Assessment of Potential Changes in Hydrologically Relevant Rainfall Statistics over the Sondu River Basin in Kenya Under a Changing Climate

Article · June 2016

DOI: 10.20987/jmrs.1.05.2016

4 authors:

Stephen Rwigi
University of Nairobi
2 PUBLICATIONS **0** CITATIONS
SEE PROFILE

Nzioka John Muthama
University of Nairobi
77 PUBLICATIONS **259** CITATIONS
SEE PROFILE

Alfred Opere
University of Nairobi
25 PUBLICATIONS **95** CITATIONS
SEE PROFILE

Franklin J Opijah
University of Nairobi
11 PUBLICATIONS **13** CITATIONS
SEE PROFILE

J. Meteorol. Relat. Sci., 9:1
ISSN: 2412-3781
http://dx.doi.org/10.20987/jmrs.1.05.2016

In the special issue of the Journal of Meteorology and Related Sciences

Volume 9, Special issue
May, 2016

Assessment of Potential Changes in Hydrologically Relevant Rainfall Statistics over the Sondu River Basin in Kenya Under a Changing Climate

Rwigi, Stephen Kibe, Nzioka John Muthama, Alfred Owour Opere and Franklin Joseph Opijah

Department of Meteorology, University of Nairobi, Nairobi, Kenya

Corresponding Author

Rwigi, Stephen Kibe,

Department of Meteorology, University of Nairobi,

email: rwigik@uonbi.ac.ke; phone: 0722693046

(*Received 1 April 2016, in revised form 9 May 2016, Accepted 31 May 2016*)

ABSTRACT

Scenarios of past, present and intermediate future climates for Sondu River basin were analysed in this study to evaluate the potential changes in hydrologically relevant rainfall statistics that are likely to be observed by the middle of this century as a result of climate change. These climate scenarios were developed by applying dynamical downscaling of the relatively course resolution climate scenarios simulated by the fourth generation coupled Ocean-Atmosphere European Community Hamburg Model (ECHAM4) using the Providing Regional Climates for Impacts Studies (PRECIS) modelling system. The regional climate scenarios, which were available at a daily time-step and a spatial grid resolution of 0.5° over the Eastern Africa region, were matched to the Sondu river basin in the western region of Kenya. The possible hydrological impacts of climate change were assessed by applying the scenarios in a daily time-step hydrological model. The analysis of hydrologically relevant rainfall statistics focussed on determining changes in rainfall patterns and the likely hydrological implications to the basin. The results indicated that more rainfall is projected for the region in the immediate and intermediate future in form of increased seasonal rainfall during the December-January-February (DJF), March-April-May (MAM) and September-October-November (SON) seasons resulting from increased number of days of rainfall and higher probabilities of a wet day following a dry day in a month. Based on these scenarios, the combination of the wetter antecedent conditions and the more rain days in a month will result in more surface runoff being generated which will not only have implications on the water balance but also the water quality in the basin.

Key Words: climate change, climate scenarios, climate modelling, climate downscaling, Sondu Basin, Kenya

Please cite this paper as: Rwigi, S. K., N. J. Muthama, A. O. Opere and F. J. Opijah, 2016. Assessment of Potential Changes in Hydrologically Relevant Rainfall Statistics over the Sondu River Basin in Kenya Under a Changing Climate. *J. Meteorol. Relat. Sci. vol 9 pg 2-12.* http://dx.doi.org/10.20987/jmrs.1.05.2016

1. Introduction

Freshwater is becoming increasingly limited due to the ever-increasing demand resulting from the rapid population growth, unsustainable use, and increasing incidences of pollution due to emissions from anthropogenic activities. Climate change, which is characterised by rises in surface temperatures and changes in precipitation patterns among others, has exacerbated the problem as it has direct impacts on water supply, human health and loss of biodiversity (IPCC, 2007). Most studies have concluded that besides being the most vulnerable, Africa is the continent that is least equipped to handle the impacts of climate change (Lubini and Adamowsky, 2013).

Majority of Africa's population depend on natural resources which to a large extent depend on the availability and supply of fresh water resources. The importance of water in agriculture, domestic use, power generation and industry calls for effective and sustainable water resources management. To achieve this, it is important to evaluate changes in the hydrological and rainfall regimes through changes in annual means and variances of rainfall scenarios, and the distribution of daily rainfall amounts at the watershed level.

The goal of this study was to examine and evaluate past, present and future changes in hydrologically relevant rainfall statistics over the Sondu River basin using observed and simulated rainfall data.

Simulated rainfall data were derived from the fourth generation coupled Ocean-Atmosphere European Community Hamburg Model (ECHAM4) using the Providing Regional Climates for Impacts Studies (PRECIS) regional climate modelling system.

