industrial period [14,15].

Since the 1850s, persistent warming has been observed with the earth being successively warmer in the last three decades [16,17,18]. A projected rise in the global temperature level by approximately 1.4 to 5.8°C by the year 2100 extrapolated from 1990 further brings the fear of impacts of climate change on a global scale [19,20]. A general increase in rainfall at the global scale has been observed at about 0.5% to 1%; while that of cloud cover has shown an expansion by approximately 2 percent especially in the northern hemisphere since the late 19th century [21].

Climate change is a serious risk factor for disease vectors [22,23]. It enables faster multiplication and spread of diseases that negatively impact human health globally [24,25]. Climate-related diseases have been evident in many parts of the world. The African continent is an example of where climate perpetuated diseases such as tuberculosis, malaria and diarrhoea have become common, claiming many lives [26,27]. Variability in rainfall patterns has resulted in elevated famine and poverty as evidenced in Eritrea, Sudan, Gambia, Ghana Ethiopia Kenya, among others [28]. A report by the Kenyan government on extrapolation of rainfall in the last 50 years shows an erratic pattern of precipitation with some areas receiving high rainfall while others experience extreme droughts [29].

The reality of climate change now, requires us to continuously assess and monitor trends in precipitation and temperature in relation to local, regional and global environments. In Kenya, for instance, the western region is endowed with important natural resources such as the Kakamega tropical forest that influence climate at all scales and provides livelihoods to the densely populated region. It becomes imperative that forest-adjacent communities be aware of climate change trends because of their vulnerability to climate change. Currently, this information is inadequate in the Kakamega tropical forest ecosystem. It is important therefore, to assess climate change trends over the last 30 years and determine sustainable interventions to be adopted by communities living within the forest ecosystem. This will enable them to prepare adequate, climate change mitigative measures. This study evaluated trends in rainfall and temperature as evidence of climate change in the Kakamega tropical forest ecosystem over the last 30 years.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out among forest adjacent communities in the Kakamega tropical forest ecosystem (Fig. 1). The Kakamega tropical forest is located in western Kenya, some 400km north of Nairobi. It has an estimated area of 24000ha of which, 15000ha are under natural forest. Kakamega forest lies between longitudes $34^0$32'and $34^0$57'30" East and $0^0$07" 30" and $0^0$15"s. The forest has a varied topography with altitude ranging from 1250m to 2000m above the sea level [30,31,32,33]. The forest lies in Kakamega County that is bordered to the north by Bungoma County, to the east by Uasin and Nandi Counties, to the south by Vihiga County and the west by Siaya County.

Kakamega forest experiences a bimodal rainfall distribution with the long rains between March and May and short rains in Septembers to October. The maximum temperature varies between 28^0C - 32^0C while the minimum temperature ranges between 10^0C-13^0C. The forest is characterized by feralchromic acrisol soils that are deeply drained and suited for agriculture [34]. Rainfall and temperature make the area conducive for agriculture that is dominated by small scale subsistence farming of food crops like maize, beans, tea and cash crops like sugarcane and tea. The forest ecosystem is surrounded by a dense population of more than 675 persons per square kilometres [35].

2.2 Data Collection

Secondary climatic data on temperature, rainfall and other climate related natural calamities around Kakamega forest over the last 30 years were obtained from the Kenya Metrological Department, Kenya Agriculture and Livestock Research Organization (KALRO) and local metrological stations within the forest ecosystem. Data obtained was analyzed to assess trends. Primary data was collected using questionnaires, focused group discussions and directed interviews.

