Vulnerability assessment and climate risks in Rwanda

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Abstract

This assessment examines Rwanda's vulnerability to climate change, emphasizing the damages and losses experienced from various climate-related events. Rwanda's geographical characteristics and population density make it particularly vulnerable. The country's topography includes highlands and lowlands, each facing unique climate-related challenges. The Western and Northern Highlands frequently experience heavy rains, landslides, and soil erosion, while the Eastern Province is prone to droughts and prolonged dry spells. From 1971 to 2018, Rwanda has witnessed a steady increase in minimum, mean, and maximum temperatures, alongside increased rainfall variability. Projections for the mid-21st century suggest a temperature rise of 0.9 to 2.2 degrees Celsius compared to 1971-2018 levels, which could intensify rainfall events and lead to more flash flooding, landslides, and soil erosion.

The study assesses the impacts of climate-related disasters from 2016 to 2023, highlighting the increasing frequency and severity of hazards such as floods, droughts, and landslides. Key findings indicate that the Rubavu District in the northwest experienced the highest number of house damages primarily due to floods and landslides, with significant events occurring between May 2nd and May 5th, 2023, affecting over 10,000 households and resulting in 131 fatalities. In contrast, Kirehe District, a drought-prone area, also recorded substantial house damages due to rainstorms and windstorms over the years.

The data underscores the need for tailored disaster preparedness and effective adaptation measures. Lightning strikes emerged as a consistent cause of injuries, peaking at 219 in 2022, followed by rainstorms and floods, which have shown variability in their impacts over the years. The varying impacts of these weather events across different regions highlight the necessity for region-specific strategies to mitigate the risks. Despite Rwanda's efforts to address climate change, the country's development is severely threatened by its geographic and demographic characteristics. The study recommends urgent implementation of adaptation strategies to prevent future damages and enhance resilience against climate-related disasters.
Keywords: Climate change, disasters, losses and damages

I. Introduction

Climate change is a critical global issue characterized by rising temperatures, with predictions suggesting a potential two-degree Celsius increase by 2050. This change is expected to significantly impact sub-Saharan African countries like Rwanda, causing greater temperature and rainfall variability and increasing the frequency and severity of hazards such as floods, droughts, and prolonged dry spells (Adhikari et al., 2015).

Rwanda, a small, hilly, and landlocked country with the second-highest population density in Africa, is particularly vulnerable due to its reliance on rain-fed agriculture and predominantly rural population. As of August 2022, Rwanda's population was 13,246,394, with an annual growth rate of 2.3% between 2012 and 2022. About 27.9% of the population lives in urban areas, meaning roughly three urban residents for every seven rural residents (72.1%) (NISR, 2022).

Between 1971 and 2018, Rwanda experienced a steady increase in annual minimum, mean, and maximum temperatures. Although changes in rainfall patterns were not consistent, they showed increased variability in frequency and intensity. By the mid-21st century, temperatures are expected to rise by 0.9 to 2.2 degrees Celsius compared to 1981-2018 levels, likely increasing the intensity of rainfall events and leading to flash flooding, landslides, and erosion (GoR, 2022). These events have already resulted in loss of life, damage to property and infrastructure, and environmental degradation.

Over the past decade, the frequency and intensity of climate-related disasters have risen, severely impacting human development and the environment in Rwanda. The country ranks 14th among the most vulnerable globally and 92nd in readiness, indicating high vulnerability and limited preparedness for climate change effects. In the 2020 ND-GAIN Index, Rwanda was 124th out of 182 countries (IMF, 2023).

Despite Rwanda's efforts and achievements in addressing climate change, its development is severely threatened by its geography and population characteristics. The country has faced devastating disasters that have caused deaths, injuries, infrastructure damage, and livelihood losses (WB, 2021). Different regions in Rwanda are affected differently: the Western and Northern Highlands suffer from heavy rains, landslides, and erosion, while the Eastern Province is prone to increasing droughts and prolonged dry spells (GoR, 2019).

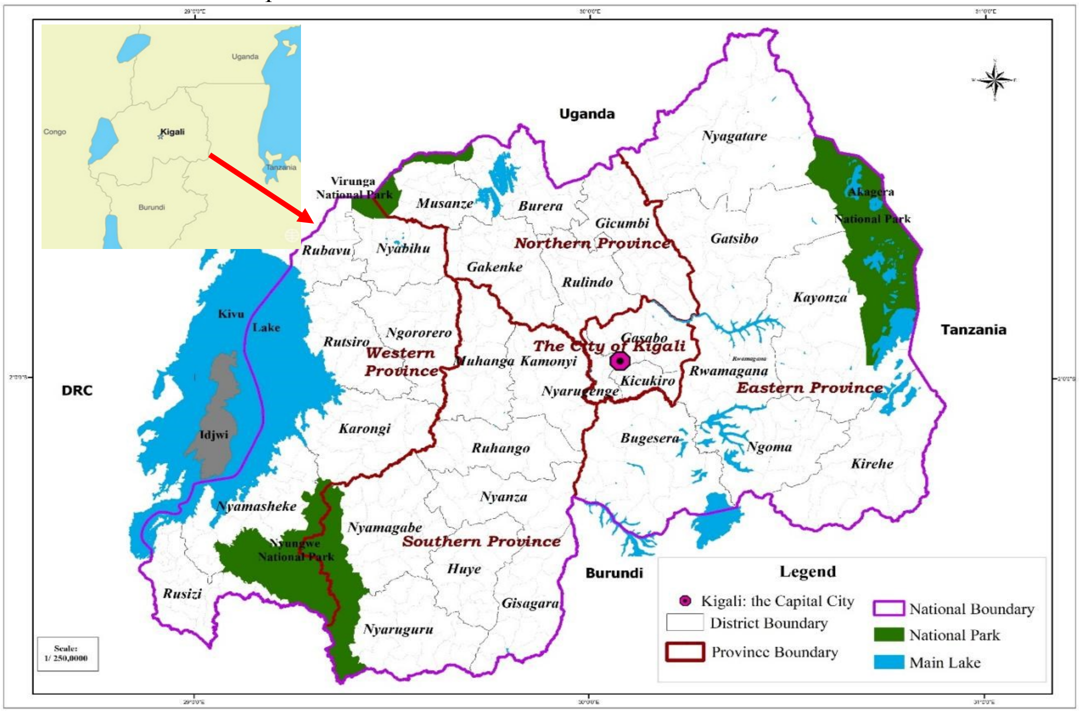
As illustration, in 2016, Rwanda faced severe floods and landslides resulting in 49 deaths, 26 injuries, and the destruction of over 500 houses, with Gakenke District being particularly hard-hit (ECHO, 2016). A similar disaster in 2017 disrupted major transportation routes, notably blocking the Musanze-Gakenke road. In 2020, extreme weather events destroyed 8,013 houses, 95 schools, four health centers, 151 roads, 102 bridges, and 22 churches, causing 290 deaths and injuring 398 people (Disaster Damages by Disaster Types, 2021). On May 2-3, 2023, floods and landslides further devastated northern, western, and southern Rwanda, affecting 51,905 people in 10,381 households across 14 districts, killing 131, and destroying 5,472 houses. Key infrastructure, including two health centers, 58 schools, 29 bridges, roads, power lines, and stations, was also damaged (ECHO, 16 May 2023). Furthermore, the education sector was significantly impacted, with 58 schools destroyed, displacing over 6,000 students and their families, and leading to nine student deaths. The estimated cost for rehabilitating damaged school infrastructure and materials is approximately 4.5 billion RWF, close to 0.5% of the 2023/24 education budget, undermining long-term quality improvements.

