Available online at https://asric.africa/agricultural-sciences
ASRIC Journal on Agricultural Sciences Vol.5(2)(2024) 32-48

The Effect of Solar Radiation Variability on Climate in Rwanda

Lydie Irababarira[1], David Mihigo[2]

[1]Environmental Sciences Department, European University of Lefke, North Cyprus.
[2]Hangzhou International Innovation Institute of Beihang University, China.
irablydie@gmail.com, mihigodavid7@gmail.com

Received 15 July 2024; revised 14 August 2024; accepted 30 September 2024

Abstract

The research assesses the effect of solar radiation variability on Rwanda's climate. It aims to evaluate factors evaluating insolation, analyze the spatial and temporal distribution of solar radiation and climate then compare their variability with climate extreme indices. A quantitative study was conducted across all 30 districts using high-resolution monthly data. The study incorporated surface shortwave radiation from METEOSAT- SARAH, temperature data from ERA5 reanalysis, and climate indices such as diurnal temperature range (DTR) and number of events per day with at least 20mm of daily precipitation simulated by CMIP models. Statistical calculations were performed using Climate Data Operators, analysis and visualization were done with Grid Analysis and Display System software. The period from 1983 to 2015 was analyzed. Maximum surface shortwave radiation (SSR) values were found in the eastern province while minimum values were found in the north. The maximum temperature was 31.2° C in Nyagatare, and the minimum value was 27.4° C in Nyabihu. (DTR) was the highest in most parts of Rwanda during June-August. The maximum number of events per day with at least 20mm of daily precipitation (R20mm) was 190 in the Rutsiro District in 2009. The study revealed significant correlations between solar radiations and climate extremes. SSR was positively correlated to temperature and negatively correlated to DTR and R20mm indicating its impact on Rwanda's climate.

Keywords: Solar radiation variability, climate, climate extreme indices, correlation, Rwanda

1. Introduction

Life has existed on Earth for at least 3.5 billion years, and the climate has been hospitable enough over that great period for life to continue (Hess, MD, MPH, Malilay, & Parkinson, 2008). The climate of an area is defined as the average weather conditions observed over an extended period, generally over 25 years. Past variations in climate are especially interesting for the climatologist; since they provide clues to the inner workings of the climate system that are difficult to infer in any other way (Gray, et al., 2010). The climate system of the earth determines the distribution of energy and water near the surface and consists primarily of the atmosphere, oceans and the land surface. If past variations in climate can be understood thoroughly, then our chances of anticipating how climate will evolve in the future are greatly increased (Hartmann, 1994).

The Sun is the source of energy for the Earth's climate system, and observations show it to be a variable star (Gray, et al., 2010). The solar variation is the change in the amount of radiation emitted by the sun and in its spectral distribution simply it refers to changes in solar activity (Rind, 2002) ; (Jager, Duhau, & Geel, 2010). There are two major causes of solar variability: one is solar evolution, driven by conditions in the

Sun's core and it speeds up, with large and rapid excursions both in brightness and radius. The other is the magnetic field of the Sun or rather the field located in the solar convection zone and the sun's atmosphere (National Academy of Sciences, 2012).

Solar radiation reaching the earth's surface varies significantly with location, atmospheric conditions including cloud cover, aerosol content, and ozone layer condition, and time of day, earth/sun distance, solar rotation, and activity(Wald, 2018). Since the solar spectra depend on so many variables, standard spectra have been developed to provide a basis for theoretical evaluation of the effects of solar radiation on climate (Iqbal, 1983). The spectrum of solar radiation at the earth's surface has several components. Direct radiation comes straight from the sun, diffuse radiation is scattered from the sky and the surroundings. Additional radiation reflected from the surroundings (ground or sea) depends on the local "albedo." The direction of the target surface must be defined for global irradiance. For direct radiation the target surface faces the incoming beam (Wald, 2018); (CUBASCH & VOSS, 2000).

The atmosphere is a dynamic fluid that is constantly in motion and plays an important role in shielding us from UV radiation, generating weather, and ultimately providing a typical climate. Solar radiation (radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy) rate and direction of motion are influenced by the geographic position of continents, ocean currents, the location and orientation of mountain ranges, atmospheric chemistry, and vegetation growing on land surface (Britannica, 2024);(Vita-Finzi, 2008);(NASA, 2009) (Bais, et al., 2018);(Neale, et al., 2021).

Rwanda's climatology using ENACTS found that rainy day frequency was greater than 1mm/day and extreme rain frequency was greater than 20mm/day in the Nyungwe cloud forest. Over 40% of the annual rainfall occurred in the March–May season, between 30 and 40% occurred in the September–December season, and about 15–20% occurred in January and February with June–August typically having only about 5% of the annual rain (Siebert, et al., 2019). Overall, understanding the growing trends and some of the factors leading to climate change and their impacts in Rwanda, it is a critical first step in tackling climate change's negative effects. Through the research topic the effect of solar radiation variability on climate in Rwanda we were able to see seasonal variability and longer-term climate change that are likely to exacerbate the country's existing vulnerabilities from high poverty and food insecurity because food security and progress of the agricultural sector is of primary concern as the majority of the country's agriculture is rain-fed and produced by small-holder farmers. Therefore, specific objectives of this study are: *(1) To evaluate factors affecting insolation in the region; (2) Spatial distribution and temporal variability of the Rwanda solar radiation; (3) Spatial distribution and temporal variability of the Rwanda climate; (4) Comparison of radiation variability and climate extreme indices variabilities in Rwanda.*

2. Methods, techniques, studied material and area description

2.1 Overview of the Study Area

Rwanda is located in central Africa at latitude 2º 00' S and longitude 30º 00' E. It is a landlocked country bordered by Uganda, Tanzania, the Democratic Republic of Congo (DRC) and Burundi. Rwanda is known as the country of a thousand hills and its mountainous topography creates a wide diversity of climatological and ecological environments, from the lush cloud forests of the mountainous west to semi-arid savannahs in the eastern lowlands (Siebert, et al., 2019). Rwanda is a low-income country, but still ranks as one of the top 30 places in the world to do business (2019) and one of the fastest-growing economies in Africa (TRT World, 2024). Despite the country's positive growth and development, Rwanda is still highly vulnerable to impacts from climate change through its high dependence on rain-fed agriculture (World Bank Group, 2021). Rwanda has a tropical climate characterized by its hilly landscape stretching from east to west. The country has four primary climatic regions: eastern plains, central plateau, highlands, and regions around Lake Kivu. The temperature and rainfall climatology of Rwanda are analyzed at both annual and seasonal timescales as are the climatological influences of topography and regional winds (World Bank Group, 2021);(Safari, 2012). This study covered all 30 districts of Rwanda where the relationship between the spatial and temporal variability of solar radiation and climate extreme indices was assessed. Thus Figure 1 demonstrates the country of Rwanda as a study area map.

