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Hydropower Potential in near Future Climate over Burundi (East Africa) : A Case study of Rwegura Catchment

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Authors' contributions

This work was carried out in collaboration among all authors. Authors CM and LAE designed the study and developed the methodology. Authors CM and MN performed the field work and computer analysis. Authors LAE, LB and MN contributed to results analysis and interpretation. All the authors wrote the original manuscript. Overall the authors contributed equally to this paper.

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ABSTRACT

This paper assessed the near future projected hydropower potential over Rwegura catchment hosting, up to date, the biggest hydropower plant of Burundi. Observed and gridded data were considered over the period $1981 - 2010$ while simulations from eight selected Regional Climate Models (RCM) provided by Africa$-$CORDEX program were used over a period spanning from 1981 to mid-21^{st} century. Two emission scenarios RCP 4.5 and RCP 8.5 were considered, and RCM data were downscaled at local climate using Empirical Statistical Downscaling method and bias adjusted using Quantile Delta Mapping method. Trends were detected through Mann-Kendall's test

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while Pettitt's test was adopted for break point detection. Regression based statistical model was utilized for streamflow prediction. The findings revealed a decrease in rainfall over the northern highlands while a general increase in temperature was detected all over the study area. At Rwegura catchment, $22.8\ m^3/s$ was estimated as low flow in the 90^{th} percentile over the current period. Furthermore, the projected changes in hydropower potential showed that decreases of 11% and 16% are expected by 2050 over Rwegura catchment respectively under RCP 4.5 and RCP 8.5. The projected decrease detected in hydropower potential may affect negatively the lifestyle of the population. Therefore, all policymakers in the energy sector of Burundi can plan alternative solutions to alleviate inconveniences of the projected decrease in hydropower energy.

Keywords: Burundi; hydropower; climate change; rwegura; trends.

1 INTRODUCTION

Future climate will influence the world through changing temperature, precipitation, snowmelt, and a host of other natural phenomena [1]. Indeed, global mean surface air temperature is projected to rise by $1.8 - 4.0$ °C in the twenty-first century [2] while global extreme precipitation is projected to increase significantly, especially in regions that are already wet under the current climate conditions, whereas dry spells are predicted to increase particularly in regions characterized by dry weather conditions in the current climate [3]. Hydropower is a dominant renewable source of energy production and has received significant worldwide attention for further development [4], but it is sensitive to climate change due to its dependence on hydrological conditions like river flow and reservoir storage. In fact, the Intergovernmental Panel on Climate Change (IPCC) has observed that climate variable changes associated with global warming are affecting regional or catchment scale hydrological processes [3]. Numerous studies showed that effects of climate change on hydropower generation have varying degrees in various regions of the world. For instance, Shamin et al. [5] observed that since 1970 the annual energy production of some European hydropower stations has decreased. Hamududu and Killingtveit [4] explained that these reductions are generally attributed to the decrease in average flow due to climatic variability. Across Africa, decrease in perennial river flows will significantly affect present surface water supplies in large parts of the continent by the end of the century [6]. However, a study made in southern Africa, in Angola over Kwanza River Basin [7], showed increasing trends in rainfall and consequently the increase of water resources would lead to the increase of hydropower potential in the basin.

In eastern Africa region, dry periods are generally associated with La Niña and/or negative Indian Ocean Dipole (IOD) events, while wet periods coincide with El Niño and/or positive IOD events [8]. This region is highly dependent on hydropower for electricity production [4], but it has not been extensively evaluated as far as the climate change effects on water resources and hydropower are concerned.

The climate of Burundi, as an East African country, is mainly influenced by the North-South movement of the Intertropical Convergence Zone (ITCZ), the topography of the country and El−Niño southern oscillation (ENSO) [9]. However, Burundi has gone through many periods of climatological disasters including droughts and floods [10, 9]. The current crucial challenge is that since 2002, Burundi is characterized by a chronic shortage of energy in general and electrical energy in particular. Therefore, since 2006, the electricity grid deficit is manifested by load shedding, and this electricity deficit is estimated at about $25\ MW$ in the dry season [11]. Burundi is then faced with a range of problems in the energy sector. Democratic Republic of the Congo (DRC) has been the major source of electric energy for Burundi since 1958 when Rusizi hydroelectric generation plant was constructed on Rusizi River on the border between Rwanda and DRC at the outlet of Lake Kivu. In order to have a secure source of energy within the country, Burundi constructed Rwegura hydropower plant on Kitenge River located in the northern highlands in September 1986. Kitenge River was believed to have sufficient water for both irrigation and future power projects downstream contradictorily to the current situation [12]. In fact, Rwegura hydropower plant is actually facing many problems due to the decrease of rainfall [13] which has resulted in a reduction of water level in the reservoir, creating the decrease in generated power, and this has become an issue of concern. Consequently, there is a fundamental need to assess the Hydropower potential in the future climate scenarios, which has been less investigated, since concerning the projected hydropower change and trends. Furthermore, impacts of climate change are mostly depending on the spatial scale considered and vary from a region to another, from country to country and even from one local area to another within the same country. This reflects the need to continue to carry out similar studies at lower scales. Therefore, this explains why the present study is oriented towards Rwegura catchment of Burundi.

