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Analysis of Climate Change Impacts in Ngerengere Sub-Basin Using Data-driven Model

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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Short Research Article

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ABSTRACT

The basic premises of this study is to analyze climate change impacts on flow rate in Ngerengere sub-basin using the data-driven model. Stream flows of sub-basin were simulated by skilled GCMs using data-driven model and Polynomial regression model. The model was setup using observed downstream flows and rainfall data. A total of 5 GCMs from CMIP5 database named as Nor ESM1-M, GFDL-ESM, Had GEM2-ES, IPSL-CM5A-LR and MIROC-ESM-CHEM were incorporated in the model. Since runoff is greatly sensitive to precipitation in comparison to other variables such as temperature, precipitation chosen as climate changing variable for projection.GCMs used in analysis and simulation of climate change impact at Ngerengere sub basin with highest skill score is 92% NorESM1-M and lowest skill score of 90% IPSL-CM5A which are above threshold value 80%. GCMs projected (2010 – 2049) at Sub basin decrease in average precipitation January to November while August is projected to suffer more average decrease in precipitation. unsimillar projection in average precipitation occour in February, March, September and December. General Circulation Models projection (2010 – 2049) of stream flow in Ngerengere sub-basin is highly dependent upon the projected changes in precipitation because the patterns drawn by the precipiation changes are similar with those of stream flows. The projected (2010 – 2049) average annual decrease in stream flow of Ngerengere sub-basin is estimated to be around 18% taken as the average of the outputs of all 5 GCMs.

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Keywords: Climate change impact; Ngeregere sub-Basin; data driven model; skill score test; polynomial regression analysis.

1. INTRODUCTION

Climate change is among the major problems currently facing the world which has severely affected food availability and many people find it hard to meet their basic needs [1,2]. Climate change has been mentioned to hold the potential to threaten the gains attained in relation to literacy and nutrition [3]. Scientists, economists and other stake holders are trying to agree on the best way forward to deal with the climate change and variability [4]. The International Pannel on Climate Change(IPCC) states that "Africa is one among the vulnerable continent to climate change and climate vulnerability" [1,5], and it is projected that by 2050, 350 - 600 milllion Africans will be at risk of increased water stress particularly in the northern and southern part of the continent [6,7]. African farmers are mainly vulnerable to precipitation changes that may result into over farming, degradation of land resources, increased pressure on wild game species and exposure to zoonotic diseases [8]. According to former researchers Climate change is projected to have both positive and negative consequences to Tanzania water resources, particularly for her three major basins Ruvu, Pangani and Rufiji [9,10,11]. The inadequate precipitation, high temperature, surface runoff and percolation may have resulted in the decrease of river discharge [12,13]. The effects brought by the Climatic Change into the Ruvu basin have resulted into decrease of its water level and discharge [2]. The study conducted by URT shows that Ruvu basin is very important in Tanzania as it supplies water to a huge population of Dar es Salaam but its runoff decline 10% [14,11]. These impacts may affect livestock and agricultural activities as this basin is the vital area for water and food production. Study on variation of temperature at Wami-Ruvu basin shows that is expected to increasing in temperature at Wami river between 2.1 and 4 degree Celsius together with increasing of rainfalls into rainy season's areas and decrease in rainfalls in areas with only one rainfall season [15,16]. Other negative prediction as result of effect of climate change in Tanzania is that by 2025 fresh water availability will be reduced to half the rate of 1990 [17]. Unfortunately the trend above has been observed in many other places in Tanzania, for example Simiyu River whose stream flow is observed to decrease which has resulted into decrease its water quantity at Zanzui dam which feed most of the people at Simiyu Region. Most small rivers and springs have either disappeared or become seasonal as the result of climate change; there have been a steady encroachment into the wetlands and water bodies in the country [18,19].

According to [20], the climate of a particular region is determined by the interaction of the several factors such as solar energy, Air pressure, Wind and ocean currents' Water availability, topography and Land cover [21]. However various physical processes that govern climate are modelled using climate models and appear to differ in the ways they do so. For example, the estimation of evapotranspiration appears to have a fair amount of uncertainty in its estimation at the landscape level in the presence of woody vegetation. Therefore the models differ depending in the exact processes they consider [22]. Furthermore, the models need have to be calibrated for the sake of their predictions to be close to reality. Calibration is normally done by adjusting the values of the variables in the model equations aiming at their predictions in recent past resemble the actual data over that period. Though predictions close to reality can be tuned by forcing models, there is no way to insure that such historic relationship will hold in future [23]. Temperature is relatively straight forward to predict as compared to precipitation, the reason behind the scenario is temperature depends on the energy balance of a particular region while precipitation incorporates numerous processes which are not clearly understood or interlinked in a complex web of feedback [24]. This scenario can be well illustrated by a vivid and concrete example of Ruvu basin whose projections are based upon 12 General Circulation Models (GCMs) being run under A2, A1B and B1 emissions scenarios and being presented by the Climate Change Knowledge Portal of the World Bank. General Circulation Models (GCMs) can also be named as Global Climate Models, constitute the foundation of climate prediction [25]. The previous studies concentrated on the use of the General Circulation Models at a number of emission scenarios to predict climate in Tanzania [26,25]. The outputs of the models have been quoted by other studies examine the impact of climate change in various sectors in Tanzania such as Wami and Ruvu basins [15], hydrology and land use [27,28] and coastal ecosystems

[17]. The climate prediction studies reported an expected increase in temperature within the range of 1.5°C - 2°C by the year 2050 and around 2°C-4°C by the year 2090s under low B1 and high emission scenarios A2 respectively [25,2]. The number of hot days and nights was predicted to increase up 40% of all days and 68% of all nights by the 2060 and up to 65% days and 99% nights by the 2090 [25]. Consequently, there is expected decrease in number of days and nights considered currently cold, these are expected to become rare by 2090.Hot days should be considered as a variable of great interest because they rise heat stress and place extra energy demand in houses and industries, affect the crops and may result into shift of ecosystem and species metabolism, migration and behaviour [20] The exploration of species in the Eastern Arc Mountains (EAM) and the hypothesis that the species would have to ascend with altitude to keep pace with warming temperatures are described using downscaled regional climate models, some species may happen to move downwards or laterally on account of variations in water availability and precipitation [12]. In case of precipitation, there is no a clear consensus on prediction of rainfall amounts unlike temperature whose prediction is quite straight forward. The amplitude of variation amongst the model is found to be above 100 mm per month in the wet season months which is tremendous variation [20]. The scenario is similar to what expected and is reflective of the far greater complexity of the factors that affect rainfall predictions that has resulted to different assumptions and parameterization between models. Depending on the type of model and how many models were run, this complexity is also reflected by usually contrasting predictions. This study analyze the climate change scenarios at Ngerengere sub-basin by using downscaled General Circulation Models (GCMs) and polynomial regression model.

Objectives of study (i) To collect the climatic data from meteorological stations (ii) To develop a polynomial regression model and analyze climate for the Ngerengere sub-basin. (iii) To simulate the impacts of climate change in Ngerengere sub-basin using climate change signals.

2. METHODOLOGY

2.1 Location of Case Study

Wami-Ruvu basin covers the catchment areas of both wami and Ruvu River systems including the coastal rivers of Dar es Salaam that drains into the Indian Ocean. Ngerengere sub-basin is within Ruvu River basin found in Morogoro, It is located in between latitudes 6º 27’24.46’’ and 7º 20’ 0.06’’ South and between Longitudes 37º 57’24.61’’ and 38º 31’30.61’’ East. The basin originates from the western part of the Uluguru mountains to the mid plains of Ruvu basin towards Indian Ocean. Ngerengere sub-basin has a total coverage area of 2,780 square kilometers. This sub-basin covers a large percent of Morogoro region including Morogoro Urban District and some parts of Morogoro rural districts acknowledged as Mlali, Mzinga, and Mgeta, Sanga-sanga, Mikese townships and Ngerengere military area.

The general climate of this sub-basin is enhanced by bimodal rainfall, which are:-Short rain season (Vuli), which lasts from November to early January followed by short dry season. Long rain season (Masika), which begins at the end of February and end up in May followed by a long dry season. In Ngerengere sub-basin,the mountainous gauging stations located above 900 mm which are Mombo, Mongwe, Ruhungo and Morning side which are observed to have high amount of annual rainfal compaired to low land gauging stations which are Mlali, Morogoro Maji and Mindu The annual rainfall of Ngerengere Sub basin lies in between (800-1000) mm with exception of Uluguru Mountains whose mean annual rainfall exceeds 1500 mm .the gauging stations found in catchement shown in Fig. 1.

