Trends and changes detection in rainfall, temperature and wind speed in Burundi
Agnidé Emmanuel Lawin, Célestin Manirakiza and Batablinlè Lamboni

ABSTRACT
This paper assessed the potential impacts of trends detected in rainfall, temperature and wind speed on hydro and wind power resources in Burundi. Two climatic stations located at two contrasting regions, namely Rwegura catchment and northern Imbo plain, were considered. Rainfall, temperature and wind speed observed data were considered for the period 1950–2014 and future projection data from seven Regional Climate Models (RCMs) for the period 2021–2050 were used. The interannual variability analysis was made using standardized variables. Trends and rupture were respectively detected through Mann–Kendall and Pettitt non-parametric tests. Mann–Whitney and Kolmogorov–Smirnov tests were considered as subseries comparison tests. The results showed a downward trend of rainfall while temperature and wind speed revealed upward trends for the period 1950–2014. All models projected increases in temperature and wind speed compared to the baseline period 1981–2010. Five models forecasted an increase in rainfall at northern Imbo plain station while four models projected a decrease in rainfall at Rwegura station. November was forecasted by the ensemble mean model to slightly increase in rainfall for both stations. Therefore, the country of Burundi may benefit more if it plans to invest in wind power.

Key words | Burundi, changes, climatic variables, trends

INTRODUCTION
Energy is the foundation of human society development. Industrial civilization was built around the exploitation of coal at the end of the 18th century and on fossil fuel in the middle of the 20th century. In developing countries, the population generally uses wood energy, which contributes to the destruction of the environment (Ramade 2005). One of the major challenges faced by the governments of those countries is to produce less expensive energy which at the same time meets the standards of environmental protection. Thus, renewable energies in general, and in particular hydro and wind power, have become a solution. However, these types of energy are linked to the trends of climatic variables (Yao et al. 2003), which is problematic. Recently, several studies revealed decreasing trends in rainfall in Iran (Talaee 2014; Talaee et al. 2014), Kerala India (Rajeevan et al. 2008), the north and east of New Zealand (Salinger & Griffiths 2003), South Asia and parts of the central Pacific (Griffiths et al. 2003), Poland (Bielec 2001) and in an ecological reserve in the Federal District of Brazil (dos Santos 2014). On the other hand, other studies showed increasing trends in rainfall in Bulgaria (Boers et al. 2014), France (Cantet 2009), China (Zhai et al. 2005), Germany (Tomassini & Jacob 2009), South Carolina (Powell & Keim 2015), south-western Montenegro (Burí et al. 2015) and Brazil (Sugahara et al. 2008). Likewise, studies conducted in Portugal (de Lima et al. 2013), Brazil (Sugahara et al. 2008) and the Netherlands revealed no significant trends in rainfall. Concerning temperature, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (2007) reported that since the early 20th century the global mean surface temperature increased by 0.8°C.
On a regional scale, many scientific papers show some different gradients. Zhao et al. (2014) reported that mean surface air temperature in Eastern China increased by 1.52°C over the last 100 years. At the same scales, Martinez et al. (2012), Karmeshu (2012) and Ceppi et al. (2012) revealed increasing trends in temperature for Florida, several northeastern states and Sweden, respectively. However, Karmeshu (2012) showed no significant trend in temperature in two of nine states studied in the Northeastern United States.

Considering wind speed, the study made in Iran at the Esfehan station (Fatemeh et al. 2011) revealed the decreasing trend of the mean annual wind speeds during the period 1961–2005. On the other hand, the study conducted in east Africa, in Tanzania (Mahongo et al. 2011), indicated that trends in the monthly mean and maximum wind speeds have generally strengthened over the past three decades, with the corresponding rates of increase at about 0.04–0.07 and 0.03–0.08 m·s⁻¹·y⁻¹, respectively.

Indeed, these results concerning climate parameter trends led the research to continue analyzing their effects on hydro and wind power generation since there is no homogeneous trend. For that matter, Shamin et al. (2011) reported that since 1970 the annual energy production of some European hydropower stations has decreased. Hamududu & Killingtveit (2012) revealed that these reductions are generally attributed to the decrease in average flow due to climatic variability. According to Yao et al. (2012), in northern Europe, Finland, the potential for wind energy could increase by 2–10% under conditions of climate change, while in the north-west of the United States (US), summer wind speeds may decrease by 5–10%, suggesting a 40% reduction in the potential of US summer wind power generation.

The study made in southern Africa, in Angola at Kwanza River Basin (Hamududu & Killingtveit 2016), showed that increasing trends in rainfall and consequently the increase of water resources would lead to the increase of hydropower production potential in the basin.

With regard to the impact of climate trends on hydropower and wind power, the central Africa region (Hamududu & Killingtveit 2012) has not yet been extensively investigated.