Specifically, the study analyzes spatial and temporal trends of rainfall and temperature over the baseline period $(1981 - 2010)$ and determines projected changes in streamflows and hydropower potential at Rwegura catchment under two climate scenarios over the near future period $(2021 - 2050)$.

2 METHODS AND MATERIALS

2.1 Methods

2.1.1 Trend analysis and change-point detection

The Mann-Kendall's (MK) non-parametric test (1945)[14, 15] was used. Whenever MK's trend was not significant at the chosen threshold of 0.05, the Theil-Sen median slope trend analysis, which is a linear trend calculation that is resistant to the impact of outliers (noise) [16, 17] was adopted for trend estimate. Furthermore, the Pettitt's test (1979) [18] has been used for break point detection. These tests are worldwide used in hydro meteorological variables trend detection [19, 13]. The package 'Trend' [20] in R program has been used for the computation.

2.1.2 Multiple-Linear Regression (MLR) Model

Simple Linear Regression establishes the relation between response variable or dependent variable and explanatory variable or independent variable, in order to minimize the square residual [21]. The Multiple linear Regression (MLR) Model used in this study is an extended form of a simple regression in which two or more independent variables are used and can be expressed as:

$$Y = \alpha + \sum_{i=1}^{p} \lambda_i X_i \tag{2.1}$$

where Y is a dependent variable; α is a constant or intercept; λ_i is a slope coefficient for X_i; and X_i is the i^{th} independent variable that explains the variance in Y.

In this paper, rainfall, temperature and catchment physical characteristics derived from the Digital Elevation Model (DEM) provided by Shuttle Radar Topography Mission $(SRTM)$ at various time step recorded at Rwegura catchment shall be considered as independent variables for estimation of the monthly stream flow (Q) being dependent variable. Regression based statistical model is one of the effective and simplest statistical tool for stream-flow prediction derived from concurrent limited data of the drainage basin if it is gauged [21]. Often, records are not available at the site, and the relation must be derived from a gauged basin of similar size in the region and transferred to the site [22]. Indeed, Joel *et al.* [12] developed a Multiple regression equation to find relationship between mean monthly flow (index flow) for the gauged sites and catchment characteristics such as catchment area, mean catchment slope, mean elevation of the catchment, station elevation, stream length, stream slope and mean annual precipitation. The derived regression equation was then used to find the index flow at Rwegura ungauged site and thereafter the flow duration curve was found as a product of dimensionless regional flow duration curve and index flow.

2.1.3 Design flow

The discharges of the Rwegura catchment were used to generate the Flow Duration Curves (FDC) of the site. The discharges were arranged from maximum to minimum and ranked from $\lambda = 1$ to N. The percentage of the time (P) flow equals or exceeds a given value was estimated using equation (2.2) [22]:

$$P = \frac{\lambda}{N+1} 100\% \tag{2.2}$$

The FDC are constructed with P in the abscissa and Q on the ordinate. The FDC were used for the selection of design flows [21]. In hydropower design practices, the design flow is selected base on the potential power generation classified as minimum, small, median or mean potential power with the exceedence probability corresponding to 100%, 95%, 50% on the FDC and the arithmetic mean of the mean annual discharges of the site for a period of 10 to 30 years for the mean potential power generation respectively [23]. However, in selecting the design discharge it is important to take into consideration residual flow, which is the minimum flow that must be maintained in the river to sustain the ecology and the requirements of downstream consumers.

According to the World Meteorological Organization, low flow percentiles from the FDC are often used as key indices of low flow, the flow that is exceeded for 95% of the period of record is commonly used to characterize the low flow.

In this study, since the river is not perennial [12], instead of 95% which is specific for perennial rivers, the design flow with 90% exceedence probability was selected as indicators of low flow characteristics at Rwegura catchment. Any flow above this value could be used for hydropower generation [24].

2.1.4 Hydropower potential estimation

The theoretical hydropower potential of Rwegura catchment was estimated using equation (2.3) [25]:

$$P_T = \frac{\rho g H Q}{1000} \ [kW] \tag{2.3}$$

where P_T is the theoretical hydropower potential, ρ is the density of water ($\rho = 1000 \ kg.m^{-3}$), g is the gravitational acceleration $[m.s^{-2}]$, Q is the turbinable flow $[m^3.s^{-1}]$ and H is the net available head $[m]$.

