Spatial and Temporal Trends of Rainfall and Temperature in the Amboseli Ecosystem of Kenya

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Spatial and Temporal Trends of Rainfall and Temperature in the Amboseli Ecosystem of Kenya

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***Abstract*— This study investigated spatial and temporal trends of rainfall and temperature in the Amboseli ecosystem of Kenya. The analysis were based on historical Climate Hazards group InfraRed Precipitation with Station (CHIRPs) and Climate Hazards group InfraRed Temperature with Station (CHIRTs) data for the period 1960-2014 and the period 2006-2100 for the projections. This data was used due to limitations in the observed station data. Projections of rainfall and temperature were based on Regional Climate Models (RCM) from Coordinated Regional Downscaling Experiment (CORDEX) over the Amboseli ecosystem. The long-term annual and seasonal trends of rainfall and temperature were analyzed via Mann– Kendall's statistical test and linear trend analysis. The annual and seasonal rainfall declined slightly between 1960 and 2014 though not significant. However the temperatures increased more in the annual minimum (1.23 °C) compared to the annual maximum (0.79 °C). The maximum temperatures for the October-November-December (OND) season had highest increases of 0.88 °C while the March-April-May (MAM) season showed an increase of 0.69 °C. The highest increase in minimum temperatures of 1.35 °C was recorded for the June-July-August-September season (JJAS), while the least increase was in MAM (1.04°C). Projected rainfall based on Representative Concentration Pathways (RCPs) for the periods 2006-2100 varied with RCP 2.6 showing a decline for the four seasons. RCP 4.5 and 8.5 project marginal increase in annual and OND with declines in the MAM and JJAS. Projected maximum and minimum temperature for RCP 2.6 indicate increments of less than 1 °C while for RCP 4.5 the maximum range is between 0.57 °C and 1.85 °Cand minimum is between 0.51 °C to 1.98 °C. RCP 8.5 projected maximum increase are the highest between 1.11°C and 4.34 °C and minimum is between 1.34 °C and 5.26 °C based on period – 2030, 2050 and 2070. The increase of temperatures and changes in rainfall can have large impacts on the resources in the savanna dry lands of East Africa especially on its livestock, agriculture, wildlife and pastoral and agro-pastoral communities.**

***Index Terms*— Climate change, dry lands, mitigation, Representative Concentration Pathways, temperature and rainfall.**

I. INTRODUCTION

According to the Intergovernmental Panel on Climate Change [1] report, the surface temperature of the earth has risen by 0.6 ± 0.2˚C over the 20th century and is projected to rise from 1.1˚C to 6.4˚C over the 21st century. Africa has been seen as one of the segments of the world extremely susceptible to the impacts of climate change [2]. It is projected that temperatures in the region are likely to increase more rapidly than other parts of the world, which might surpass 2˚C by midway of the 21st century and 4˚C by the close of the 21st century [2]. Warmer temperatures are expected to occur in the East African region with a 5% - 20% increase in rainfall from December-February and a 5% - 10% decrease in rainfall from June to August by 2050 [3]. The stated variations are likely not to be uniform throughout the year and are expected to occur erratically. It is anticipated that the East African region will experience a reduction in the amount of precipitation received during the already dry season, which is likely to trigger more recurrent and severe droughts in the region. East Africa is an important biodiversity landscape and many of the species especially the large herbivore are driven by variability and seasonal patterns in rainfall and temperatures [4] [5] [6]. Parameters for climate analysis include; air temperature, precipitation, air pressure and sea surface temperature .This study focused mainly on precipitation and temperature because they are the two most important variables in the field of climate sciences and hydrology .The two are frequently used to trace the extent and magnitude of climate change and variability [1]. They are also key elements that determine the duration of availability of habitat, water and forage to an individual or group of species [7]. Trend analysis of these parameters is increasingly gaining popularity amongst scientific scholars [8]. For this study other parameters were not experimented and therefore their sensitivity to the results is unknown.

In savanna ecosystems of Africa, availability of forage varies depending on the changes in the seasonal rainfall [9]. These changes are likely to have negative effects on countless species, since the intensity and swiftness of such changes have been unique within the past millions of years [10]. As climate changes, majority of the species are likely to be subjected to climatic environments that surpass their physiological tolerance. Due to this exposure, animals will experience physiological stress [11], reduced level of fitness [12] [13] [14] or the threat of being extinct [15]. [16] reports massive declines of wildlife in Kenya. About 68% of the wildlife has disappeared in the Kenya rangelands between 1977 and 2016, whilst sheep, goats and camels increased significantly and cattle declined over the same period. The declines in both wildlife and cattle have been attributed to rapid human population growth; land use and land cover changes, land fragmentation, infrastructural development, poaching, climate change and variability, outbreaks of

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infectious diseases, competition with livestock for space, water and pasture. The increase in sheep and goats is mainly attributed to climate variability and change in the region [16]. In Africa the impacts of climate change are not well investigated because of lack of data in many parts especially in the dry lands where there has been no big investments in setting up rain gauges or establishing meteorological stations [17] [18]. The objective of this study therefore was to analyse the historical and projected rainfall and temperature changes for Amboseli ecosystem in southern rangelands of Kenya. However, there is limited observed rainfall data for the Amboseli ecosystem represented by a few stations with a lot of missing data. Furthermore there is no *in–situ* temperature data for Amboseli. To overcome this challenge, the study used the blended Climate Hazards InfraRed Precipitation (CHIRPs) and Climate Hazards InfraRed Temperature (CHIRTs) gridded observation-satellite data. The projected rainfall and temperature for the period 2006 to 2100 was based on Regional Climate Models derived from Coordinated Regional Downscaling Experiment (CORDEX) project.

II. METHODS

A. *Study Area*

The Amboseli ecosystem is situated in the southwest of Kenya, bordering Tanzania. Geologically, the ecosystem covers part of a dry Pleistocene lake basin, which has a temporary lake that floods during years of heavy rainfall. The Amboseli ecosystem is famous for its biodiversity globally. It hosts more than 50 mammal species, comprising the elephant, zebra, wildebeest, giraffe, antelopes and their predators such lions, cheetahs, hyenas and vultures. The name "Amboseli" comes from a Maasai word meaning "salty dust", and it is one of the best places in Africa to view large herds of elephants up close. Habitats in Amboseli ecosystem range from the dried-up bed of Lake Amboseli, wetlands with Sulphur springs, the savannah and woodlands. The richness of these habitats and variation of rainfall across the ecosystem gives rise to high diversity of species. However, these species are threatened by land fragmentation, land use, increase in agriculture in the area and climate change [19] [20].

Rainfall in Amboseli ecosystem is bi-modal with short rains in October-November-December (OND) and long rain period starts in March-April-May (MAM) and the dry seasons are January-February and June-July-August-September (JJAS). The average annual rainfall for Amboseli ecosystem is 569 (SD = 187) mm with OND contributing on average 254 (SD = 129) mm and MAM about 226 (SD = 108) mm. The rains in the ecosystem fall in the rain-shadow of Mt Kilimanjaro placing it amongst the driest places in Kenya. However, water flowing underground from Mt Kilimanjaro wells up here in a series of lush swamps that provide dry season water and forage for wildlife. This attracts high concentrations of migratory animals during the dry season.

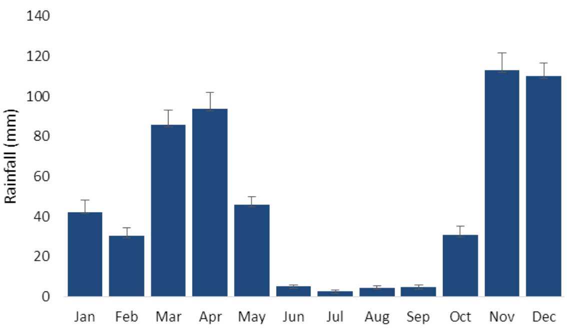


Figure 1: Mean monthly rainfall with the standard errors for Amboseli ecosystem based on historical data from 1960 to 2014.

The ecosystem covers an area of approximately 5700km^2 stretching between Chyulu Hills and Tsavo West National Parks South to Mt Kilimanjaro in Tanzania (Fig 1). Administratively, the Amboseli ecosystem consists of Amboseli National park (ANP; 392km^2) and the six surrounding communally-owned Maasai group ranches that are important dispersal areas for wildlife. These group ranches cover an area of about 5063 km^2 in Kajiado County (Fig 2).The tenure of the community owned land is changing rapidly from group ranch to private land. Olgulului-Ololorashi Group Ranches envelopes the park and they contain critical habitats and wildlife dispersal areas. It borders Eselenkei Group Ranch to the north which provides a wet season foraging area for the elephants while Kuku and Mbirikani group ranches provide critical linkages to Chyulu and Tsavo West ecosystem respectively. Kimana group Ranch is to the southeast and Tanzania international border to the south. Olgulului-Ololorashi surrounds 90% of the Amboseli National Park and it covers an area of 1232 km^2.

III. DATA

A. Rainfall Station Data

Observed rain gauge data were sourced from Isara Range Station, Mashuru Dispensary, Olkelunyiet Park Headquarters and Amboseli Baboon Research Camp and were obtained from the archives of Kenya Meteorological Department (KMD) and Amboseli Baboon Research Camp. The time series were chosen for their record data collection length, proximity to the study area, and the reliability of observations that were checked for missing data before analysis. Quality assurance of the data was ascertained before the analysis to guarantee temporal consistence and homogeneous records. Details of the stations, geographical placement and years of recorded rainfall are given in Table 1.