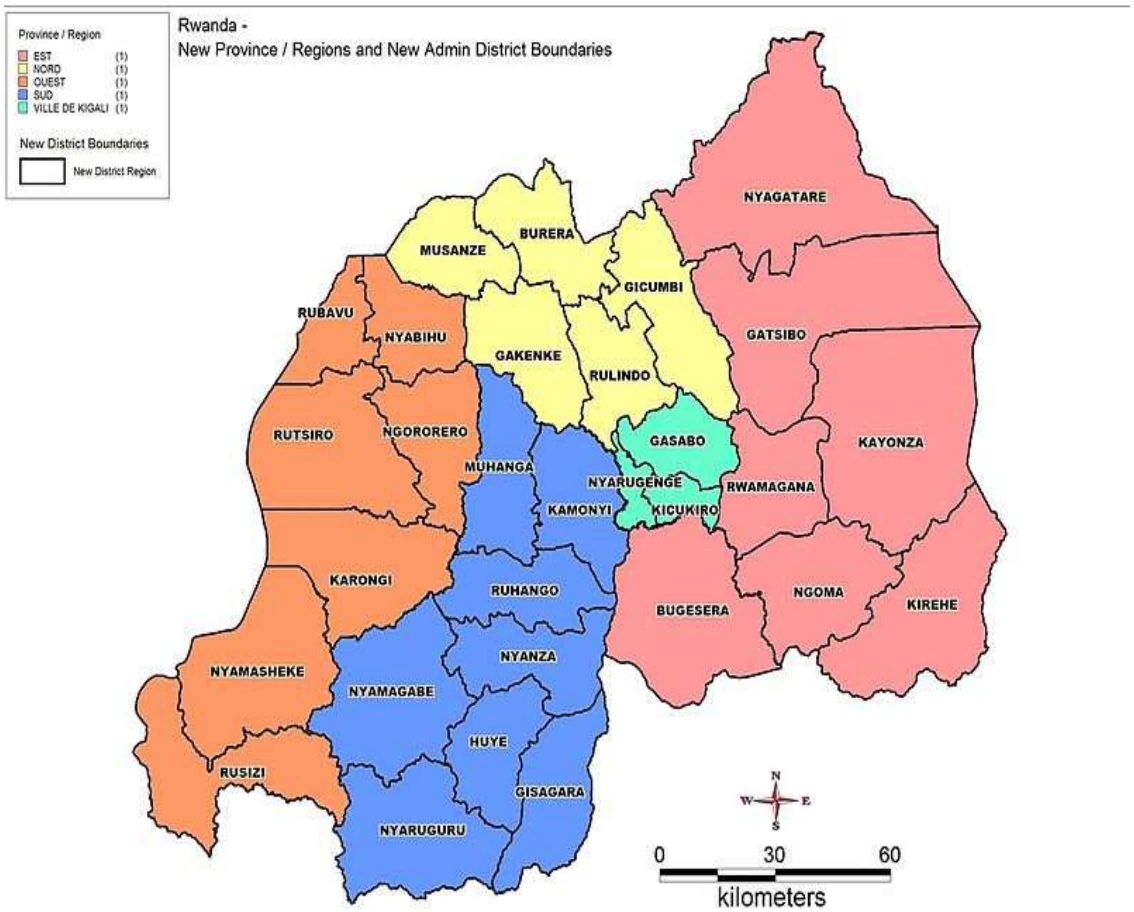

Figure 1: Study area Map (Country of Rwanda)

Source: (Wikimedia Commons, 2024).

2.2 *Data Collection Procedures and Analysis*
2.2.1 Data Collection Procedures

The following data and software were used in this research:

- The surface direct shortwave flux observed from 1983 to 2015 with a spatial resolution of 0.05˚×0.05˚ observed by METEOSAT-SARAH satellite;
- The meteorological data from ERA5 *European Center* for Medium-Range Weather Forecasts (*ECMWF*) reanalysis from 1983 to 2015 with a spatial resolution of 0.25˚× 0.25˚for temperature data;
- The Climate Data Operators (CDO) software was used for statistical calculations while the Grid Analysis and Display System (GrADS) software was used for analysis, visualizing and plotting spatial maps and trendy variability.
- The rainfall and temperature climate extreme indices simulated by CMIP3 and CMIP5 models based on the Expert Team on Climate Change Detection and Indices (ETCCDI) from 1983 to 2015 of 0.25˚ × 0.25˚spatial resolution; in this study temperature, diurnal temperature range which is the difference between the maximum temperature recorded during the day and the minimum temperature recorded

during night and number of events per day with at least 20mm of daily precipitation were chosen as climate extreme indices.

2.2.2 Data Analysis

The temporal analysis methods were used to assess the variability of surface shortwave radiation, temperature, diurnal temperature range, and number of events per day with at least 20mm of daily precipitation (R20mm) and their corresponding trend. The temporal analysis consisted of determining the variability of the above parameters per province and subjected to a time series analysis. Due to the topic being the effect of solar radiation variability on climate in Rwanda, to compare trends of annual flow surface shortwave radiations and temperature (DTR, rainfall (monthly climatology average)) the usage of two y-axes with an independent variable on the right-hand side and a depending one on the left-hand side where the baseline period of 33 years was used as an x-axis from 1983 to 2015 in 30 districts. The advantage of this method is that it provides quick visual observation of the presence of a trend in a given time series. Also, plotting maps were implemented to assess the spatial distribution of the climate extreme indices as well as surface shortwave radiation. The correlation analysis was also adopted to statistically know how surface shortwave radiation affects our climate through its impact on the climate extreme indices. This analysis is based on negative and positive correlations and then assessing the highest values and the minimum ones in respective provinces.

3. Results

3.1 Presentation of the results

3.1.1Seasonal spatial maps

Rwanda's climate season is made of dry and wet seasons they are short and long dry (wet) seasons. The long dry season starts in June and ends in August (JJA) while the short dry season starts in January and ends in February (JF) the long-wet season starts in March and ends in May (MAM) and its shortest starts in September and ends in December (SOND).

3.1.1.1 SSR Seasonal maps

The spatial map labeled as Figure 2 was used to illustrate the surface shortwave radiation annual variability over Rwanda from 1983 to 2015, in the dry and wet seasons.

Dry seasons.

Normally when comparing the long dry to the short dry season one could easily say that by observation JJA should be the one having the highest value of SSR received. The spatial map shows that JF especially the eastern part has much SSR compared to JJA and this is meaningful and possible because even though the JF dry seasonal is short, it doesn't imply that throughout that period they didn't receive the sun with so much intensity compared to the JJA in the eastern part of Rwanda. The north-west and south regions of Rwanda show that they receive less amount of shortwave radiation on the surface and this is justified because the southwest part is with Nyungwe forest which blocks these radiations from reaching the surface and for north-west is made of the volcanoes which leads to topographic shading comprised of two components: shaded relief and cast shadows where the shaded relief due to slope and aspect occurs when a surface is blocked from the sun's rays due to its relief while the cast shadows that occur when solar rays project shadows from one topographic feature onto another, which occurs commonly in valleys surrounded by steep valley walls. With this shaded relief it can clearly explain the reduction in the received amount of shortwave radiation in this region and also for the cast shadows the intensity of shortwave radiation decreases as well thus explain clearly what is observed in those regions in Figure 2.

Wet seasons.

Solar radiation warms the atmosphere and is fundamental to atmospheric composition, while the distribution of solar heating across the planet produces global wind patterns and contributes to the formation of clouds, storms, and rainfall. The wet season is comprised with significant rainfall which means this season quite faces many clouds which blocks the shortwave radiation from reaching the surface. When comparing SOND to MAM, SOND shows that it received so much SSR compared to MAM and this goes by the fact that SOND is the short-wet season while MAM is the long-wet season meaning that within MAM, Rwanda is covered with clouds than in SOND so the cloud cover limits the emitted radiation from reaching the earth that’s why compared to the dry season (JF and JJA) we can see a decrease in SSR in the Northern, Western and some part of the southern province. Thus, Figure demonstrates SSR seasonal variability spatial maps since 1983-2015.