2. Materials and Methods

2.1. The study area – Sondu River Basin

Sondu River basin (Figure 1) was selected for this study in view of its economic, social, and environmental importance in the western part of Kenya. Agriculture is the mainstay of the people in this basin while the Sondu-Miriu Hydropower station derives its flow from Sondu River. The basin is located within latitudes 00˚23'S and 01˚10'S and longitudes 34˚46'E and 35˚45'E and covers an area of about 3500 km^2. The landform of the basin consists of low plains near the lakeshore and rises eastwards to volcanic plateaus with dissected margins in the middle parts and rugged terrain with deep gorges and V-shaped valleys in the upper eastern parts (JICA, 2013). Land elevation in the basin varies from about 1134 m at the lakeshore to 2900 m above sea level at the summit of Londiani Mountains. The basin generally slopes from east with relatively flat areas as it approaches Lake Victoria.

Rainfall in the basin depicts a trimodal pattern with the main rainfall season coming in the months of March-April-May (MAM) followed by June-July-August (JJA), and the short rains in September-October-November (SON).

The mean monthly rainfall ranges from about 60 mm in January to about 284 mm in May while the mean annual rainfall exceeds 1500 mm, the threshold values for a tropical wet type of climate (Ahrens, 2009). The dominant land use activities in the basin include agriculture and forestry accounting for about 64% and 27% respectively of the total basin area.

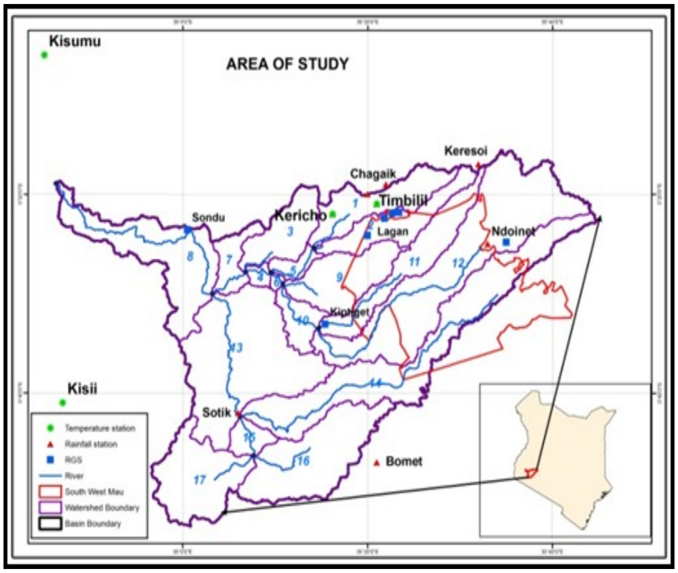


Figure 1: Sondu River basin showing its location in, the 17 sub basins, and the river, rainfall and temperature gauging stations networks

2.2. Regional Climate Scenario Modelling

Downscaled General Circulation Model (GCM) outputs have been used in hydrological studies to translate projected climate scenarios into hydrological responses (Akhtar *et al,* 2009). In this study, PRECIS regional climate modelling system was used to downscale the coarse global climate scenarios from ECHAM4 following the Special Report on Emission Scenarios (SRES) A2 emissions to 0.5˚grid resolution for eastern Africa where the model domain was set up with a horizontal resolution of 50 km by 50 km spanning latitudes 12˚S to 18˚N and longitudes 22˚E to 52˚E (Wilson *et al*, 2009: Jones *et al,* 2004). The study focussed on the future global climate scenarios simulated based on the SRES A2 emissions scenario defined by the IPCC (2000) Special Report on Emissions Scenarios (SRES) which assumes that efforts to reduce global emissions this century will be relatively ineffective (Lumsden *et al,* 2009).

Regional scenarios of daily time series of rainfall for the periods 1961-1990 (baseline), 1991-2020 (present and immediate future), and 2021-2050 (intermediate future) were developed. Changes between the projected rainfall (1991-2020 and 2021-2050) and the baseline rainfall (1961-1990) were evaluated to determine the possible climate change in the region.

Hydrologically relevant rainfall statistics that include; Mean annual rainfall, coefficient of variation of annual rainfall, average number of rainfall days in a month, probability of a wet day following a dry day and the probability of a wet day following a wet day in a month, were assessed at the watershed scale since the possible hydrological impacts of climate change are normally assessed using watershed scale hydrological models. In order to represent the regional climate scenarios at the watershed scale, three 0.5˚ grid squares that cover most of the Sondu river basin were used to extract time series of daily rainfall using the coordinates of at least one existing rain gauge within the grid square.