Table 1: Location of rainfall station and number of data used

Station Number	Rainfall station name	Longitude	Latitude	Period	Number of years
1	Isara Range Station	37.27°	-2.16°	1973-1987	14
2	Mashuru Dispensary - Kajiado	37.08°	-2.06°	1970-2013	33
3	Olkelunyiet Parks Headquarters	37.20°	-2.45°	1973-1987	11
4	Amboseli Baboon Research Camp	37.26°	-2.65°	1970-2013	33

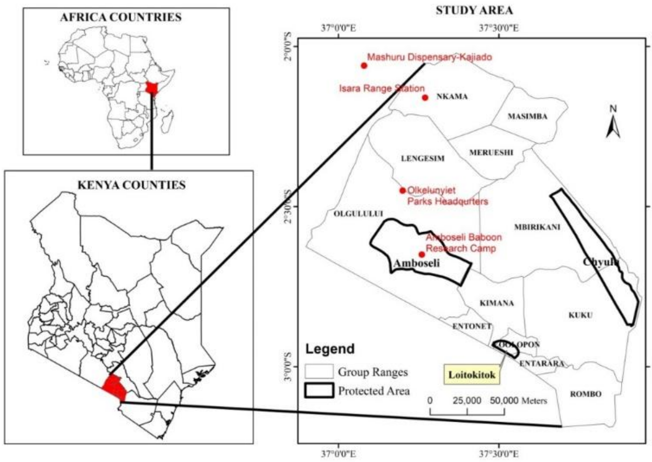


Figure 2: Map showing location of study area the Amboseli ecosystem and the rainfall stations

B. Historical Rainfall And Temperature Data

The historical trends covered the period 1960 to 2014 .The resolution of the dataset was 0.05° and was received from ICPAC. The data was based on gridded observation/satellite blended Climate Hazards Group Infrared Precipitation with Station (CHIRPs). CHIRPs is a 30+ year quasi-global rainfall dataset spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present. [21] Indicates that at present and on a global scale there is an important gap in types of gridded precipitation datasets. There are datasets with a long period of record with very long latency, like the GPCC and CRU products, and there are low latency precipitation estimates based solely on satellite information, like the TMPA 3B42 RT, Climate Prediction Center MORPHing Technique (CMORPH), or Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) products. On the other hand, the Climate Prediction Center Merged Analysis of Precipitation (CMAP) blends station data and satellite estimates to produce a continuous 1979-present time series. However this dataset has a coarse 2.5° resolution. CHIRPs was explicitly designed to fill this gap, providing blended gauge-satellite precipitation estimates that cover most global land regions and have a fairly low latency, high resolution, low bias, and long period of record [21].

CHIRPs provide data at higher spatial and temporal resolutions and it is updated frequently with new observations. It has been established that the merging of precipitation observations from several sources (e.g. satellite and in-situ observations) improves the overall quality of the satellite product [22] [23] performed validation tests of CHIRPs products all over Cyprus and found good matches with ground-based rain gauge data.[24] carried out cross-comparisons of several open-source satellite products for the Nile basin and found CHIRPS to be one of the best products currently available for hydro-meteorological applications. [25] compared CHIRPS products with African Rainfall Climatology version2 (ARC2) and Tropical Applications of Meteorology using Satellite and ground based observations (TAMSAT) and the results showed that CHIRPS products are significantly better than ARC2 with low or no bias. These products were also found to be slightly better than the latest version of the TAMSAT product at dekadal and monthly timescales, while TAMSAT performed better at the daily timescale.

This study conducted accuracy assessment of the relevance of adapting the use of CHIRPs and CHIRTs data to analyse the historical rainfall and temperature for the Amboseli Ecosystem. GeoCLIM was used to extract the data since it offers option for simple interpolation with no background and allows blending station data (e.g rain gauge) with gridded satellite data (e.g. CHIRPS) to create more accurate datasets to analyze historical climate data. Furthermore it is a spatial analysis tool designed for climatological analysis of historical rainfall and temperature data. The alternative methods include: GeoWRSI, GeoCOF, and the Early Warning eXplorer (EWX), among other programs**.**

C. Projected Rainfall and Temperature Data Based on RCP 2.6, 4.5 and 8.5

The projected climate data used in this study was generated from the Rossby Center Regional Atmospheric Model (RCA4). This model was selected based on a study by [26]. The Rossby Centre is the World Climate Research Program (WCRP) recommended Regional Climate Model (RCM) for downscaling phase 5 Coupled Model Inter-comparison Project (CMIP5) Global Climate Models (GCMs) under the Coordinated Regional Downscaling Experiment (CORDEX) initiatives [27]. The RCA4 has undergone both physical and technical changes with a large degree of the spread in the CMIP5 ensemble implying that it can be used to illustrate uncertainties and robustness in future climate change. It also has an added advantage of high resolution (e.g [28]).The model was integrated into the CORDEX-Africa domain, with a horizontal grid spacing of 0.44 degrees which translates to a 50 by 50 km grid([26][29]. The data was obtained from the IGAD Climate Prediction and Applications Centre (ICPAC)

The three Representative Concentration Pathways; 2.6, 4.5 and 8.5 gives various possibilities of rainfall and temperature changes based on global initiatives to limit gaseous emissions. RCP 2.6 represents an optimistic projection characterized by a very low concentration and emissions levels of greenhouse gases. RCP 4.5 scenario represent medium emission scenario where international communities are working on limiting emissions with limited implementation of climate change policies. RCP 8.5 scenario represents a pessimistic projection with high levels of concentrations of gases emitted; this scenario assumes no implementation of climate change policies.

IV. STATISTICAL ANALYSIS

A. Checking reliability of gridded data against station data

To assess the reliability of the gridded data, correlation between the gridded data and station data were undertaken using correlation coefficient statistic. Relationship between the station and CHIRPs data was established by testing if the relationship were linear or quadratic or inverse or logarithmic. The choice of the model was based lower corrected Akaike Information Criterion (AICc) over the Chi-Squared, Kolmogorov-Smirnoff and Anderson-Darling goodness of fit statistics. The lower the AIC the better the model since they indicate a trade-off between the nonexistence of fit and the number of parameters in the model [30]. This method was selected because it has high likelihood and at the same times not too many parameters k, which prevents over parameterization. In the case that the normal error model is not appropriate, the model selection by information criteria also yields the proper non-normal model like generalized or contaminated distributions.

V. TRENDS FOR HISTORICAL AND PROJECTED RAINFALL AND TEMPERATURE

Trend analysis of a time series comprises of the magnitude of trend and its statistical significance. Understandably, different researchers have used different methodologies for detecting trends [31].Generally the magnitude of trend in a time series is determined by either using regression analysis (parametric test) or using Sen.'s estimator method (non-parametric method). The two methods assume a linear trend in the time series. In this study regression models, both linear and quadratic were used because they are, powerful for modelling a target element as a function of a set of predictors, allowing for a description of relationships and the construction of tests of the strength of the relationships. Analysis is performed with time as the independent variable and rainfall/temperature as the dependent variable. The regression analysis can be carried out directly on the time series as is the case in this study or on the anomalies (i.e. deviation from mean). A linear equation, $y = mt + c$, defined by c (the intercept) and trend m (the slope), can be fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provided the rate of rise/fall in the variable. In regression it is also assumes that the regression residuals, are approximately normal in distribution, homoscedastic and statistically independent.

VI. SIGNIFICANCE OF TRENDS

To ascertain the presence of statistically significant trends in hydrologic climatic variables such as temperature and precipitation with reference to climate change, non-parametric Mann–Kendall (MK) test has been in use. [32] [33]. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The method was selected because it is less sensitive to outliers and skewed distributions

The statistics (S) is defined as

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i), \qquad \text{Equation (1)}$$

Where N is the number of data points. Assuming $(xj - xi) = \theta$, the value of sgn (θ) is computed as follows:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta > 0 \\ -1 & \text{if } \theta > 0, \end{cases} \qquad \text{Equation (2)}$$

The test statistic tau gives a positive (negative) trend when the value of tau is positive (negative) and no trend when tau is zero. The level of significance used in this study was 0.05, and the trends were considered significant when the P-value was less than or equal to 0.05" [34]

VII. RESULTS

The annual rainfall of all the four stations showed association between rain gauge and CHIRPS data (Table 2). The strongest associations were between annual rain and CHIRPS which were observed in Mashuru Dispensary (r^2=0.972, p = 0.0000), Amboseli Baboon Camp (r^2 = 0.903 p = 0.0000) and Isara Range Station (r^2= 0.961, p = 0.0000) and moderate Olkelunyiet Park headquarters (r^2 = 0.756, p = 0.0000). In terms of seasonality the OND (r^2varied between 0.447 and 0.700) were more strongly related to CHIRPS compared to the months of MAM (r^2varied between 0.471 and 0.592 –refer to Table 2).