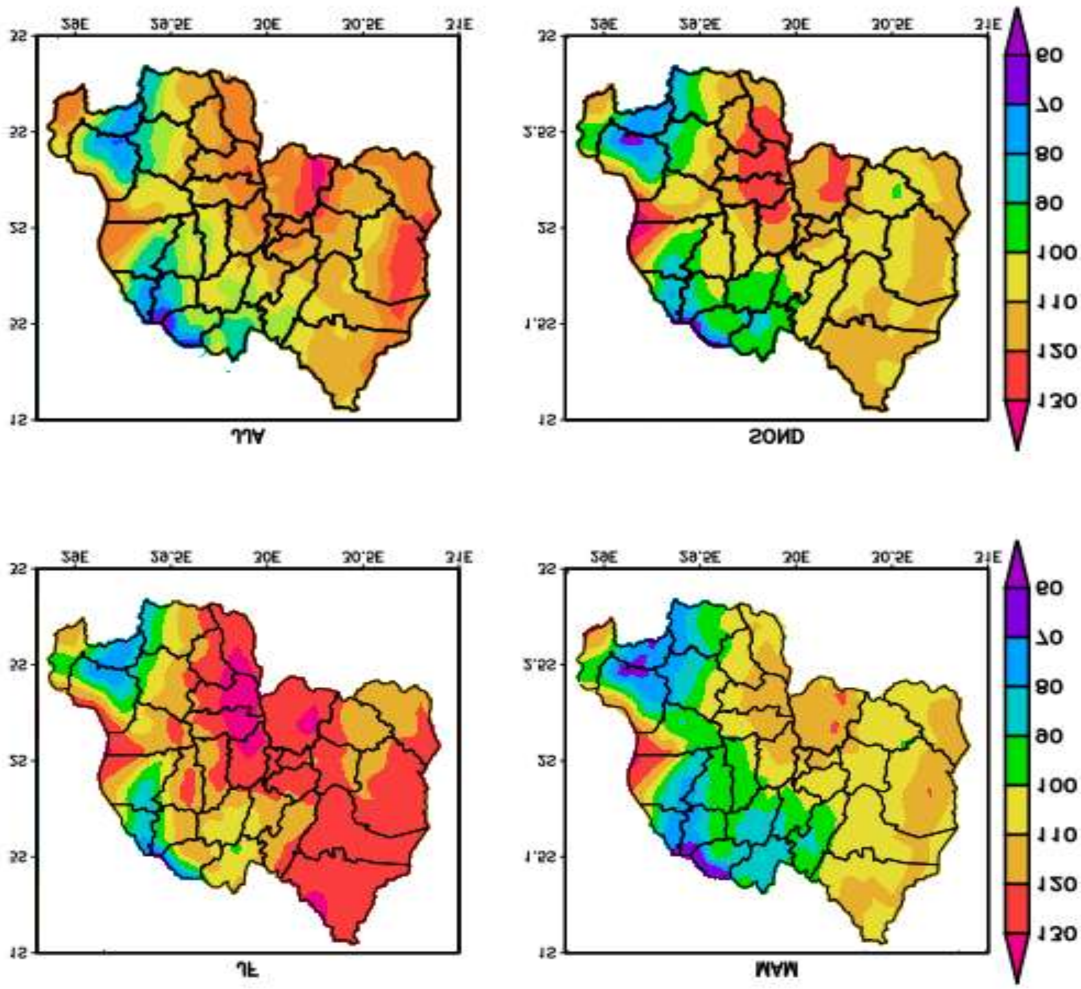

Figure 2: SSR seasonal variability spatial maps since 1983-2015.
Source: Author, 2022

3.1.1.2 Temperature Seasonal Variation

Rwanda’s average temperature varies according to its topography and seasons. Low temperatures are observed in the regions of high altitude with average temperatures ranging between 27.6 and 29.4°C. Moderate temperatures are found in areas with intermediary altitudes where average temperatures vary between 29.4 and 30°C. In the lowlands (east and southwest), temperatures are higher and the extreme can go beyond 30°C in JF and JJA. Figure 3 shows the temperatures across the country for seasons.

Dry season.

In dry seasons generally, the temperature range is high compared to wet seasons, and this is because there are no clouds in these seasons to block the incoming solar radiation. The eastern province, Kigali City and some districts in the northern (Gicumbi and Rulindo) and in the southern province (Kamonyi, Ruhango, Nyanza, Gisagara, and a large part of Huye district) experienced a temperature above 30.6^{0}C in both JJA and JF except southwest part of Rwamagana, Ngoma, Kirehe and east part of Bugesera having a decrease in temperature in JF where they had a temperature variation between 30.3 to 30.6^{0}C. The northwestern part of Rwanda experiences a low temperature where it ranges between 27.6 to 29.4^{0}C and the rest part of the western province, has a temperature above 29.7^{0}C but doesn't exceed 30.3^{0}C this is applied to Musanze and Gakenke in the northern province and Muhanga, Nyamagabe, and Nyaruguru in the southern province.

Wet seasons.

During the wet seasons, clouds are often seen and this is part of the causes of the sudden decrease in the received amount of solar radiation thus tending to a drop-in temperature. In MAM, the eastern province, Kigali City, Southern province and southwestern province experienced temperature between 30 to 30.3^{0}C except for Nyagatare whose range was between 30.3 to 30.6^{0}C and this clearly shows a decrease in temperature for semi-arid region throughout this long-wet season. For the highland's region, the temperature didn't vary that much compared with the temperature they had in the dry seasons which quite shows that the temperature variation is almost the same across the country throughout the year. In SOND a significant change in temperature is seen when comparing both SOND and MAM. This change is seen in Kamonyi, Muhanga, Ruhango, Nyanza, Huye, Gisagara and in large parts of Kigali city, Bugesera, Rulindo and Gicumbi where they have increased by 0.3^{0}C than in MAM. Figure 3 shows temperature seasonal variability spatial maps since 1983-2015.

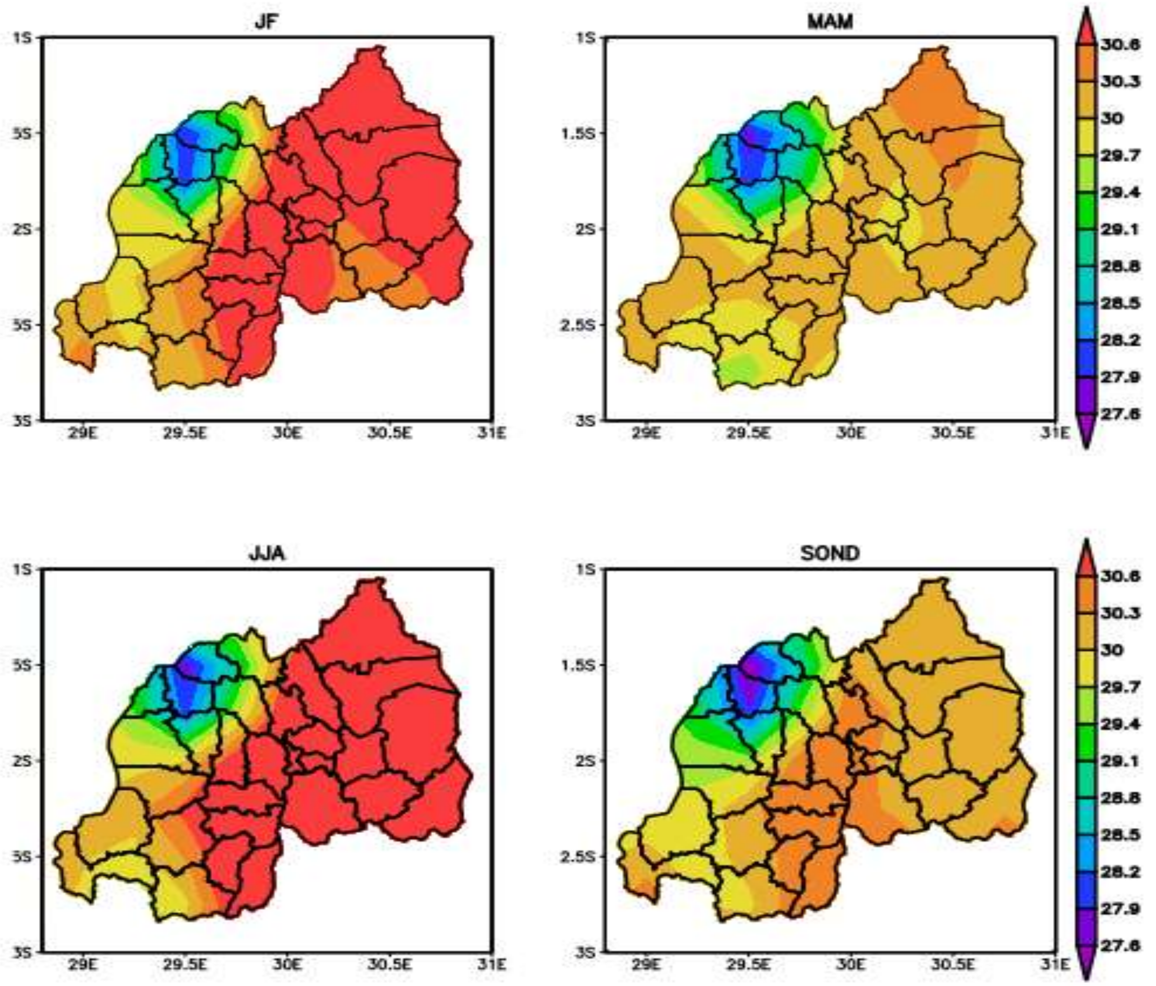

Figure 3: Temperature seasonal variability spatial maps since 1983-2015.
Source: Author, 2022

3.1.1.3 Diurnal Temperature Range Seasonal Maps

In meteorology, diurnal temperature variation is the variation between a high air temperature and a low temperature that occurs during the same day. The diurnal range of temperature generally as shown in the DTR seasonal spatial maps increases with distance from the west to the east regardless of the seasons because where solar radiation reaching the surface is strong due to the topography found in the eastern province. The diurnal temperature range strongly rely on the seasons because cloud cover plays an important role in having a maximum and minimum temperature as shown in Figure 4.