2.3. Climate Model Output Validation

PRECIS model-simulated rainfall scenarios were validated using corresponding observed rainfall data from the area of study for the baseline period (CCC, 2009; Islam *et al*, 2008) which were considered representative of the location. Grid values of the model data were, extracted at three observation sites of Kenya Meteorological Department (KMD) (i.e. Kericho, Keresoi, and Sotik) and processed to monthly, seasonal, annual and long-term mean values, were compared with the corresponding observed data representing the grid.

Simulated monthly rainfall values were regressed on corresponding observed values to calculate the regression parameters (slopes and constants) that were used as validation parameters to validate the model projected values (CCC, 2009) using Equation (1).

$$E_{RF} = a_{RF} + b_{RF} \times S_{RF} \quad \text{.......... Eqn (1)}$$

E_{RF} in Equation 1 is the projected rainfall, a_{RF} is the rainfall regression constant, b_{RF} is the rainfall regression slope, and S_{RF} is the model simulated rainfall scenario.

The model performance was evaluated as the percentage difference between the observed and model-estimated rainfall (Equation 2). Positive values indicated model underestimation while negative values indicated model overestimation (Islam *et al*, 2008).

$$P_{Rnfl} = \left(\frac{Obs_{Rnfl} - Est_{Rnfl}}{Obs_{Rnfl}} \right) \times 100 \quad \text{.......Eqn (2)}$$

P_{Rnfl} in Equation 2 is the percentage overestimation or underestimation of rainfall by the model, Obs_{Rnfl} is the observed rainfall, Est_{Rnfl} is the estimated rainfall from the model-simulated scenarios.

2.4. Rainfall Statistics Characterizing Basin Hydrology

The hydrologically relevant rainfall statistics assessed in this study focused on characterising the annual means and variances of rainfall amounts as well as the distribution of daily rainfall amounts in terms of the number of days of rainfall and the probabilities of a wet day following a dry day and a wet day following a wet day in a month (Neitsch *et al,* 2011). Mean annual rainfall (MAR), coefficient of variation of annual rainfall (CV), average number of rainfall days in a month (PCPD), probability of a wet day following a dry day (PR_W1) in a month, and the probability of a wet day following a wet day in a month (PR_W2) were evaluated and their changes from the baseline values used to determine rainfall trends under conditions of climate change. The average number of days of rainfall in a month and the probabilities of a wet day following a dry day or a wet day following a wet day in a month, have significance in terms of the general antecedent wetness index and therefore impact on the hydrology of a watershed (Lumsden *et al,* 2009).

3. Results and Discussion

3.1. Observed Rainfall Characteristics

Figure 2 shows the changes in mean monthly rainfall totals over Sondu basin from the baseline rainfall climatology, averaged over three 30-year periods: 1961-1990 (1970s), 1971-2000 (1980s), and 1981-2010 (1990s). The difference between the baseline (1970s) and the 1980s and 1990s monthly rainfall totals, expressed as a ratio, was used as an indicator of observed changes in rainfall patterns in this part of Kenya (Figure 2). It was noted that there was a general increase in monthly rainfall from the baseline period during DJF and SON seasons while there was a general decline during MAM and JJA seasons (Figure 3).

The increases in monthly rainfall in 1980s ranged between 1% in February and 8% in November while in 1990s it ranged between 2% in May and September and 16% in December of the baseline rainfall. On the other hand decreases in monthly rainfall in 1980s ranged between 1% in August and 10% in March while in 1990s it ranged between 1% in July and 10% in June of the baseline rainfall (Figure 2).

From these results, it was established that the overall observed seasonal changes in rainfall indicate a likely shift in rainfall patterns where the relatively dry DJF and SON seasons are becoming relatively wetter and the relatively wet MAM and JJA seasons are becoming relatively drier compared to the baseline period (Figure 3). These observed changes in monthly rainfall across the three regimes have a direct impact on the hydrology of the watershed.

3.2. PRECIS Model Validation and Baseline Rainfall

Using model-simulated and the corresponding observed monthly rainfall totals at Kericho, Keresoi, and Sotik stations, validation parameters (Table 1) were obtained through regression analysis. These parameters were used to validate PRECIS model-projected rainfall. Correlation coefficients between observed and simulated rainfall, which range between 0.75 and 0.93, were tested for significance using student t-statistic at $\alpha = 0.05$ level of significance and confirmed to be significant.