In Burundi, the crucial challenge is that in 2004–2005 two provinces in the north of the country (Kirundo and Muyinga) were severely hit by famine following the drought, while the period 2002–2012 was characterized by a chronic shortage of energy in general, and electrical energy in particular. Thus, 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. Few studies have been conducted in this country concerning climatic parameters trends and effects on hydro and wind power generation. Joel et al. (2011) developed a method that can be used to assess the hydrology in periods of low flow but the paper did not assess the impact of climatic variables trends either on hydropower or wind power. Therefore, this paper aims to revisit rainfall, temperature and wind speed variability by considering two stations from two contrasting regions of Burundi; one station at low altitude (774 m) at Imbo north plain and the other station at high altitude (1,800–2,621 m) at Rwegura catchment. Thus it fills the gap by assessing historical trends in climate variability as well as future changes for the period 2021–2050 to the considered climate parameters at Rwegura station and Imbo north plain. Specifically, the study focuses on detecting trends in the rainfall and interannual temperature variability at Rwegura, and repeats the same analysis at the Imbo north plain, adding wind speeds.

**DATA AND METHODS**

**Study area**

Figure 1 shows the study area location in Burundi, an east African country between longitudes 28.8° and 30.9° east and latitudes 2.3° and 4.45° south (Bidou et al. 1991). Bounded to the north by Rwanda, to the east and south by Tanzania and to the west by the Democratic Republic of Congo, Burundi covers an area of 27,834 km² (Ministry of Water Resources, Environment & Land Management of Burundi 2014). The annual rainfall in the high altitude regions is almost double that of low altitude regions. Average maximum annual temperatures range from 21.8 to 29.5°C. The average wind speeds vary between 4 and 6 m·s⁻¹. The studied station at Rwegura catchment is entirely located in Kibira national park of Burundi, at 29.5° longitude east and 3° latitude south, where climate is tropical. The northern Imbo plain site is in the west of
Burundi, to the north coast of Lake Tanganyika at 29.32° longitude east and 3.32° latitude south, and contains a part of the Rukoko savanna nature reserve.

Data used

Two sets of data were used in this study. The first set groups observed data collected from the synoptic stations of Burundi belonging to the Geographical Institute of Burundi (IGEBU), completed using Food and Agriculture Organization climate data. The IGEBU also has in its archives all historical meteorological data collected throughout the country and grouped according to each climatological network. Each study area contains meteorological stations (Figure 1) which provide daily information on rainfall, temperature and wind speed. The concise information on climate stations considered for the period of study, 1950–2014, are presented in Table 1. The records vary in their lengths, start and end dates. The selection of the time series data was based on the quality of the data collected from various stations at various times as presented in Table 1. However, only two principal stations, Rwegura and Bujumbura Airport (located at Imbo north plain), where climatic data are hourly collected, were selected for the period 1950–2014. The annual rainfall, temperature and wind speed data collected over this period of more than 60 years were used, as recommended by the World Meteorology Organization, for a climate study. Missing observed data have been filled using cross validation methods. Table 2 gives a statistical summary of the used data on an annual scale.

The data on wind speeds presented in Table 2 were collected at a height of 12 m and, during the whole period of study, the dominant direction of the wind was south.

The second set of used data groups daily rainfall, temperature and wind speed from seven regional climate models (RCMs). These data are available in the context of the Coordinated Regional Climate Downscaling Experiment (CORDEX) over Africa at 0.44° resolution for the period
1950–2100 (Giorgi et al. 2009) and can be accessed online (www.cordex.org) through user registration. Table 3 shows the used climatic models, with the third column giving their acronyms adopted in this paper.

In this study, only experiments performed following the most extreme IPCC Representative Concentration Pathways scenario (RCP8.5) for the period 2021–2050 in the CORDEX database have been considered. The RCP8.5 is

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Table 1 | Geographic characteristics of the meteorological stations used

<table>
<thead>
<tr>
<th>Station name</th>
<th>ID (IGEBU)</th>
<th>Lon.</th>
<th>Lat.</th>
<th>Period</th>
<th>D (%)</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gatara</td>
<td>10036</td>
<td>29.65</td>
<td>2.98</td>
<td>1951–1998</td>
<td>75</td>
<td>1806</td>
</tr>
<tr>
<td>Munanira</td>
<td>10106</td>
<td>29.57</td>
<td>2.92</td>
<td>1954–2002</td>
<td>75</td>
<td>2120</td>
</tr>
<tr>
<td>Ndora</td>
<td>10133</td>
<td>29.40</td>
<td>2.92</td>
<td>1936–1991</td>
<td>64.1</td>
<td>2120</td>
</tr>
<tr>
<td>Rwegura</td>
<td>10164</td>
<td>29.52</td>
<td>2.92</td>
<td>1950–2014</td>
<td>100</td>
<td>2302</td>
</tr>
<tr>
<td>Teza</td>
<td>10167</td>
<td>29.57</td>
<td>3.18</td>
<td>1963–1996</td>
<td>51.56</td>
<td>2166</td>
</tr>
<tr>
<td>Bujumbura (Airport)</td>
<td>10011</td>
<td>29.32</td>
<td>3.32</td>
<td>1927–2014</td>
<td>100</td>
<td>783</td>
</tr>
<tr>
<td>Bujumbura (Kamenge)</td>
<td>10014</td>
<td>29.40</td>
<td>3.35</td>
<td>1977–2000</td>
<td>36</td>
<td>890</td>
</tr>
<tr>
<td>Gihanga</td>
<td>10038</td>
<td>29.30</td>
<td>3.20</td>
<td>1952–1986</td>
<td>53</td>
<td>819</td>
</tr>
<tr>
<td>Imbo (Sems)</td>
<td>10052</td>
<td>29.35</td>
<td>3.18</td>
<td>1971–2014</td>
<td>67</td>
<td>820</td>
</tr>
<tr>
<td>Kivoga</td>
<td>10080</td>
<td>29.42</td>
<td>3.28</td>
<td>1935–1990</td>
<td>62.5</td>
<td>877</td>
</tr>
<tr>
<td>Maramva</td>
<td>10087</td>
<td>29.32</td>
<td>3.27</td>
<td>1977–1992</td>
<td>23.43</td>
<td>785</td>
</tr>
<tr>
<td>Murukaramu</td>
<td>10115</td>
<td>29.32</td>
<td>3.30</td>
<td>1970–1984</td>
<td>22</td>
<td>785</td>
</tr>
<tr>
<td>Musenyi (Bubanza)</td>
<td>10118</td>
<td>29.40</td>
<td>3.22</td>
<td>–</td>
<td>–</td>
<td>882</td>
</tr>
<tr>
<td>Rukoko</td>
<td>10151</td>
<td>29.22</td>
<td>3.25</td>
<td>1973–1995</td>
<td>34.4</td>
<td>790</td>
</tr>
</tbody>
</table>