Dry seasons.

Dry seasons where the maximum temperature is high and minimum temperature low compared to wet seasons, is because throughout these seasons the coming radiation isn't blocked by clouds thus receiving so much radiation that warms the earth tending to have a high temperature during the day and the night because they are no clouds present to block the emitted longwave radiation the earth loses its warmth thus leading to having a low minimum temperature. So, this significant difference in temperature variation during the same day, causes the DTR in dry seasons to be higher than in the wet seasons. In JJA, the average difference between the day's highest and lowest temperatures was 12 °C while in JF it was between 10.5 to 12°C.

Wet seasons.

Wet seasons is mostly characterized with having many clouds that gets to produce rainfall. These clouds during the day block some incoming solar radiation and those that manage to reach the earth warm the earth at a low rate comparatively when they would be if some radiation hadn't been blocked thus leading to having a low maximum temperature during the day. At night time due to cloud cover, the reflected longwave radiation is entrapped by the clouds some return back at the surface to warm the earth during night time thus making the minimum temperature a little bit higher than when there would be no clouds during the night. The eastern province faces a range of 10.8 to 11.7^{0}C, part of Kigali city mostly in the Gasabo district their DTR was between 11.1 to 11.4^{0}C while the rest was between 10.8 to 11.1^{0}C; the northern province, the southern province, and the western province ranges between 10.2 to 11.1^{0}C and while districts that bothers the lake Kivu their DTR is below 10.2^{0}C in MAM. In SOND, most regions have an increase in DTR which is justified due to a decrease in cloud cover during this season. The variation in DTR in the western province and some districts of the southern province that touches lake Kivu have a diurnal temperature range of 10.8 to 11.1^{0}C, the rest districts in the southern province, Musanze and Gakenke in the northern province, Kirehe in the eastern province had a range of 11.1 to 11.4^{0}C; for Kigali city, Burera, Rulindo and Gicumbi in the northern province and the rest of eastern province had a variation range of 11.4 to 11.7^{0}C and above 11.7^{0}C for Gastibo and Nyagatare districts throughout SOND. Thus, Figure 4 stipulates DTR seasonal variability spatial maps from 1983-2015.

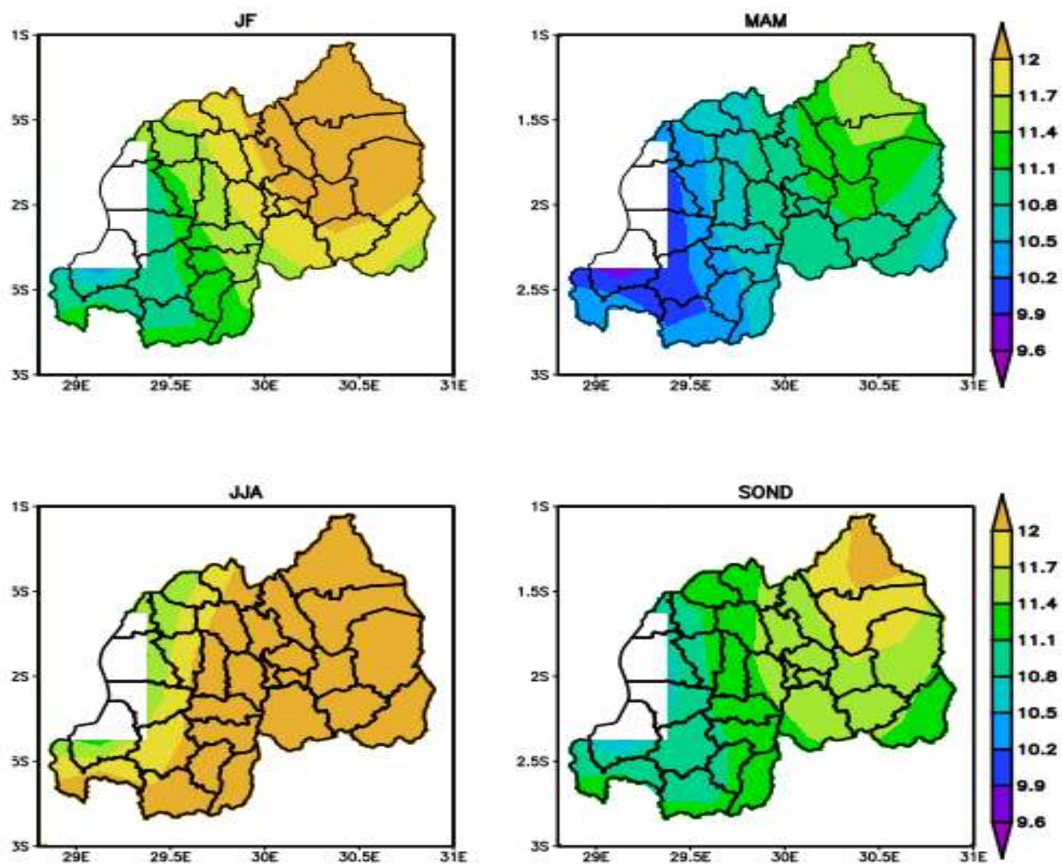

Figure 4: DTR seasonal variability spatial maps since 1983-2015.

Source: Author, 2022

3.1.1.4 R20mm Seasonal Spatial Map

Analysis of rainfall trends has shown an increasing occurrence of extremes over time and in various regions of the country. Rainy seasons are becoming shorter and more intense, especially in the northern and western provinces, which increases erosion risks in these mountainous parts of the country. Eastern regions have experienced serious rainfall deficits in several years over previous decades, alternating with rainfall excesses in other years.

Dry seasons.

In both short and long dry seasons, it is quite normal to have a few days that have rainfall with at least 20mm. Regarding the JF the R20mm days increased westward where there are the Gishwati and Nyungwe forest which attracts rainfall thus making this southwest area having days with at least 20mm in JF. The whole eastern provinces have days less than 12 with R20mm, which quite the same for a great part of the Northern Province. For Kigali City its variation is between 12 to 13 days and the province with the highest number of days is Western province in Rusizi district where during the JF period, they received R20mm for 16 to 17 days throughout the baseline period. The long dry season JJA, the whole country throughout 1983 to 2015 experienced R20mm for days less than 12.

Wet season.

For the wet seasons there is a remarkable change in colors as shown in Figure 5 whereby for both long and short wet seasons throughout 1983 to 2015, the R20mm have exceeded 12days as the color bar indicates except during SOND in the south-east part which has a small region near the borders where the days were below 12. Both MAM and SOND share the same maximum of 18 days with at least rainfall of 20mm with the minimum being 14 days and below 12 days for MAM and SOND respectively. These days are quite immense because such rainfall is intense and results in increased erosion risk in mountainous areas of the country.