Figure 4 shows a comparison of simulated mean monthly rainfall with corresponding observed values during the baseline period at Kericho Meteorological Station. The observed rainfall peaks in May, August, and November are fairly well replicated by the model. The model results are therefore consistent with observed values. However, the model was found to slightly overestimate monthly rainfall between the months of June and December by between 3% and 10% of the baseline rainfall. The percentage variability in the simulated mean monthly rainfall that could be explained by the corresponding observed rainfall was 86% (Figure 5). Based on these results it was concluded that the model could be used to project monthly rainfall climatology of the basin.

Table 2 presents a comparison of observed and model simulated mean monthly rainfall and the model performance as a percentage difference between model-simulated and corresponding observed rainfall during the baseline period. Positive values in the model performance column indicate

On a month-by-month scale, the percentage deviation between observed and model-estimated rainfall ranges between -12% and 22%. From the validation results of the PRECIS model outputs using observed values, it was established that the model captures the baseline climate of the area of study quite well as shown by the regression statistics (Table 1) and the model performance statistics (Table 2). Hence the model was found suitable for simulating rainfall in this part of Kenya.

3.3 Projected Changes in Rainfall Statistics Characterizing Basin Hydrology

Table 3 shows an overview of the general differences in climate by 2030 and 2050 compared to that of the baseline period. On average, there will be notable changes in mean annual rainfall from the baseline values. From the analyses of 30-year averages of rainfall, it was established that mean annual rainfall of Sondu and that of the surrounding areas is projected to change from the baseline values by about 5% and 19% by 2030 and 2050 respectively. These changes are expected to influence the hydrology of the catchment through changes in evapotranspiration and runoff generation.

Figures 6 and 7 show projected changes of mean monthly and seasonal rainfall respectively by years 2030 and 2050. It is apparent that there will be substantial increases in monthly and seasonal rainfall during the DJF and SON seasons by 2030 and 2050. The relatively dry DJF and SON seasons are projected to become relatively wetter by 2030 and 2050. The highest changes in mean seasonal rainfall were observed during DJF ranging between 2.5 and 2.7 times by 2030 and 2050 respectively of the baseline rainfall. It was followed by SON where projected increases range between 1.6 and 1.8 times by 2030 and 2050 respectively of the baseline rainfall. The least projected increases in seasonal rainfall were in MAM ranging between 1.1 and 1.2 times by 2030 and 2050 respectively of the baseline rainfall. JJA is the only season with projected decreases in seasonal rainfall ranging between 0.87 and 0.86 times by 2030 and 2050 respectively of the baseline rainfall.

The probability of a wet day following a dry day (PR_W1) is projected to increase during the DJF and SON months and to decrease during the MAM and JJA months except the month of August in 2030s (Figure 8). During the DJF months, PR_W1 is projected to be higher by between 1.6 and 2.0 times and 1.6 and 2.5 times by 2030 and 2050 respectively of the baseline probabilities. During the SON months, PR_W1 is projected to be higher by between 1.1 and 1.9 times and 1.1 and 2.2 times by 2030 and 2050 respectively of the baseline probabilities. On the other hand, PR_W1 is projected to decrease during MAM and JJA months by between 0.7 and 0.9 times and 0.8 and 0.9 times by 2030 and 2050 respectively of the baseline probabilities which is consistent with the projected decreases in rainfall during these seasons.

The probability of a wet day following a wet day (PR_W2) is projected to increase in all the

The number of rainfall days in a month (PCPD) in all the months of the year is projected to increase by between by between 1.1 and 2.4 times and 1.1 and 2.5 times by 2030 and 2050 respectively of the baseline days (Figure 10). The changes in the number of days of rainfall in a month indicate an increase in the period that the soil will remain moist and hence a possible increase in the runoff generation from the basin.

4. Conclusions

The analysis of rainfall changes has shown that there is a general tendency towards more rainfall in the Sondu basin and the neighbouring regions as we move from the baseline period towards future climate periods. More rainfall is projected for the area as we move towards 2030 and 2050. This rainfall is in form of more rain days in a month and higher probabilities of wet days following dry days and wet days following wet days in a month. The combination of wetter antecedent conditions and more days of rainfall in a month are likely to bring about higher runoff generation from particular rainfall events. This would have implications not only on the amount of water available in the basin but also on the quality of this water as well as the flood related risks. The higher amounts of water are likely to cause an increase in flooding incidents in the lower parts of the basin. We recommend that efforts be stepped up and sustained to conserve the upper

Tables

***Table 1:* Validation *parameters of PRECIS model rainfall projections for monthly rainfall totals where* (a_{RF}), is the regression constants, b_{RF} is the regression slopes R^2 is the coefficients of determination, and r_{os} is the correlation coefficient between observed and model simulated monthly rainfall totals**