A similar methodology to estimate hydropower potential was also adopted by Hamududu and Killingtveit [4] in 2012 while assessing climate change impacts on global hydropower, and by Umaru [26] in 2013 while estimating hydropower potential of an ungauged stream.

In brief, the methodology has been worldwide used to estimate the theoretical hydropower potential of a given site which is very important in our study.

2.2 Study Area

The Fig. 1 locates the study area in Burundi, an East African country between longitudes $28.8°$ and $30.9°$ East and latitudes $2.3°$ and $4.45°$ South [27]. Bounded to the North by Rwanda, to the East and South by Tanzania and to the West by the Democratic Republic of Congo (DRC), Burundi covers an area of $27834 \ km^2$. The annual rainfall in the high altitude regions is almost the double that of low altitudes. Average maximum annual temperatures range from 21.8 to $29.5°$C.

The considered study region is the highlands hosting the Rwegura catchment.

The elevation of the considered highlands is between 1800 and $2650 \ m$ altitude. For better analysis, the highlands were split into Northern Highlands (NHL) and Southern Highlands (SHL) like in Manirakiza *et al.* [28].

Indeed, up to date, the Burundi biggest hydropower plant is constructed at Rwegura catchment on Kitenge River. The delineated catchment area considered in this study is $232 \ km^2$ [12].

2.3 Data Source

Three sets of data are used in this study. The first set consists of observed data collected from the synoptic stations of Burundi belonging to the Geographical Institute of Burundi (IGEBU). The fig. 1 shows the spatial distribution of the fourteen meteorological stations considered. However, three stations with an elevation inferior to $1800 \ m$ were excluded in order to have reliable results. Indeed, Lawin et al. [13] showed that the climatological characteristics of the considered highlands are different from those of lowlands where these three excluded stations are located. In fact, the Table 1 gives the names of the used stations and their geographical characteristics. Rainfall and temperature observed data were collected at daily scale. The selection of the time series data was based on the quality of the data collected from various stations. However, six climate stations for rainfall and temperature had shorter period than the normal of 30 years considered and recommended by World Meteorology Organization (WMO).

To complement observed values at monthly scale, the second set of data grouping gridded monthly precipitation from Global Precipitation and Climate Centre (GPCC V7) downloaded from https://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html and temperature data from Climate Research Unit (CRU TS 4.01) available online at https://crudata.uea.ac.uk/cru/data/hrg/ were used. The gridded data set is very useful in view of the fact that weather stations are limited in number, unevenly distributed, have missing data problem and short period of observation [29]. Missing observed data have been filled using cross validation method following Ioannis [30].