In response, the Rwandan government has implemented the Green Growth and Climate Resilience Strategy (GGCRS) since 2011, revised in January 2023, aiming for a climate-resilient, low-carbon economy by 2050 (RoR, 2018). Sectoral strategic plans, including the 2020 Updated Nationally Determined Contribution (NDC), the National Strategy for Transformation (NST1), and various environmental policies, underscore the country's commitment to sustainability and climate resilience (MINECOFIN, 2019; SPCR, 2017).

II. Climate vulnerability assessment of high risk in Rwanda

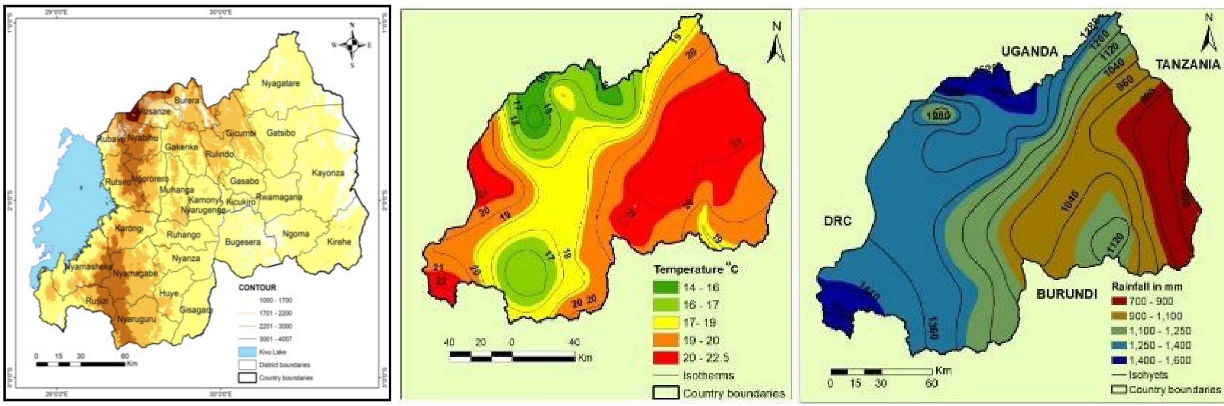
Rwanda is a landlocked country in east-central Africa, covering an area of 26,338 km². It is situated between 1°4' and 2°51' south latitude and 28°53' and 30°53' east longitude, approximately 120 kilometers south of the Equator. Rwanda is 1,100 kilometers from the Indian Ocean, 1,920 kilometers from the Atlantic Ocean, 3,750 kilometers from the Mediterranean Sea, and 3,980 kilometers from South Africa's Cape. It borders Uganda to the north, Tanzania to the east, Burundi to the south, and the Democratic Republic of Congo to the west.

Figure 1: Administrative map of Rwanda



Rwanda’s administrative structure includes four provinces (Eastern, Western, Northern, and Southern) and the City of Kigali, subdivided into 30 districts (Figure 1). Despite its equatorial proximity, Rwanda has a tropical climate moderated by its hilly terrain. It features four main climatic regions: the eastern plains, central plateau, highlands, and Lake Kivu area. The eastern plains receive 700-1,100 mm of annual rainfall over 57 to 100 days, with mean temperatures between 20°C and 22°C The central plateau region of Rwanda receives 1,100-1,300 mm of annual rainfall over 90 to 150 days, with temperatures ranging from 18°C to 20°C (figure 2). The highlands, including the Congo-Nile Ridge and Birunga volcanic chains, get 1,300-1,650 mm of annual rainfall over 140 to 210 days, with temperatures ranging from 10°C to 18°C (Ilunga et al., 2004; Muhire et al., 2016).

Figure 2: Spatial variation of temperature and rainfall in relation of Rwandan topography

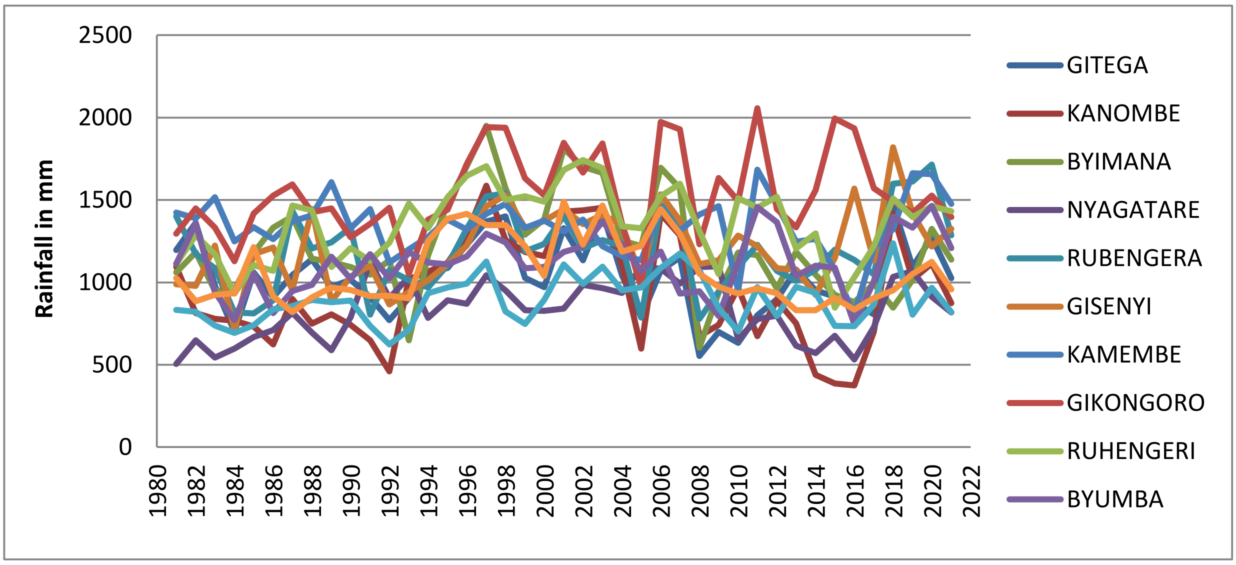


Source of data: Meteo Rwanda, 2024

The areas around Lake Kivu and the Bugarama plains receive annual rainfall between 1,200 mm and 1,500 mm over 150 to 210 days, with mean annual temperatures fluctuating between 18°C and 22°C (Ilunga et al., 2004; Muhire et al., 2016). Furthermore, Rwanda has four climatic seasons: long rainy (March-May), short rainy (September-November), long dry (June-August), and short dry (December-February). Landslides, soil erosion, and floods occur mainly during rainy seasons, while droughts and long dry spells are more intense during dry seasons (Anyah and Semazzi, 2007; Kizza et al., 2009).

Changes in temperature and precipitation are key drivers of climate-related disasters in Rwanda, adversely affecting its people and economy. Analysis from 1981 to 2021 shows a steady increase in minimum, mean, and maximum annual temperatures. However, changes in mean rainfall did not show significant trends of increase or decrease across different climatic regions.