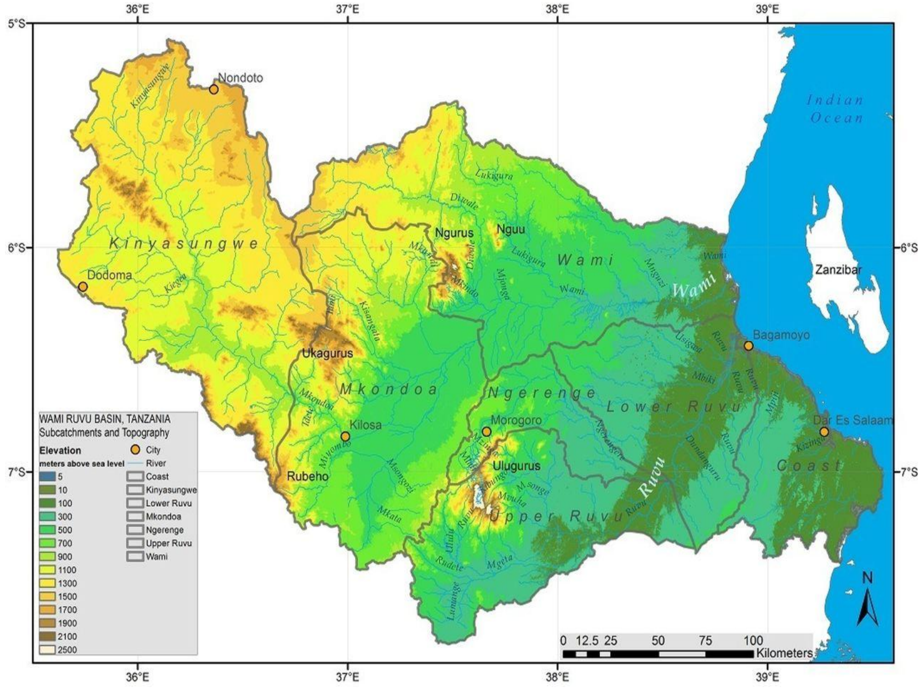
2.2 Research Design

2.2.1 Rain fall and river flow data collection

These hydrological and meteorological data collected from Wami-Ruvu basin offices and meteorological station which are within the Ngeregere sub-basin. For the sake of enhancing quality control system of rainfall and flow data, robust system have been designed where every station is allocated to a person who takes care of all issues such as data compilation, screening and quality control [28].

2.2.2 Sample size

The rainfalls and downstream flows data used were forty (40) years climate data. The daily rainfalls data from 29 observed gauging stations and downstream flows of Ngerengere sub-basin for the 1970 to 2011 period were aggregated into monthly values. CMIP5 climate data were 70 years data from four selected regions of Ngerengere sub-basin from 1979 to 2049.



Map 1. Map of Wami Ruvu Basin show the study area

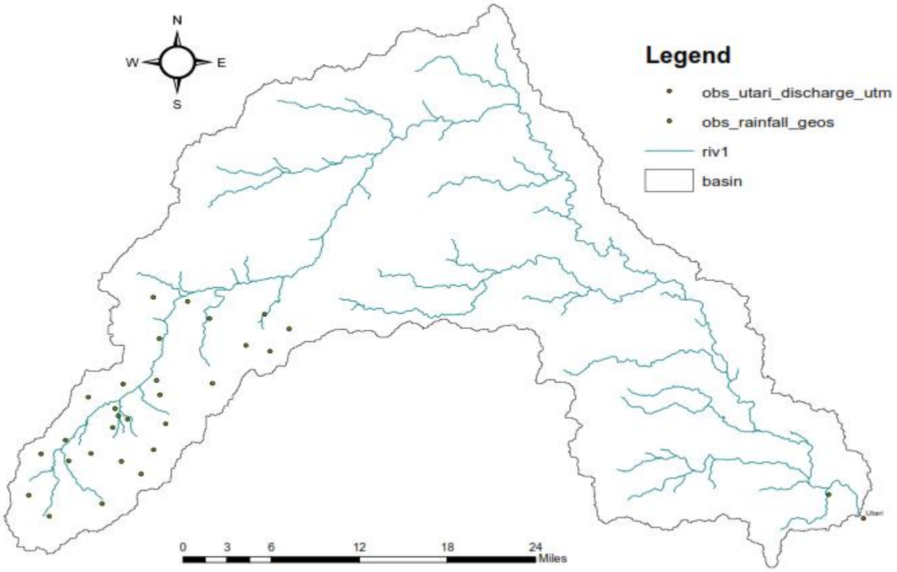


Fig. 1. Observed gauging stations at Ngerengere sub-basin

2.2.3 GCM scenarios

Simulation of climate change impacts in Ngerengere sub-basin done by using climate change signals. Representative Concentration Pathways (RCPs) are for four greenhouse gas concentrations (not emissions) trajectories adopted by the IPCC for the fifth Assessment Report (AR5) in 2014. There are several RCP scenarios such as +2.6, +4.5, +6 and +8.5 W/m^2. RCP 8.5 was selected because it had highest rising radioactive forcing pathways resulting to 8.5 W/.The baseline period (1980 – 2009) was selected because it incorporates some of strongest natural variability of climate such as strongest El Nino Southern Oscillation (ENSO) warm event in 1997/1998 to strong La Nina strong event 1999/2000.

2.3 Data Collection Tools

2.3.1 Geographic information system (Arc Gis)

Through the use of Arc Gis sofware, the areas of the sub-catchments were computed so as to include their impacts to the outflow of Ngerengere sub-basin, also distances between the gauging stations was computed in estimating the missing rainfall data of the sub-catchments using distance power method.

2.4 Data Analysis Methods

Polynomial regression model used as Data-driven model , which relate the streamflow of Ngerengere sub-basin in terms of the observed climate data. Ms Excel computer software used in developing polynomial regression analysis. Model setup, climate change analysis and simulating climate change impacts using climate change signals were done in separate excel sheets.

2.4.1 Model setup

Downstream flow (Q) and real rainfall data used in Ms Excel to develop polynomial regression model for Ngerengere sub-basin.The sub basin was divided into 124 sub basins, out of which only 29 were provided with rainfall data. The missing rainfall data of other sub-basins within the catchment were found using distance power method (Equation 1) and the areal rainfalls of the entire sub basin were found by arithmetic mean method Equation 2).The formula of distance power method used in the estimation of missing rainfall data of Ngerengere sub basin is shown by Equation 1 [29].

$$P_{\mathrm{x}} = \frac{\sum_{i=1}^{N} \frac{P_{\mathrm{i}}}{d^2}}{\sum_{i=1}^{N} \frac{P_{\mathrm{i}}}{d^2}} \qquad (1)$$

Whereby:-

d = distance of the estimator station from the estimated station.
P_i = known precipitation of the gauging station.
P_x = Unknown precipitation of the gauging station.

The formula of arithmetic mean method in finding the areal rainfalls of the sub-basin as explained by Equation 3.2 [30]

$$\overline{P} = \frac{P_1 + P_2 + \ldots.. + P_i + \ldots..P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i \qquad (2)$$

Whereby:- $\overline{P}$ = Areal rainfall of the basin.P_1, P_2, …, P_n = Rainfalls of the subbains, N = Number of stations.

2.4.2 Procedures for performing regression analysis in Microsoft Excel

- Estimated rainfall and available rainfall data for a given meteorological station are collected in compute the areal rainfall of the Ngerengere sub basin.
- 16th degree of the polynomial regression Equation filled by collected estimated and available rainfall data.
- In By using Ms. Excel the data tool opened in order to open analysis Tool Pack in order to allow regression tool to check.
- Y ranges values (dependent variable which are streams flows) and X range values (independent variables which are areal rainfalls) are selected and filled in 16th degree of the polynomial regression equation.

The form of the general polynomial regression equation for multiple variables is as shown by Equation 3 [31].

$$y = a + a_1 x + a_2 x^2 + \cdots + a_k x^k + e \qquad (3)$$

The polynomial regression equation relating flow and rainfall climate data is shown by Equation 4:-

$$\text{Folw, } Q = c + m_1 * \text{areal rainfall} + m_2 * \text{rainfall}^2 + \ldots\ldots\ldots M_k * \text{areal rainfall}^{k} + \text{error} \qquad (4)$$

Where by:-Q = Observed downstream flow (dependent variable).The m_i 's are called the population regression coefficients $(\mathrm{i} = 1, 2, 3 \ldots \mathrm{n})$. $Areal\ rainfall^i$ = Observed monthly areal rainfalls month i $(\mathrm{i} = 1, 2, 3 \ldots \mathrm{k})$ (independent variables). c = Constant term Error, is the random variation "e" that incorporates uncertainty due to various factors. The portion which has to be determined $c + m_1 * Areal\ rainfall + m_2 * Areal\ rainfall^2 + \cdots + m_k * Areal\ rainfall^k + error,$ is called population regression function.Since the data driven model type used is hybrid, there is a necessity to incorporate some of the processes that contribute to the downstream flow of the Ngerengere catchment / sub-basin, the areal rainfall of each sub-basin was multiplied by its corresponding sub-basin area as indicated by the Equation 5.

$$Rainfall_i = \mathrm{C} * Rainfall_i * Area_i \qquad (5)$$

Where by:-$Rainfall_i$ = Observed mean monthly precipitation for month i $(\mathrm{i} = 1, 2, 3 \ldots \mathrm{n})$, $Area_{\,i}$ = Area of the sub-basin within which a particular station is located. The output from the analysis of polynomial regression will give the values for the intercept (C), the coefficients (M_i), standard error and the value of coefficient of determinacy, R^2 which determines the model fitness. The model is said to be fitted when the value of R^2 range between 0.8 and 0.999 [31]. All these outputs will be used in developing a Polynomial regression model for Ngerengere sub-basin.