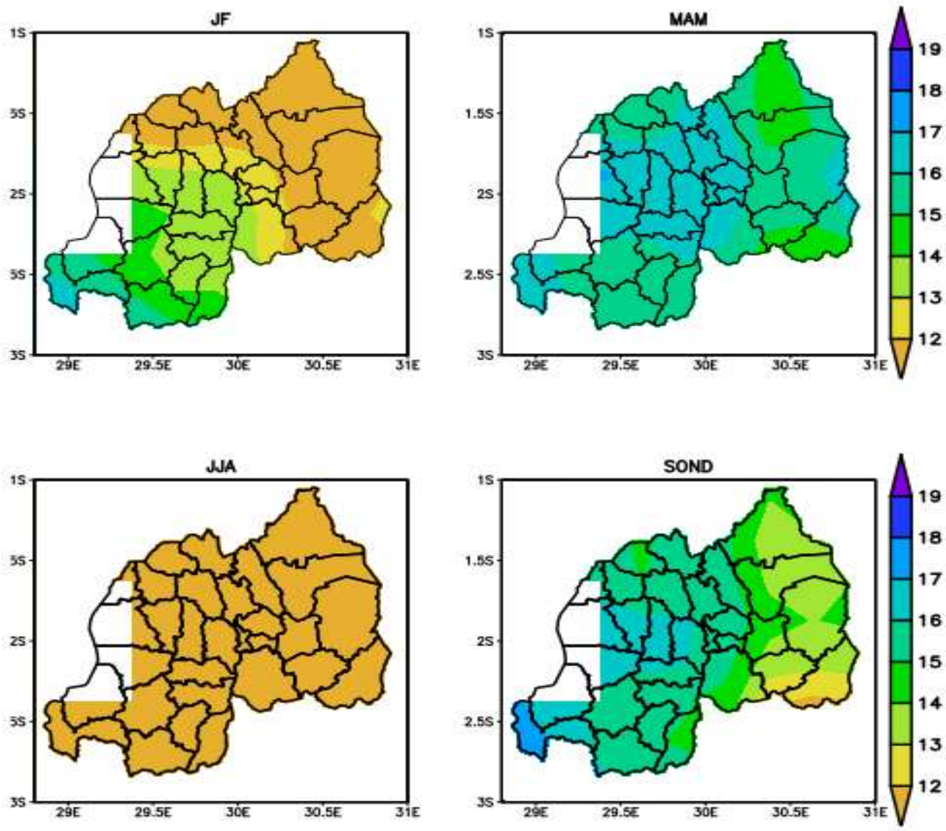

Figure 5: R20mm seasonal variability spatial maps since 1983-2015.
Source: Author, 2022

3.1.2 Trend Analysis

Trend analysis is necessary to determine the presence of significant trends in a climate index, and to quantify the magnitude of trends in a dataset. The trends in datasets can either be monotonic, where a variable consistently increases or decreases through time, or a step trend, where abrupt changes in data may occur at a specific time. Various studies on some parameters such as Temperature (T), Diurnal temperature range (DTR) and number of events per day with at least 20mm of daily precipitation (R20mm) were put in comparison with surface shortwave radiation (SSR) to see how its variation affects these parameters. The solid line indicates the SSR while the broken line indicates the dependent parameter.

3.1.2.1 SSR-T Trend Analysis

Trend analysis of surface shortwave radiation (SSR) and Temperature (T) was done with 33 years of temperature data from Copernicus (1983-2015) along with 33 years of surface shortwave radiation data from METEOSAT-SARAH (1983–2015). SSR and T indicate a warming trend whereas the years pass the average annual temperature increases. This finding of increase in temperature agreed with the report of the Inter-governmental Panel on Climate Change (IPCC) (2013) which states clearly that temperature trends on a global scale show a warming of 0.85 (0.65-1.06) °C, over the period 1880–2012 (The Core Writing Team & Meyer, 2015).

Eastern Province.

In the east part of Rwanda, the maximum temperature they got over a period of 33 years was 31.2^0C in Nyagatare district in 2005 while the minimum was 29.6^0C in 1985 and it was in Kayonza district. Regarding the amount of solar radiation received the maximum was 134.1 W/m^2 in Bugesera in 2015 while it is minimum 120.7 W/m^2 in Ngoma in 2013. The presented Figure 6 indicates that the eastern province SSR-

T trend exhibit an upward trend. This implies that surface shortwave radiation and temperature increase over the period of 1983 -2015.

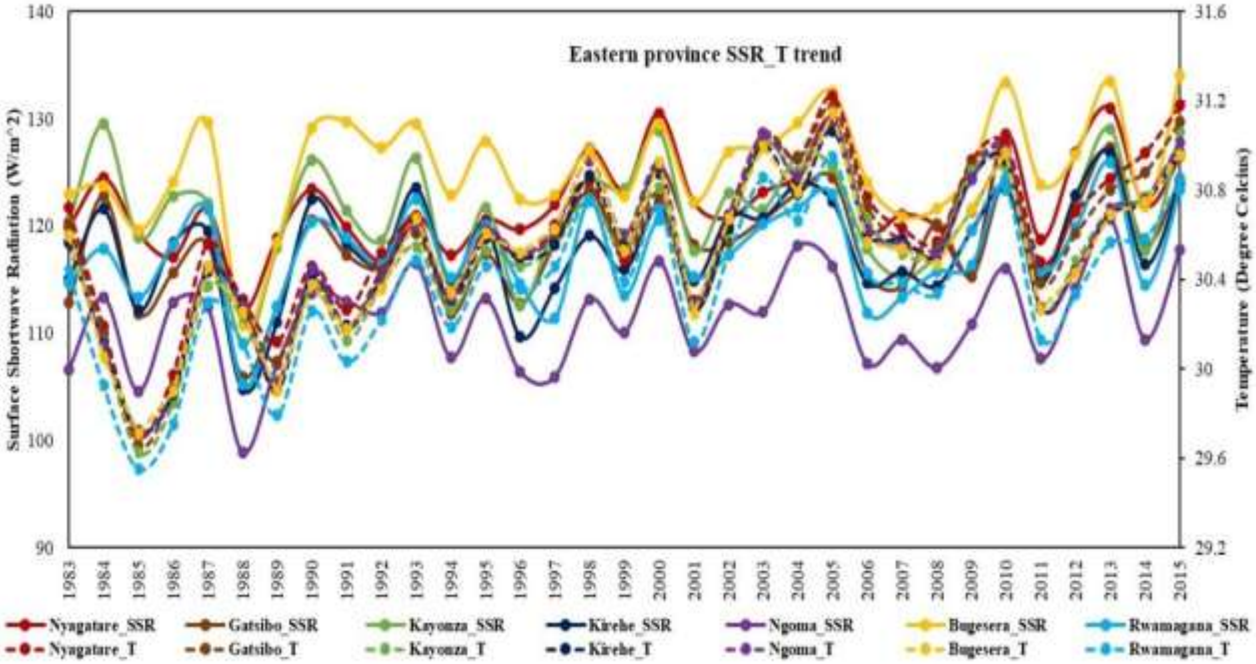

Figure 6: SSR and T trend of the Eastern Province in Rwanda.
Source: Author, 2022

Kigali City.

For Kigali City the Figure 7 shows, the maximum temperature was found to be in 2005 in Nyarugenge district which is 31.3^{0}C whereas the minimum temperature was in 1985 in Kicukiro district at a degree of 29.7^{0}C. Kigali City received a maximum SSR of 128.6 W/m^2 in 2013 and this was in Nyarugenge district while the minimum observed was 102.1 W/m^2 in 1998 and it was in Gasabo district. In general, for the SSR-T trend for Kigali City, there was a remarkable decline of temperature in 1985 and an increase in 2005 for the three districts. It can be concluded that the trend analysis of annual SSR-T for Kigali city shows a positive trend and statistical significance due to the fact that as years pass the warmer the globe becomes due to destruction of ozone layer as well as increased greenhouse gases. Thus, the increasing trend of temperature due to surface shortwave radiation variability and other factors can lead to weather extremes in the capital city.