Figure 3: Variations of annual mean rainfall of selected weather stations

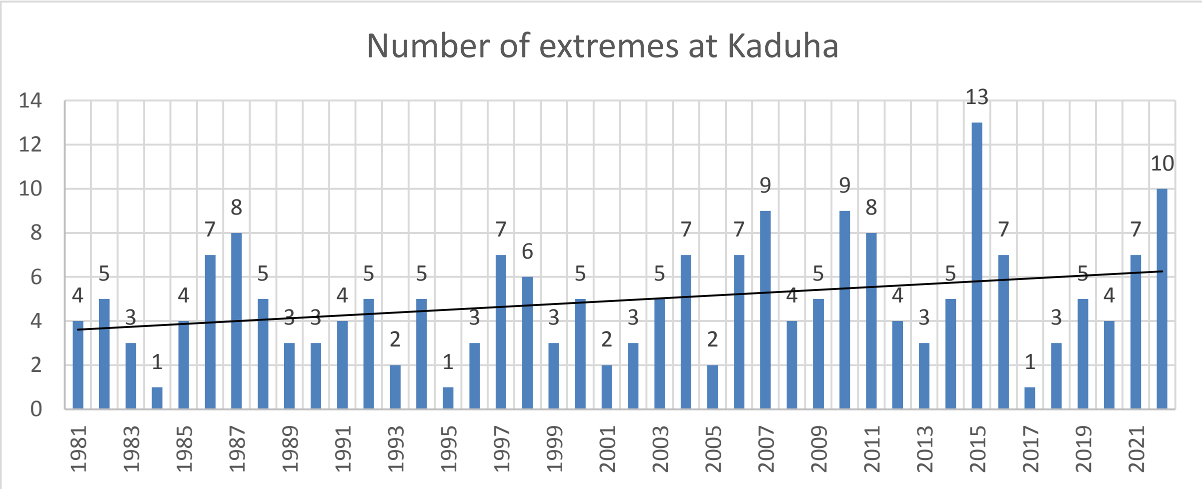


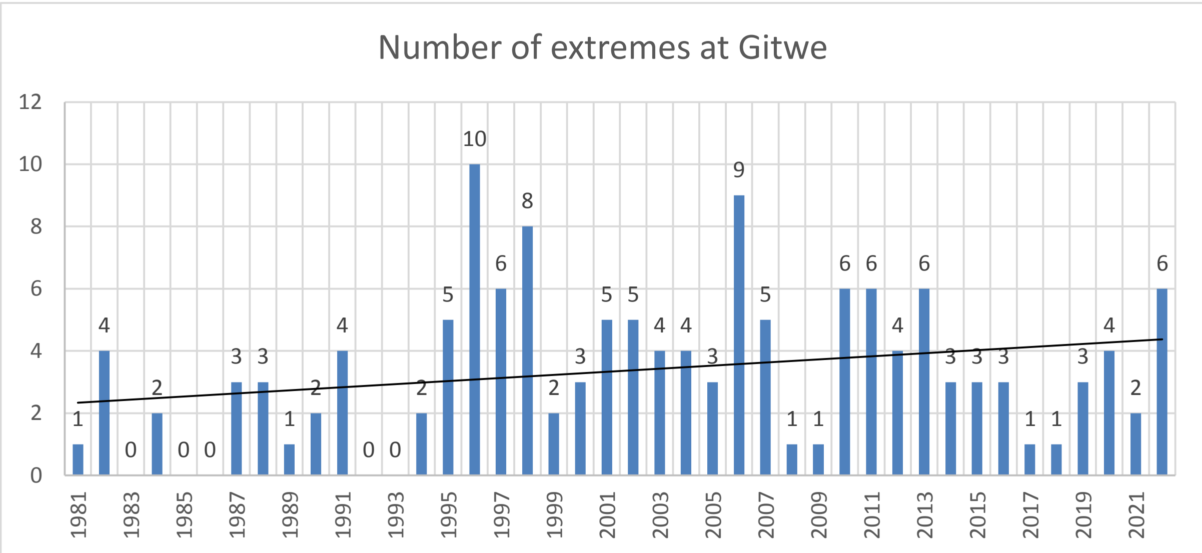
Source of data: Meteo Rwanda

Data from 12 weather stations show annual rainfall generally ranging between 400 mm and 1600 mm, with some outliers (figure 3). Notably, there has been an increase in extreme rainfall events, defined by the World

Meteorological Organization (WMO) as daily rainfall of 40 mm or more. The figure below highlights these extreme rainfall events recorded at the Kaduha and Gitwe weather stations from 1981 to 2022.

Figure 4: Number of annual extreme rainfalls

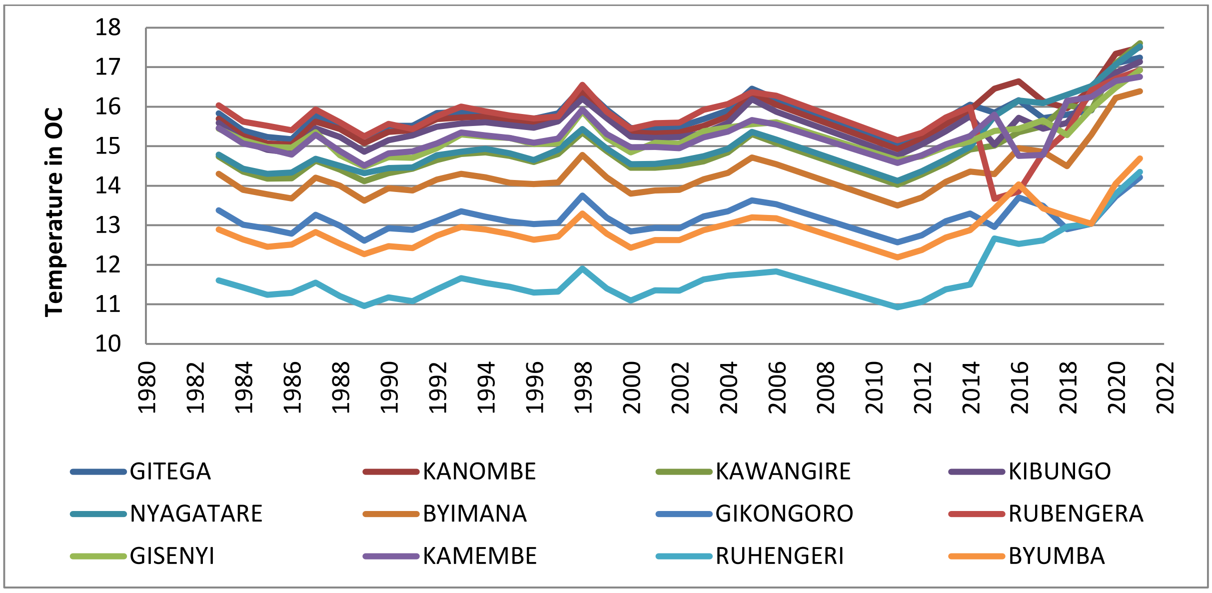




Source of data: Meteo Rwanda

Figure 4 indicates an increasing trend in extreme rainfall events from 1981 to 2022 at Kaduha and Gitwe weather stations in Rwanda's central plateau, an area known for less rainfall variability. This increase in rainfall intensity could lead to landslides, soil erosion, and flooding, adversely affecting natural environment, human and their properties. Additionally, analyzing mean temperature trends is essential for estimating warming and aridity trends, which could heighten drought frequency and negatively impact human life and ecosystems.