2.5 Skill Score Test of GCMs

Before analysis of climate change and simulation of its impacts, the performances of the GCMs were tested in simulating the past historical climate data. Selection of skilled GCMs was done using the season lag skill score test shown by Equation 6 [32]. This test weighs the relative lag between GCM precipitation and observed precipitation. A comparable measure of the relative similarity between GCM and observed precipitation are usually presented using seasonal variability curves (SVCs) [27]. SVCs are interpreted based on the extent of overlapping between the two curves, if there is negligible overlapping between observed and modelled SVCs, this implies the skill score is close to 0 and if there is a big overlap between the two, this implies skill score is close to 1. Therefore if the GCM simulates the observed conditions perfectly, the skill score values to 1.

$$SL_{score} = \sum_{n=1}^{12} Minimum\left(\frac{GCM_{JK}}{GCM_{MAPK}}, \frac{OBS_{JK}}{OBS_{MAPK}}\right) \qquad (6)$$

Where by:-

SL_{score} = Season Skill Score
GCM_{JK} = Baseline mean monthly precipitation for month j and GCM_k
OBS_{JK} = Observed mean monthly precipitation for month j
GCM_{NAPK} = Baseline mean annual precipitation for month j and GCM_K
OBS_{MAPK} = Observed mean annual precipitation

2.6 Climate Change Analysis

The analysis of the climate change at Ngerengere sub-basin done by follow same procedures as for the model setup by replacing the observed rainfalls with the new rainfalls. The Coupled Model Inter comparison project Phase 5 (CMIP5) Climate data from the IPCC used in the computation of new rainfalls which done using equation 7 and the projected precipitation computed by using equation 8 Where by:-

$$Rainfall_{new} = OBS_{past}\left(1 + \frac{GCM_{future} - GCM_{baseline}}{GCM_{baseline}}\right) \qquad (7)$$

OBS_{past} is the observed past climatology precipitation.

$GCM_{baseline}$ is the future climatology precipitation of a GCM.

GCM_{future} is the future climatology precipitation of a GCM.

2.6.1 Model simulation

In simulating the impact of climate change, the ratio of mean of precipitation between future projection of GCM and its baseline applied to the observed data to get future precipitation. The Simple Delta Method (SDM) for downscaling the precipitation is expressed formally by Equation 8 [23]. Finally the impacts of climate change on the discharge of Ngerengere sub-basin simulated by using the climate change signals. The output of the model presented in the form of graphs based on the baseline and the near term (2010 – 2049) climatology using RCP 8.5 scenario.

$$PCP_{future} = OBS_{past}\; x \left(\frac{\overline{\mathrm{GCM}}_{\mathrm{future}}}{\overline{\mathrm{GCM}}_{\mathrm{baseline}}}\right) \qquad (8)$$

Where by:- $\mathrm{PCP}_{\,\mathrm{future}}$ is the projected future precipitation, $\mathrm{OBS}_{\,\mathrm{past}}$ is the observed past climatology precipitation, $\overline{\mathrm{GCM}}_{\,\mathrm{future}}$ is the mean of future climatology precipitation, $\overline{\mathrm{GCM}}_{\,\mathrm{baeline}}$ is the mean of baseline climatology precipitation.

2.6.2 Rainfall data and downstream flow data

Through the use of Ms excel, the observed time series rainfalls and downstream flows data in the 1970 - 1979 for Ngerengere sub-basin were

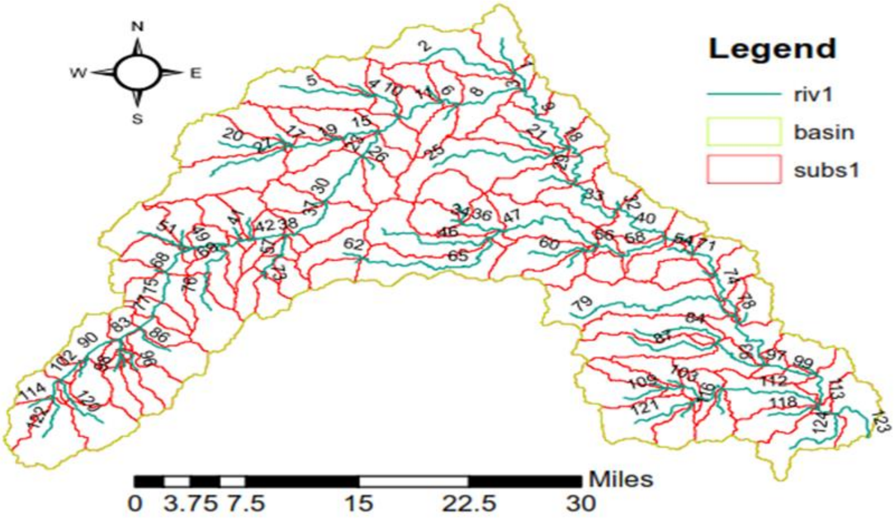


Fig. 2. Time series comparison of observed and simulated average daily flow for Ngerengere Sub-basins

aggregated into monthly (average daily values). The months with days missing flow data were excluded from the analysis. The sub-basin was divided into 124 smaller sub-basins out of which 29 were provided with the rainfall data Fig. 2.

The effects of the sub-basins contributing to the downstream flow was incorporated by multiplying the areal rainfall of each sub-basin by its corresponding sub-basin area (Equation 9).

$$Rainfall_i = \mathrm{C} * Rainfall_i * Area_i \tag{9}$$

Where by:-$Rainfall_i$ = Observed mean monthly precipitation for month i $(\mathrm{i} = 1, 2, 3 \ldots \mathrm{n})$,$Area_{\,i}$ = Area of the sub-basin within which a particular station is located = constant term will be encountered in the regression coefficients.The areal rainfall of the entire sub-basin was calculated using the arithmetic mean method, shown by Equation 4.3 (Yemen Water, 2013).

$$\overline{P} = \frac{P_1 + P_2 + \ldots.. + P_i + \ldots..P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i \tag{10}$$

Whereby:- $\overline{P}$ = Areal rainfall of the basin,P_1, P_2, …, P_n = Rainfalls of the sub-bains,N = Number of stations.

2.6.3 GCMs skills / performances

The skill score test was done by testing the baseline or control predictions of five (5) GCMs against the observed precipitation of the entire Ngerengere sub-basin. The GCMs scenario of RCP 8 used because has highest rising radioactive forcing pathways resulting to 8.5 W/m^2 and its control drivers are similar to A2 scenario [33].

3. RESULTS

3.1 Polynomial Regression Analysis

The 16th degree of the areal rainfalls were computed, using these results as independent variables and the observed monthly downstream flows as the dependent variables. Based on the findings from the Polynomial regression analysis, Polynomial regression model of Ngerengere sub-basin is shown by Equation 11 in Fig. 2 where x stands for the areal rainfall of the entire sub-basin and Q represents the downstream flow response of the sub-basin.

$$\begin{aligned} Flow, Q = {} & 5.422 - (1.079E-03)x - (4.64E-05)x^2 + (1.07E-07)x^3 - (1.064E-10)x^4 + \\ & (5.98E-14)x^5 - (2.11E-17)x^6 + (5.00E-21)x^7 - (8.26E-25)x^8 + (9.74E-29)x^9 - \\ & (8.31E-33)x^{10} + (5.31E-37)x^{11} - (2.27E-41)x^{12} + (6.97E-46)x^{13} - (1.42E-50)x^{14} + \\ & (1.70E-55)x^{15} - (9.13E-61)x^{16} + 1.80 \end{aligned} \tag{11}$$

Table 2 Ngerengere polynomial regression model.

3.1.1 Outputs of analysed polynomial regression model

Results for polynomial regression analysis from Ms excel are shown in Tables 1, 2 and 3. The value of R^2 is 85% and less close to 1 by 15% and the value of standard error is 1.80 then model is suitable and valid. Therefore the model used for climate change analysis and simulation of its impacts to ngerengere sub basin.

Table 1. Summary output

Regression statistics	
Multiple R	0.92239748
R square	0.85
Adjusted R square	0.81168717
Standard error	1.80385492
observation	78

3.2 Observed and Simulated Flow of Ngerengere Sub Basin

Observed and simulated monthly flow of Ngerengere sub Basin (average daily flow per month) for period of 9years are shown in Table 4 and Fig. 3.