Table 2: Regression statistics between the observed and modeled CHIRPS rainfall data

Station name	Survey period	Season	Intercept	Slope	F-ratio	r-squared	P-value
Mashuru Dispensary	33	Annual	-3.884	0.965	343.540	0.972	0.000
		MAM	37.566	0.477	27.579	0.471	0.000
		OND	12.716	0.762	72.465	0.700	0.000
Amboseli Baboon Camp	33	Annual	3.068	1.758	92.622	0.903	0.000
		MAM	47.574	0.660	26.260	0.459	0.000
		OND	38.64	0.616	34.561	0.527	0.000
Isara Range Station	14	Annual	3.462	1.191	248.012	0.961	0.000
		MAM	33.148	0.764	17.386	0.592	0.001
		OND	10.872	1.080	14.857	0.553	0.002
Olkelunyiet Park headquarters	11	Annual	18.925	0.833	31.062	0.756	0.000
		MAM	24.678	1.157	8.451	0.484	0.017
		OND	34.805	0.467	7.267	0.447	0.025

A. Historical trends in rainfall in Amboseli Ecosystem based on gridded data

Table 3: Mann– Kendall's test for historical trends in rainfall

Period	S-Value	Slope/Tau	P value	Significance
Annual	68	0.0327	0.70443	No significant Monotonic trend
MAM	18	0.0087	0.92332	No significant Monotonic trend
JJAS	-123	0.0592	0.48971	No significant Monotonic trend
OND	164	0.0790	0.35606	No significant Monotonic trend

Table 3 shows results for Mann– Kendall's test for trends in historical rainfall for Amboseli.

There were no significant trends recorded though there was a decline in both annual and seasonal rainfall.

Table 4: Regression analysis of historical trends in rainfall in Amboseli Ecosystem 1960 – 2014

Season	Equation	R-squared	F-Ratio	P-value
Annual	Y = 4626.69892-2.03534x	0.032	1.728	0.1943
MAM	Y = 1440.94291-0.61023x	0.008	0.446	0.5070
JJAS	Y = 704.13476-0.34537x	0.080	4.577	0.0370
OND	Y = 1814.34409-0.78111x	0.009	0.474	0.4943

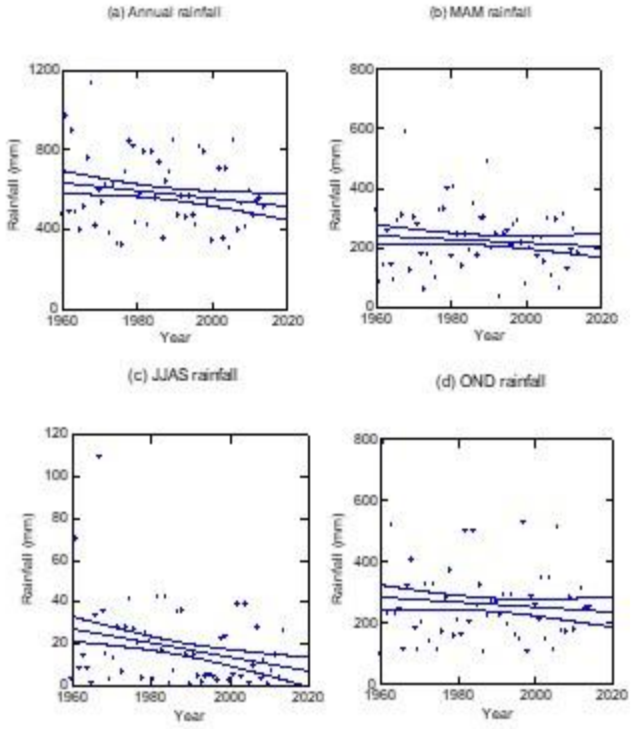


Figure 3: Historical trends including the 95% confidence levels of rainfall in Amboseli Ecosystem 1960 -2014. The data points represent the annual and seasonal totals.

Table 4 and Figure 3 show the historical changes in the annual and seasonal rainfall components over the Greater Amboseli for the period 1960 to 2014 based on the regression analysis. The annual showed decline in rainfall in the Amboseli ecosystem was mainly driven by steep decline in dry season rainfall of JJAS (P = 0.0307) and wet seasons decline of MAM and short rains of OND season.

A. Historical trends in maximum and minimum temperature in Amboseli ecosystem

Historical trends in average temperatures for maximum and minimum temperatures for the annual, MAM, JJAS and OND were positive and significant (.refer to table 5).The trends increased significantly in the Amboseli ecosystem (refer to Table 6). Figure 4a and 4b shows the seasonal changes in the annual maximum and minimum temperatures respectively. The maximum average temperature increased from 28.08 ∘C in 1960 to 28.87 ∘C in 2014, .the MAM increased from 28.81 ∘C to 29.49 ∘C, JJAS increased from 26.40 ∘C to 27.10 ∘C and OND increased from 28.47 ∘C to 29.36 ∘C (Figure 4a). The averaged minimum annual temperature increased significantly from 15.88 ∘C in 1960 to 17.11 ∘C in 2014, the MAM increased from 17.14 ∘C to 18.18 ∘C, JJAS increased from 14.02 ∘C to 15.37 ∘C and OND increased from 16.62 ∘C to 17.95 ∘C (Figure 4b).

Table 5: Mann– Kendall's test for historical trends in Maximum and Minimum Temperatures

	Period	S-Value	Slope/Tau	P value	Significance
Maximum	**Annual**	748	0.371	1.50E-05	Significant positive trend
	MAM	511	0.254	0.00313	Significant positive monotonic Trend
	JJAS	694	0.344	5.95E-05	Significant positive trend
	OND	602	0.299	0.0005	Significant positive monotonic Trend
Minimum	**Annual**	772	0.383	7.99E-06	Significant positive trend
	MAM	488	0.242	0.00478	Significant positive monotonic Trend
	JJAS	748	0.371	1.50E-05	Significant positive trend
	OND	570	0.283	0.00098	Significant positive monotonic Trend

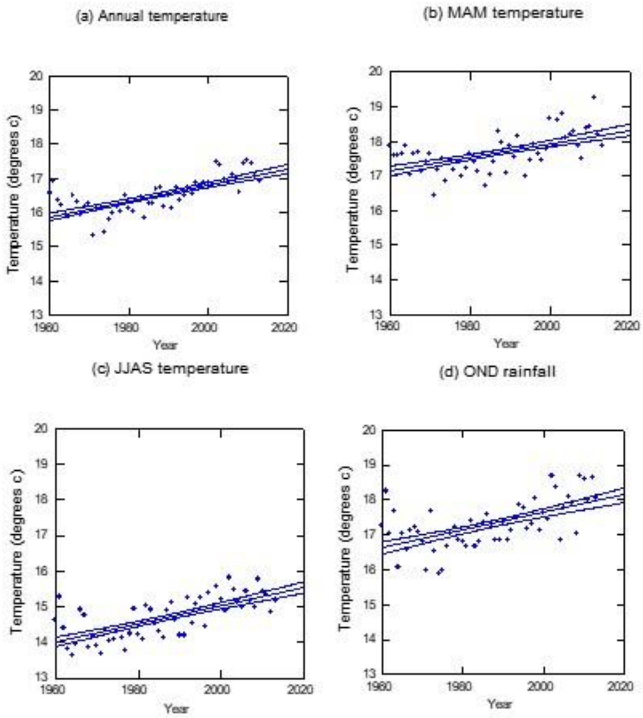


Figure 4b: Historical minimum temperatures trends including the 95% confidence levels of Amboseli Ecosystem. The data points represent the annual and seasonal totals.

Table 7 shows the absolute seasonal changes in both maximum and minimum temperatures in Amboseli ecosystem between 1960 and 2014.The increases in temperature were higher in the minimum temperatures compared to the maximum temperatures. The total increase in the average annual minimum temperatures between 1960 and 2014 was 1.23°C, while the average maximum temperatures increase was by 0.79°C over the same period of time. Similarly it was observed the minimum seasonal temperatures for the periods MAM, JJAS and OND were much higher compared to the seasonal maximum temperatures. The highest increases in maximum temperatures were observed in the months of OND (0.88°C) and least increases in MAM (0.69°C).The minimum temperatures increased more in the months of JJAS (1.35°C) and slightly low increase in MAM (1.04°C).

Table 7: Summary of maximum and minimum temperature changes forAmboseli ecosystem from 1960 to 2014

	Season	Year	Degree (°C)	Change (°C)
Maximum	Annual	1960	28.08	0.79
		2014	28.87	
	MAM	1960	28.81	0.69
		2014	29.49	
	JJAS	1960	26.40	0.70
		2014	27.10	
	OND	1960	28.47	0.88
		2014	29.36	
Minimum	Annual	1960	15.88	1.23
		2014	17.11	
	MAM	1960	17.14	1.04
		2014	18.18	
	JJAS	1960	14.02	1.35
		2014	15.37	
	OND	1960	16.62	1.33
		2014	17.95	

A. Projected trends in rainfall and temperatures based on the three RCPs 2.6, 4.5 and 8.5

The projected seasonal rainfall in Amboseli ecosystem varies across the three RCPs; 2.6, 4.5 and 8.5. Table 8a, 8b and 8c summarizes annual, MAM, JJAS and OND seasonal rainfall for the three RCPs. The RCPs 2.6 indicate a decline in rainfall for the all the four seasons though not significant (refer to Table 8a). The mean annual rainfall is projected at 632mm with most rainfall occurring in OND with a mean rainfall of 313mm compared to MAM mean rainfall of 211mm and the driest season JJAS is projected will have an average of 34mm of rainfall. The co-efficient of variation is projected to vary across the seasons with highest co-efficient of variation being observed in JJAS (63.9%) and least in OND (31.4%) for RCP 2.6.