Station	a_{RF}	b_{RF}	R^2	r_{os}
Kericho	45.5	1.03	0.86	0.93
Keresoi	15.5	0.495	0.81	0.90
Sotik	45.5	0.368	0.56	0.75

Table 2: Predicted and observed mean monthly rainfall and model performance in calibration and validation periods

Month	Observed Rainfall (mm)	Predicted Rainfall (mm)	Model Performance (%)
Jan	99.7	78.0	21.7
Feb	104.1	107.5	-3.3
Mar	155.1	173.2	-11.7
Apr	253.9	233.1	8.2
May	299.8	237.4	20.8
Jun	221.5	243.0	-9.7
Jul	205.6	223.9	-8.9
Aug	225.7	239.4	-6.0
Sep	179.0	189.7	-5.9
Oct	165.1	179.6	-8.8
Nov	147.6	147.8	-0.2
Dec	98.1	101.2	-3.1

Table 3: 30-year average annual rainfall and the corresponding standard deviations (Stdev) together with changes relative to the baseline period where MAR is the 30-year mean annual rainfall, Stdev is the standard deviations of annual rainfall, CV is the coefficient of variation, ΔMAR is the change in mean annual rainfall and ΔCV is the change in the coefficient of variation

Climate Period	**Mean Annual Rainfall Statistics**				
	2	**3**	**4**	**5**	**6**
	MAR (mm)	**Std Dev (mm)**	**CV**	**ΔMAR**	**ΔCV**
1961-1990 (1970s)	2122.3	341.9	0.16	1	1
1991-2020 (2010s)	2222.6	264.4	0.12	1.05	0.75
2021-2050 (2030s)	2524.3	245.3	0.10	1.19	0.625

Figures

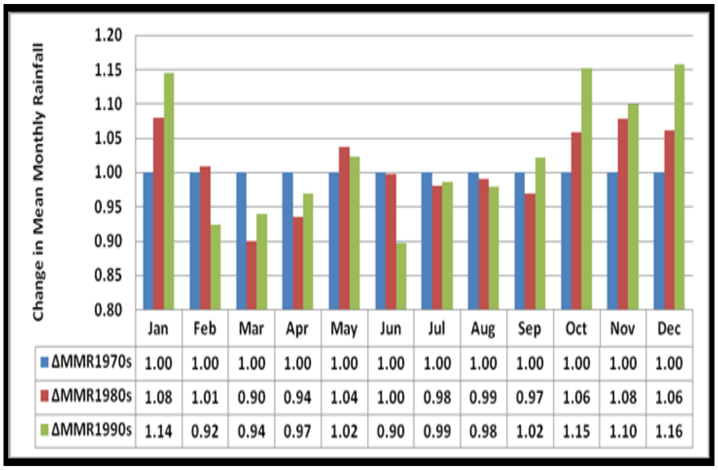


Figure 2: Changes in observed mean monthly rainfall (MMR) relative to the baseline period at Kericho Meteorological Station

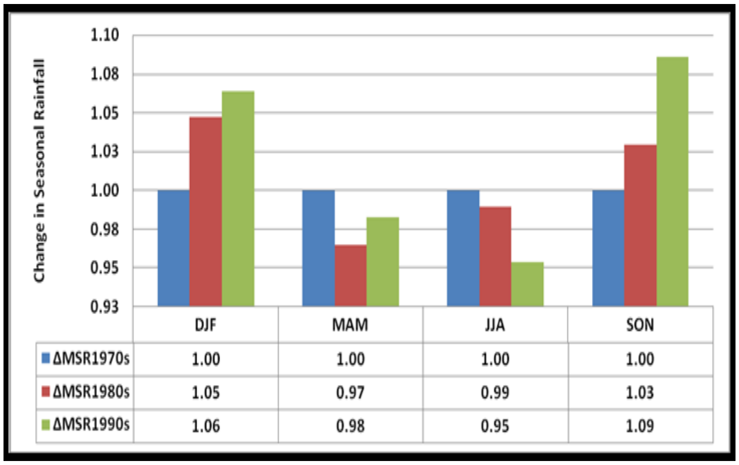


Figure 3: Changes in observed mean seasonal rainfall (ΔMSR) relative to the baseline period at Kericho Meteorological Station