*aLon: longitude east.

bLat: latitude south.

cD: time period in percentage included in the period of study.

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Table 2 | Description of data collected at Rwegura and at northern Imbo plain upon the period 1950–2014

<table>
<thead>
<tr>
<th>Variable</th>
<th>Station</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>Rwegura</td>
<td>1,012</td>
<td>2,073</td>
<td>1,658.15</td>
<td>237.55</td>
</tr>
<tr>
<td></td>
<td>Northern Imbo plain</td>
<td>212</td>
<td>1,213</td>
<td>802.18</td>
<td>217.24</td>
</tr>
<tr>
<td>TM*</td>
<td>Rwegura</td>
<td>13</td>
<td>17.70</td>
<td>16.28</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>Northern Imbo plain</td>
<td>20</td>
<td>26.42</td>
<td>24.39</td>
<td>1.60</td>
</tr>
<tr>
<td>Tminb</td>
<td>Rwegura</td>
<td>10.26</td>
<td>12.40</td>
<td>11.60</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Northern Imbo plain</td>
<td>16.79</td>
<td>20.02</td>
<td>18.90</td>
<td>0.85</td>
</tr>
<tr>
<td>Tmaxc</td>
<td>Rwegura</td>
<td>19</td>
<td>20.97</td>
<td>20.18</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>Northern Imbo plain</td>
<td>27.03</td>
<td>29.96</td>
<td>29.01</td>
<td>0.69</td>
</tr>
<tr>
<td>WSd</td>
<td>Rwegura</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Northern Imbo plain</td>
<td>2.7</td>
<td>5.8</td>
<td>3.7</td>
<td>0.84</td>
</tr>
</tbody>
</table>

*aTM = Mean temperature (°C).

bTmin = Minimum temperature (°C).

cTmax = Maximum temperature (°C).

dWS = Wind speed (m.s⁻¹).
based on the A2r scenario which combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long-term to high energy demand and greenhouse gas emissions in the absence of climate change policies (Riahi et al. 2007). This set of data is the most up-to-date ensemble of high-resolution RCM projections. RCM historical data have been used for bias correction.

**METHODS**

**Trend detection**

For trend detection, the Mann–Kendall (MK) non-parametric test (Mann 1945; Kendall 1962) was used. Break points were detected through Pettitt (1979). These tests are used worldwide in hydro meteorological variables trend detection (Rajeevan et al. 2012; Karmeshu 2014; Telemu 2013; Talaei 2014; Talaei et al. 2014). In cases where a break point existed, Mann–Whitney (MW) and Kolmogorov–Smirnov (KS) non-parametric tests were used to test the two time subseries (before and after the break point). Those tests are used to measure the mean equality of the two time subseries and thus prove whether the difference between the two means was significant or not.

Details of the Mann–Whitney test can be found in many papers (Mann & Whitney 1947; Vincent & Gilles 2012). It tests whether one of two subseries is stochastically larger than the other.

The second mean equality test (KS (Rice 2007; Vincent & Gilles 2012)) is a non-parametric adequacy test to determine whether the distribution functions of two populations are identical. The test statistic $D$ is defined by:

$$D = \sup_{x} |T_{1}(x) - T_{2}(x)|$$

where $T_{1}(x)$ is the empirical distribution function of the time subseries $(x_{1}, \ldots, x_{n})$ and $T_{2}(x)$ the empirical distribution of the time subseries $(y_{1}, \ldots, y_{m})$.