RCP 4.5 annual rainfall is projected to increase marginally and is mainly driven by increases in rainfall for the OND season (Table 8b and also refer to Figure 5a (e) to 5a (h)). It is projected that MAM and JJAS will decline slightly as compared to RCP 2.6. The projected mean annual rainfall for RCP 4.5 will be 692mm, for OND is 340mm, for MAM is 261mm and for JJAS is 33mm. The coefficient of variation between the seasons is large. The OND is projected to have an increase in rainfall but also the coefficient of variation is projected at 29% compared to MAM where the coefficient of variation is projected at 39%. It is projected for OND the maximum rainfall will reach 757mm and minimum will be 158mm. MAM maximum rainfall is projected at 561mm and minimum of 61mm, whilst for JJAS the maximum rainfall is projected at 100.89mm and minimum at 5.21mm.

RCP 8.5 is projected to have an increase in annual rainfall significantly for the period 2006-2100 (P = 0.0002; refer Table 8c). The increase in annual rainfall is contributed by both the MAM and OND. The increase in OND is highly significant (P = 0.0001, refer to Table 8c). The mean annual rainfall for RCP 8.5 is projected at 720mm. The variation between the maximum (1267mm) and minimum (388mm) is the highest amongst the three RCPs. The OND maximum rainfall is projected at 782 mm and minimum 167mm while the maximum in MAM is 523mm and minimum is 51mm (Figure 5a(i)to 5a(j)). The projected rainfall trend for JJAS shows a significant decline (P = 0.0126; Table 8c). The RCP 8.5 JJAS season has the highest coefficient of variation of 69% the maximum projected rainfall is set at 107mm and minimum at 3mm (Figure 4k).

Table 8a: Seasonal rainfall trend for Amboseli Ecosystem for RCP 2.6

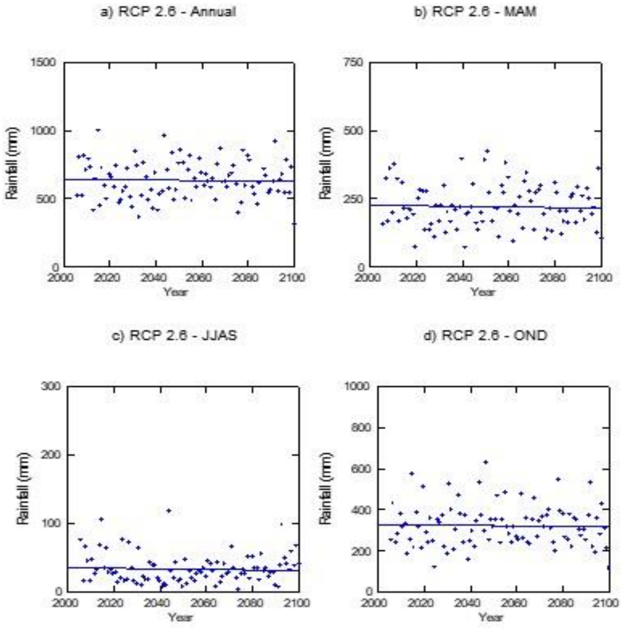
Month	Equation	F-Ratio	P-Value
Annual	Y = 763.587 – 0.0640x	0.015	0.9014
MAM	Y = 346.714 – 0.0615x	0.043	0.8354
JJAS	Y = 94.4536 – 0.0295x	0.131	0.7183
OND	Y = 485.237 – 0.0799x	0.045	0.8333

Table 8b: Seasonal rainfall trend for Amboseli Ecosystem for RCP 4.5

Month	Equation	F- Ratio	P-Value
Annual	Y = 287.983 + 0.1968x	0.099	0.7536
MAM	Y = 465.295 – 0.0996x	0.068	0.7946
JJAS	Y = 81.2521 – 0.0236x	0.108	0.7428
OND	Y = -25.1041 + 0.2879x	0.614	0.4352

Table 8c: Seasonal rainfall trend for Amboseli Ecosystem for RCP 8.5

Month	Equation	F- Ratio	P-Value
Annual	Y = -400.653 + 2.3022x	15.266	0.0002
MAM	Y = -344.632 + 0.2937x	0.795	0.3748
JJAS	Y = 390.734 – 0.1767x	6.459	0.0126
OND	Y = -3017.99 + 1.6509x	17.251	0.0001



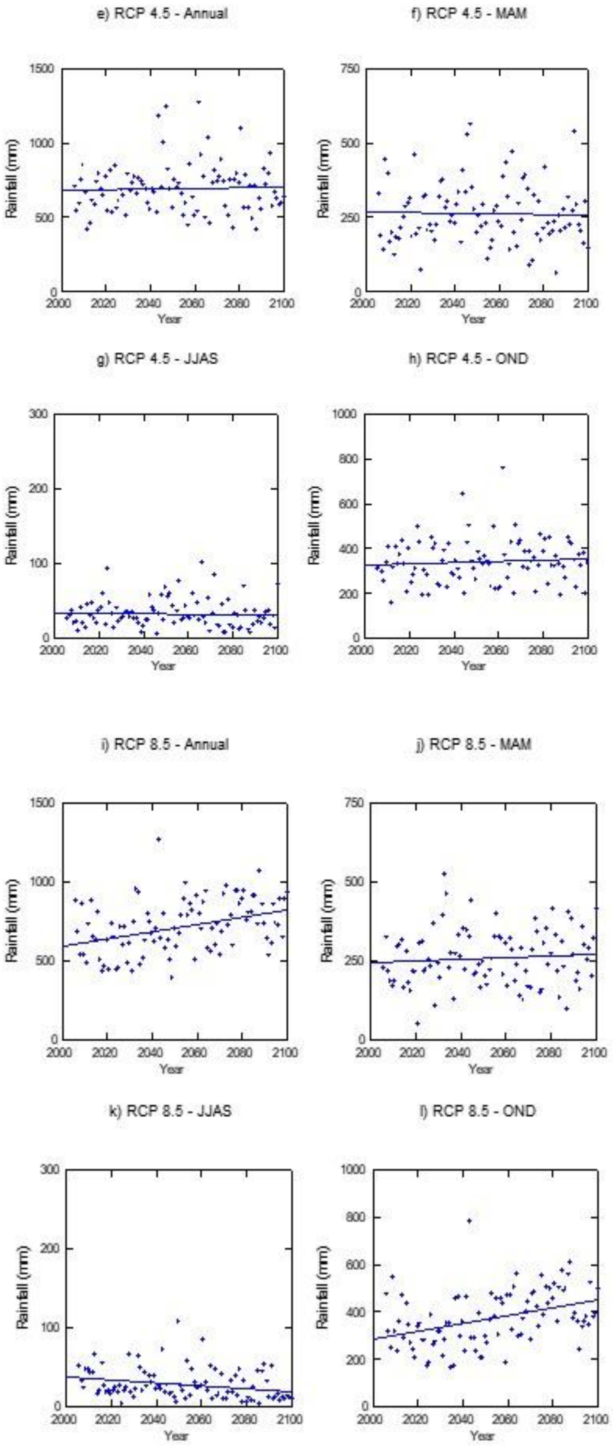


Figure 5a: Projected seasonal rainfall for Amboseli ecosystem for RCP 2.6, 4.5 and 8.5 for the period 2006-2100. The data points represent the annual and seasonal totals.

The projected changes in rainfall based on the RCP 2.6, RCP 4.5 and RCP 8.5 scenarios were analysed for three future time slices 2030s (2016-2045), 2050s (2036-2065) and 2070s (2055-2085) to provide information on the expected magnitude of the climate response over each time window. The period 1971-2000 is considered as a reference for the present climate. The projected climates change signals for each time window are calculated as the difference between the future time windows (averages calculated over 30 years) and the reference period. Figures 5b, 5c and 5d summarize the spatial change over the three time slices.

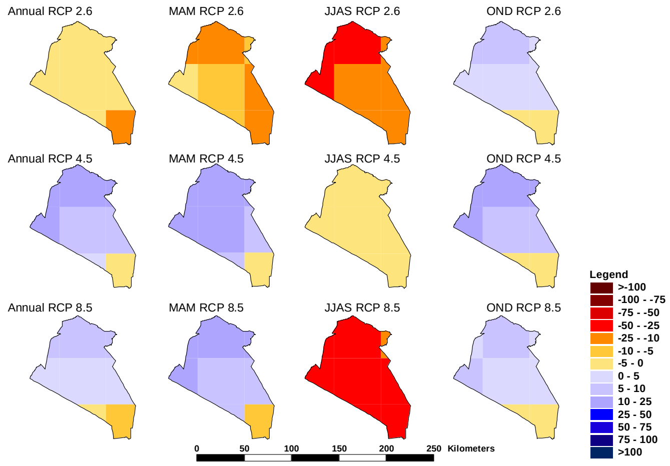


Figure 5b: Projected annual and seasonal rainfall (in percentage) for Amboseli Ecosystem for the period 2030s

In the near future (2030s), there will be a decrease in the annual rainfall for RCP 2.6 resulting from reduced percentages in rainfall witnessed in the MAM and JJAS seasons. Although the OND season is expected to have an increase in rainfall, the amount is not sufficient to increase the annual rainfall. For the annual rainfall a greater percentage of the entire ecosystem will receive very low rainfall especially southern areas of Rombo. The JJAS season will receive the least rainfall with the northern parts of the ecosystem expected to be very dry similar to the MAM season. OND season will receive moderately low rainfall in the northern and central parts of the ecosystem, However the southern regions will remain relatively dry (Figure 5b) RCP 4.5 displays an increase in the annual which is contributed by increases in the MAM and OND seasons The Northern region will receive slightly low rainfall yearly while the central region will be depressed in rainfall and the far south areas will remain dry. JJAS season will be fairly dry while MAM and OND seasons will receive low rainfall amounts in the north and fairly low rainfall in the central plains and southern regions. RCP 8.5 projects low increase in annual rainfall due diminishing seasonal rainfall in MAM and OND with most of it being received in northern parts of the ecosystem. (Fig5b). The JJAS season is predicted to remain dry in the entire ecosystem. MAM and OND season will receive some rainfall in the northern parts with MAM receiving more amounts than the OND.