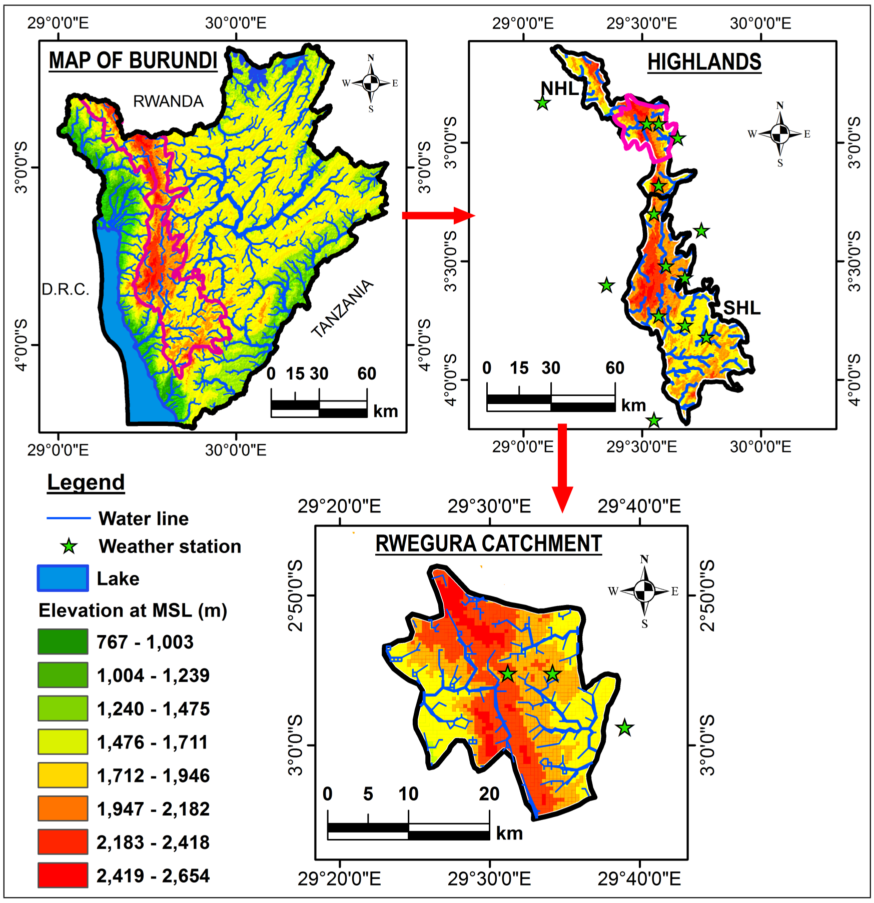

Fig. 1. Localization of Rwegura catchment

Table 1. Geographic characteristics of meteorological stations used

Site	Station name	ID (IGEBU)	Lon[1]	Lat[2]	Alt[3]
NHL	Bugarama (B. aeronaut)	10003	29.55	3.3	2240
	Gatara	10036	29.65	2.98	1806
	Munanira	10106	29.57	2.92	2120
	Mparambo (ES)[4]	10095	29.08	2.83	887
	Rwegura	10164	29.52	2.92	2302
	Teza	10167	29.57	3.18	2166
SHL	Gisozi	10044	29.68	3.57	2097
	Kibumbu	10068	29.75	3.37	1814
	Matana (Lycee)	10089	29.68	3.77	1934
	Mpota (Tora)	10098	29.57	3.73	2160
	Mutumba (ES)[4]	10123	29.35	3.6	971
	Nyakararo	10141	29.6	3.52	2228
	Ruvyironza	10161	29.77	3.82	1822
	Nyanza Lac (Project)(ES)[4]	10145	29.6	4.35	792

[1] Lon = Longitude East
[2] Lat = Latitude South
[3] Alt = Altitude above mean Sea level in (m)
[4] ES = Excluded station $(Alt < 1800\ m)$

The third set consists of data from eight Regional Climate Models. These data are available in the context of the COordinated Regional Climate Downscaling Experiment (CORDEX) over Africa at $0.44°$ resolution for the period 1950 to 2100 and accessed online (https://www.cordex.org) through user registration. The Table 2 shows the climatic models used to generate the multi-model ensemble, where the third column gives their acronyms adopted in this paper.

Table 2. Climatic models used

Global Climate Model Name	Institute ID	Model Short Name	Origin country
CanESM2	CCCma	CCCma	Canada
CNRM-CM5	CNR-CERFACS	CNRM	France
EC-EARTH	ICHEC	ICHEC	Europe
GFDL-ESM2M	NOAA-GFDL	NOAA	USA
IPSL-CM5A-MR	IPSL	IPSL	France
MIROC5	MIROC	MIROC	Japan
MPI-ESM-LR	MPI-M	MPI	Germany
NorESM1-M	NCC	NCC	Norway

Two experiments performed following the stabilization and the most extreme IPCC Representative Concentration Pathways scenarios (RCP 4.5 and RCP 8.5) available over the period $2006-2100$ in CORDEX database have been considered. Details on RCP 4.5 and RCP 8.5 emission scenarios have been provided by Thomson et al.[31] and Riahi et al. [32], respectively.

The data biais correction and the change signal detection were adopted using Quantile Delta Mapping (QDM) [33, 34] as in Manirakiza *et al.* [28]. Furthermore, the spatial interpolation was done using Kriging method [8].

3 RESULTS AND DISCUSSION

3.1 Current Climate over the Highlands

3.1.1 Seasonal rainfall

The fig. 2 shows the spatial distribution of seasonal and annual rainfall over the period $1981 - 2010$ at NHL and SHL. The analysis shows that the center of NHL receives a big amount of rainfall in all seasons except in DJF season (December – February) where the center of SHL receives the highest rainfall. Indeed, the season MAM (March – May) has the biggest amount of rainfall over the whole study area with a seasonal precipitation reaching $620\ mm$ in the center of NHL.