The null hypothesis $H_{0}$, which assumes there is no difference between the two distributions, is rejected at the significance level $\alpha$ if $D$ is greater than the value of the Smirnov’s table $t_{n,m,1-\alpha}$ with $n, m$ and $(1 - \alpha)$ parameters.

**Interannual variability analysis**

For each variable, the discrimination of surplus years and deficit years was determined using the standardized variable index ($I$) created by McKee et al. (1993) and can be found in many articles (Lawin et al. 2010; Soro et al. 2014):

$$I(i) = \frac{X_{i} - \bar{X}_{m}}{\sigma}$$

where $X_{i}$, $\bar{X}_{m}$ and $\sigma$ are the value for the year $i$, the average and the standard deviation of the time series, respectively.

Thus, in this work, a year will be considered normal if its index is included between $-0.5$ and $+0.5$. It will be in surplus if its index is greater than $+0.5$ and deficit is below $-0.5$. This interval is criticized since it is relatively weak. However, it clearly makes it possible to discriminate the deficit years from surplus years. The standardized variable index also makes it possible to analyze the interannual variability of the key variable at considered spatial scales.

**Future climate analysis**

The comparison of the changes on future climatic variables were carried out with respect to the baseline period (1981–2010) and referred to as the current or historical period. Delta change factors were computed and added to daily fluctuations.
time series of observation records in order to disaggregate
the local climate projection into a daily time step. Calcula-
tions of delta change factors were based on the
climatology of a selected projection interval (2021–2050)
and a baseline period (1981–2010) using Equations (3) and
(4). Change factors for temperature and wind speed were
determined by:

$$\Delta \omega_{ij,k} = \bar{\omega}_{ij,k} - \bar{\omega}_{ref,k}$$

(3)

where $$\Delta \omega$$ is the change factors (${\degree}C \text{ or } m/s$), $$\bar{\omega}$$ is the monthly
mean (${\degree}C \text{ or } m/s$), $$i$$ is the RCM, $$j$$ is the projection period, $$ref$$
is the reference period and $$k$$ is the month.

Rainfall change factors were computed as follows:

$$\Delta P_{ij,k} = \frac{P_{ij,k} - P_{ref,k}}{P_{ref,k}} \times 100$$

(4)

where $$\Delta P$$ is the rainfall change factor ($%$), $$P$$ is the mean
monthly rainfall.

RESULTS AND DISCUSSIONS

Rainfall trend

Figure 2 presents the monthly rainfall at Rwegura catchment
and northern Imbo plain. The consecutive months JJAS and
MJJASO are characterized by low rainfall at Rwegura and
Imbo, respectively. These months of low rainfall correspond
to the dry season in Burundi where highlands are ranked in
the climatic zone, recording three dry months while the low-
lands count six dry months. Analysis of the figure shows a
minimum of rainfall in February which is explained by the
small dry season.

In September 1986, a power plant was built in Rwegura
catchment on Kitenge River.

Recently, the water level in the Rwegura reservoir has
decreased and this has resulted in a reduction in generated
hydropower and hence, in the dry season hydropower
rationing is difficult, especially in the capital Bujumbura
located in northern Imbo plain. There is thus a fundamental
need to find a climate variable having an opposite trend to
the rainfall.

Figure 3 shows the rainfall pattern at Rwegura and at
Imbo north plain stations. The standardized rainfall indices
divide the rainfall pattern into three time subseries including
the period 1950–1973 (24 years) where there is no de-
ficit year, the period 1974–1992 (19 years) which is a mixture
of deficit and surplus years, and the period 1993–2014
(22 years) where there is no surplus year. From 1950 to
2014, there are 19 surplus years at Rwegura against 24
surplus years at Imbo north plain, and 14 deficit years at Rw-
egura against 17 deficit years at Imbo north plain. Thus, the
period 1950–1973 has 78.95% of surplus years at Rwegura
against 66.67% of surplus years at northern Imbo plain. In
a similar analysis, the period 1993–2014 has 77.78% of deficit
years at Rwegura against 70.59% at Imbo. All other missing
fractions which represent less than 40% for either surplus
or deficit years are found in the second time subseries (the
period 1974–1992). Overall, this analysis points out the
dercrease of surplus years and the increase of deficit years
which may have effects on water availability.

Table 4 shows the mean rainfall in the three time
periods for Rwegura and Imbo north plain. The analysis
shows that from the period 1950–1973 to 1974–1992, the
mean rainfall decrease of 11.03% at Rwegura against
16.57% at Imbo north plain. From the period 1974–1992
to 1993–2014, the mean rainfall decrease of 11.21% at Rwe-
gura against 19.65% at Imbo north plain. Overall, from the
first period (period 1950–1973) to the last (1993–2014) the
mean rainfall decrease of 21.01% at Rwegura against
32.97% at Imbo. These findings show that the mean rainfall in time periods declines at a higher rate at Imbo north plain than at Rwegura.

On an annual scale, the MK test showed a decreasing trend in annual rainfall pattern for the two studied areas where the Kendall’s tau is $-0.474$ for Rwegura and $-0.351$ for Imbo north plain with a $p$-value of $<0.0001$ for the two regions as given in Table 5 at the $\alpha = 0.05$ level. The Pettitt test showed break points in 1978 and in 1990 at Imbo north plain and at Rwegura, respectively, as given in Figure 4, where $\mu_1$ and $\mu_2$ are the means of the time subseries before and after the break point, respectively.