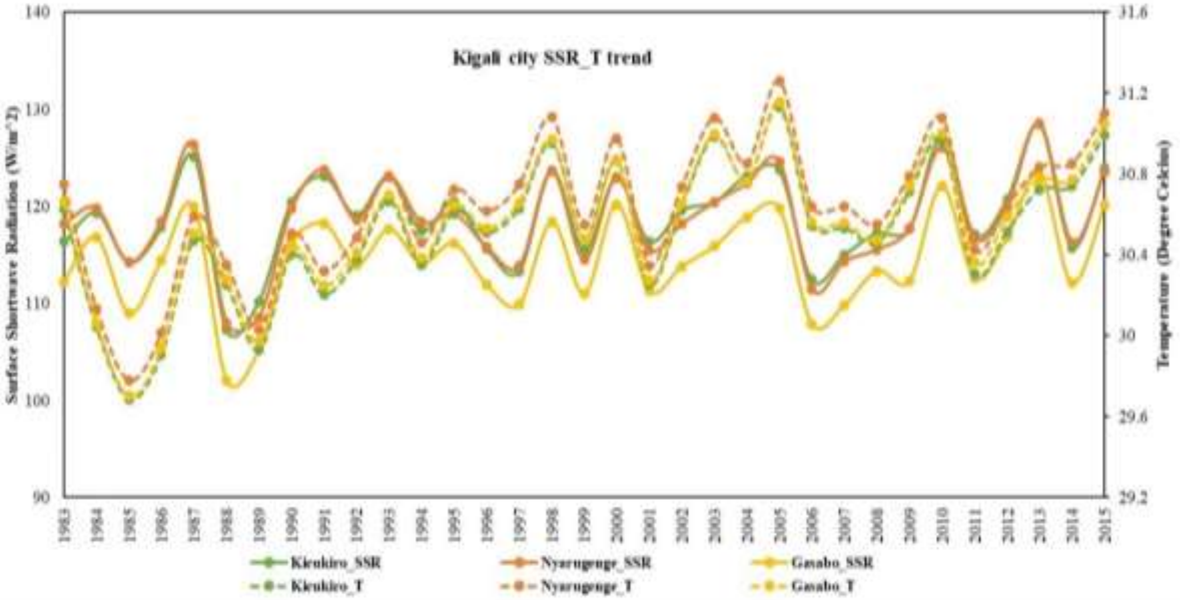

Figure 7: SSR and T trend of the Kigali City in Rwanda.
Source: Author, 2022

Northern Province.

In the Northern part of Rwanda as Figure 8 indicates, the maximum temperature obtained over this period (1983-2015) was 31.1^{0}C in the Gicumbi district in 2005 while the minimum was 27.9^{0}C in 1985 and it was in Musanze district. Regarding the amount of solar radiation received the maximum was 117.3 W/m^2 in Gicumbi in 2013 while its minimum was 69.5 W/m^2 in Musanze in 1988. When observing the trend, the variation of SSR is in the range of 60-120 W/m^2 and its low compared to the rest of other provinces where it is justifiable due to its topography which mountainous thus making the amount reaching the low and making the temperature low as well.

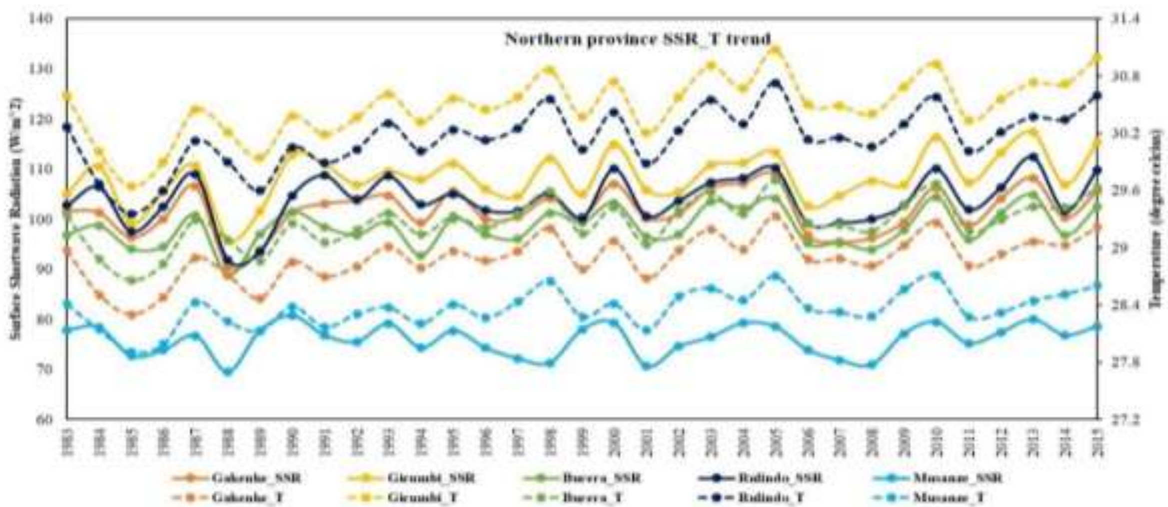

Figure 8: SSR and T trend of the Northern Province in Rwanda.
Source: Author, 2022

Southern Province

The annual value of minimum temperature and maximum temperature for the period of 33 years, (1983 to 2015) were analyzed for trends. From the Figure 9, the maximum temperature was 31.2^0 C in 2005 in Nyanza district, the minimum temperature was 29.3^{0}C in 1985 in Nyaruguru district and for the SSR the maximum was 136.1 W/m^2 in Gisagara and that was in 2013 while it is minimum was 87.7 W/m^2 in 1985 and it was seen in Gisagara district and there was a warming trend, although the changes were very small. This implied that values of surface shortwave radiation and temperature in the southern province would keep on increasing.

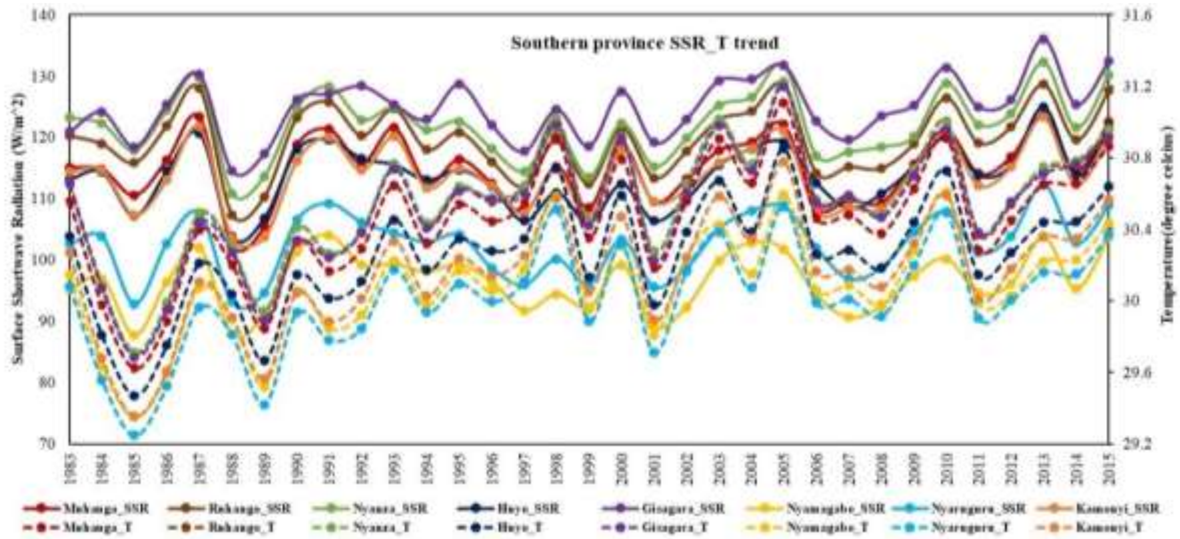

Figure 9: SSR and T trend of the Southern Province in Rwanda.
Source: Author, 2022

Western Province

Figure 10 shows the actual, trend lines of SSR and temperature in Western province (1983–2015). The trend lines show an upward (positive) trend. This implies that there is an increase in the values of temperature and surface shortwave radiation. The maximum temperature observed was 30.7^{0}C in 2005 in Nyamasheke district while the minimum was 27.4^{0}C in 1985 in Nyabihu district; for the SSR, the maximum was 122.9 W/m^2 and the minimum was 74.9 W/m^2. In addition, no definite break in the trend of SSR-T is observed, although the values fluctuate. The rate of increase in trend is very small. However, an increase in SSR and T leads to climate change which can negatively affect weather and consequently cause many climatological hazards like drought.