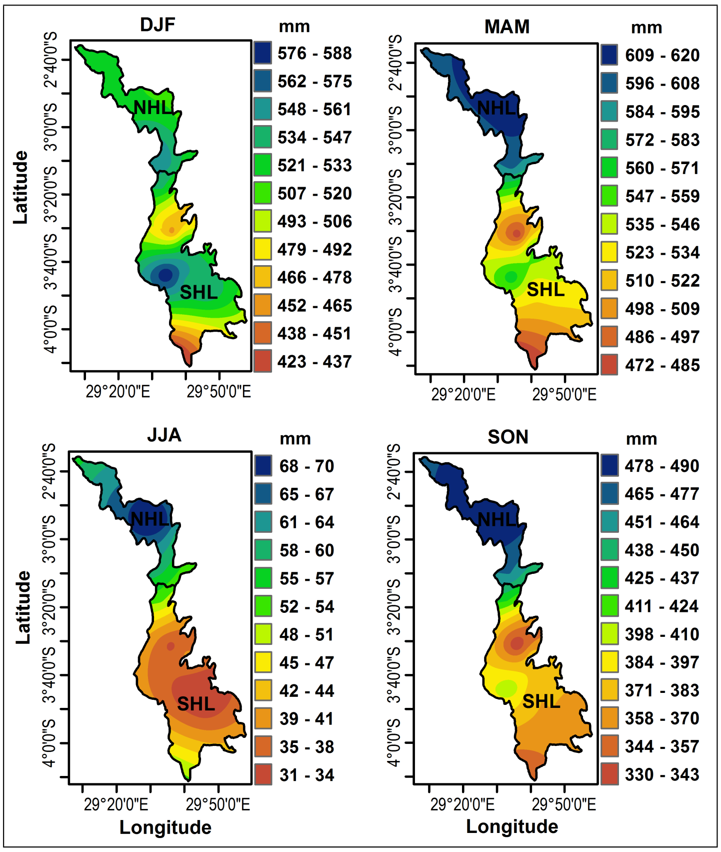

Fig. 2. Spatial distribution of seasonal rainfall

Overall, the rainfall is more abundant in the NHL than SHL. On the other hand, in all the four seasons, the lowest amount of rainfall is observed in the southern parts of SHL. Furthermore, the features show that the season JJA (June – August) has the lowest quantity of rainfall all over the year. Indeed, the season JJA corresponds to the dry season in Burundi where June, July and August almost receive no rainfall. During this dry season, the water level in the Rwegura reservoir decreases and this results in a reduction of generated hydropower and hence, as Burundi is dependent on hydropower energy, it becomes very difficult rationing the population in electrical energy. Furthermore, the temporal and spatial unven distribution of rainfall found over the study area may have negative impact on water availability including extreme events [13], especially at Rwegura catchment where the biggest hydropower plant of Burundi is located up to date.

On the other hand, over the period $1981 - 2010$, MK's test detected a significant decreasing trend in interannual rainfall only at NHL where Kendall's tau equals -0.29 with a p-value of 0.026. Indeed, Pettitt's test revealed the break point in 1995 at NHL. The analysis shows a decrease of $95\ mm$ in average rainfall over the sub period after the rupture at NHL. Furthermore, Sen's slope estimated downward trend at SHL with -0.5. Pettitt's test found no significant break point at SHL. This downward trend in rainfall is consistent with the findings in many studies from the East Africa [8, 10]. For instance, in Central Kenya, Funk [35] reported that long rains have decreased by more than $100\ mm$ since the mid 1970s and that this decline in rainfall is most likely due to warming in the Indian Ocean.

3.1.2 Seasonal Temperature

The fig. 3 presents the spatial distribution of seasonal and annual average temperature over the period $1981 - 2010$ at NHL and SHL. In all the four seasons, the features show that the south of SHL is hotter (greater than $20°$C) than other parts of the study area (less than $17°$C). Indeed, this difference in temperature gradient is obviously explained by the low elevation above the mean Sea level of the southern parts (see figure 1).