Consequently, Table 6 gives the results of the MW and KS tests applied upon the subseries where they all reported that the decrease in rainfall for both the studied regions was significant at $\alpha = 0.05$ level. In Table 5, $\tau$ gives 318 mm or 17.90% and 270.212 mm or 28.39% as the mean rainfall decrease at Rwegura and at Imbo, respectively. The rate of the rainfall decrease is higher (almost double) at Imbo

Table 4 | Mean rainfall in the three time subseries

<table>
<thead>
<tr>
<th>Period</th>
<th>Rwegura</th>
<th>Imbo north plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950–1973</td>
<td>1849</td>
<td>955</td>
</tr>
<tr>
<td>1974–1992</td>
<td>1645</td>
<td>797</td>
</tr>
<tr>
<td>1993–2014</td>
<td>1461</td>
<td>640</td>
</tr>
</tbody>
</table>

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Table 5 | Subseries mean comparison before and after the break point

<table>
<thead>
<tr>
<th>Variable</th>
<th>Station</th>
<th>Kendall’s tau</th>
<th>$p$-value</th>
<th>$\mu_1$</th>
<th>$\mu_2$</th>
<th>$\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>Rwegura</td>
<td>$-0.474$</td>
<td>$&lt;0.0001$</td>
<td>1776</td>
<td>1458</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>$-0.351$</td>
<td>$&lt;0.0001$</td>
<td>951.834</td>
<td>681.622</td>
<td>270.212</td>
</tr>
<tr>
<td>TM</td>
<td>Rwegura</td>
<td>0.590</td>
<td>$&lt;0.0001$</td>
<td>15.254</td>
<td>17.008</td>
<td>1.754</td>
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<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.606</td>
<td>$&lt;0.0001$</td>
<td>23.281</td>
<td>25.606</td>
<td>2.325</td>
</tr>
<tr>
<td>Tmin</td>
<td>Rwegura</td>
<td>0.424</td>
<td>$&lt;0.0001$</td>
<td>11.150</td>
<td>11.943</td>
<td>0.793</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.451</td>
<td>$&lt;0.0001$</td>
<td>18.214</td>
<td>19.410</td>
<td>1.196</td>
</tr>
<tr>
<td>Tmax</td>
<td>Rwegura</td>
<td>0.540</td>
<td>$&lt;0.0001$</td>
<td>19.743</td>
<td>20.604</td>
<td>0.861</td>
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<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.473</td>
<td>$&lt;0.0001$</td>
<td>28.561</td>
<td>29.447</td>
<td>0.886</td>
</tr>
<tr>
<td>WS</td>
<td>Rwegura</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.627</td>
<td>$&lt;0.0001$</td>
<td>2.950</td>
<td>4.974</td>
<td>1.724</td>
</tr>
</tbody>
</table>

$\tau = |\mu_1 - \mu_2|$ is the rate of decrease (when Kendall’s tau is negative) or the rate of increase (when Kendall’s tau is positive) of the climatic variable.
north plain than at Rwegura. The downward trend in rainfall observed in this analysis is consistent with the findings in many studies. For instance, the mean annual rainfall in Tanzania (Telemu 2013) has declined by about 4% between the periods 1981–1989 and 2000–2010. In central Kenya, Funk (2010) reported that the total rainfall of the long rainy season has 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.

Temperature trend

Figure 5 presents the monthly temperature pattern at Rwegura (Figure 5(a)) and Imbo (Figure 5(b)). At Rwegura, Tmin shows minimum values in JJA while Tmax reaches its maximum value in September. TM does not show remarkable variations. For Northern Imbo plain station (Airport), TM and Tmax show maximum values in September while Tmin reveals its minimum values in JJA, which is the dry season in Burundi.

The analysis pointed out that the average temperature at Rwegura is almost three-quarters of Imbo north plain’s average temperature. The explanation for the difference in temperature gradient resides in the altitude separating the two zones, which varies between 1,026 and 1,847 m.

Table 6 | Results from MW and KS tests at $\alpha = 0.05$ level

<table>
<thead>
<tr>
<th>Variable</th>
<th>Station</th>
<th>Test statistic</th>
<th>$p$-value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\text{MW(D1)}^a$</td>
<td>$\text{KS(D2)}^b$</td>
<td>$\text{MW(\text{ev})}^c$</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>Rwegura</td>
<td>895.5</td>
<td>0.780</td>
<td>492</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>922.5</td>
<td>0.689</td>
<td>522</td>
</tr>
<tr>
<td>TM</td>
<td>Rwegura</td>
<td>34</td>
<td>0.926</td>
<td>513</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>42</td>
<td>0.850</td>
<td>527</td>
</tr>
<tr>
<td>Tmin</td>
<td>Rwegura</td>
<td>146</td>
<td>0.679</td>
<td>518</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>100.5</td>
<td>0.714</td>
<td>518</td>
</tr>
<tr>
<td>Tmax</td>
<td>Rwegura</td>
<td>109.5</td>
<td>0.656</td>
<td>528</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>107</td>
<td>0.602</td>
<td>528</td>
</tr>
<tr>
<td>WS</td>
<td>Rwegura</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>8.5</td>
<td>0.952</td>
<td>483</td>
</tr>
</tbody>
</table>

$^a$MW(D1) – difference of location between the samples computed by MW test.