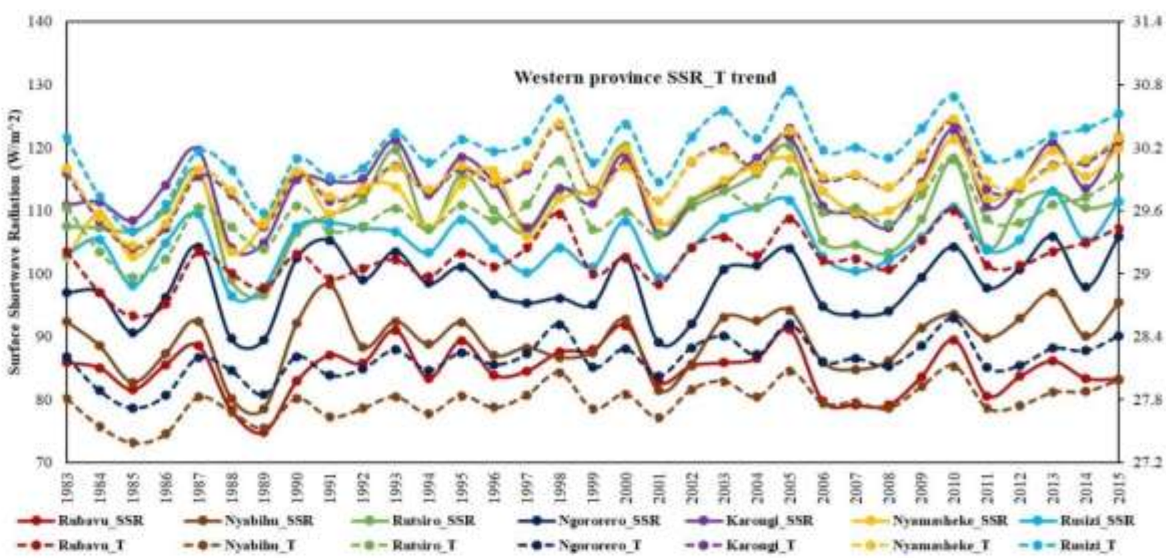

Figure 10: SSR and T trend of the Western Province in Rwanda.

Source: Author, 2022

3.1.3 Correlation Analysis

Correlation Analysis is a statistical tool for determining whether or not two variables/datasets have a link and how strong that relationship is. As the research topic is about the effect of solar radiation variability on climate in Rwanda, temperature, diurnal temperature range, and R20mm was chosen. Temperature is positively correlated to surface shortwave radiation while for DTR and R20mm, they are negatively correlated to SSR.

3.1.3.3 R20MM Correlation Analysis

R20mm indicates the number of events per day rainfall greater or equal to 20mm has fallen. Rainfall is an imperative condition to lead to the decrease in received amount of solar radiation due to cloud cover. SSR_R20mm is negatively correlated because as the SSR increases then the chances of getting R20mm decreases. In Kigali city, the highest correlation value was -0.24 found in the Gasabo district, in the eastern province it was -0.49 in the Nyagatare district, for the southern province it was in the Gisagara district with a value of -0.39 while for the northern province it was in Burera district with a value of -0.34 and for the western province the highest value was -0.29 in Ngororero district. Therefore, Figure 11 stipulates correlation.

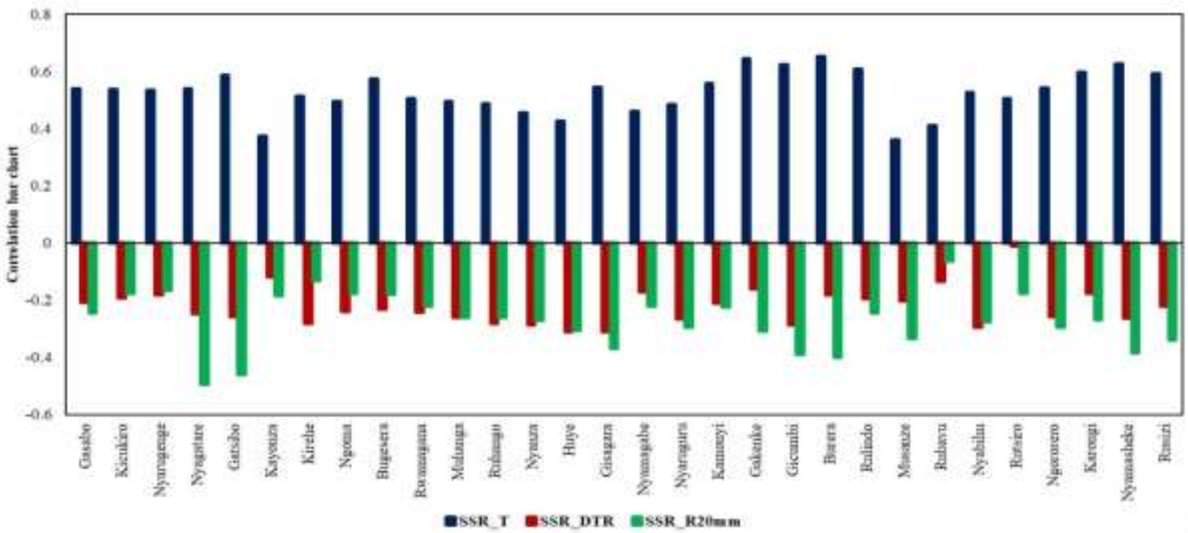

Figure 11: Correlation bar chart
Source: Author, 2022

4. Discussion

The results of this research were discussed in recognition of what was mentioned in the literature review. Findings indicate an impact of surface shortwave radiation on climate variables. Variability in surface shortwave radiation leads to a changing climate which leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes (Easterling, et al., 2012). The trend analysis showed an increase in temperature and DTR throughout the baseline period (1983-2015) whenever the SSR was increasing, and also it also showed an increase in intensity and frequency of rainfall as the literature review mentioned through an increase in number of events per day with rainfall atleast greater than 20mm (R20mm).

The first objective was about evaluating factors affecting insolation in the region and topography, cloud cover were mainly the basic factors that affects our insolation (Muhire, Ahmed, & Abutaleb, 2014). The seasonal spatial maps and trend analysis these two based on parameters were clearly seen affecting insolation where by in the north-western part of Rwanda there is a drop in temperature and received amount of solar radiation due its topography and for wet seasons, either long or short due to the presents of clouds, the surface solar radiation decreases across the country (REMA, 2009).

The second objective concerning spatial distribution and temporal variability of the Rwanda solar radiation variability was achieved. Generally, it was observed that on average, there was a steady rise in SSR and Temperature and there was an increase in the intensity of rainfall across the country. A significant incline in temperature was registered mainly over the eastern region and the number of rainy days decreased significantly over the eastern and central plateau. The Diurnal temperature range was found to increase sharply in all over the country and this increase is especially seen in JJA and the increase in DTR is eastward. The wet areas located in the highlands and around Kivu Lake as well as Kigali city and the southern province have high number of events per day with R20mm compared to the rest of the country's seasons in MAM followed by SOND. The highlands were consequently experiencing more flooding, with the eastern lowlands and the central plateau becoming warmer. The third objective was spatial distribution and temporal variability of the Rwanda solar radiation variability. The maximum SSR was 136.1 W/m^2 in Gisagara district where as the minimum value was 69.5 W/m^2 in the Musanze district and JJA seasons were the one with the highest amount of Solar radiation received. These two values from the trends, as well as observations, confirm shows that true insolation is affected by the relief of a particular region.

The fourth objective was about the Comparison of solar radiation variability and climate extreme indices variabilities in Rwanda. Low temperatures were observed in the regions of high altitude with average temperatures ranging between 27.6 and 29.4°C. Moderate temperatures were found in areas with intermediary altitudes where average temperatures varied between 29.4 and 30°C and in the lowlands, temperatures were higher and the extreme could go beyond 30°C in JF and JJA. Regarding the diurnal temperature range, each year they were a rise in SSR, DTR was also forming a crest even though it was not at the same rate but if this increase in SSR continues, the correlation between these will end up being positive contrary to R20mm where the increase in SSR showed a decrease in R20mm and as other findings had said, the dry seasons tending to become longer than wet seasons (Ngarukiyimana, et al., 2017). According to climatic projections concerning rainfall and temperature in the 2050s, where there is high chance of reaching 35^{0}C and having more intense rainfall, if no serious measures are taken then as an agricultural based country we will be facing measure problems because we have already started to have temperature variations which are already in 30s and intense rainfall whereby we even reached a frequency of 190 events per day with rainfall at least greater than 20mm (Richardson, Calow, Pichon, New, & Osborne, 2022). The discussion of research results conducted the researcher to confirm that the solar radiation variability affects the climate of Rwanda but not in scandalous way that leads to these floods and droughts Rwanda is facing from time to time, but they must find a new way to collect solar radiation data all over the country so as to readapt to trustworthy source of data for they are useful for researchers as well as for climatologists.