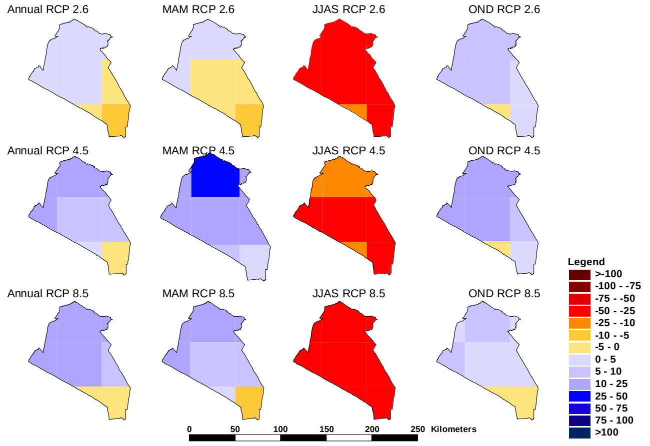


Figure 5c: Projected annual and seasonal rainfall (in percentage) for Amboseli Ecosystem for the period 2050s.

It is anticipated that by the 2050s Amboseli ecosystem will experience an increase in the annuals for all the three RCPs but RCP 8.5 will record the highest increase in rainfall annuals. The increase will be contributed by the increases in the seasons of MAM and OND and not JJAS which will remain dry in most locations (Fig 5c). In terms of the geographical distribution the northern parts are expected to receive moderately low rainfall of between 10 to 25 percent while the regions to the south will remain dry in all the RCPs. The same scenario will be witnessed in the 2070s with the rainfall amounts increasing more in OND season for RCP 8.5 (Fig5d). The rainfall will be received in most parts of the ecosystem except in Rombo near the Tanzania border where the amount of rainfall will be less. The upper northern region of the ecosystem is projected to record increased rainfall in the OND season of RCP 4.5, annual rainfall of RCP 8.5. The rainfall amounts will be between 50 to 75 percent. The same amount will be received in the OND season of RCP 8.5 on an increased spatial scale stretching from the north to the central plains of Amboseli.

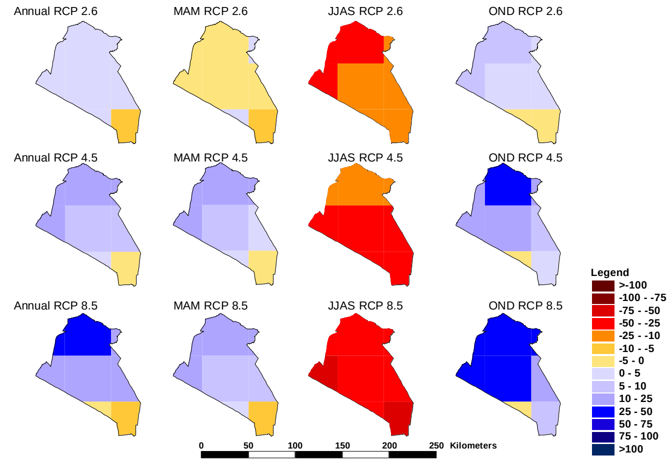
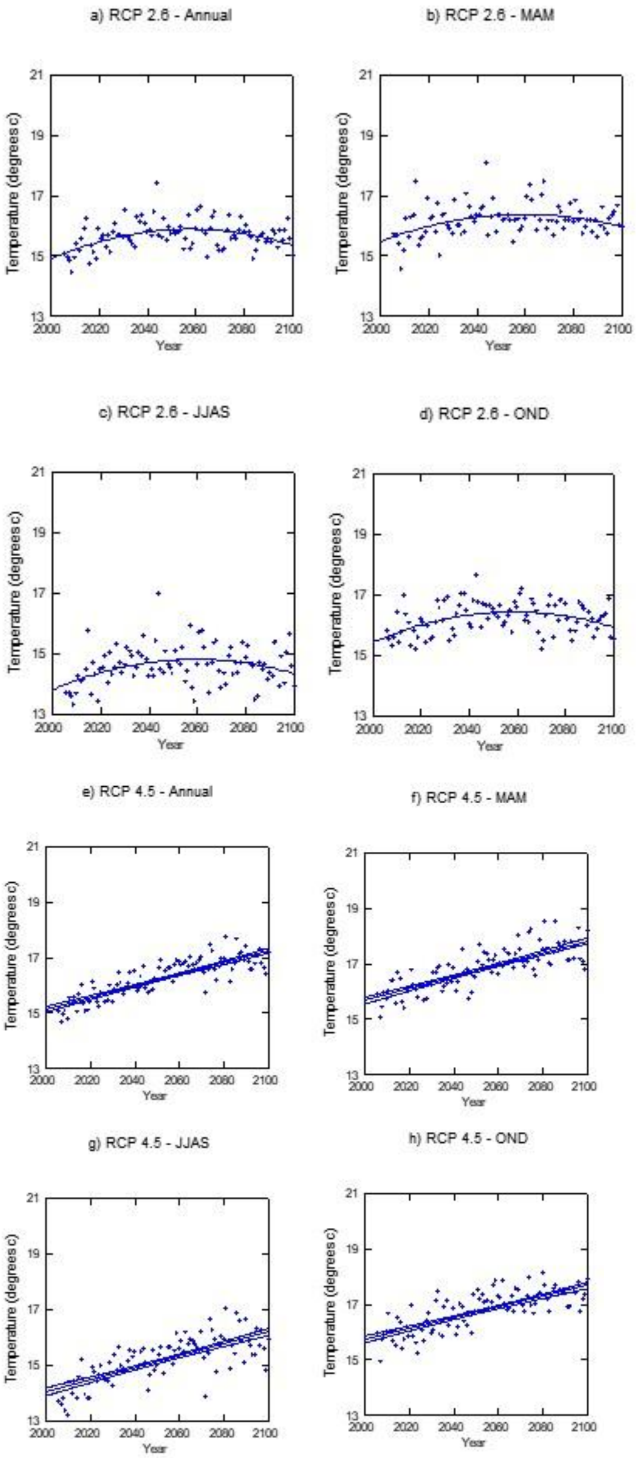


Figure 5d: Projected annual and seasonal rainfall (in percentage) for Amboseli Ecosystem for the period 2070s.

A. Projected minimum temperatures for RCP 2.6, 4.5 and 8.5 for Amboseli ecosystem

Figures 6 illustrates the temporal trends of minimum annual and seasonal (MAM, JJAS, OND) temperature change over Amboseli ecosystem between 2006 and 2100 for the three emission scenarios RCP 2.6, 4.5 and 8.5. Table 10a summarizes the absolute projected minimum temperature changes based on the three RCPs. RCP 2.6 projects lowest level of annual warming and by 2030 where temperatures are projected to increase moderately by 0.53°C and by 2050 it will reach an all-time high of 0.71°C by 2100 it then decrease to near base temperature of 2006. In terms of seasonal changes for RCP 2.6highest minimum changes are projected to occur in OND in that by 2050 the temperature is projected to increase by 0.81°C and the least seasonal temperatures will be observed in MAM (0.62°C). By 2100 for RCP2.6 we expect the temperature to reduce to almost the base temperature for 2006 figures (Table 7a).



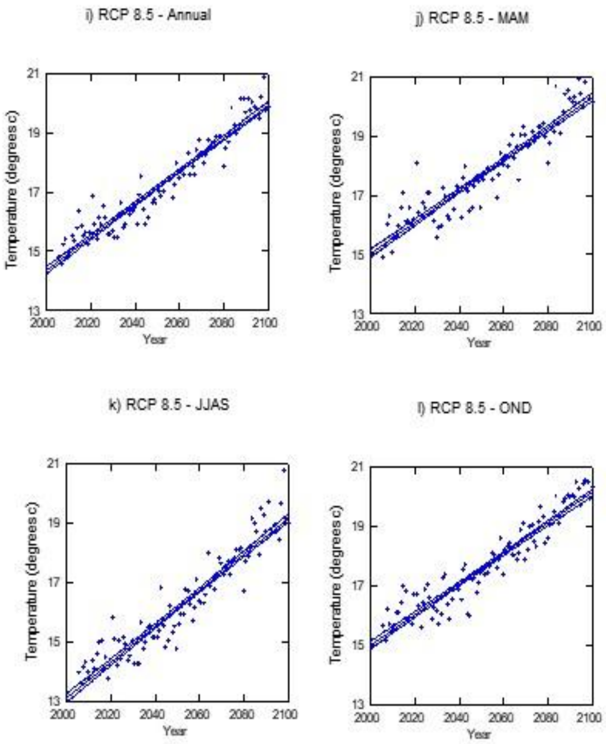


Figure 6: Projected trends in minimum temperatures changes in Amboseli 2006-2001 for RCPs 2.6, 4.5 and 8.5

As for RCP 4.5 the highest seasonal increases in minimum temperatures by 2030 is projected to be observed in MAM (0.52 °C) and JJAS seasons (0.52°C) while OND will have the least temperature increase of 0.46 °C (refer to Table 10a). In 2050 both MAM and JJAS the temperature increase by 0.95 °C and OND by 0.85 °C and by 2070s all seasonal the temperatures will be expected to reach 1.38 °C except for OND where the increase will be 1.24 °C. By 2100 MAM (2.02 °C), JJAS (2.02 °C) and OND (1.82 °C) will register the highest temperatures increases for this climate scenario where MAM and OND will hit above the 2°C (Table 9a).