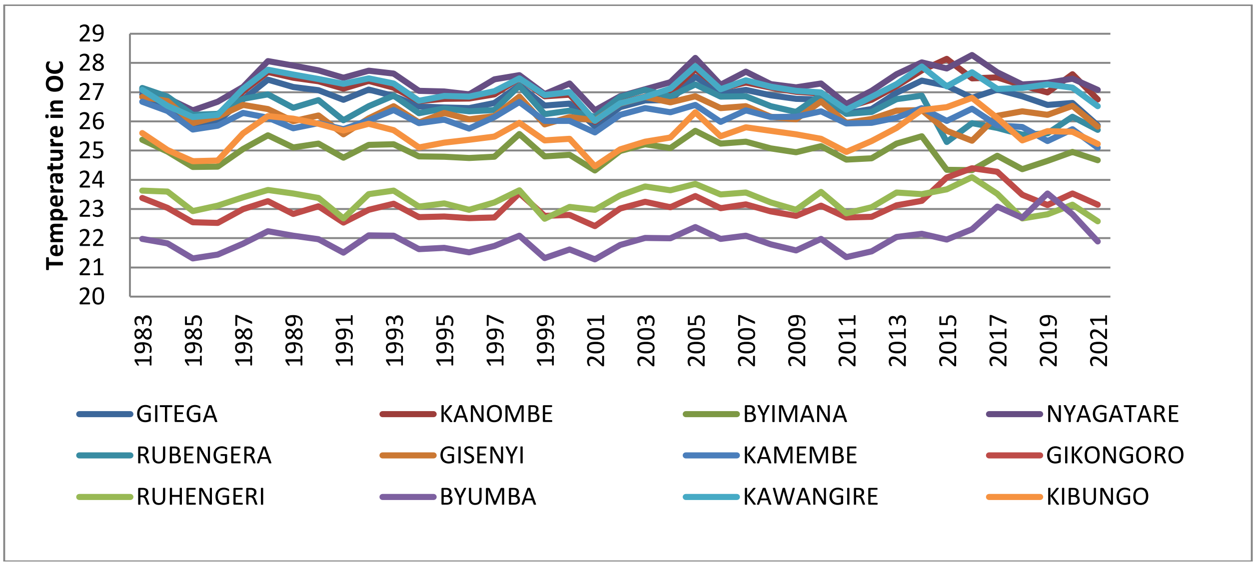
Figure 5: Temporal variations of minimum temperatures



Source of data: Meteo Rwanda

The analysis shows a progressively increasing trend in mean minimum annual temperatures, ranging from 10ºC to 17.5ºC across Rwanda, with a notable rise from 2012 to 2022 (figure 5). The rise in temperatures significantly contributes to the intensification of aridity, resulting in more frequent drought episodes, land degradation, and a reduction in water resources (Liu et al. 2008; Chamchati and Bahir 2011; Henninger, 2013). This trend could negatively impact agriculture and other livelihood activities. Maximum temperature trends are also analyzed and presented in the figure below.

Figure 6: Variations of maximum temperatures over selected weather stations

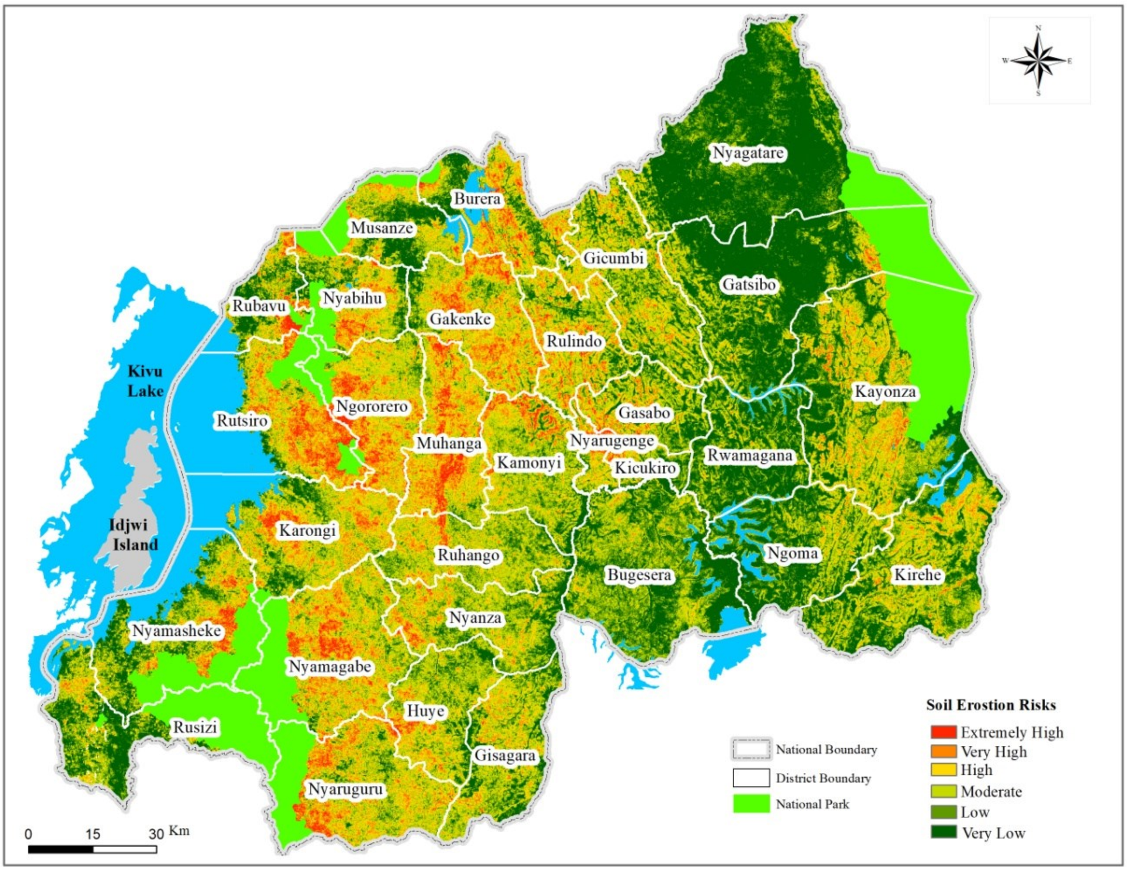


Source of data: Meteo Rwanda

Figure 6 illustrates an overall increase in mean maximum annual temperatures, ranging from 21°C to 28.5°C at selected weather stations, with a notable rise observed since 2001 to 2019, although there were periods of stagnation in 2000, 2008, and 2011 possibly linked to La Niña episodes during those years (Ndayisaba et al., 2020). The cumulative increase in both mean minimum and maximum temperatures, especially during extended dry periods, poses a significant threat to biodiversity.

In 2015, Rwanda launched its National Risk Atlas, the first in Africa to create a comprehensive disaster risk profile to integrate disaster risk management into national policies and planning. The Atlas assessed risks from natural hazards such as droughts, floods, landslides, windstorms, and earthquakes on various sectors (MIDIMAR, 2015). In 2022, IUCN conducted erosion control mapping in Rwanda but did not establish a clear link between climate risks and topography. Vulnerability mapping to soil erosion, landslides, drought, and flood risks was undertaken to assess the correlation between highly vulnerable areas and the resultant damages and losses (IUCN, 2022).