5. Conclusion and Recommendations

5.1 Conclusion

The baseline period analysis of the effects of solar radiation variability on climate in Rwanda has shown significant trends in maximum and minimum temperature, diurnal temperature range, and R20mm during the period from 1983 up to 2015. The correlation analysis of these datasets with time series for some districts exhibited a weak negative correlation between SSR and climate extreme indices such as R20mm and DTR variables because as the SSR variable increased in value, the R20mm and DTR variable would decrease in value which means that SSR_DTR and SSR_R20mm were negatively correlated while for temperature and SSR they were positively correlated. The analyses of data from trends representing the study area showed an average maximum of surface shortwave radiation being 127.8W/m^2 and the average minimum being 86.6W/m^2 with significantly increasing trends in maximum and minimum temperature where the average maximum temperature was seen to be 31.1^{0}C and average minimum to be 28.7^{0}C and these both goes in accordance to the projection manifested during analysis of projected temperature datasets (Richardson, Calow, Pichon, New, & Osborne, 2022). The average maximum and minimum diurnal temperature range was 13.1^0C and 5.3^0C respectively which tends to increase if the temperature rate increases as it is positively correlated and negatively correlated to rainfall and this led to having seen the average maximum and minimum of R20mm being 180.85 and 80.75 respectively. Rwanda as the part of the most vulnerable country concerning the aspect of climate, it is a necessity to understand the climate extremes which are climatologically rare events depending on how they negatively affect the society and the environment. It is therefore important to know the limitations and ability of society and the environment to cope with climate extremes without serious stress.

5.2 Recommendations

The variation of surface shortwave radiation impacts, directly affects our climate as shown in this research and it is highly recommended to do deep research concerning to what extent it does affect the climate. Rwanda is also ranked as the top country being vulnerable as other research has shown so it is in this aspect, that We would recommend having ground data information concerning the received amount of solar radiation for further research and also reinvesting in research concerning, factors affecting climate in Rwanda and the impact of cloud cover to incoming solar radiation in Rwanda.

References

Bais, F., Luca, R. M., Bornman, J. F., Williamson, C. E., Sulzberger, B., Austin, A. T., . . . Taki, Y. (2018, February 14). Environmental Effects Of Ozone Depletion, Uv Radiation And Interactions With Climate Change: Unep Environmental Effects Assessment Panel, Update 2017. Environmental Protection Agency, 127–179. Doi:10.1039/C7pp90043k

Britannica. (2024 , September 27). Climate Change: Facts & Related Content. (I. Britannica, Producer) Retrieved From Britannica: Https://Www.Britannica.Com/Facts/Climate-Change

Cubasch, U., & Voss, R. (2000, March 7). The Influence Of Total Solar Irradiance On Climate. Kluwer Academic, 185–198.

Easterling, D., Goodess, C. M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., . . . Zhang, X. (2012). Changes In Climate Extremes And Their Impacts On The Natural Physical Environment.

Gray, L. J., Beer, J., Geller, M., Haigh, J. D., Lockwood, M., Matthes, K., . . . White, W. (2010, October 30). Solar Influences On Climate. American Geophysical Union, 1 - 53. Doi:10.1029/2009rg000282.

Hartmann, D. L. (1994). Global Physical Climatology. London : Academic Press. Retrieved From Http://Www.Academicpress.Com

Hess, J. J., Md, Mph, Malilay, J. N., & Parkinson, A. J. (2008). Climate Change The Importance Of Place. American Journal Of Preventive Medicine, 468–478. Doi:10.1016/J.Amepre.2008.08.024

Iqbal, M. (1983). An Introduction To Solar Radiation. Canada: Academic Press Canada.

Jager, C. D., Duhau, S., & Geel, B. V. (2010, May 27). Quantifying And Specifying The Solar Influence On Terrestrial Surface Temperature. Elsevier Ltd., 926–937. Doi:10.1016/J.Jastp.2010.04.011

Muhire, I., Ahmed, F., & Abutaleb, K. A. (2014, October 14). Relationships Between Rwandan Seasonal Rainfall Anomalies. Springer. Doi:10.1007/S00704-014-1299-4

Nasa. (2009, January 14). Climate And Earth’s Energy Budget. Retrieved From Earth Observatory: Https://Earthobservatory.Nasa.Gov/Features/Energybalance

National Academy Of Sciences. (2012). The Effects Of Solar Variability On Earth's Climate. Washington, Dc: National Academies Press. Retrieved From Https://Nap.Nationalacademies.Org/Read/13519/Chapter/2

Neale, R. E., Barnes, ·. P., Robson, T. M., Neale, P. J., Williamson, C. E., Zepp, R. G., . . . Bruckman, ·. L. (2021, January 20). Environmental Efects Of Stratospheric Ozone Depletion, Uv Radiation,And Interactions With Climate Change: Unep Environmental Efects Assessment Panel, Update 2020. Perspectives. Doi:10.1007/S43630-020-00001-X

Ngarukiyimana, J. P., Fu, A. Y., Yang, Y., Ogwang, A. B., Ongoma, V., & Ntwali, D. (2017, May 12). Dominant Atmospheric Circulation Patterns Associated With Abnormal Rainfall Events Over Rwanda, East Africa. International Journal Of Climatology, 16. Doi:10.1002/Joc.5169

Rema. (2009). Rwanda State Of Environment And Outlook: Summary For Decision Makers. Kigali: Rwanda Environment Management Authority (Rema).

Richardson, K., Calow, R., Pichon, F., New, S., & Osborne, R. (2022). Climate Risk Report For The East Africa Region. Uk: Met Office. Retrieved From Www.Metoffice.Gov.Uk

Rind, D. (2002, April 26). The Sun's Role In Climate Variations. Science , 296(5568), 673-677. Doi:10.1126/Science.1069562

Safari, B. (2012, June). Trend Analysis Of The Mean Annual Temperature In Rwanda During The Last Fifty Two Years . Journal Of Environmental Protection, 538-551. Doi:10.4236/Jep.2012.36065

Siebert, A., Dinku, T., Vuguziga, F., Twahirwa, A., Kagabo, D. M., Delcorral, J., & Robertson, A. W. (2019, February 10). Evaluation Of Enacts-Rwanda: A New Multi-Decade, Highresolution Rainfall And Temperature Data Set—Climatology. International Journal Of Climatology, 3104 – 3120. Doi:10.1002/Joc.6010

The Core Writing Team, R. K., & Meyer, L. (2015). Climate Change 2014 Synthesis Report. Intergovernmental Panel On Climate Change. Switzerland: Intergovernmental Panel On Climate Change (Ipcc). Retrieved From Http://Www.Ipcc.Ch

Trt World. (2024, September 27). What Makes Rwanda One Of Africa's Fastest Growing Economies? Retrieved From Trt World: Https://Www.Trtworld.Com/Magazine/What-Makes-Rwanda-One-Of-Africa-S-Fastest-Growing-Economies-23410

Vita-Finzi, C. (2008). The Sun: A User's Manual. London : Springer. Doi:10.1007/978-1-4020-6881-2

Wald, L. (2018). Basics In Solar Radiation At Earth Surface. O.I.E. – Observation, Impacts, Energy Center, O.I.E. – Observation, Impacts, Energy Center. Sophia Antipolis, France: Mines Paristech, Psl Research University. Doi:10.13140/Rg.2.2.36149.93920

Wikimedia Commons. (2024, September 27). File:Rwanda Districts Map.Jpg. Retrieved From Wikimedia Commons: Https://Commons.Wikimedia.Org/Wiki/File:Rwanda_Districts_Map.Jpg

World Bank Group. (2021). Climate Risk Profile: Rwanda. Washington, Dc: World Bank Group. Retrieved From Www.Worldbank.Org