As for RCP 8.5 by 2030,JJAS season is projected that the temperatures will increase by 1.45 °C and least temperature increase is projected to occur in OND (1.23 °C). Projections for 2050 indicate that temperatures for all the seasons will be above 2 °C and by 2070s they will be above 3 °C and by 2100 JJAS temperature is projected to increase drastically by 5.7 °C, MAM by 5.03 °C and OND by 4.82 °C (Table 9a).

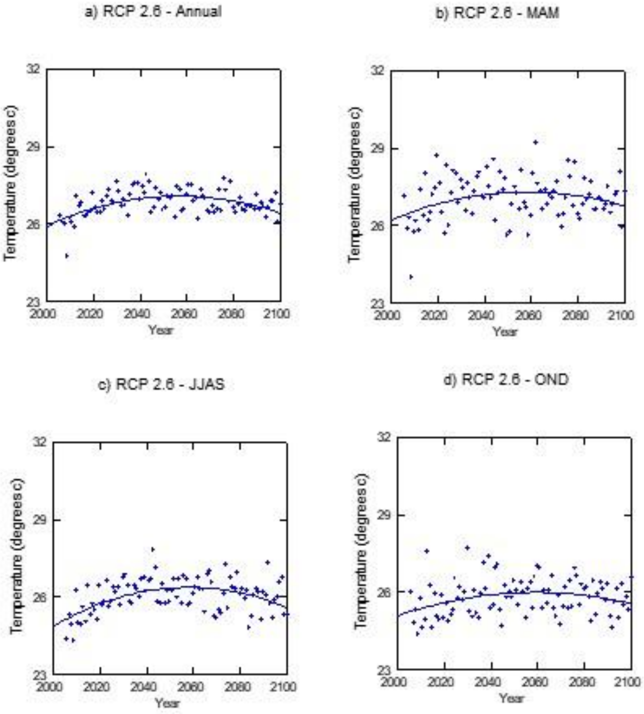
Table 9a: Summary of projected minimum temperature changes in Amboseli ecosystem in 2030, 2050, 2070 and 2011 based on RCP 2.6, 4.5 and 8.5

		Season	Base	2030	2050	2070	2100
RCP 2.6	Minimum	Annual	13.52	0.53	0.71	0.65	0.11
		MAM	14.48	0.47	0.64	0.62	0.2
		JJAS	13.52	0.53	0.71	0.65	0.11
		OND	13.92	0.58	0.81	0.79	0.33
RCP 4.5	Minimum	Annual	15.26	0.51	0.93	1.35	1.98
		MAM	15.8	0.52	0.95	1.38	2.02
		JJAS	14.18	0.52	0.95	1.37	2.02
		OND	15.86	0.46	0.85	1.24	1.82
RCP 8.5	Minimum	Annual	14.7	1.34	2.46	3.58	5.26
		MAM	15.34	1.28	2.35	3.42	5.03
		JJAS	13.5	1.45	2.67	3.88	5.7
		OND	15.32	1.23	2.26	3.28	4.82

A. *Projected maximum temperature projection for RCP 2.6, 4.5 and 8.5 for Amboseli ecosystem*

Figures 7 shows the temporal trend patterns of maximum annual and seasonal (MAM, JJAS, OND) temperature change over Amboseli ecosystem between 2006 and 2100 for the three emission scenarios RCP 2.6, 4.5 and 8.5. Table 9b summarizes the absolute projected maximum temperature changes based on the three RCPs. RCP 2.6 is projected to have the least increases in temperature. By 2030 the annual, MAM, JJAS and OND will increase by 0.69 °C, 0,60 °C, 0.87 °C, and 0.50 °C respectively. The highest increment in temperature for RCP 2.6 is projected to occur in 2050 and 2070 and by 2100 the temperatures will near the base temperatures of 2006 (Table 9b).

RCP 4.5 is more or less similar to RCP 2.6 for the periods 2030 and 2050. However, in 2070s the MAM (1.32 °C) and JJAS (1.29 °C) would increase by more than 1 °C. However, by 2100 the projected maximum temperatures for Amboseli ecosystem would surpass the 1.5 °C with the annual increasing by 1.85 °C contributed by high increases in MAM (1.93 °C) and JJAS (1.90 °C) and least by OND (1.31 °C) – refer to Table 9b.



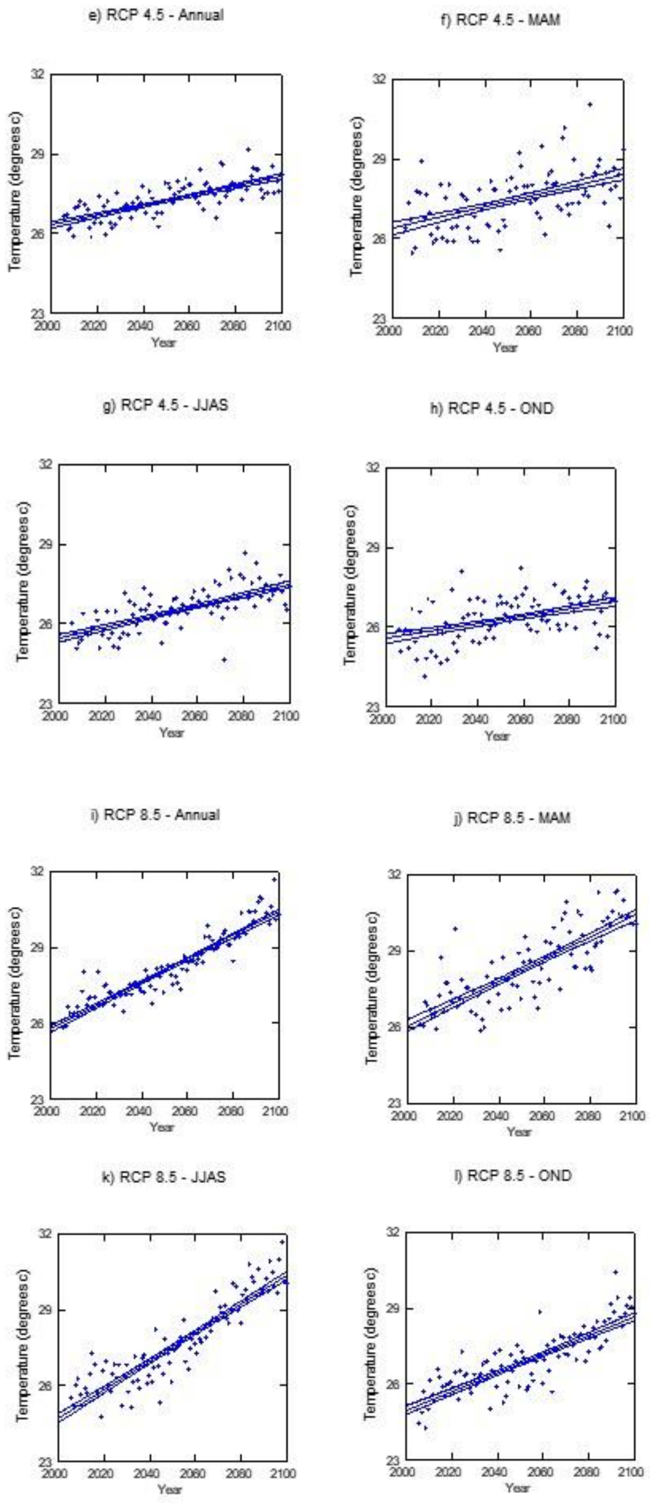


Figure 7: Projected maximum temperature for Amboseli ecosystem for RCP 2.6, 4.5 and 8.5 for the period 2006-2100.

The maximum temperature increases under the RCP 8.5 shows drastic increases of temperature for the periods 2050, 2070 and 2100 (Table 9b). The annual increase in maximum for RCP 8.5 for period 2050 is projected to increase by 2.03 °C and this will be driven mainly by JJAS (2.48 °C), MAM (2.02 °C) and OND (1.63 °C) high increases in temperature. In 2070 the MAM (2.94 °C), JJAS (3.60 °C) and OND (2.37 °C) had indicated more than 50% increases of temperature compared to 2050. The highest increases in projected temperatures are predicted to occur by 2100. The highest annual increase will be 4.34 °C and this will be driven mainly by the extremely high increases in the dry season of JJAS (5.30 °C) and also extremely high temperature of the wet season of MAM (4.32 °C) and OND (3.48 °C) – refer to Table 9b.