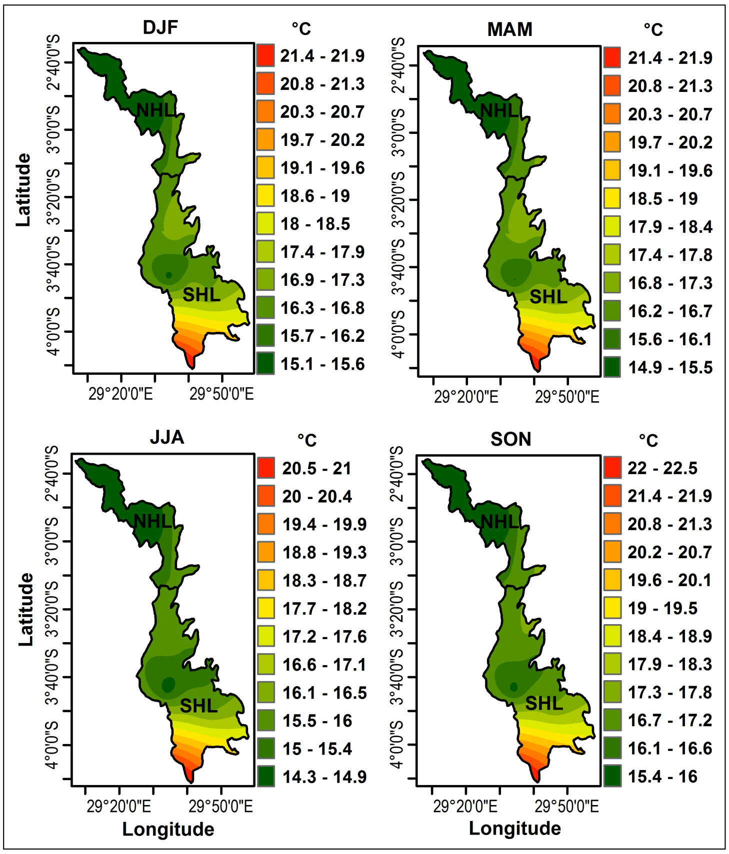

Fig. 3. Spatial distribution of seasonal average temperature

On the other hand, the center of NHL and SHL are the coolest parts of the study area where the average temperature is less than $16°$C throughout the four seasons. At seasonal scale, the season SON has the highest temperatures of the year which can reach $22.5°$C in the South of SHL. The highest temperatures observed in SON are explained by the fact that September is the hottest month in Burundi [13]. In the same way, the features reveal that the season JJA is the coolest season with average temperatures reaching $14.3°$C explained by the fact that July is the month with the lowest average temperature in Burundi. Furthermore, the features show no difference in spatial distribution of temperature between DJF and MAM seasons. The same analysis is observed between JJA and SON seasons. Overall, the difference in temperature gradient detected between the northern parts and the southern parts may favor the creation of wind storms on one hand and increase water evaporation on the other hand [28].

Indeed over the period $1981 - 2010$, MK's test detected significant upward trends in interannual average temperature all over the two sites where Kendall's tau equal to 0.44 and 0.53 with p-value equal to 0.0012 and < 0.0001 were respectively revealed at NHL and SHL. The Pettitt's test detected the rupture in temperature in 1996 all over the two sites. Comparing the period before and after the break point, the average temperature increased of 0.28 °C and 0.44 °C at NHL and SHL, respectively. These findings seem not to be a particular case because there are in accordance with the findings in many studies which show increasing in temperature over the last century due to climate warming. Consequently, high temperatures may increase evaporation and reduce water availability [13, 36].

3.2 Estimation of hydropower potential over Rwegura catchment

The current hydropower potential has been estimated over the period $1981 - 2010$ at Rwegura catchment located by the fig. 1, while the future hydropower potential was projected over the period $2021 - 2050$. The fig. 4 presents the rainfall, average temperature and flow characteristics over Rwegura catchment at monthly scales. The features show a decrease in rainfall during the summer time or long dry season including June, July and August. Indeed, the rainfall starts to decrease in May and reach approximatively zero in July. Meanwhile, the flow feature shows that the flow starts to decrease in May and reach its lowest value in August. Likewise, the feature points out June and July as the coolest months at Rwegura catchment.

3.2.1 MLR model calibration

Rwegura catchment is one of ungauged catchments of Burundi. Kitenge River has only daily streamflow records for four years (1980 - 1983). Therefore, flow data from literature by Ntigambirizwa [37] on Rwegura catchment have been used to complement those IGEBU published data. The MLR model has been used for streamflow simulation as in Joel *et al.* [12]. Indeed, the MLR model used by these authors over Rwegura catchment does not integrate temperature; which has been modified in this study. Overall, the fig. 5 (top) shows that the streamflows have been calibrated over the period of 30 years (1981-2010) and validated over a period of 6 years (1981-1986).

The model peformance was measured with an objective method based on error function which defines the goodness of fit, the Nash efficiency criterion, R^2 between the observed and modelled flows. The fig. 5 (bottom) presents the results from the model which shows the good fitness with observations from stations where $R^2 = 0.94$. An approaching value of $R^2 = 0.91$ was found by Joel *et al.* [12].

3.2.2 Projected streamflows

The fig. 6 presents the expected Flow Duration Curves (FDC) at Rwegura catchment over the period $2021 - 2050$ according to the reference period $1981 - 2010$. The FDC are projected following two climate emission scenarios RCP 4.5 and RCP 8.5. The low flow estimated in the 90^{th} percentile over the current period is equal to $22.8\ m^3/s$. This is the minimum flow which must be maintained in the river [26]. However, the fig. 6 and the table 3 show the decrease of the streamflows in the future climate at Rwegura catchment. The projected decline in streamflows will affect both residual and turbinable flows. Indeed, the decrease is projected to be higher in RCP 8.5 than RCP 4.5 for both low flow and turbinable flow.