3.3 Analysis of Climate change in Ngerengere Sub-basin

3.3.1 GCMs skills / performances

The GCMs were provided with climate data from four selected climatological zones of sub-basin numbered as 10489, 10515, 10514 and 10539, shown by Fig. 3. Precipitation was used in the selection of GCMs since it is the independent variable contributing greatly to the downstream flow. The skill scores were calculated using the skill score equation shown by Equation 4.5 (26) 1980 – 2009 was taken as baseline or control period. The observed and GCMs rainfall data in between these period were aggregated into the average mothly values and applied into the Equation 12.

$$SL_{score} = \sum_{n=1}^{12} Minimum\left(\frac{GCM_{JK}}{GCM_{MAPK}}, \frac{OBS_{JK}}{OBS_{MAPK}}\right) \qquad (12)$$

Where by:-SL_{score} = Season Skill Score,GCM_{JK} = Baseline mean monthly precipitation for month j and $GCM_{k,}$ OBS_{JK} = Observed mean monthly precipitation for month j, GCM_{NAPK} = Baseline mean annual precipitation for month j and $GCM_{K,}$ OBS_{MAPK} = Observed mean annual precipitation.

Table 2. ANOVA

	df	SS	MS	F	Significance F
Regression	16	1132009932	70.75062	21.7434	2.40772E-19
Residual	61	198.4874469	3.253893		
Total	77	1330.497379			

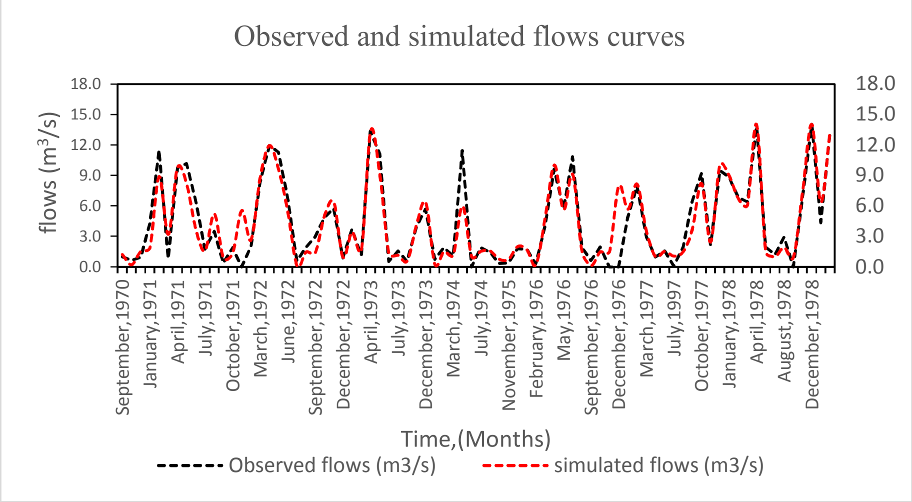


Fig. 3. Ngerengere outflow gauge - Observed and simulated flow curves, 1970 – 1979 (missing data skipped)

Table 3. Regression analysis output

	Coefficient	Standard error	t-stat	p-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	5.422E+00	188.8491	0.0287	0.9772	3.7221E+02	3.8305E+02	3.7221E+02	3.8305E+02
x	-1.079E-03	0.0199	-0.0541	0.9570	-4.0932E-02	3.8775E-02	-4.0932E-02	3.8775E-02
X^2	-4.644E-05	0.0001	-0.7241	0.4718	-1.7469E-04	8.1809E-05	-1.7469E-04	8.1809E-05
X^3	1.066E-07	0.0000	1.1646	0.2487	-76459E-08	2.8972E-07	-76459E-08	2.8972E-07
X^4	-1.064E-10	0.0000	-4512	0.1519	-2.5305E-10	4.0220E-11	-2.5305E-10	4.0220E-11
X^5	5.981E-14	0.0000	1.6211	0.1101	-1.3964E-14	1.3358E-13	-1.3964E-14	1.3358E-13
X^6	-2.113E-17	0.0000	-1.6947	0.0952	-4.6061E-17	3.8017E-18	-4.6061E-17	3.8017E-18
X^7	5.002E-27	0.0000	1.6936	0.0954	-9.0396E-22	1.0908E-20	-9.0396E-22	1.0908E-20
X^8	-8.259E-25	0.0000	-1.6386	0.1064	-1.8337E-24	1.8194E-25	-1.8337E-24	1.8194E-25
X^9	9.743E-29	0.0000	1.5477	0.1269	-2.8452E-29	2.2332E-28	-2.8452E-29	2.2332E-28
X^{10}	-8.312E-33	0.0000	-1.4345	0.1565	-1.9898E-32	3.2746E-33	-1.9898E-32	3.2746E-33
X^{11}	5.131E-37	0.0000	1.3092	0.1954	-2.7058E-37	1.2968E-36	-2.7058E-37	1.2968E-36
X^{12}	-2.267E-41	0.0000	-1.1792	0.2429	-6.1105E-41	1.5771E-41	-6.1105E-41	1.5771E-41
X^{13}	6.973E-46	0.0000	1.0494	0.2982	-6.31**47E-46**	2.0261E-45	-6.31**47E-46**	2.0261E-45
X^{14}	-1.46E-50	0.0000	-0.9230	0.3596	-4.4830E-50	1.6514E-50	-4.4830E-50	1.6514E-50
X^{15}	1.701E-55	0.0000	0.8.022	0.4255	-2.5390E-55	5.9412E-55	-2.5390E-55	5.9412E-55
X^{16}	-9.133E-61	0.0000	-0.6883	0.4939	-3.5666E-60	1.7400E-60	-3.5666E-60	1.7400E-60

Table 4. Observed and simulated flows of Ngerengere subbasin (1970 – 1979) (missing data skipped)

Month	Observed flow (m^3/s)	Simulated flow (m^3/s)
September,1970	0.99	1.22
October,1970	0.65	0.21
November,1970	0.93	1.52
January,1971	4.21	1.90
February,1971	11.51	8.87
March,1971	0.78	3.20
April,1971	9.75	9.77
May,1971	10.16	8.15
June,1971	6.43	3.68
July,1971	1.73	1.58
August,1971	3.49	5.23
September,1971	0.36	0.85
October,1971	1.90	1.36
December,1971	0.00	5.54
February,1972	2.02	2.64
March,1972	8.33	8.80
April,1972	11.95	11.93
May,1972	11.30	9.55
June,1972	6.74	5.42
July,1972	0.60	0.12
August,1972	1.94	1.47
September,1972	2.97	1.42
October,1972	4.88	5.06
November,1972	5.73	6.37
December,1972	0.87	0.96
February,1973	3.72	3.45
March,1973	1.11	1.61
April,1973	13.32	13.32
May,1973	11.13	9.13
June,1973	0.51	1.27
July,1973	1.57	1.15
October,1973	0.54	0.59
November,1973	3.96	4.13
December,1973	5.70	6.34
January,1974	0.72	0.26
February,1974	1.89	1.54
March,1974	1.08	1.16
May,1974	11.45	5.99
June,1974	0.00	1.01
July,1974	1.89	1.54
September,1975	1.45	1.57
October,1975	0.35	0.76
November,1975	0.38	0.74
December,1975	1.75	2.00
January,1976	1.73	1.69
February,1976	0.29	0.22
March,1976	4.04	4.86
April,1976	9.62	10.00
May,1976	5.69	5.61
June,1976	10.84	9.06
July,1976	1.90	1.53
September,1976	0.61	0.13
October,1976	1.94	1.49

Month	Observed flow (m^3/s)	Simulated flow (m^3/s)
November,1976	0.00	1.51
December,1976	0.00	7.95
January,1977	4.85	5.67
February,1977	7.96	8.12
March,1977	2.94	3.56
April,1977	0.96	1.01
May,1977	1.56	1.53
July,1997	0.09	1.06
August,1977	1.94	1.48
September,1977	6.42	3.68
October,1977	9.20	8.21
November,1977	2.08	2.45
December,1977	9.48	10.02
January,1978	8.84	8.98
February,1978	6.83	6.72
March,1978	6.39	6.08
April,1978	13.87	13.98
June,1978	1.94	1.47
July,1978	1.19	1.01
August,1978	2.92	1.92
October,1978	0.00	0.93
November,1978	6.75	7.39
December,1978	14.03	14.01
January,1979	4.36	6.35
February,1979	13.43	13.42

3.3.1.1 SVC$_s$ for each GCM

The Figs. 4 to 8 graph present the seasonal variability curves (SVCs) which are the ratios of $\frac{GCM_{JK}}{GCM_{MAPK}}\ and\ \frac{OBS_{JK}}{OBS_{MAPK}}$ for each of the GCM.

The Figs. 4 to 8 shows the computed cumulative sum of minimum values of either $\frac{GCM_{JK}}{GCM_{MAPK}}\ or\ \frac{OBS_{JK}}{OBS_{MAPK}}$ for each GCM to determine their skill scores. SVCs for each GCM show that, there is adequate overlapping between the two curves, this implies that the skill scores of all the GCMs used in this study are observed to be close to 1 and hence, the performances of all GCMs are termed to be good.