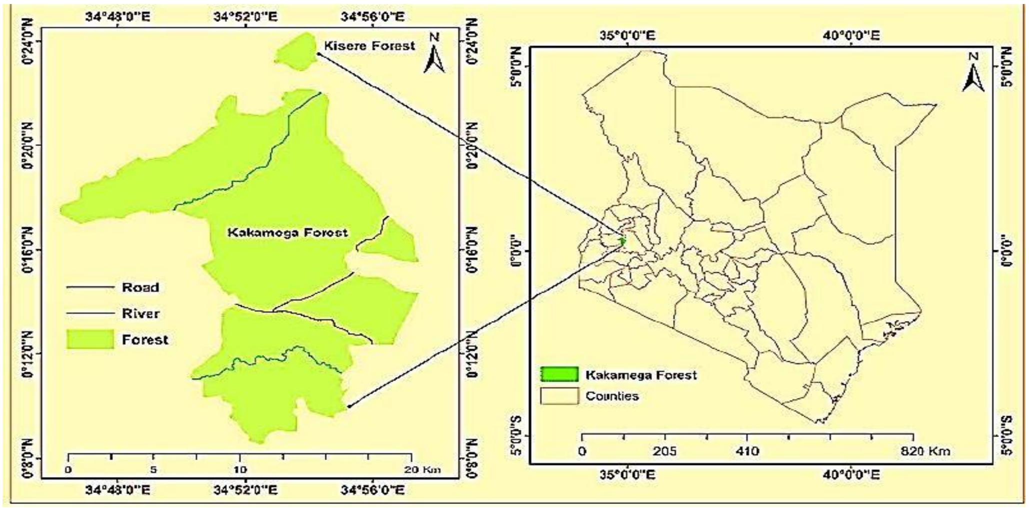

Fig. 1. Map of the Kakamega forest ecosystem forest complex (Source: [36])

3. RESULTS

3.1 Rainfall Trends

Analysis of the mean rainfall trends over the last 30 years (1980-2018) are shown in Fig. 2. Mean monthly rainfall ranged from a minimum 36mm (2012) to a maximum mean of 402.30mm (2018). Mean monthly rainfall remained relatively stable for a decade after which it increased significantly (e.g.,1980-1900). Rainfall trend also reveals changes in precipitation between decades that may be due to bouts of deforestation and afforestation.

Analysis of the mean monthly rainfall reveals dissimilarities in amounts of rainfall in each year over the last 30 years. There is evident increasing rainfall trend towards 2018. Consequently, it was possible to forecast the mean monthly rainfall for the year 2019. The year 2019 received a mean maximum monthly rainfall of 225mm and a mean minimum rainfall of 100mm (Fig. 3). Mean monthly rainfall fluctuations appear to increase overtime, due perhaps to afforestation (1990 onwards) and deforestation (1980-1990) are a result of effective enforcement of regulations on deforestation and the shamba system respectively [37].