$^b$KS(D2) – maximum distance computed by KS test between the repartition function of the distribution before the break point and the distribution after the break point.

$^c$MW(\text{ev}) – MW expected value.
Imbo north plain in the period 1950–2014. The standardized temperature index revealed three subseries in TM time series. The first period is 1950–1966, where there is no year with TM greater than the mean. The second period, 1967–1976, is a mixture of two years with normal TMs, two years with TMs higher than the mean, and six years with TMs lower than the mean. The last period, 1977–2014, has lower TM than the mean. Analysis of Table 7 shows that from the first period to the second, the TM increased by 0.65 and 0.64°C at Rwegura and at Imbo north plain, respectively. From the second period to the last, the TM increased by 1.35 and 2.07°C at Rwegura and at Imbo north plain, respectively. Overall, from the first period (1950–1966) to the last (1977–2014), the TM increased by 2 and 2.71°C at Rwegura and at Imbo north plain, respectively.

The results of the MK test revealed that the increasing trend in temperature was significant at $\alpha = 0.05$ level for both study areas where the Kendall’s tau is equal to 0.590, 0.424 and 0.540 for TM, Tmin and Tmax at Rwegura, respectively, and 0.606, 0.451 and 0.473 for TM, Tmin and Tmax at Imbo north plain, respectively (their respective p-values are given in Table 5). The Pettitt test revealed the break points in 1976 and 1983 for TM at Rwegura and at Imbo north plain, respectively, as given in Figure 7(a) and 7(b). For Tmax and Tmin, break points were detected in 1981 and 1977 respectively for the two stations, as presented in Figure 7(c)–7(f).

![Figure 5](image-url) Monthly temperature patterns at Rwegura (a) and at Imbo north plain (b).

![Figure 6](image-url) Standardized TM index at Rwegura and Imbo north plain (1950–2014).
The analysis shows that at Imbo north plain, the difference between $\mu_2$ of Tmax and $\mu_2$ of Tmin is smaller than the difference between $\mu_1$ of Tmax and $\mu_1$ of Tmin. This reveals the decrease of the distance between Tmax and Tmin after the break point year. Table 6 gives the results of the MW and KS tests applied upon the temperatures time subseries. Overall, they all confirmed the upward trend in temperature patterns for the two study stations at

<table>
<thead>
<tr>
<th>Period</th>
<th>Average TM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rwegura</td>
</tr>
<tr>
<td>1950–1966</td>
<td>15.01</td>
</tr>
<tr>
<td>1967–1976</td>
<td>15.66</td>
</tr>
<tr>
<td>1977–2014</td>
<td>17.01</td>
</tr>
</tbody>
</table>

Figure 7 | Break point in TM, Tmax and Tmin at Rwegura and at Imbo north plain.
a significance level of $\alpha = 0.05$. Furthermore, Table 5 gives the rates of increase of the subseries temperatures (TM, Tmin and Tmax) mean after the break point. For instance, the values of $\tau$ for temperatures show that the TM mean before the break point (1976) increased by 1.754°C after the break point at Rwegura, while at Imbo north plain, the TM mean before the break point (1983) increased by 2.325°C after the break point. The upward trend in temperature observed in this analysis is in accordance with the findings in many studies which show increases in temperature over the last century due to climate warming.

Wind speed trend

Figure 8 shows the monthly wind speed pattern at Imbo north plain (Bujumbura Airport station) where the months JJAS (June-July-August-September) reveal the highest wind speed values of the year. This period matches with the dry season in Burundi. The analysis of this output figure over 65 years shows that mean wind speeds are optimized during summer time and this may reveal the period when wind power turbines would expect to receive maximum wind speeds.

Figure 9 shows the standardized WS pattern from 1950 to 2014 and reveals three parts of the time subseries. The first part, including 1950–1977, is characterized by lower wind speeds than the annual mean. In the second part, including 1978–1997, the standard indices reveal 11 normal years in WS and nine years with lower wind speed than the annual mean. In contrast with the first part, the third part, including the period 1998–2014, shows only higher wind speeds. The analysis of the three time periods in mean WS (Table 8) shows that from 1950–1977 to 1978–1997 the mean WS has strengthened by 0.34 m·s$^{-1}$, whereas from 1978–1997 to 1998–2014 the rate of increase in mean WS is 2.07 m·s$^{-1}$. It is clear that the mean WS in the last period is almost double that of the first period.

The MK test recorded a significant increasing trend in WS at Imbo north plain station. The Kendall’s tau was 0.627 for $p$-value <0.0001 at a significance level of $\alpha =$
0.05, as given in Table 5. The Pettitt test showed the break point in 1991 as given by Figure 10.