3.3.2 Skill score of GCMs for observed data

Fig. 9 shows the scores of the five GCMs were all are above the threshold value of 80%. The highest skill score was 92% as shown by a GCM named NorESM1-M and IPSL-CM5A had the lowest skill score of 90% while the rest GFDL-ESM2M, Had GEM2-ES and MIROC-ESM-CHEM had an average skill score of 91%. Since all the GCMs have nearly equal performances, hence all the GCMs used for climate change analysis and simulation of climate change impacts in the Ngerengere sub-basin.

3.4 Precipitation Responses

The average measured areal precipitation (1980 – 2009) in Ngerengere sub-basin is very heavy from November to May, but decreases from June to August and then start to rise again from September towards November (Fig. 10 to Fig. 14). For Ngerengere sub-basin 161 mm/month during heaviest rainfall (November-May) for the entire sub-basin. Also, in Fig. 10 to Fig. 14, small amounts of rainfalls are experienced in June, July, August and September with 32.35 mm/month in average.

In Fig. 10, the MIROC-ESM-CHEM scenario (2009 – 2049) at Ngerengere sub-basin shows that, the maximum average projected precipitation occurs in April with a magnitude of about 202.6 mm/month. Furthermore, an average decrease in precipitation is projected (2010 – 2049) from February to August, October and November by a magnitude of 28%. However the average projected precipitation is observed to increase significantly by 46% in September and slight average increase in projected precipitation is observed in January and December by 4.2% and 3.2% respectively.