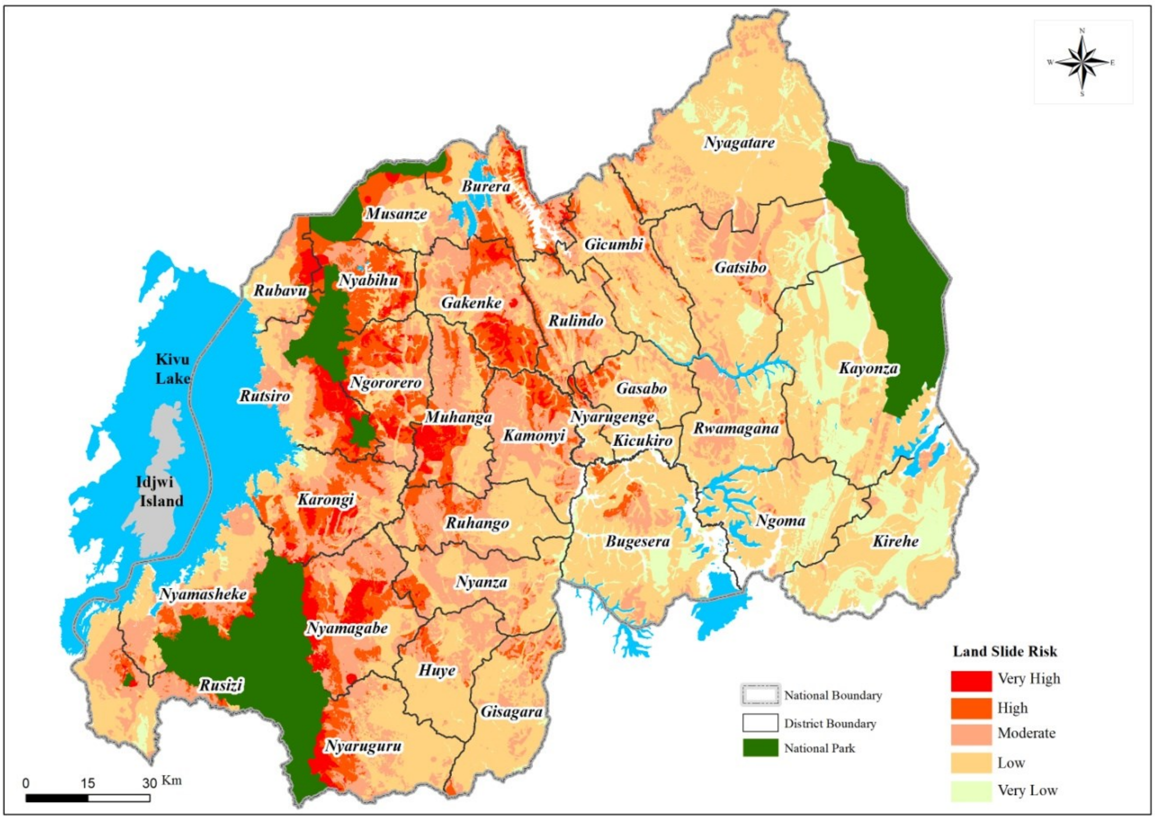
Figure 7: Vulnerability assessment to soil erosion risks



Source: Prepared by authors, 2024

Figure 7 emphasizes that the highlands in northwest and western Rwanda face significantly higher soil erosion risks compared to the eastern lowlands and the southeastern region ("Amayaga"). The analysis shows varying levels of erosion risk across the region, with the largest portion categorized as very low erosion loss (30.92%), indicating minimal soil degradation. Following are regions characterized by low (17.70%) and moderate (26.59%) erosion risks, indicating stable to moderately affected soil conditions that impact agricultural productivity and land stability. High (15.15%), very high (7.30%), and extremely high (2.34%) erosion risk areas highlight critical zones experiencing severe soil erosion, necessitating immediate soil conservation and sustainable land management interventions. Addressing these vulnerabilities is crucial for mitigating environmental degradation and protecting local livelihoods in Rwanda's high-risk areas.

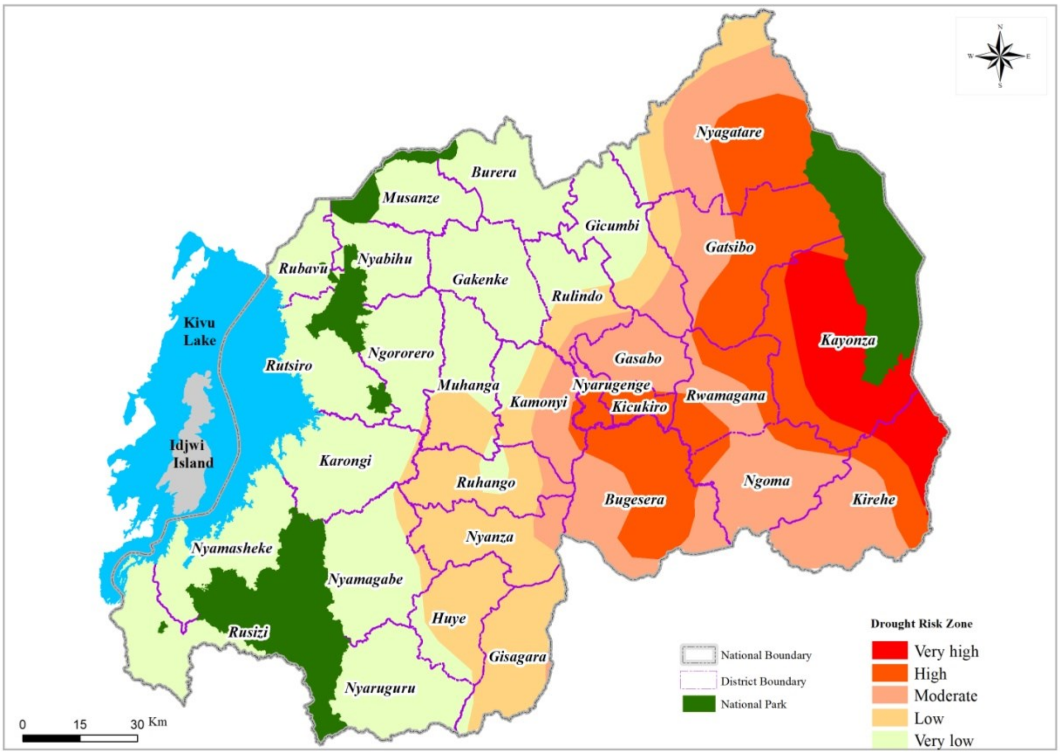
Figure 8: Vulnerability assessment to landslide risks



Source: Prepared by authors, 2024

The figure 8 indicates that northern west and western regions of Rwanda face significantly higher landslide risk compared to the eastern lowlands. Nearly half of the area (48.94%) is categorized as low-risk, while moderate-risk areas cover 23.18%. High and very high-risk zones constitute 18.2% of the land, posing substantial challenges to infrastructure and habitation. Only 9.68% of the region is at very low risk. Urgent action is needed in disaster preparedness, resilient infrastructure, and community education to mitigate landslide impacts and promote sustainable development in vulnerable areas.