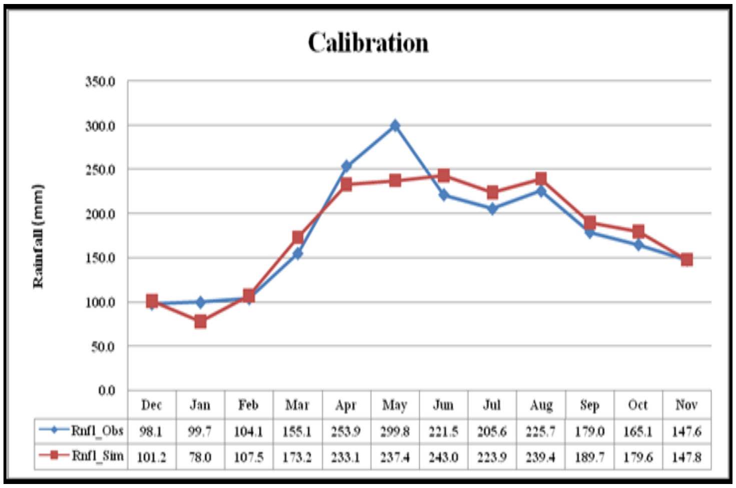


Figure 4: Annual cycles of observed and model-simulated mean monthly rainfall (mm) during the baseline period at Kericho Meteorological Station

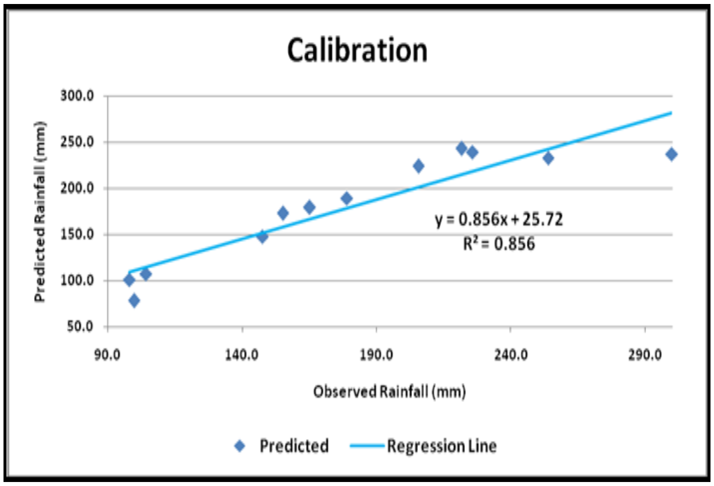
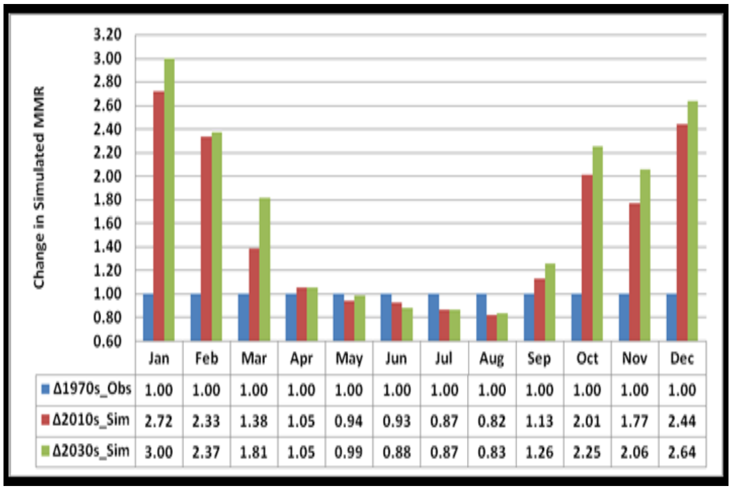
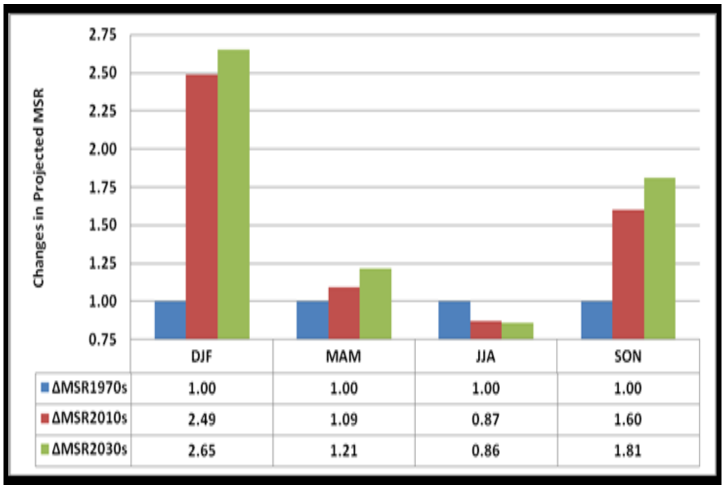


Figure 5: Regression of mean monthly model-simulated on corresponding observed rainfall (mm) during the baseline period at Kericho Meteorological Station