Furthermore, Table 6 shows the results from the MW and KS tests applied upon the subseries before and after the break point. All of them confirmed the increasing trend in WS at Imbo north plain at $\alpha = 0.05$.

The upward trend detected in wind speed in this study is consistent with the observations by Mahongo et al. (2011) who recorded an increasing trend in monthly mean velocity at Zanzibar during 1985–2004.

This increasing trend in wind speed may be attributed to changes in global climate. According to AR4 of IPCC (Intergovernmental Panel on Climate Change 2007), mid-latitude, westerly winds have strengthened in both hemispheres since the 1960s as a result of climate change.

The analysis of Figures 9 and 10 pointed out two main parts, before and after 1980. The first part does not show a significant change in wind speed, while the second part shows a jump. In addition to the reasons given above for the increase in the wind speed observed, Nzigidahera (2003) reported the devastation of vegetation in Rusizi national park around the studied station. In fact, the need for fire wood, agricultural fields, wooden materials for house construction and exploitation of vegetation for sales, especially *hyphaene petersiana* which was creating a stable microclimate in the area, grew with the increase of the surrounding population (Gihanga, Gatumba, Rukaramu and Buringa), estimated at 9000 families in 1950. In addition, since 1993, the start of the socio-political crisis in Burundi, many families fled from other localities to Gatumba and Gihanga, which caused a demographic explosion. For example, in 2005, Gihanga had 50,792 inhabitants and in 2010 the population had increased by 17.8%. Therefore, the jump in observed wind speed may have been accelerated by the environmental destruction.

Table 9 shows the average increase over a period of 10 years in rainfall and temperature for both stations, and the average increase in wind speed at Imbo north plain. The average increase in the mean rainfall over the period of 10 years is negative, showing the declining trend of the rainfall. Thus, lower rainfall and higher temperature due to climate variability may impact water flow, extend the dry season, increase evaporation from water and soil surfaces and transpiration from plants leading to drought. In the Maldives, Mörner et al. (2004) linked the intensification of north-east winds in over 30 years from the 1970s to increased evaporation.

Table 8 | Mean WS in the three time subseries

<table>
<thead>
<tr>
<th>Period</th>
<th>Rwegura</th>
<th>Imbo north plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950–1977</td>
<td>–</td>
<td>2.89</td>
</tr>
<tr>
<td>1978–1997</td>
<td>–</td>
<td>3.23</td>
</tr>
<tr>
<td>1998–2014</td>
<td>–</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Figure 10 | Break point in WS at Imbo north plain.

Table 9 | Average increase upon a period of 10 years

<table>
<thead>
<tr>
<th>Variable</th>
<th>Region</th>
<th>Average increase upon a period of 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>Rwegura</td>
<td>–87.21</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>–58.70</td>
</tr>
<tr>
<td>TM</td>
<td>Rwegura</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.63</td>
</tr>
<tr>
<td>Tmin</td>
<td>Rwegura</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.25</td>
</tr>
<tr>
<td>Tmax</td>
<td>Rwegura</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.20</td>
</tr>
<tr>
<td>WS</td>
<td>Rwegura</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Imbo north plain</td>
<td>0.51</td>
</tr>
</tbody>
</table>
**Future climate**

The future climate in monthly patterns using seven RCMs (CNRM, ICHEC, IPSL, MIROC, MPI-M, NCC and NOAA) are presented in Figures 11–13. Figure 11(a) and 11(b) respectively relate to the monthly projection in rainfall at northern Imbo plain and Rwegura stations in the period 2021–2050 according to the baseline period 1981–2010. Figures 12(a) and 12(b) forecast the monthly mean temperature at northern Imbo plain station and Rwegura station, respectively, with respect to the above periods. Figure 13 shows the projected monthly wind speed pattern at Imbo north plain station over the period 2021–2050 according to the reference period (1981–2010).

**Monthly scale changes**

On a monthly scale, the findings showed that between months with more rainfall (November, March and April), only November is projected to increase in rainfall by 18 and 11% at Imbo north plain and Rwegura stations, respectively (Figure 11). In contrast, the month of October will experience a decrease in rainfall of 24 and 17% at Imbo north plain and Rwegura stations, respectively. This change in rainfall pattern may translate to months with heavy rains or increase in number of rain events and extend the long dry season by 2050 compared to the baseline period.

The temperature (Figure 12) is forecasted to increase in both stations. From May to October, the mean temperature will increase between 3 and 3.9°C at Imbo station, and between 2.3 and 2.9°C at Rwegura station by 2050. May will experience the highest increase at Imbo north plain, while at Rwegura the month with the highest increase will be October.