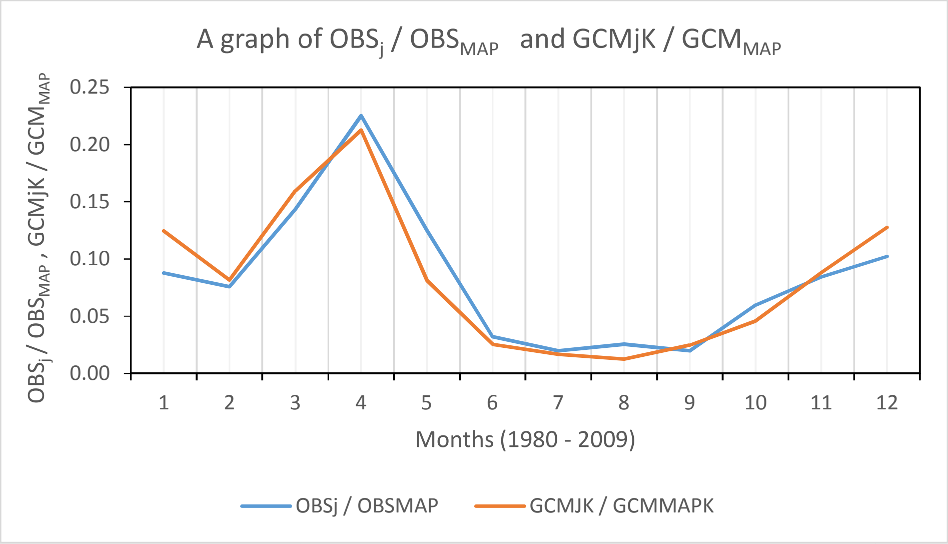


Fig. 4. A graph GCMJK /GCMMAP and OBSj /OBSMAP for GFDL-ESM

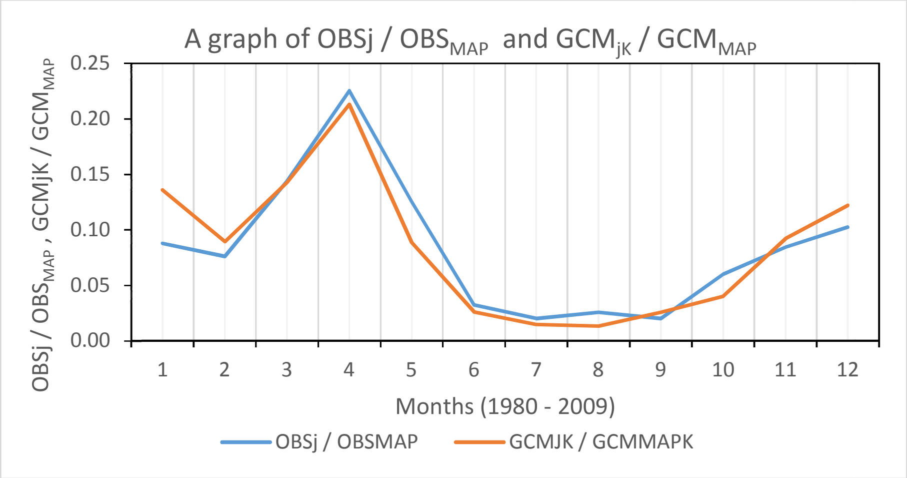


Fig. 5. A graph of GCMJK /GCMMAP and OBSj /OBSMAP for Had GEM2-ES

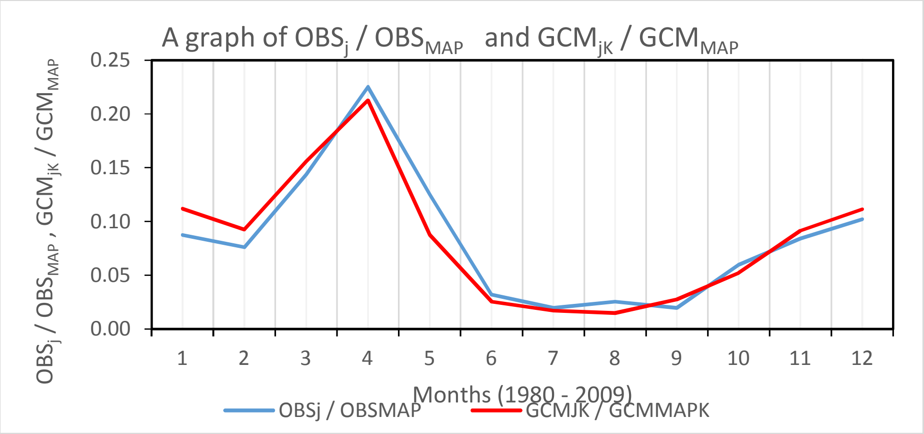


Fig. 6. A graph of GCMJK /GCMMAP and OBSj /OBSMAP forIPSL-CM5A-LR

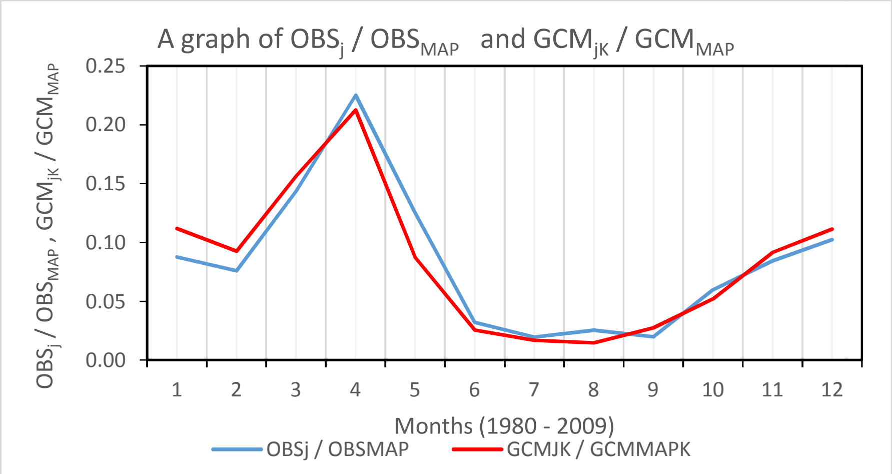


Fig. 7. A graph of GCMJK /GCMMAP and OBSj /OBSMAP for Nor ESM1-M

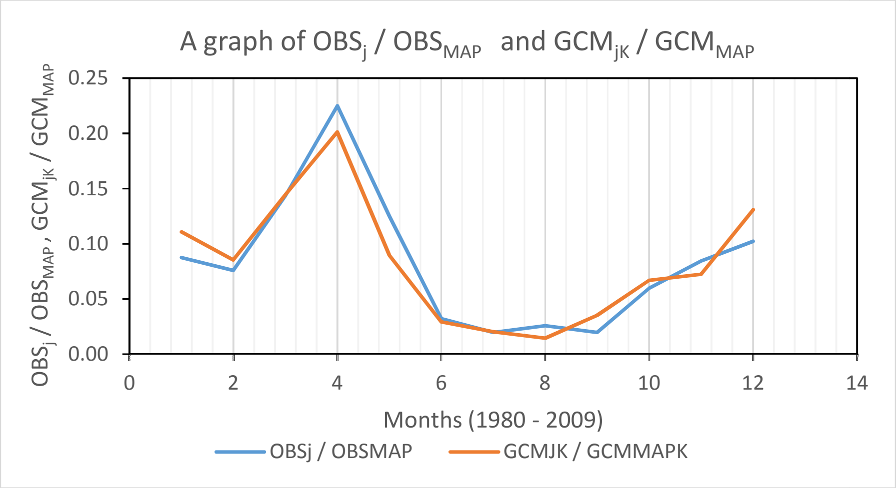


Fig. 8. A graph of GCMJK /GCMMAP and OBSj /OBSMAP for MIROC-ESM-CHEM

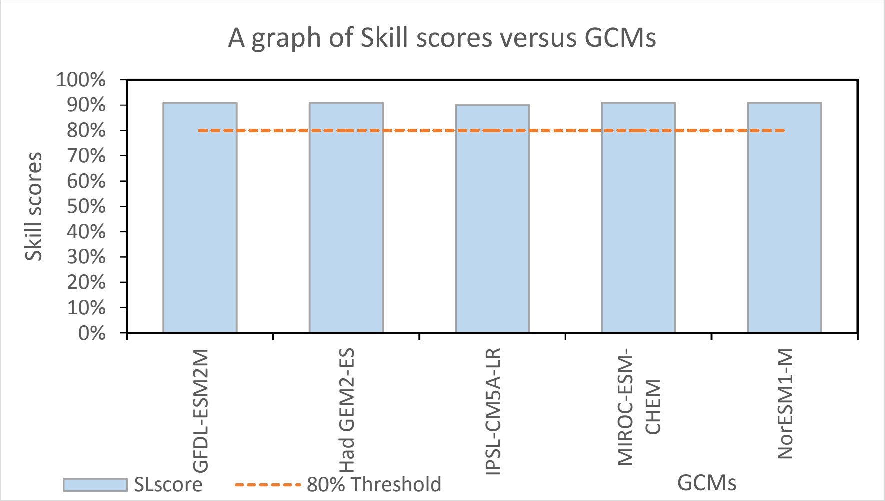


Fig. 9. Skill Scores of GCMs against observed data

In Fig. 11, the Had GEM2-ES average projected precipitation is maximum in April with a magnitude of 193.8 mm/month. More over, an average decrease (-30%) in precipitation is projected (2010 – 2049) from February to December while August is projected to have severe average decrease in precipitation by 65%. However, January is projected to have slightly average increase in precipitation and It is estimated to be around 109%.

In Fig. 12, the GFDL-ESM-ES scenario (2010 – 2049) shows that, the maximum average projected precipitation occurs in April with a magnitude of 240.9 mm/month. Continuous average decrease in precipitation is projected from April to August and from October to November by 31% and 26% respectively while severe decrease in precipitation is projected in August by 64%. Average increase in precipitation is projected from December to March by a magnitude of 6.8% while highest average increase in precipitation is projected in June and it is estimated to be around 122%.

In Fig. 13, the IPSL-CM5A-LR average projected (2010 – 2049) precipitation is maximum in April with a magnitude of 254 mm/month and minimum average projected precipitation is observed in July by 16 mm/month. The average increase in precipitation is projected (2010-2049) from April to December by the magnitude of 27.4% while great decrease in precipitation are projected in April and November by 53% and 51% respectively. IPSL-CM5A-LR also projects (2010 – 2049) an average increase in precipitation from January to March and it is estimated to be around 116% whereby maximum increase (+29%) in precipitation is expected in January.

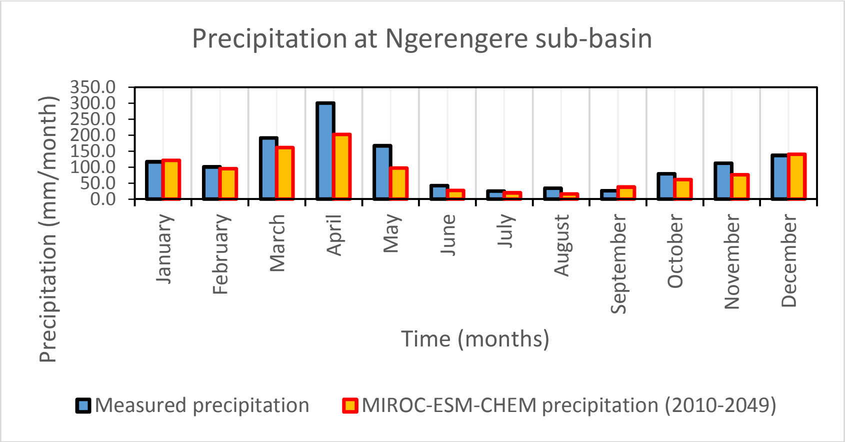


Fig. 10. Precipitation response at Ngerengere sub-basin using MIROC-ESM-CHEM

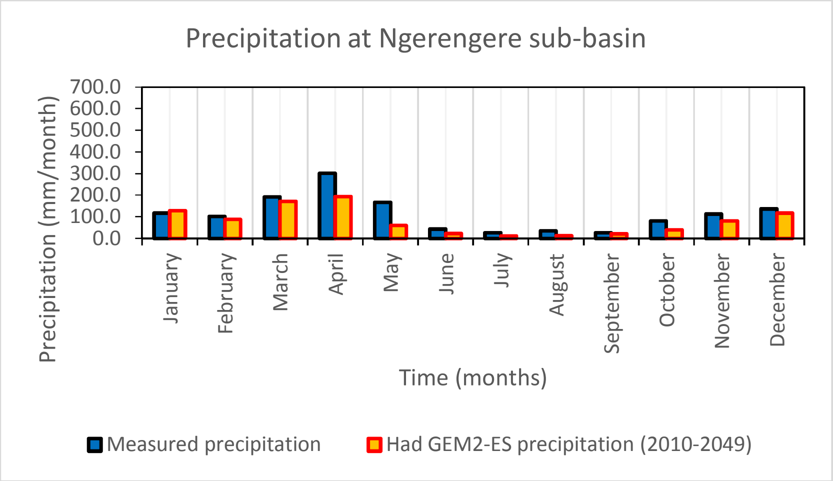


Fig. 11. Precipitation response at Ngerengere sub-basin using Had GEM2-ES

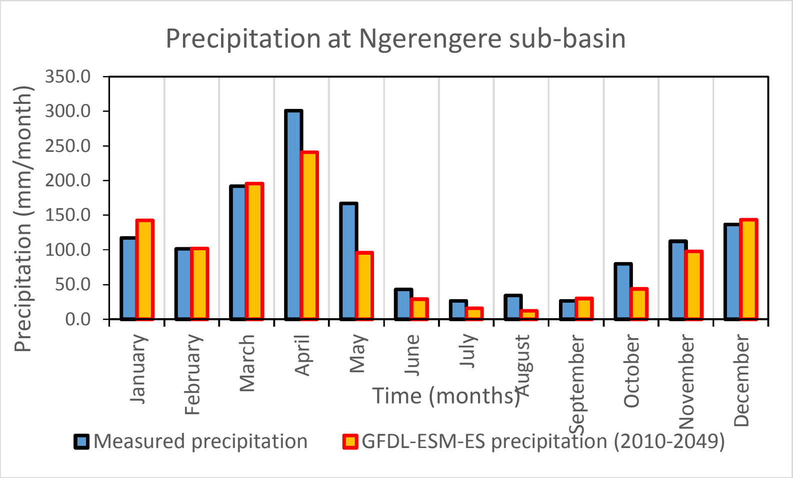


Fig. 12. Precipitation response at Ngerengere sub-basin using GFDL-ESM-ES

In Fig. 14 the Nor ESM1-M (2010 – 2049) scenario shows that, the maximum average projected precipitation occurs in April and it is estimated to be 209 mm/month. More over, average decrease in precipitation in Ngerengere sub-basin is projected from February to August and from October to december by magnitudes of 25.3% and 21.3% respectively. However, very slight increase (+1.5%) in precipitation is projected in January and very slight decrease (-2.5%) in precipitation is projected in February while August is projected to have great decrease in precipitation by 54%.

3.5 Simulation of Climate Change Impacts (2010 – 2049)

3.5.1 Stream flow responses

The downstream of the sub-basin shown in Figs. 15 to 19, the average baseline flow (1980 – 2009) and the projected flow patterns from all the GCMs (MIROC-ESM-CHEM, Had GEM2-ES, GFDL-ESM, IPSL-CM5A-LR and Nor ESM1-M) are more or less the same. The maximum average baseline flow (321 m^3/s) occurs at March and minimum average baseline flow (66 m^3/s) occurs in July. However, there are slight differences in projected stream flow (2010 – 2049) from each type of GCMs.

3.5.1.1 Results of stimulates flow (2010-2049)

The results of simulated flows by MIROC-ESM-CHEM indicated In Fig. 15, the maximum average projected flow (2010 – 2049) occurs in March and the minimum average projected projected flow occurs in July. MIROC-ESM-CHEM projects high decrease (-86.3 m^3/s) in flow from March to May and average decrease (-21.5 m^3/s) in flow from October to January in the downstream of Ngerengere sub-basin. The highest average decrease in flow (-117 m^3/s) occurs in May and slight average decrease in flow (-1.2 %, -6 %) is projected in June and July respectively. However, MIROC-ESM-CHEM projects slight increase in flow (+23%) in May and August.