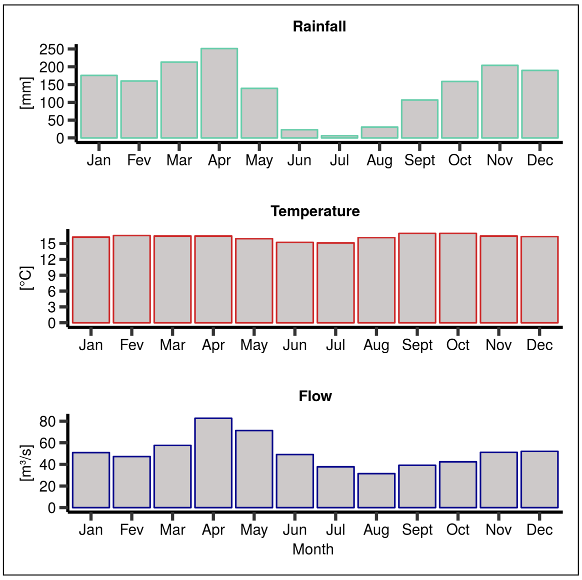

Fig. 4. Climate at Rwegura catchment

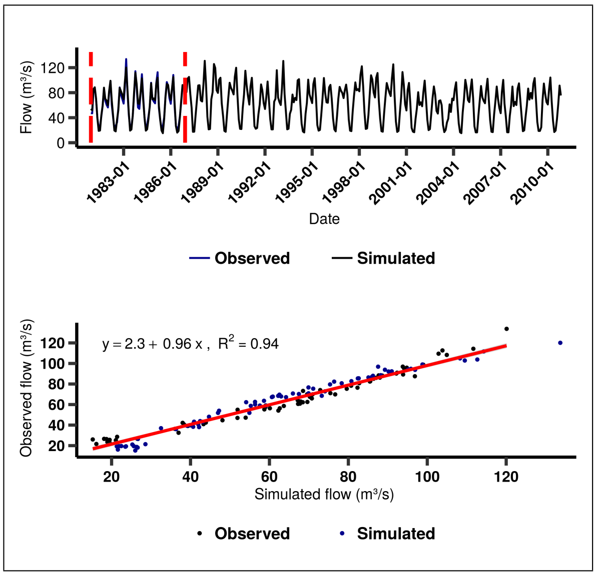

Fig. 5. Streamflows MLR model calibration and validation

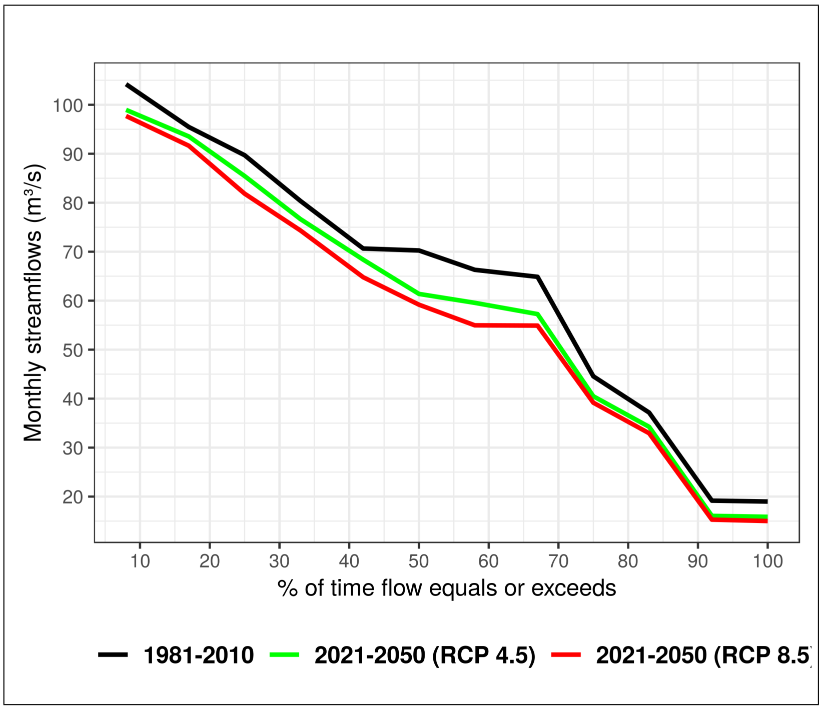

Fig. 6. Projected monthly streamflows at Rwegura catchment

Table 3. Projected streamflow characteristics

Flow type	$2021-2050$				
	Flow ($m^3.s^{-1}$)			Change (%)	
	Reference	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
LF[1]	22.8	20	18	-12.28	-21.05
TF[2]	40.67	38.99	38.82	-4.13	-4.55

[1] LF = low flow

[2] TF = turbinable flow ($TF =$ measured flow $- LF$).

3.2.3 Projected changes in seasonal streamflows

The fig. 7 reveals the forecasted streamflows changes at Rwegura catchment over the period $2021-2050$ under RCP 4.5 and RCP 8.5 according to the baseline period $1981-2010$. In fact, the figure shows that a general decrease in seasonal streamflows is expected by 2050. The season 1 including December, January and February, and the season 4 including September, October and November are projected to experience the highest rate of the decrease in seasonal streamflows. These two seasons correspond respectively to the small dry season and small rainy season in Burundi. The figure also shows that the decrease in seasonal streamflows is expected to be higher under RCP 8.5 than RCP 4.5.