A general increase is projected for wind speed (Figure 13) for all months at Imbo north plain. The increase is expected to be between 1 and 1.6 m/s from April to October, with August being the month with the highest change. The changes pointed out in the wind speed will obviously have a positive impact on wind power potential in the long dry season.
Interannual scale changes

Figure 14 presents the interannual projection in rainfall for the period 2021–2050 compared to the baseline period (1981–2010) for the two sites. At Imbo station (plain region) model projections are closer than at Rwegura (mountainous region). Future rainfall will be characterized by high interannual variability, including a decreasing trend from 2029 to 2041 and an increase from 2042 to 2050 at Rwegura. Table 10 shows the mean change for the period 2021–2050. It is found that the ICHEC model projected the highest rate of increase in rainfall (+17.5% for Imbo and +15.4% for Rwegura) while the NOAA model forecasted the highest rate of decrease for both stations (−12.9% for Imbo and −14.1% for Rwegura). The analysis using multi-model mean (Ensemble mean model) revealed that at northern Imbo plain station, the rainfall will increase by 1.73% while at Rwegura station the rainfall is projected to decrease slightly by 0.33% over the period 2021–2050 compared to the baseline period (1981–2010). However, the MK test revealed no significant new trend despite those rates of change.
Figure 15 presents the projected average annual temperature. Despite the high deviation between the models contrarily to the precipitation, all the models projected an increasing trend of the mean temperature. The IPSL model forecasted the highest values while ICHEC projected the lowest for both stations. As summarized in Table 11 for the period 2021–2050, all the models projected a higher increase at the plain site than the mountainous site, except for ICHEC. The IPSL model forecasted an increase of 3.88°C at Rwegura and 4.33°C at Imbo, while the ICHEC model projected an increase of 0.68°C at Rwegura and 0.47°C at Imbo. The analysis using multi-model mean revealed that the average annual temperature is projected to increase by 2.29°C at northern Imbo plain station and by 2.08°C at Rwegura station for the period 2021–2050.

The projected fluctuations of wind speed for the period 2021–2050 are presented in Figure 16, which shows a good agreement of models, except MIROC which projected lower values. This figure also clearly shows the increasing trend of the wind speed. Table 12 summarizes the average annual

| Changes in average annual rainfall (RCMs outputs) |
|---|---|---|---|
| Average rainfall (mm) | Average rainfall (mm) | Change in % |
| RCM | Imbo | Rwegura | Imbo | Rwegura | Imbo | Rwegura |
| CNRM | 667 | 1542 | 655 | 1557 | –1.8 | 1.0 |
| ICHEC | 667 | 1542 | 784 | 1780 | 17.5 | 15.4 |
| IPSL | 667 | 1542 | 675 | 1516 | 1.2 | –1.7 |
| MIROC | 667 | 1542 | 690 | 1574 | 3.4 | 2.1 |
| MPI-M | 667 | 1542 | 675 | 1534 | 1.2 | –0.5 |
| NCC | 667 | 1542 | 682 | 1521 | 2.2 | –1.4 |
| NOAA | 667 | 1542 | 581 | 1325 | –12.9 | –14.1 |

Figure 15 | Observed (1981–2010) and projected average annual temperature over the period 2021–2050: a) Imbo and b) Rwegura.
wind speed as projected by the RCMs and highlights that the highest value of increase (1.61 m/s) is forecasted by the MPI-M model, while the lowest value (0.91 m/s) is projected by the MIROC model.

These findings are in accordance with many scientific reports on Burundi which generally forecast the decrease in rainfall in some northern parts of Burundi and the increase in rainfall in the southern parts from east to west (Liersch & Rivas 2014). They also projected the increase in temperature across the country.

The non-homogenous trend in projected rainfall seems not to be a particular characteristic of the studied sites. Indeed, it was reported for several areas over the world and for different climate contexts (NTcha MPo et al. 2017a, 2017b).

The increases in temperature and wind speed found in this study are aligned with several studies in the region as well as in other regions of the world as a result of the general warming reported by the IPCC (Intergovernmental Panel on Climate Change 2007).

In Burundi, electricity production is largely dependent on hydropower production. Therefore the non-clear trend in rainfall is not beneficial for hydropower production planning. However, other sources positively impacted by climatic variation, such as wind speed, will be beneficial for the country.

CONCLUSIONS

The study of interannual variability using the standardized variable index discriminated three time periods at Rwegura and at Imbo north plain stations for each climatic parameter. In the rainfall pattern, the period 1950–1973 is widely in excess with no deficit year and the period 1974–1992 is a mixture of normal, deficit and excess rainfall, while the period 1993–2014 has no excess year. For the mean temperature pattern analyzed, the period 1950–1966 has no excess mean temperatures and the period 1967–1976 is a mixture of normal, deficit and surplus mean temperatures while the period 1977–2014 is in high surplus with no deficit mean temperature. In the wind speed time series, the period 1950–1977 is deficit and the period 1978–1997 is a mixture of deficit and normal wind speeds, while the
The mean increase for the period 2021
April), November will experience the highest increase in
the months with more rainfall (November, March and
is no signi-
at Rwegura. On an interannual scale, it is found that there
ence a decrease which could reach 24% at Imbo and 17%
Rwegura. Furthermore, the month of October will experi-
cence period will not be altered in the period 2021–2050.
Therefore, the country would benefit from wind power if it
invests more in wind power production.
One of the causes of the trends detected in wind speed
historical data has been attributed to the environmental
degradation due to global climate change and demographic
explosion.

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