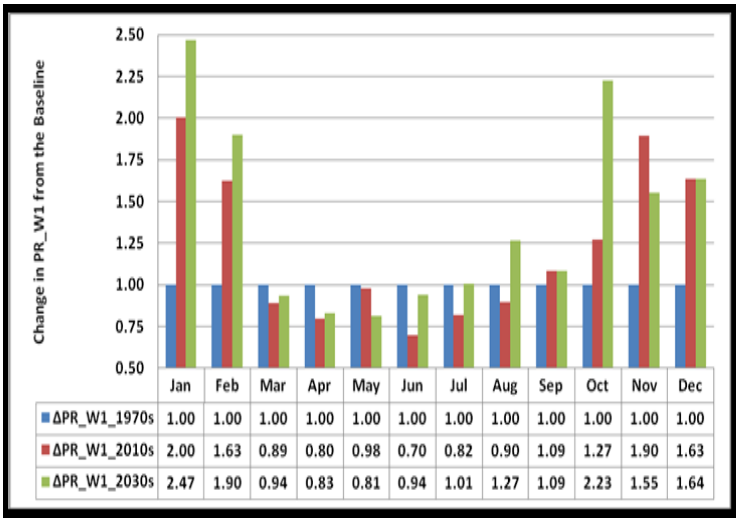
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 Δ1970s_Obs	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
🟥 Δ2010s_Sim	2.72	2.33	1.38	1.05	0.94	0.93	0.87	0.82	1.13	2.01	1.77	2.44
🟩 Δ2030s_Sim	3.00	2.37	1.81	1.05	0.99	0.88	0.87	0.83	1.26	2.25	2.06	2.64

Figure 6: Projected changes in mean monthly rainfall (MMR) relative to the baseline at Kericho Meteorological Station



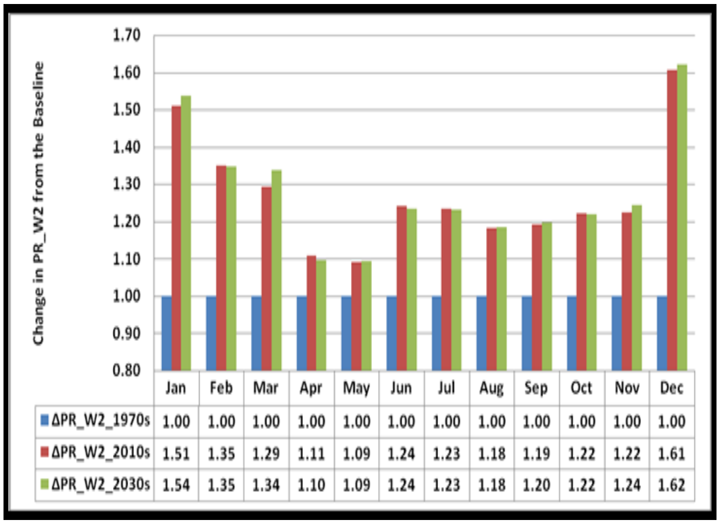
	DJF	MAM	JJA	SON
🟦 ΔMSR1970s	1.00	1.00	1.00	1.00
🟥 ΔMSR2010s	2.49	1.09	0.87	1.60
🟩 ΔMSR2030s	2.65	1.21	0.86	1.81

Figure 7: Changes in projected mean seasonal rainfall (ΔMSR) relative to the baseline period at Kericho Meteorological Station



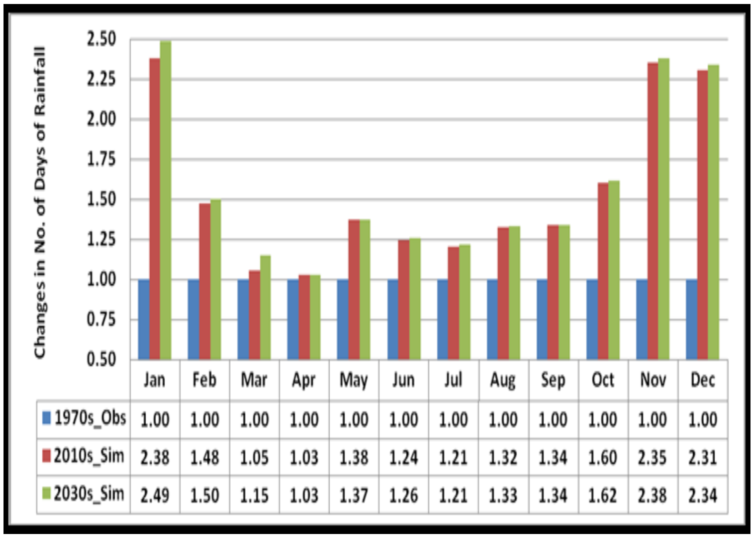
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 ΔPR_W1_1970s	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
🟥 ΔPR_W1_2010s	2.00	1.63	0.89	0.80	0.98	0.70	0.82	0.90	1.09	1.27	1.90	1.63
🟩 ΔPR_W1_2030s	2.47	1.90	0.94	0.83	0.81	0.94	1.01	1.27	1.09	2.23	1.55	1.64