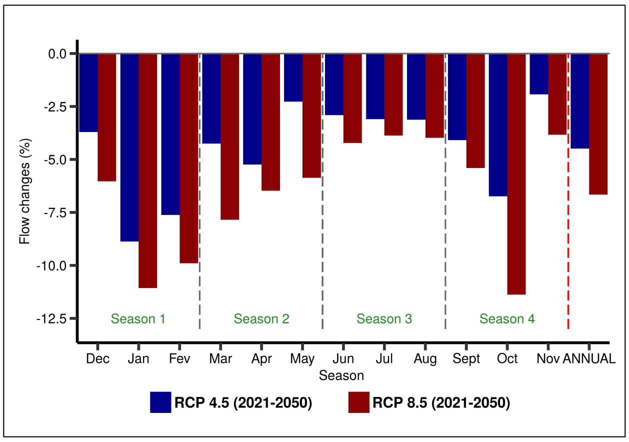

Fig. 7. Projected changes in seasonal streamflows at Rwegura catchment

3.2.4 Projected hydropower potential and changes

The fig. 8 presents the expected hydropower potential at Rwegura catchment over the period $2021-2050$ under RCP 4.5 and RCP 8.5 according to the reference period $1981-2010$. The figure highlights that the future hydropower potential will be characterized by a lot of fluctuation. Furthermore, the table 4 reveals a decrease in hydropower potential in the future climate over time. The findings also show that the rate of the decrease in hydropower potential is expected to be higher under RCP 8.5 than RCP 4.5. Indeed, in $2040s$ for instance, the hydropower potential is projected to decrease with respective rates greater than 2.58% and 8.35% under RCP 4.5 and RCP 8.5 at Rwegura catchment.

Overall, the projected decrease in hydropower potential found in this study is not a particular case for Rwegura catchment. Actually, the decrease in hydropower generation as result of the climate change has already been reported in many other parts of the world [4, 38, 39].

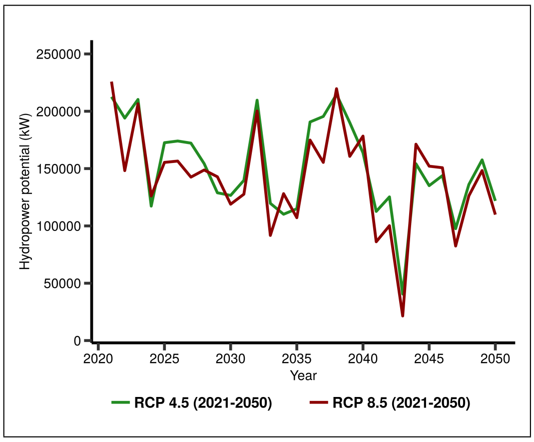

Fig. 8. Projected hydropower potential at Rwegura catchment

Table 4. Projected changes in hydropower potential

Climate Scenario	Current HPP [1]	Change (%)		
	$1981-2010$	$2021-2030$	$2021-2040$	$2021-2050$
RCP 4.5	$169,975.7$	-2.17	-2.58	-11.03
RCP 8.5	$169,975.7$	-7.53	-8.35	-16.37

[1] HPP = hydropower potential in $[kW]$

4 CONCLUSIONS

Climate change is one of the threats of the 21^{st} century. This study assessed effects of climate change on hydropower potential in near future climate scenarios over Rwegura catchment. In fact, the historical climate over the highlands of Burundi hosting Rwegura catchment has been analyzed over the period $1981-2010$. The findings showed that rainfall has the decreasing trend especially over the northern highlands, while average temperature has increasing trend all over the considered highlands of Burundi.

Furthermore, the current hydropower potential of Rwegura catchment has been estimated over the period $1981-2010$ and effects of climate change on future hydropower potential has been analyzed over the future period $2021-2050$ under both RCP 4.5 and RCP 8.5. Indeed, the low flow of $22.8\ m^3/s$ has been estimated in the 90^{th} percentile at Rwegura catchment over the current period. On the other hand, the findings showed that a general decrease in seasonal streamflows is expected by 2050. The projected negative trend in streamflow will affect both residual and turbinable flows. Indeed, the detected decrease in future streamflow will obviously have negative impact on hydropower potential over Rwegura catchment by 2030, 2040 and 2050. Overall, the future projected decrease in hydropower potential at Rwegura catchment over the period $2021-2050$ under both RCP 4.5 and RCP 8.5 may have negative effect on lifestyle of the population. Therefore, Burundi can plan alternative strategies to face the projected decrease in hydropower potential over Rwegura catchment in order to alleviate inconveniences of the projected decrease in hydropower energy.

COMPETING INTERESTS

Authors have declared no competing interests exist.

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