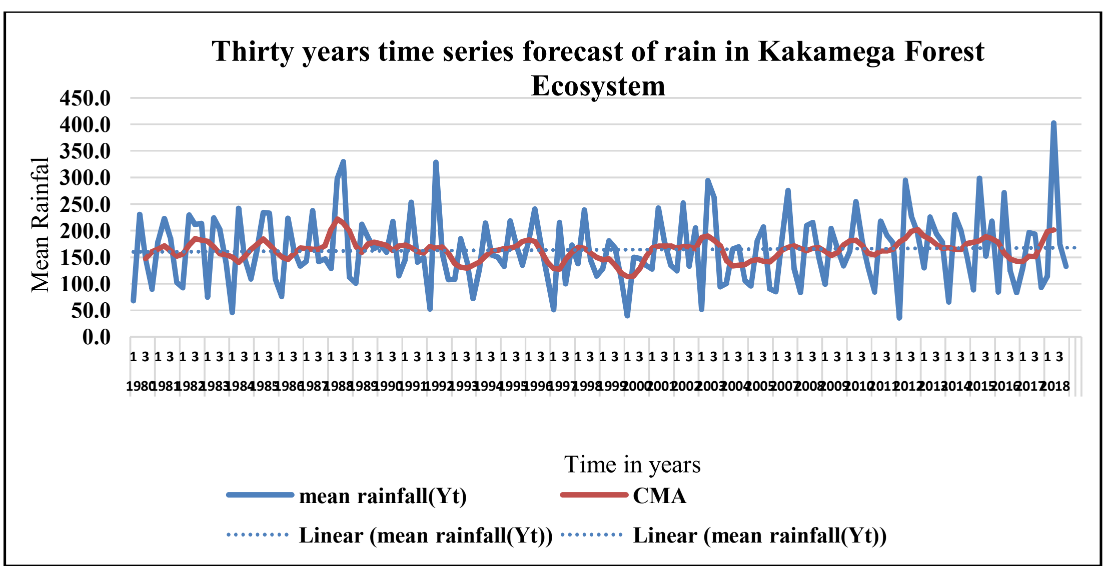

Fig. 2. Kakamega forest ecosystem thirty-year rainfall trend

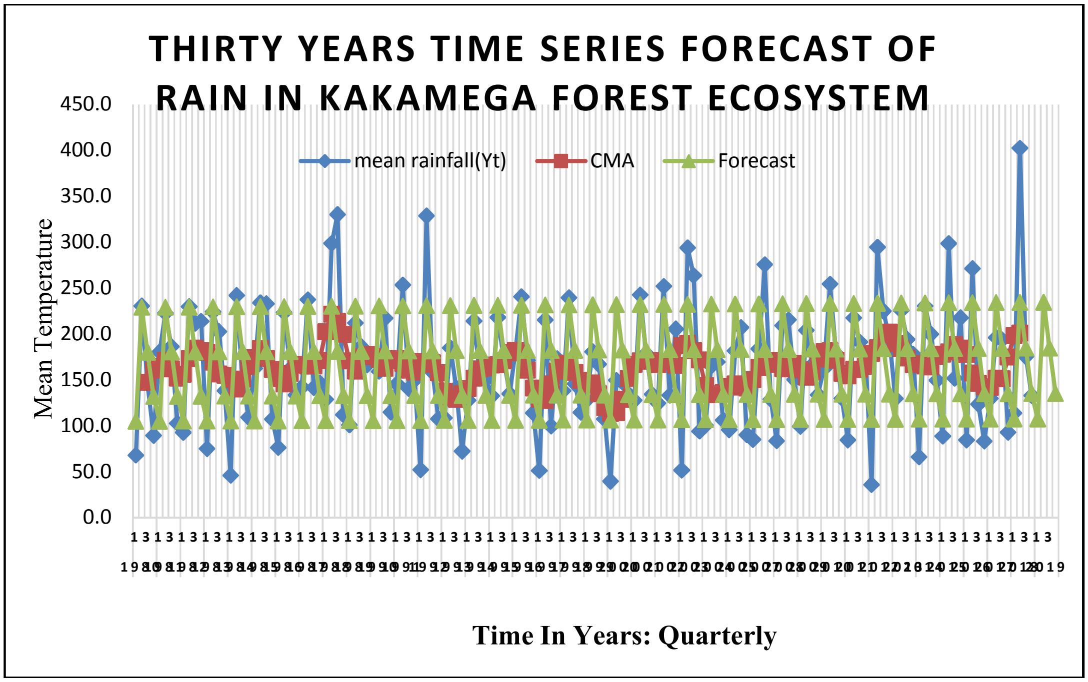

Fig. 3. Thirty years' time series forecast of rainfall after forecast (CMA=Cumulative Moving Mean)

Analysis of temperature for the last 30 years (1990-2018) revealed a maximum mean daily temperature of 27.7^{0}C, a minimum temperature of 25.4^{0}C and a maximum of 31.96^{0}C with a range of 25^{0}C - 30^{0}C (Fig. 4). In some years (1997; 2015-2018), extreme temperatures of over 30^{0}C were recorded. This is may be attributed to the changing climate triggered by anthropogenic activities within the forest ecosystem. Under devolution, there are increased industrialization activities and coupled with the rising population, may explain the increased release of greenhouse gases, responsible for global warming. The year 2007 recorded temperatures below 25^{0}C, which may be explained by excessive rainfall and long overcasts for most part of that year.

When a moving cumulative mean, using data on the minimum temperature over the last 30 years (1982–2018) was calculated, a forecasted temperature trend of a mean minimum temperature of 14. 4^{0}C, the minimum temperature of 12.3^{0}C and the maximum temperature of 18.7^{0}C was computed for the year 2019 (Fig. 5). Minimum temperature over the years has been 15^{0}C. In the year in the year 1990, however, the minimum temperature rose to 18^{0}C.