Figure 8: Projected changes in the probability of a wet day following a dry day (ΔPR_W1) relative to the baseline at Kericho Meteorological Station



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 ΔPR_W2_1970s	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
🟥 ΔPR_W2_2010s	1.51	1.35	1.29	1.11	1.09	1.24	1.23	1.18	1.19	1.22	1.22	1.61
🟩 ΔPR_W2_2030s	1.54	1.35	1.34	1.10	1.09	1.24	1.23	1.18	1.20	1.22	1.24	1.62

Figure 9: Projected change in the probability of a wet day following a wet day (ΔPR_W2) relative to the baseline at Kericho Meteorological Station



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 1970s_Obs	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
🟥 2010s_Sim	2.38	1.48	1.05	1.03	1.38	1.24	1.21	1.32	1.34	1.60	2.35	2.31
🟩 2030s_Sim	2.49	1.50	1.15	1.03	1.37	1.26	1.21	1.33	1.34	1.62	2.38	2.34

Figure 10: Projected change in the average number of days of rainfall in a month relative to the baseline at Kericho Meteorological Station

References

Ahrens C. D., (2009): Meteorology Today, an introduction to weather, climate and the environment, Ninth Edition, *Brooks/Cole 10 Davis Drive, Belmont CA94002, USA, 439-499*

Akhtar, M., N. Ahmad, and M. J. Booij (2009): Use of regional climate model simulations as input for hydrological models for the Hindukush-Karakorum-Himalaya region. *Hydrol. Earth Syst. Sci., 13, 1075–1089*

Climate Change Cell (CCC), (2009): Generation of PRECIS scenarios for Bangladesh (Validation and Parameterization), *Climate Change Cell, DoE, MoEF; Component 4b, CDMP, MoFDM. Month 2009, Dhaka, 84*

Githui, F.W, W. Gitau, F. Mutua, and W. Bauwens (2009): Climate change impact on SWAT simulated streamflow in western Kenya. *Int. J. Climatol.* 29: 1823–1834

IPCC, (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon et al). *Cambridge University Press, Cambridge, United Kingdom and New York, NY, 93-217*

IPCC, (2000): IPCC Special report: Emissions' Scenarios, summary to policy makers: *A special report of IPCC working group III; Published for the Intergovernmental Panel on Climate Change, 27*

Islam, M. N., M. Rafiuddin, A. U. Ahmed and R. K. Kolli (2008): Calibration of PRECIS in Employing Future Scenarios in Bangladesh *Int. J. Climatol. Vol. 28 (5) 617-628*

JICA, (2013): The Project on the Development of the National Water Master Plan 2030, *Final Report Volume –I, Executive Summary, October 2013, Ex-46 -Ex-65*

Jones, R.G., Noguer, M., Hassle, G.G., Hudson, D., Wilson, S.S., Jenkins, G.J. Mitchell, J.F.B., (2004): Generating High Resolution Climate Change Scenarios Using PREIS, *Met Office Hadley Centre, Exeter, UK, 44pp, April 2004*

Lubini1 A. and Adamowski J (2013): Assessing the Potential Impacts of Four Climate Change Scenarios on the Discharge of the Simiyu River, Tanzania Using the SWAT Model, *International Journal of Water Sciences (Int. j. water sci., 2013, Vol. 2, 1: 2013)*

Lumsden T.G., Schulze R.E., Hewitson B.C., (2009): Evaluation of Potential Changes in Hydrologically Relevant Statistics of Rainfall in Southern Africa under Conditions of Climate Change, *Water SA 35(5), 649-656*

Neitsch S. L., J. G. Arnold, J. R. Kiniry, J. R. Williams (2011): Soil and Water Assessment Tool Theoretical Documentation Version 2009. *Grassland Soil and Water Research Laboratory – Agriculture Research Service Blackland Research Centre – Texas AgriLife Research, 596*

Wilson, S., D. Hassel, D. Hein, R. Jones and R. Taylor (2009): Installing and using the Hadley Centre regional climate modelling system, PRECIS; version 1.8.2, precis.metoffice.com, September 11, 2009, *167*