Table 9b: Summary of projected maximum temperature changes in Amboseli ecosystem in 2030, 2050, 2070 and 2011 based on RCP 2.6, 4.5 and 8.5

		Season	**Base (2006)**	**2030**	**2050**	**2070**	**2100**
RCP 2.6	Maximum	Annual	27.11	0.69	0.95	0.93	0.36
		MAM	25.97	0.6	0.82	0.79	0.28
		JJAS	25.99	0.87	1.21	1.19	0.51
		OND	25.01	0.5	0.7	0.68	0.28
RCP 4.5	Maximum	Annual	26.43	0.57	0.94	1.3	1.85
		MAM	26.5	0.49	0.9	1.32	1.93
		JJAS	25.58	0.48	0.89	1.29	1.9
		OND	25.66	0.33	0.61	0.89	1.31
RCP 8.5	Maximum	Annual	26.06	1.11	2.03	2.95	4.34
		MAM	26.28	1.1	2.02	2.94	4.32
		JJAS	25.06	1.35	2.48	3.6	5.3
		OND	25.2	0.89	1.63	2.37	3.48

VII. Discussion

In this study we sought to establish the climatic trends of Amboseli ecosystem using blended climate data and further analyse the climate projections based on Representative Concentration Projections using Regional Climate Models. In many parts of Africa and especially in dry ecosystem there is lack of meteorological rainfall gauges and their densities are low[17]. [35] reports that blended satellite-rainfall data should be used when the number of meteorological stations is low, and that availability of satellite rainfall estimates improves the analysis. Blending of these two sources of information mitigates the shortcomings of the respective data sets to produce blended precipitation estimates [36] [37] [22] and offer greater spatial coverage with higher temporal frequency than many of the current gauging networks. In this analysis there was a strong correlation between rainfall station data and blended CHIRPs data for the study site. The strength of the relation for the three stations varied more by the season. For the annual correlation the r-squared ranged from 0.756 to 0.972, for MAM the range was from 0.459 to 0.592 and OND it ranged from 0.447 to 0.700.Similar studies have reported high correlation between rainfall station and blended data [38] [39]. Based on this strength of evidence we used CHIRPS data to analyse the historical changes in rainfall and temperature for Amboseli ecosystem.

The historical rainfall changes in the Amboseli ecosystem shows slight declines in annual which was driven by the declines in long rains of MAM and short-rains of OND and a significant decline in dry season rainfall for JJAS. The interannual variability was high for both the annual and season rainfall. In East Africa the inter-annual variability is mainly associated with perturbations in the global sea surface temperatures (SSTs), especially over the equatorial pacific and the Indian Ocean basins [40] [41]. The annual and seasonal maximum and minimum temperatures indicated significant increase. The increases were higher in the minimum temperatures than the maximum temperatures. The total increase in the annual minimum temperatures between 1960 and 2014 was 1.2°C higher than the annual maximum temperatures that increased by 0.79°C. Maximum temperatures were higher in the OND season by 0.88°Cwith minimal warming during the MAM season of 0.69°C. Minimum temperatures on the other hand witnessed greater warming trends with the highest increase occurring in the JJAS season (1.35°C) and slightly lower increase in MAM (1.04°C).

Additionally our results show further declining of rainfall and increasing temperatures in Amboseli. An earlier study by [42] had indicated both increases of maximum and minimum temperatures in Amboseli. The increase was about 0.275°C for the daily maximum temperatures and 0.071°C for the daily minimum temperatures. Recent studies by[16] focusing on 21 arid and semi-arid (ASALs) counties of Kenya indicated warming of these counties. Fifteen out 21 counties showed declining rainfall and all 21 counties showed increases in both maximum and minimum temperatures. The annual average maximum temperature ranged between 24.3 and 33.2 °C and increased persistently by 0.7 to 1.9 °C between 1960 and 2014 in all the 21 counties. The average annual minimum temperature ranged between 10.6 and 24.0 °C and increased by 0.6 °C to 1.7 °C between 1960 and 2014. These changes in rainfall and temperature can have huge impacts on both livestock and wildlife populations in the area. The recent Kenya national livestock and wildlife trends analysis that also covered Kajiado where Amboseli ecosystem is located reported a decline of 41.7% of population of cattle, 36.8% of population on donkey and increase of 39.9% in the population of Sheep and goats [16]. The impacts on wildlife was even much greater with severe declines reported in the populations of buffalo (-76.2%), wildebeest (-80.3%), giraffe (-52.3%), gerenuk (-74.6%), warthog (84.4%), lesser kudu (-62.2%), Thompson’s gazelle (-49.0%), oryx (89.4%), Coke hartebeest (-88.0%), Impala (-90.2%) and waterbuck (86.3%). Rainfall and temperature variability and change are some of the factors which contributed to the declines of these species [16]. Only Burchell’s zebra (0.5%) and elephant (14.0%) were stable even with increase in temperatures.

In terms of rainfall and temperatures projections there are number of reports that have projected climate change but it has been mainly focusing at continental level or regional level and not at the country or landscape level (refer to [3] [2] [43]. [2] reports that temperature in Africa is projected to rise faster than the rest of the world, which could exceed 2°C by mid-21st century and 4°C by the end of the 21st century. It further reports that the future precipitation projections are more uncertain but likely to increase in eastern Africa and decrease in the southern part. [43] Projects a 3 °C global warming that will reduce savannas by approximately one-seventh of their total current land area. [44] Projects that in east Africa there will be areas that will have increase in rainfall and in other areas declines. The predicted impact of temperature changes in East Africa is that it will experience warmer temperatures and a 5-20% increase in rainfall for December to February period and a 5-10% decrease in rainfall for June to August by 2050 [26] [3]. Further, a study by World Bank [43] projects aridity in sub-Sahara Africa will increase due to these temperature and rainfall changes. The same report projects that in a 4°C world, total hyper-arid and arid areas are projected to expand by 10 percent compared to the 1986–2005 period and regime shifts in African ecosystems could result in the extent of savanna grasslands being reduced. This study indicated detailed studies at landscape levels that average temperatures have surpassed the global average temperatures.

The projected declines in long rainy season (MAM) and short rainy season (OND), an increase in spatial and temporal variability of rainfall and increase in both maximum and minimum temperatures as projected by all the three RCPS 2.6, 4.5 and 8.5 will have impact of the both vegetation and livestock and wildlife in the area. This will reduce the availability of forage for grazing animals. An exceptionally warm Amboseli ecosystem will lead to decline of most herbivore species as temperature would have surpassed species thresholds temperatures as indicated in the recent studies on potential impacts of climate on wildlife in the savanna ecosystems of Kenya by [45] and [16]. In the study [45] projected that “for RCP 2.6 three out of the 15 species might lose more than 50% of their range by the year 2030s, and 5 out 15 by 2050s and 4 of 15 by 2070s. The second climate scenario of RCP 4.5 projects that by 2030s, 3 species will lose more than 50% of their range, and in 2050s and 2070s 5 species. The RCP 8.5 which is the extreme scenario of temperature changes projects 5 species to lose their range by 50% in 2030s, 7 species by 2050s and 10 species by 2070s. The extent of range loss was different among species but was severe for buffalo, Thomson’s gazelle, waterbuck, and wildebeest which are also water dependent species. However, the elephant, gerenuk, hartebeest, lesser kudu, and oryx are expected to retain most of their range in all the RCPs scenarios”. These range contractions raise serious concerns about the future of wildlife in the Africa savannah where large populations of wildlife still exist.

VIII. CONCLUSION

This study examined annual and seasonal rainfall and temperature trends on a landscape scale for Amboseli ecosystem. The results showed a decreasing trend for the historical and projected annual rainfall as well as the MAM and JJAS seasons. The OND season showed slight increase in rainfall. However the trends were not statistically significant. Historical and projected trends in minimum and maximum temperatures were significantly positive. An appreciation of the spatial and temporal distribution of rainfall and temperature patterns is an important requirement for planning and management of water resources. The future temperature projections for Amboseli indicate that RCP 8.5 and RCP 4.5 scenarios exhibit a consistent increase in annual and seasonal temperatures which range between by1.85 °C and 4.34 °C for maximum temperatures and between 1.98 °C and 5.26 °C for the minimum temperatures. This study was based on the RCM and focused its analysis on climate changes at a landscape level. Other analysis of the trends indicating far increases of temperatures compared to the continental include; [3] [2] and regional projections [46] [47] [43]

Regardless of many international negotiations, there is continued increase in greenhouse gases and land use – land cover changes are not showing any signs of becoming stable. Consequently, the future trends may be much larger than what has been observed so far and temperature rise may be more evident. The findings of the study have implications for both science and public policy. For example, "with respect to temperature data there is overwhelming evidence that the planet has warmed during the past century. But could this warming be due to natural dynamics? Given what we know about the complexity, long-term persistence, and non-linearity of the climate system, it seems the answer might be yes" [48].Climate change is likely to affect all key resources in an ecosystem. Decreasing rainfall and increase in temperatures, as anticipated, will result in decreased water availability [49] and will drive the loss of savanna vegetation mainly grasses [43]. For Amboseli ecosystem the effects on wildlife and livestock will be immense as indicated in the recent studies by [50] [19] [16]; [51] and [20]. There is a great need to undertake studies to look at the potential impacts of the various drivers such land use, human settlement and projected climate change on wildlife dynamics especially in savannah ecosystem as increasing availability of climate data is made accessible.

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Supplementary Material

Table S1: Mann Kendall test for trends.