Figure 9: School vulnerability to drought risks



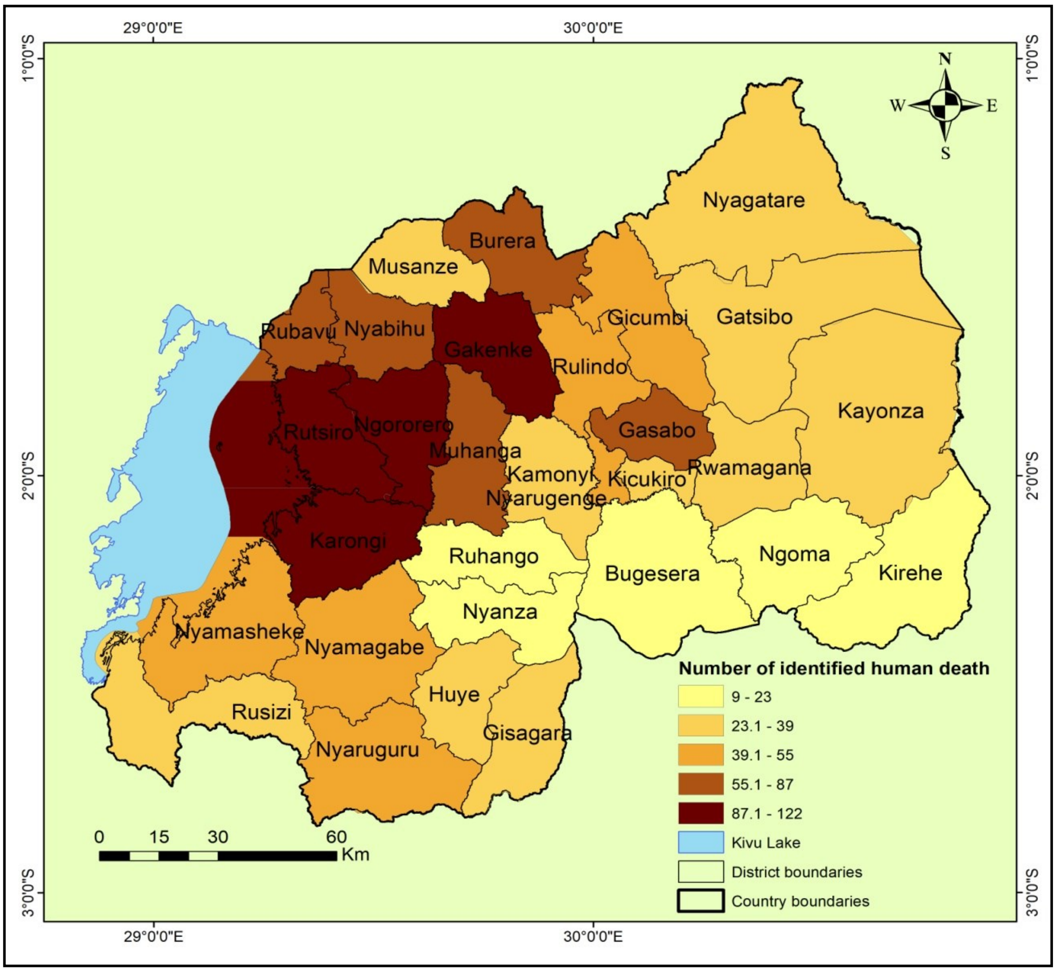
Source: Prepared by MINEDUC, 2024

The assessment of drought vulnerability in Rwanda (figure 9) identifies high vulnerability in the eastern lowlands and southeast regions due to low rainfall and high temperatures year-round. Conversely, the central plateau faces moderate to low risk, while the highlands, receiving the highest annual rainfall, are at very low risk of drought. Moderate risk areas constitute the largest proportion (31.55%), indicating significant but manageable drought conditions impacting agriculture and water availability. High-risk areas (30.09%) suggest more severe impacts, potentially reducing crop yields and causing water stress, requiring adaptive strategies. Very high-risk regions (12.87%) face critical challenges like severe water scarcity and agricultural losses, necessitating urgent intervention. Low-risk areas (25.41%) maintain stable agricultural and water systems, while very low-risk areas (0.08%) experience minimal drought impacts. This underscores the need for tailored interventions in high-risk areas to enhance community resilience, emphasizing region-specific adaptation strategies across Rwanda.

III. Climate related losses and damages in Rwanda

Over the past decade, the frequency and intensity of disasters triggered by natural hazards have surged in Rwanda, primarily due to the adverse impacts of climate change on human development, infrastructure, properties, and the environment. Recent disasters, such as floods, landslides and soil erosion have caused significant human and infrastructural losses, underscoring the urgent need for climate resilience measures. The figure below show the spatial distribution of identified human death. Among the fatalities were students, teachers, and other educational stakeholders, although their specific number was not separately identified from the total fatalities.

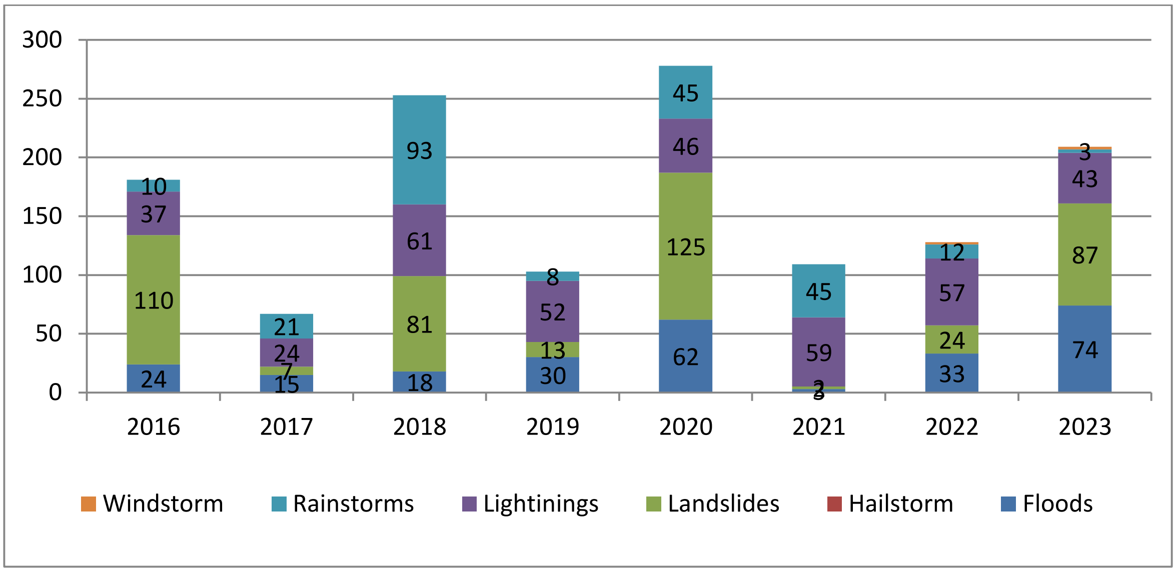
Figure 10: Spatial distribution of climate related human deaths in Rwanda (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

It is evident that the highest number of human fatalities (figure 10), ranging between 87 and 122, occurred in the northwestern region of the country, which is characterized by susceptibility to landslides, soil erosion, and floods. Conversely, the lowest number of fatalities was recorded in the southeastern and eastern parts, known for their vulnerability to drought. This discrepancy suggests that the highlands in the northwest, prone to landslides, soil erosion, and floods, pose a greater risk to human life compared to the eastern regions. As a result, an investigation into the correlation between extreme weather events and resultant damages was conducted. The table summarizes occurrences of extreme weather events causing human fatalities in the country from 2016 to 2023.