4. DISCUSSION

Mean monthly rainfall over the last 30 years shows a variation from a mean minimum of 36.00mm to a maximum mean of 402.30mm. It is clear from analyses that there are decadal variations in the mean annual rainfall with a tendency for increasing trends. Rainfall time series trends show a higher fluctuation of rainfall from 1988 at an interval of 10 years with an increasing trend every decade. Rainfall fluctuations increase with time, due to afforestation and deforestation, mediated by increases in population, which leads to cutting of trees for construction and farming [37]. Similar findings were reported in a study in central Panama [38]. Rainfall in many forest-adjacent ecosystems is modulated by the forests, and this study is in agreement with a similar study in Amazon where 60% of the local precipitation is recycled with the adjacent vegetation playing a pivotal role [39]. Precipitation patterns in the Kakamega tropical forest ecosystem shows a 9-year low-rainfall with an abrupt increase in the 10th year. The trend is in tandem with the predictions by [40] that there will be low amounts of rainfall for a larger area especially along forested areas due to perhaps, deforestation. Deforestation is linked to changes in rainfall

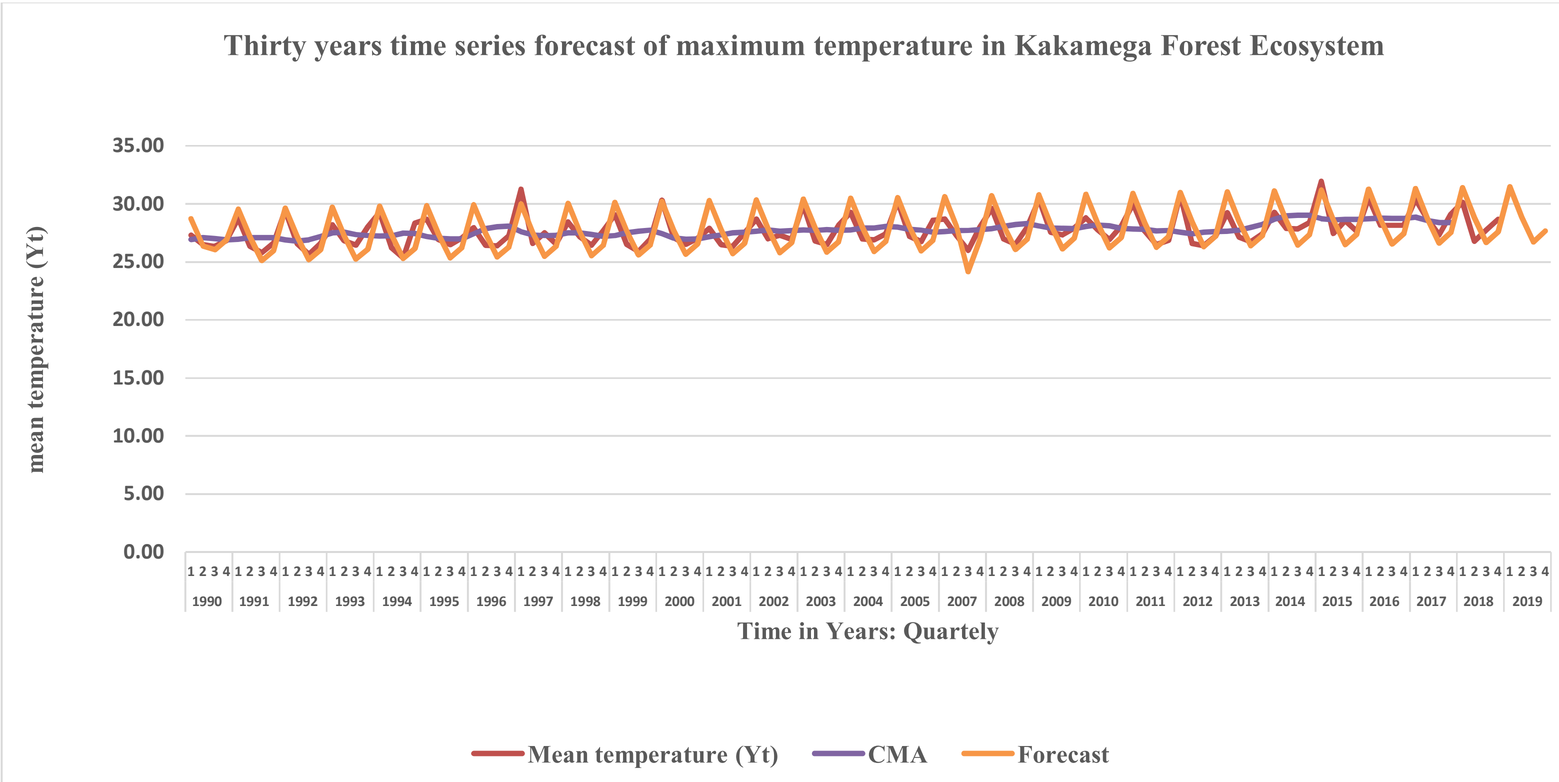

Fig. 4. Thirty years series forecast of maximum temperature with forecasted trends in Kakamega forest ecosystem