Scenarios		S value	Slope/Tau	P value	Significance
Amboseli Rainfall RCP 2.6	**Annual**	25	0.0056	0.93849	No significant Monotonic trend
	MAM	-69	-0.0155	0.82694	No significant Monotonic trend
	JJAS	187	0.0419	0.54984	No significant Monotonic trend
	OND	-3	-0.0007	0.99487	No significant Monotonic trend
Amboseli Rainfall RCP 4.5	**Annual**	67	0.015	0.83195	No significant Monotonic trend
	MAM	-15	-0.0034	0.9641	No significant Monotonic trend
	JJAS	-243	-0.0544	0.43654	No significant Monotonic trend
	OND	269	0.0602	0.38888	No significant Monotonic trend
Amboseli Rainfall RCP 8.5	**Annual**	1155	0.259	0.00021	Significant positive Monotonic Trend
	MAM	271	0.0607	0.38535	No significant Monotonic trend
	JJAS	-1019	-0.228	0.00106	Significant negative Monotonic Trend
	OND	1365	0.306	1.16E-05	Significant Positive
Amboseli Max Temp RCP 2.6	**Annual**	389	0.0871	0.21223	No significant Monotonic trend
	MAM	177	0.0396	0.57149	No significant Monotonic trend
	JJAS	507	0.114	0.10377	No significant Monotonic trend
	OND	553	0.124	0.07594	No significant Monotonic trend
Amboseli Max Temp RCP 4.5	**Annual**	2391	0.535	2.22E-16	Significant Positive
	MAM	1669	0.374	1.19E-07	Significant Positive
	JJAS	2375	0.532	2.22E-16	Significant Positive
	OND	1463	0.328	2.62E-06	Significant Positive
Amboseli Max Temp RCP 8.5	**Annual**	3560	0.797	2.22E-16	Significant Positive
	MAM	2755	0.617	2.22E-16	Significant Positive
	JJAS	3324	0.745	2.22E-16	Significant Positive
	OND	2939	0.658	2.22E-16	Significant Positive
Amboseli Min Temp RCP 2.6	**Annual**	425	0.0952	0.17282	No significant Monotonic trend
	MAM	428	0.0959	0.1698	No significant Monotonic trend
	JJAS	531	0.119	0.08838	No significant Monotonic trend
	OND	479	0.107	0.12434	No significant Monotonic trend
Amboseli Min Temp RCP 4.5	**Annual**	2862	0.641	2.22E-16	Significant Positive
	MAM	2703	0.605	2.22E-16	Significant Positive
	JJAS	2527	0.566	2.22E-16	Significant Positive
	OND	2381	0.533	2.22E-16	Significant Positive
Amboseli Min Temp RCP 8.5	**Annual**	3750	0.84	2.22E-16	Significant Positive
	MAM	3529	0.79	2.22E-16	Significant Positive
	JJAS	3633	0.814	2.22E-16	Significant Positive
	OND	3571	0.8	2.22E-16	Significant Positive

Table S2a: Maximum temperature trend for Amboseli Ecosystem for RCP 2.6

Month	Equation	R-Squared	F-Ratio	P-Value
Annual	$Y = -1480.32030 + 1.465596x - 0.000356x^2$	0.267	16.729	0.0000
MAM	$Y = -1302.72508 + 1.292243x - 0.000314x^2$	0.078	3.867	0.0244
JJAS	$Y = -1842.56537 + 1.816131x - 0.000441x^2$	0.241	14.609	0.0000
OND	$Y = -1063.47064 + 1.058156x - 0.000257x^2$	0.075	3.734	0.0276

Table S2b: Maximum temperature trend for Amboseli Ecosystem for RCP 4.5

Month	Equation	R-Squared	F- Ratio	P-Value
Annual	$Y = -10.25669 + 0.01829x$	0.541	109.795	0.0000
MAM	$Y = -14.764\ 06+ 0.02057x$	0.279	36.023	0.0000
JJAS	$Y = -15.14669 + 0.02030x$	0.497	91.979	0.0000
OND	$Y = -2.20172 + 0.01389x$	0.220	26.171	0.0000

Table S2c: Maximum temperature trend for Amboseli Ecosystem for RCP 8.5

Month	Equation	R-Squared	F- Ratio	P-Value
Annual	$Y = -66.55904 + 0.04617x$	0.869	617.725	0.0000
MAM	$Y = -65.79247 + 0.04590x$	0.658	179.126	0.0000
JJAS	$Y = -88.00049 + 0.05636x$	0.835	469.961	0.0000
OND	$Y = -48.93941 + 0.03696x$	0.702	218.787	0.0000

Table S3a: Minimum temperature trend for Amboseli Ecosystem for RCP 2.6

Month	Equation	R-Squared	F-Ratio	P-Value
Annual	$Y = -1256.85080 + 1.237090x - 0.000301x^2$	0.206	11.963	0.0000
MAM	$Y = -1038.80122 + 1.024560x - 0.000249x^2$	0.130	6.901	0.0016
JJAS	$Y = -1231.58667 + 1.210657x - 0.000294x^2$	0.121	6.316	0.0026
OND	$Y = -1225.22324 + 1.206537x – 0.000293x^2$	0.170	9.938	0.0002

Table S3b: Minimum temperature trend for Amboseli Ecosystem for RCP 4.5

Month	Equation	R-Squared	F- Ratio	P-Value
Annual	$Y = -26.96316 + 0.02105x$	0.698	214.557	0.0000
MAM	$Y = -27.32936 + 0.02150x$	0.622	152.990	0.0000
JJAS	$Y = -28.90549 + 0.02148x$	0.543	110.282	0.0000
OND	$Y = -22.98012 + 0.01936x$	0.566	121.270	0.0000

Table S3c: Minimum temperature trend for Amboseli Ecosystem for RCP 8.5

Month	Equation	R-squared	F- Ratio	P-Value
Annual	$Y = -97.53562 + 0.05595x$	0.920	1074.175	0.0000
MAM	$Y = -91.96018 + 0.05349x$	0.875	651.761	0.0000
JJAS	$Y = -108.16650 + 0.06065x$	0.895	794.244	0.0000
OND	$Y = -87.38234 + 0.05120x$	0.893	775.972	0.0000

Table S4a: Summary of projected minimum temperature changes in Amboseli in 2030, 2050, 2070 and 2011 based on RCP 2.6, 4.5 and 8.5

		Season	Base	2030	2050	2070	2100
RCP 2.6	Minimum	Annual	13.52	14.05	14.23	14.17	13.63
		MAM	14.48	14.95	15.12	15.10	14.68
		JJAS	13.52	14.05	14.23	14.17	13.63
		OND	13.92	14.50	14.73	14.71	14.25
RCP 4.5	Minimum	Annual	15.26	15.77	16.19	16.61	17.24
		MAM	15.80	16.32	16.75	17.18	17.82
		JJAS	14.18	14.70	15.13	15.56	16.20
		OND	15.86	16.32	16.71	17.10	17.68
RCP 8.5	Minimum	Annual	14.70	16.04	17.16	18.28	19.96
		MAM	15.34	16.62	17.69	18.76	20.37
		JJAS	13.50	14.95	16.17	17.38	19.20
		OND	15.32	16.55	17.58	18.60	20.14

Table S4a: Summary of projected maximum temperature changes in Amboseli in 2030, 2050, 2070 and 2100 based on RCP 2.6, 4.5 and 8.5

		Season	Base(2006)	2030	2050	2070	2100
RCP 2.6	Maximum	Annual	27.11	27.80	28.06	28.04	27.47
		MAM	25.97	26.57	26.79	26.76	26.25
		JJAS	25.99	26.86	27.20	27.18	26.50
		OND	25.01	25.51	25.71	25.69	25.29
sRCP 4.5	Maximum	Annual	26.43	26.87	27.24	27.60	28.15
		MAM	26.50	26.99	27.40	27.82	28.43
		JJAS	25.58	26.06	26.47	26.87	27.48
		OND	25.66	25.99	26.27	26.55	26.97
RCP 8.5	Maximum	Annual	26.06	27.17	28.09	29.01	30.40
		MAM	26.28	27.38	28.30	29.22	30.60
		JJAS	25.06	26.41	27.54	28.66	30.36
		OND	25.20	26.09	26.83	27.57	28.68

Mildred Aduma is an experienced educator with demonstrated ability of attracting research funding and carrying out high impact research. She is an assistant lecturer in the department of Geosciences and Environment at the Technical University of Kenya. She is finalizing her PhD in the Institute of Climate Change and Adaptation of the University of Nairobi. Her major research area is climate modeling and wildlife conservation using Tran's disciplinary approach. After four years studying she has gotten proper understanding of scientific research and an understanding of her research field. In the course her research she attended workshops and international conferences which promoted her feasibility in academic research and two publications. In summary she is an innovative and energetic graduate student.

Dr Ouma Gilbert Ongi'sa is a Self-motivated qualified meteorologist relishing new and dynamic challenges. Currently a Senior Lecturer in the Institute for Climate Change and Adaptation & Department of Meteorology, University of Nairobi with close to twenty one years of experience in the University. Specific area of specialization is Remote Sensing and Satellite Meteorology. Has a broad experience in Participatory Action Research methodology and Climate Change Adaptation through involvement in several application-related projects working directly with vulnerable communities. He is highly motivated, has experience of training in other African countries and has well-developed communication skills

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