The results of simulated flows by Had GEM2-ES indicated In Fig. 16, maximum average projected flow (253 m^3/s) occurs in April and minimum average projected flow (59 m^3/s) occurs in July. High decrease (-86.3 m^3/s) in flow in projected in from March to May and decrease (-38 m^3/s) in flow in between September to February, slight decrease (-11%) in flow is projected in July. However high increase (+63%) in flow is projected in June and increase in flow (+62%) is being projected in June by Had GEM2-ES.

The results of simulated flows by GFDL-ESM-ES indicated In Fig. 17, the maximum average GFDL-ESM-ES projected flow (266 m^3/s) occurs in March and minimum average projected flow (41 m^3/s) occurs July. GFDL-ESM-ES also projects high decrease (-88.6 m^3/s) in flow from March to May. July, October, December and January are projected to have flow decrease (-38%, -30%, -15% and -12%) respectively. However average increase in flows are projected in February (+35%), June (+16%), August (+32%), and November (+22%).

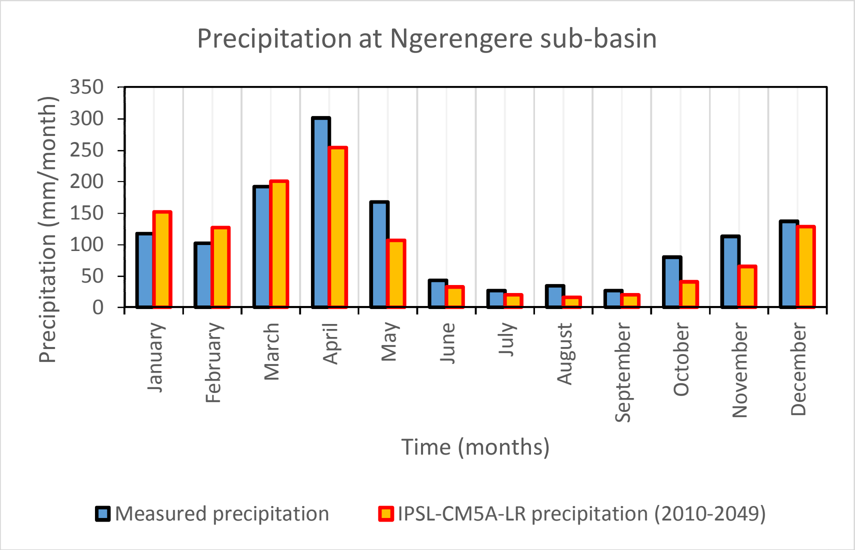


Fig. 13. Precipitation response at Ngerengere sub-basin using IPSL-CM5A-LR

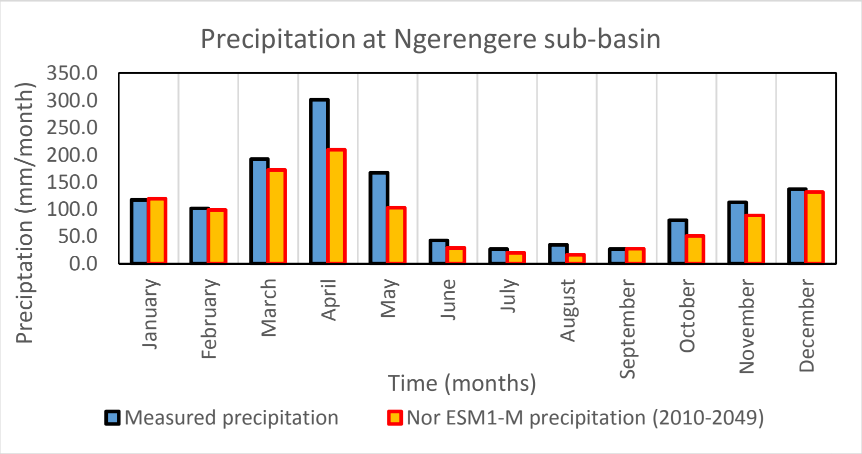


Fig. 14. Flow response at Ngerengere sub-basin using Nor ESM1-M

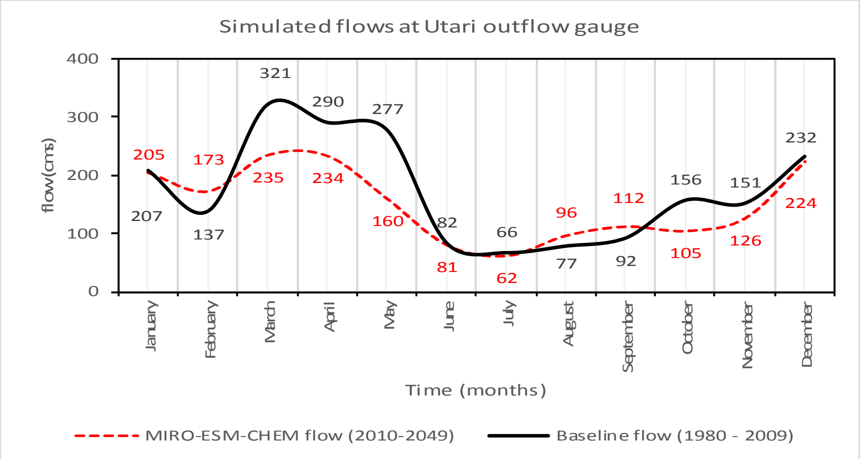


Fig. 15. Simulated flows (2010 – 2049) at Ngerengere subbasin, using MIROC-ESM-CHEM

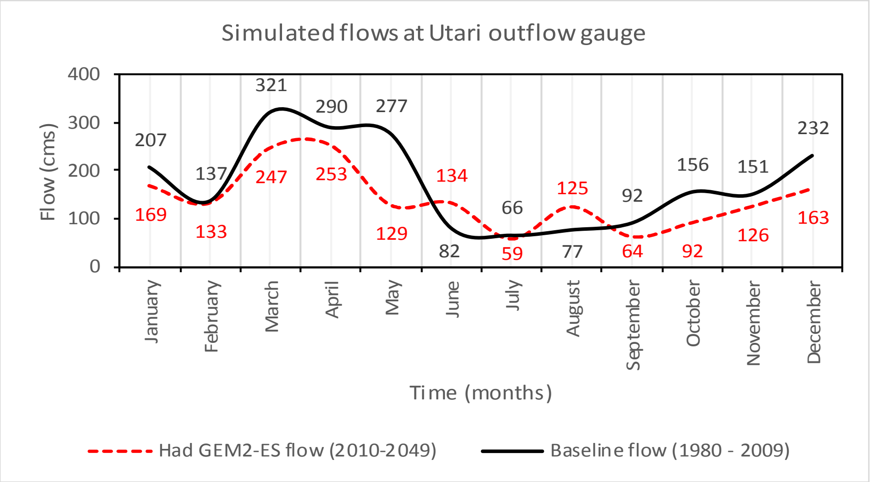


Fig. 16. Simulated flows (2010 – 2049) at Ngerengere sub-basin, using Had GEM2-ES

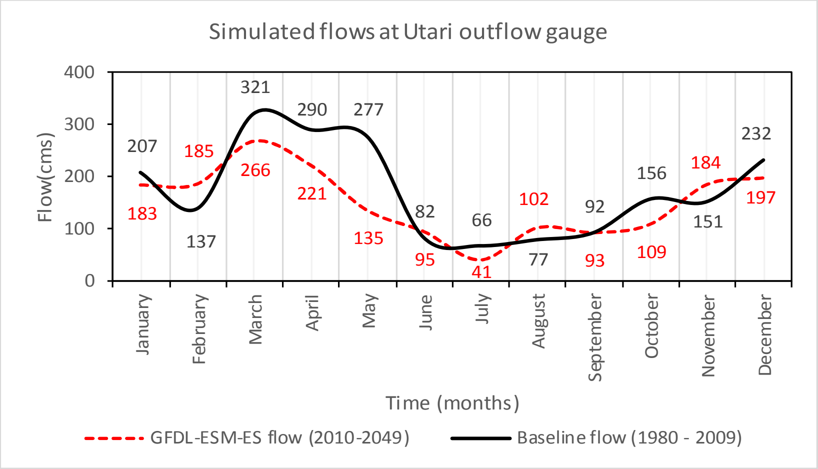


Fig. 17. Simulated flows (2010 – 2049) at Ngerengere sub-basin, using GFDL-ESM-ES