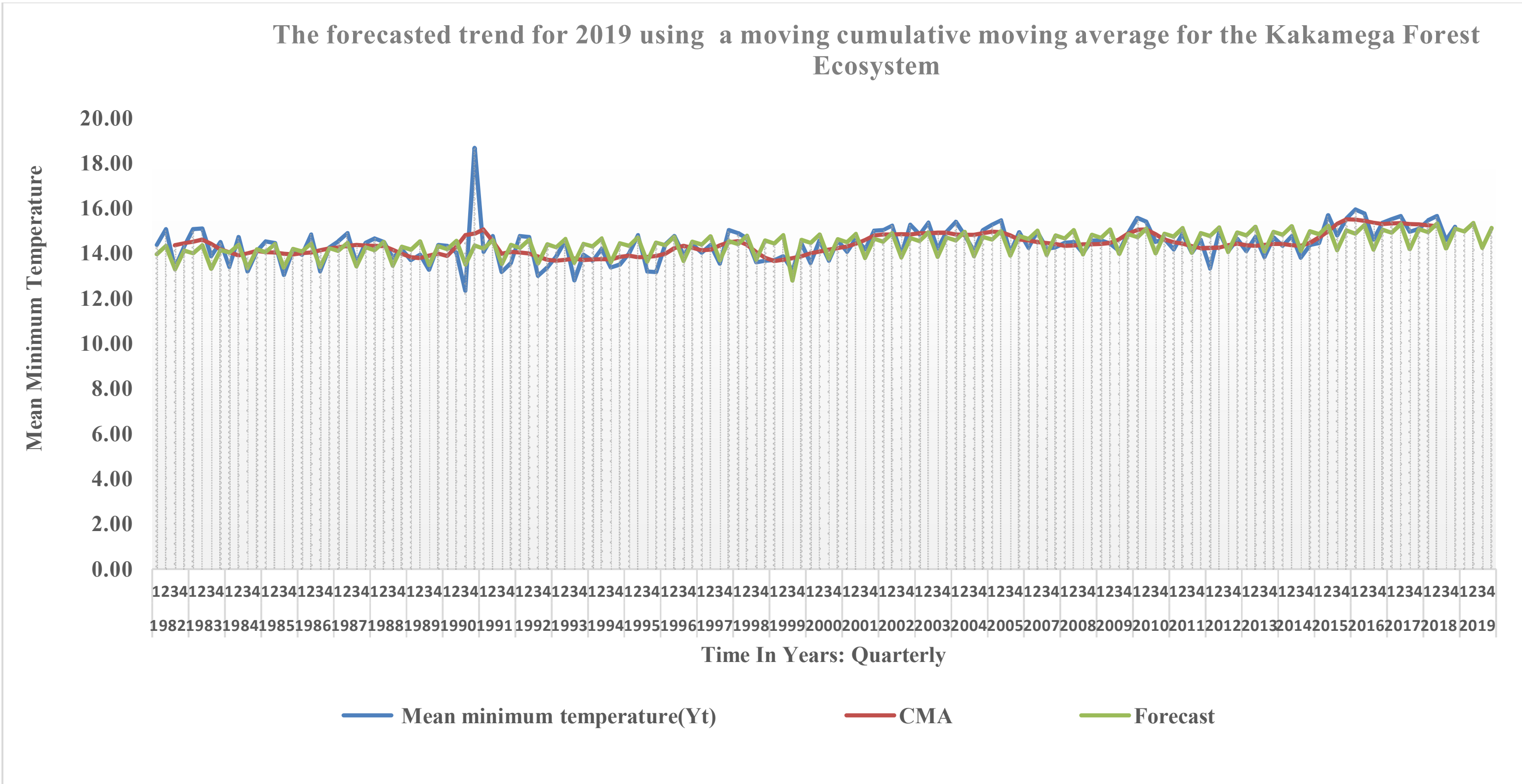

Fig. 5. The forecasted trend for 2019 using the moving cumulative average

patterns because it destabilizes the local ecological processes. This has been observed in similar ecosystems like Amazon drought of 1982/1983, 1986/1987 and 1997/1998 [41], and other current occurrences like the low rainfall and multidecadal oscillation in Atlantic [42]. The reduction and extreme precipitation events at the interval of 10 years in Kakamega forest is likely to be caused by human activities such as agriculture, forest encroachment and logging. These activities have been shown to affect rainfall patterns along the Congo and Amazon forests [43]. The large-scale disturbances of forests can lead to alterations in rainfall amounts and intervals such as the 10-year interval observed in the Kakamega tropical forest ecosystem [44]. Such changes in rainfall patterns may result in positive feedbacks [45], that increase the susceptibility of the ecosystem to climate change impacts. In conclusion this study has produced a long-term seasonality and interactions between climate, precipitation and deforestation. Anthropogenic drivers that include agriculture, settlements and deforestation are fundamental in determining precipitation patterns in most adjacent forest regions [46].

Maximum temperature averaged 25.35 ^{0}C with a maximum temperature of 31.96 ^{0}C, and mean temperature of 27.1^{0}C for the past 30 years. These temperature values are above the tropical forested environs which are characterized by warm and humid climate [47]. The 2019 predicted temperature follows the same trend. Recent research suggests [48] that there is climatic warming in and along broad-tropical forests which will have devastating effects on tropical flora [23]. Mean annual temperature of 