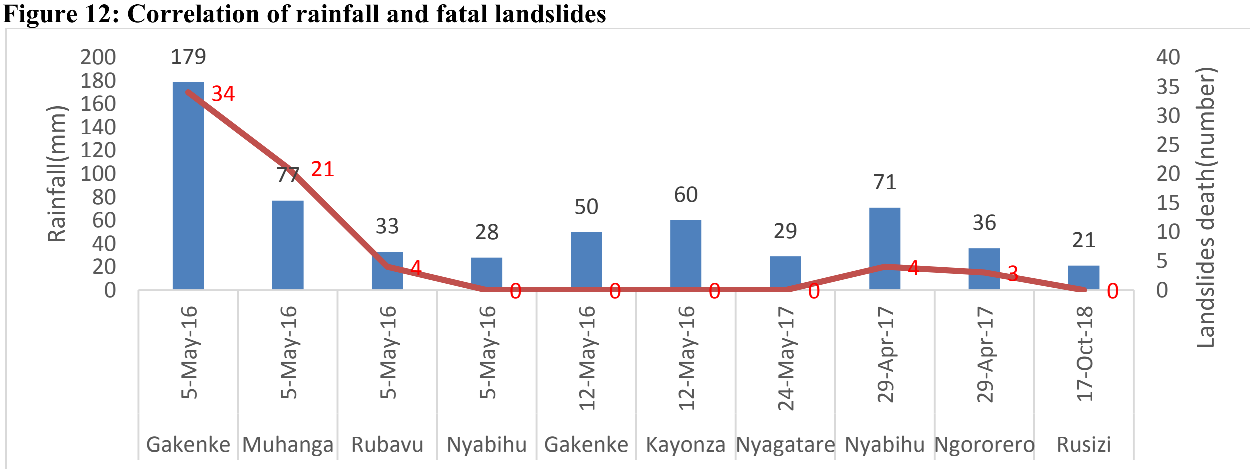
Figure 11: Human fatalities by extreme weather events in the country (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

Notably, landslides accounted for significant fatalities, with peaks in 2020 and 2016 but a low in 2021. In total the landslides caused 449 deaths since 2016 to 2023. Lightning strikes resulted in high number of fatalities 379 which are varying each year with peaks in 2018 and 2021. Floods also contributed significantly, with a total of 259 fatalities. With the highest registered in 2023. Rainstorms with a total of 237 fatalities caused the highest deaths in 2018, while windstorms had fewer occurrences and caused four deaths. These fluctuations highlight the diverse impact of extreme weather events on human life, informing disaster preparedness and mitigation efforts. It is important highlighting that the occurrence fatal landslides are linked to the heavy rainfall received in the specific days. The figure below shows such correlation.

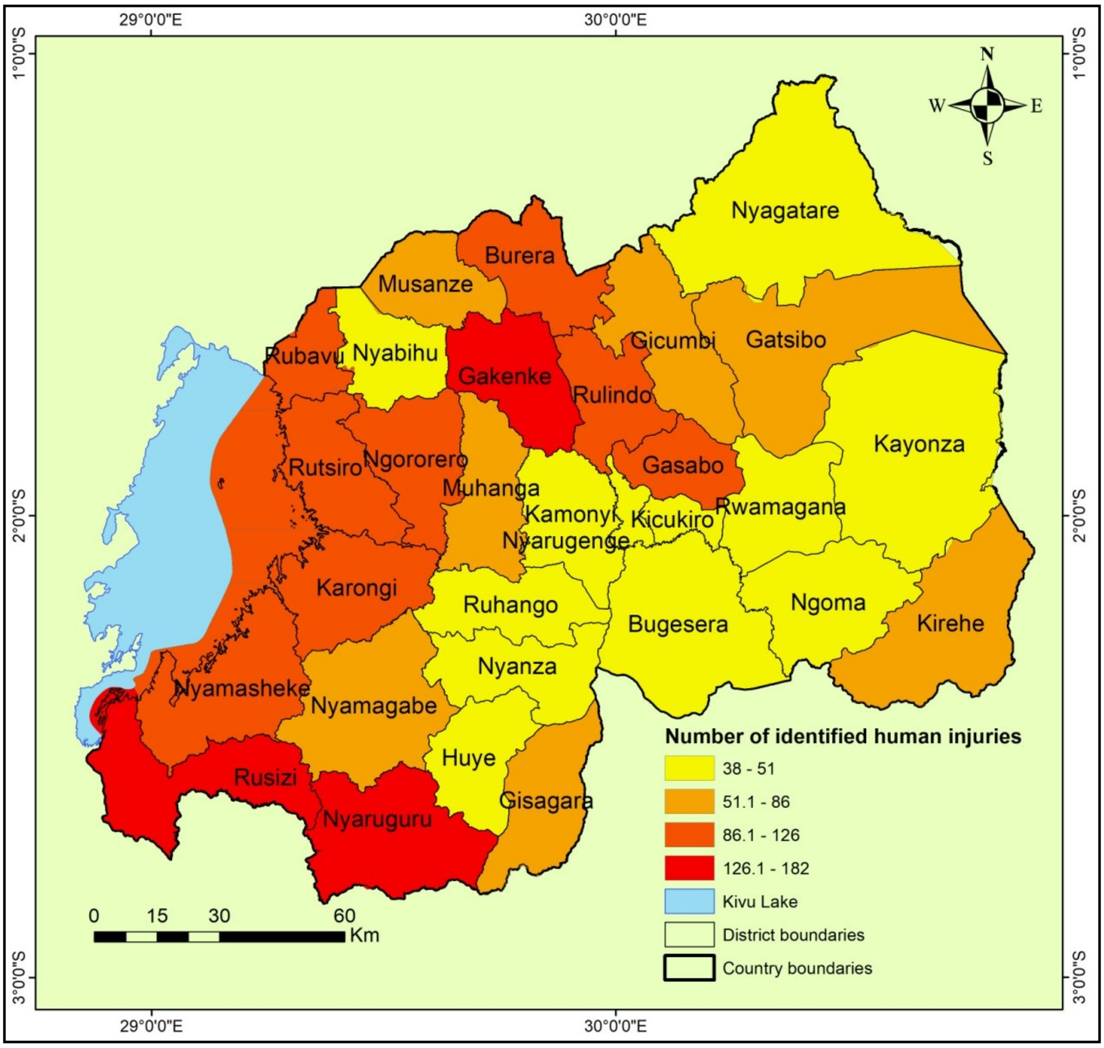
Figure 12: Correlation of rainfall and fatal landslides



Source of data: Flash report release by MIDIMAR, 2019

The data (figure 12) highlights the significant impact of rainfall on mortality and injuries in Rwanda's districts. On May 5, 2016, Gakenke experienced the highest rainfall (179 mm), resulting in 34 deaths, while Muhanga recorded 77 mm of rainfall and 21 deaths. Lower rainfall levels in Rubavu on the same day (33 mm and 28 mm) led to fewer fatalities (4 and 0 deaths, respectively). Other incidents, such as in Nyabihu (71 mm of rainfall on April 29, 2017, with 4 deaths) and Ngororero (36 mm of rainfall on the same day, with 3 deaths), illustrate the varied impacts of rainfall intensity. This underscores the urgent need for effective disaster preparedness and mitigation strategies. The following figure delineates the spatial distribution of human injuries stemming from these extreme weather occurrences, providing crucial insights into the geographic patterns of such impacts.