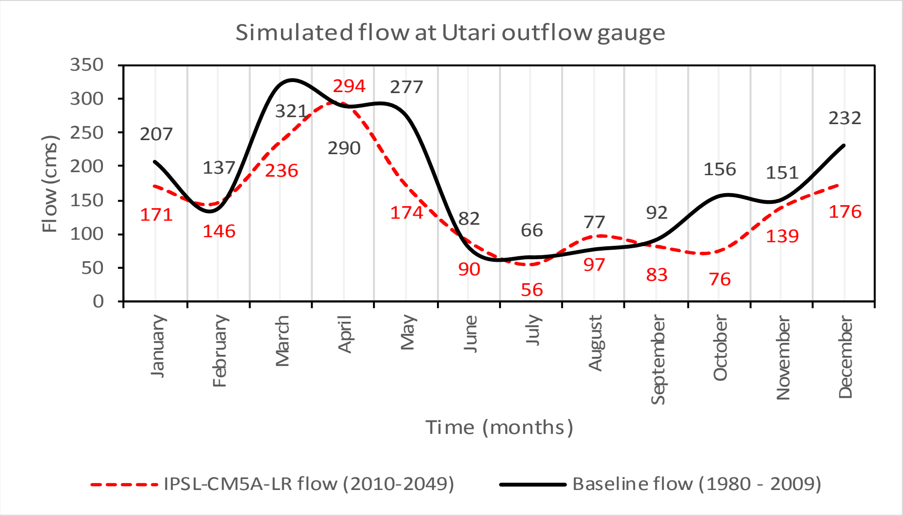


Fig. 18. Simulated flows (2010 – 2049) at Ngerengere subbasin, using IPSL-CM5A-LR

The results of simulated flows by IPSL-CM5A-LR in Fig. 18, flow projection show that, maximum average projected flow occurs in April and minimum projected flow occurs in July. Average decrease (-26%) in flow is projected from September to January. March, May and July are also projected to have decrease in flow (-85 m^3/s, -103 m^3/s and -10 m^3/s) respectively. However, slight increase (+26%) in flow is projected in August. More over, unique projection is shown by IPSL-CM5A-LR in April by having a slight increase in flow by +1.4% while all other GCMs show decrease in flow in this month.

In Fig. 19, Maximum average projected flow (156 m^3/s) occurs in March and Minimum average projected flow (48 m^3/s) occurs in July. Nor ESM1-M flow projection also show high average decrease (-151.3 m^3/s) and average decrease (-18%) in flow from December to Februay. June is also projected to have average decrease in flow by 27%. However, slight increase (+17%, +10.4%, +14% and +15%) in flow are projected in June, August, September and November respectively.

3.6 Summary of Stream Flow of Ngerengere sub Basin

Summarry base on baseline and average annual stream flow of ngerengere river indicated in graph (Fig. 20).

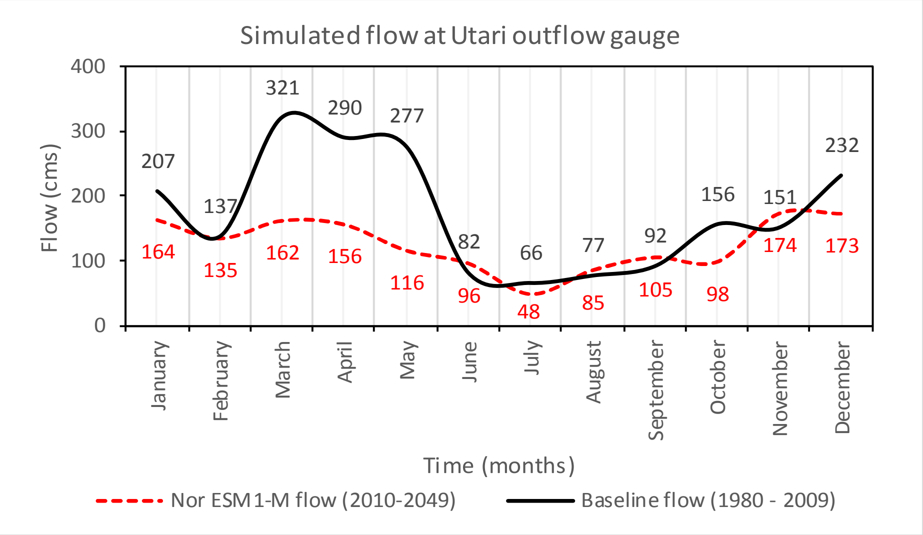


Fig. 19. Simulated flows (2010 – 2049) at Ngerengere subbasin, using Nor ESM1-M

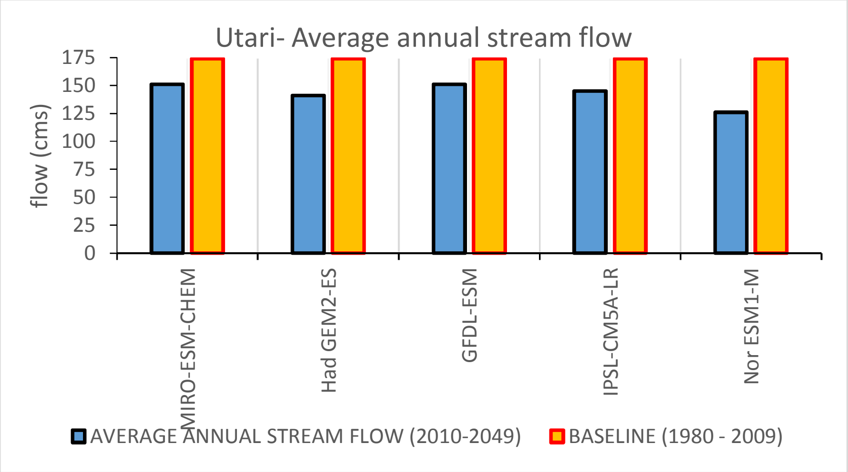


Fig. 20. Average annual stream flow Ngerengere river sub-basin

In Fig. 20, the average annual baseline downstream flow of Ngerengere sub-basin is 174 m^3/s and the average annual projected (2010 – 2049) downstream flow is 141 m^3/s for Had GEM2-ES, 151 m^3/s for GFDL-ESM and MIROC-ESM-CHEM, 145 m^3/s for IPSL-CM5A-LR and 126 m^3/s for Nor ESM1-M . The average annual downstream flow of the sub-basin is projected (2010 – 2049) to decrease by 19% for Had GEM2-ES, 13% for GFDL-ESM and MIROC-ESM-CHEM, 16% for IPSL-CM5A-LR and 28% for Nor ESM1-M. Generally, the Nor ESM1-M climate model of RCP 8.5 scenario projects (2010 – 2049) high decrease in flow in Ngerengere river sub-basin as compared to other GCMs. The average annual flow decrease projected by Nor ESM1-M is almost twice to the average annual flow decrease projected by GFDL-ESM and MIROC-ESM-CHEM. The projected annual average decrease in downstream flow of Ngerengere sub-basin is estimated to be around 18% in magnitude, computed as the average of the outputs of all 5 GCMs.

4. DISCUSSION AND CONCLUSION

GCMs of RCP 8.5 scenario were used for analysing the precipiation change patterns of the Ngerengere sub-basin against the observed precipitation data. Simulation of climate change impacts was done using the climate change signals of the sub-basin. Analysis of climate change impacts to water resources is very much crucial for their long term management. Polynomial regression model for Ngerengere sub-basin captures well both low and peak flows with a performance of 85%. Nevertheless, flows in very few months were not well captured and this may have resulted due to the errors in recording flow measurements some months. The model provides good working tool in simulating climate change impacts on of Ngerengere river sub-basin.Value of R square or coefficient of multiple determination is 0.85 which signifies good fitness of polynomial regression and the value of standard error is 1,also the skill scores of all the GCMs used in this study are observed to be close to 1 and hence, the performances of all GCMs are termed to be good.All GCMs project (2010 – 2049) decrease in average precipitation in Ngerengere sub-basin in January, April, May, June, July, August, October and November while August is projected to suffer more average decrease in precipitation. Further more, unsimillar projection in average precipitation is shown in February, March, September and December.In General Circulation Models have shown that, projection (2010 – 2049) of stream flow in Ngerengere sub-basin is highly dependent upon the projected changes in precipitation because the patterns drawn by the precipiation changes are similar with those of stream flows. The projected (2010 – 2049) average annual decrease in stream flow of Ngerengere sub-basin is estimated to be around 18%,taken as the average of the outputs of all 5 GCMs.The average annual baseline downstream flow of Ngerengere sub-basin is 174 m^3/s and the average annual projected (2010 – 2049) downstream flow is 141 m^3/s for Had GEM2-ES, 151 m^3/s for GFDL-ESM and MIROC-ESM-CHEM, 145 m^3/s for IPSL-CM5A-LR and 126 m^3/s for Nor ESM1-M . The average annual downstream flow of the sub-basin is projected (2010 – 2049) to decrease by 19% for Had GEM2-ES, 13% for GFDL-ESM and MIROC-ESM-CHEM, 16% for IPSL-CM5A-LR and 28% for Nor ESM1-M. Generally, the Nor ESM1-M climate model of RCP 8.5 scenario projects (2010 – 2049) high decrease in flow in Ngerengere river sub-basin as compared to other GCMs. The average annual flow decrease projected by Nor ESM1-M is almost twice to the average annual flow decrease projected by GFDL-ESM and MIROC-ESM-CHEM. The projected annual average decrease in downstream flow of Ngerengere sub-basin is estimated to be around 18% in magnitude, computed as the average of the outputs of all 5 GCM .Further studies cover the impacts of land use/ cover changes, water balance in Ngerengere river and other tributaries of Ruvu – river should be conducted for management and planning of the Wami- Ruvu basin sustainability.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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