27.71^{0}C and the fluctuations in some years like in 1996 and 2005 where the maximum temperature exceeded 30^0 C are beyond the reported maximum temperature for forested area of 28^{0}C indeed confirm the evidence of changes in climate [49]. Temperature in a forest ecosystem is regulated by vegetation and prevailing anthropogenic activities. Temperatures normally alternate between the minimum and maximum temperature and this can be attributed to precipitation, cloud cover, vegetation and prevailing winds [50]. This study used a two-time forecast trend for minimum and maximum temperature. Evidence of the rising temperature in the Kakamega tropical forest ecosystem is in agreement with the Kyoto protocol prediction that by 2005 there would be a spike in temperatures due to deforestation and industrialization. Fluctuations in temperature over the last 30 years confirm evidence of climate change, which may be due perhaps to the activities in and along the forest ecosystem by the forest-adjacent communities. These activities include burning of charcoal, forest encroachment and industrialization, key drivers of global warming.

5. CONCLUSION

Mean rainfall over the last 30 years clearly shows changes in amounts, intensities and regularity. The trend in rainfall in the Kakamega tropical forest ecosystem shows changes in precipitation between decades as a result of dissimilarities in amounts of rainfall in each year over the last 30 years. It is possible, based on the current rainfall to forecast future rainfall trends. Records of temperature for the last 30 years also reveal fluctuations with a tendency towards increasing temperatures. The fluctuations of temperature clearly confirm evidence of climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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