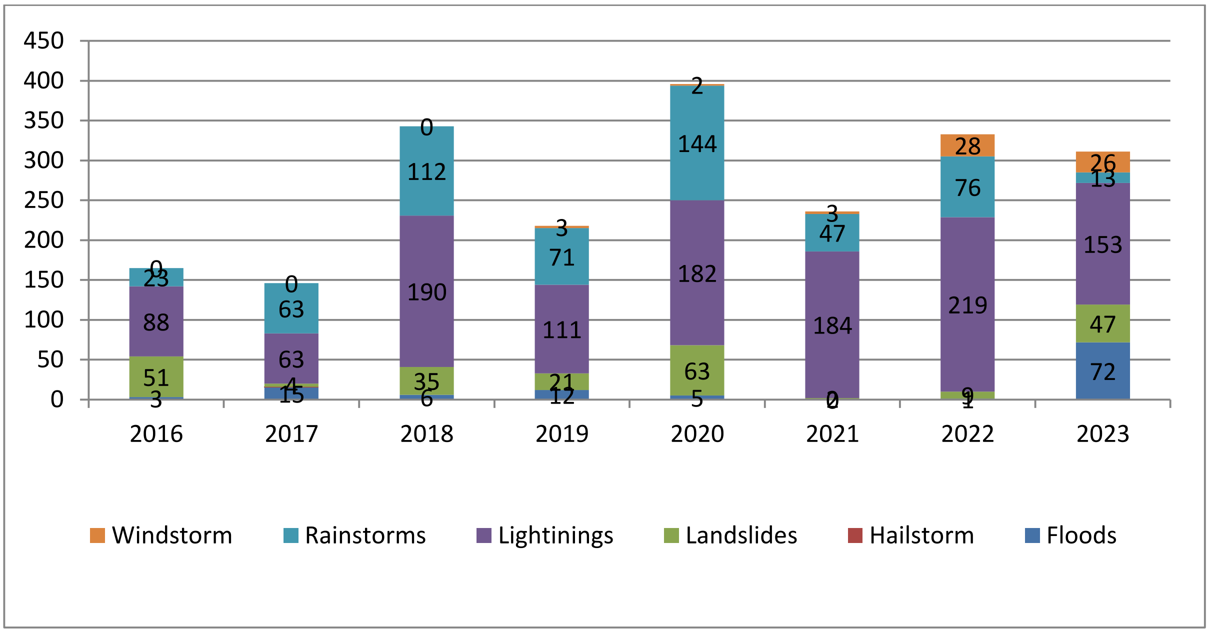
Figure 13: Spatial distribution of climate related human injuries in Rwanda for 2016-2023



Source of data: https://www.minema.gov.rw/publications, 2024

The figure 13 presented indicates that Gakenke District remains among the top districts with the highest incidence of human injuries, echoing its status concerning human fatalities. This trend is mirrored by Rusizi and Nyaruguru Districts, situated in the southwestern region of the country, renowned for their significant annual rainfall averaging around 1600 mm. Conversely, the southeastern region continues to exhibit the lowest occurrences of human injuries resulting from extreme weather events, while the majority of districts in the western and northwestern regions rank second highest in terms of injury rates, ranging from 86 to 126. The table shows human injuries caused by extreme weather events in the country from 2016 to 2023, highlighting significant fluctuations and trends.

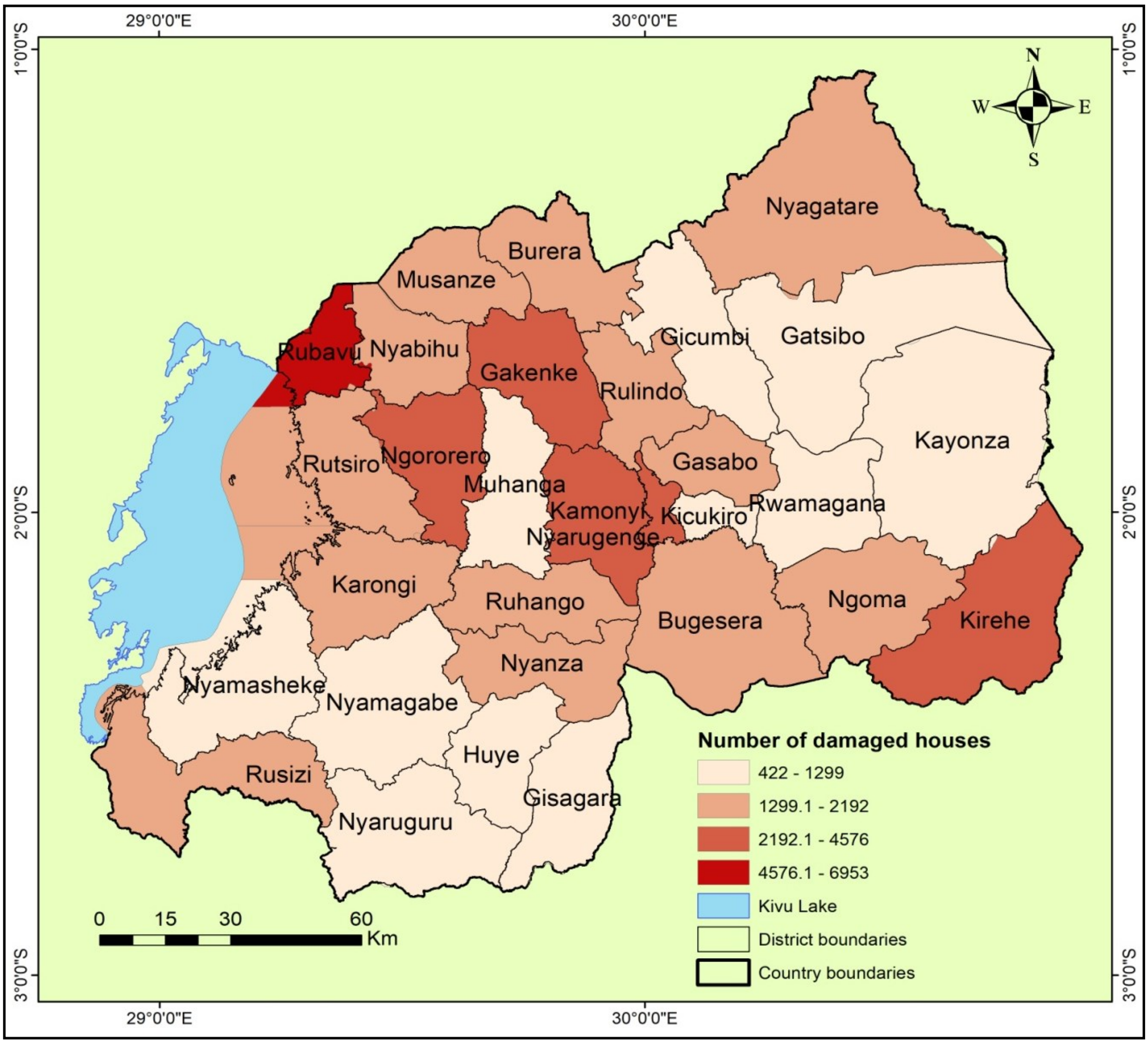
Figure 14: Human injuries by extreme weather events in the country (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

The figure 14 indicates that lightning strikes consistently caused numerous injuries annually, peaking at 219 in 2022, totaling 1,190 injuries over the period. Rainstorms caused 549 injuries overall, with peaks in 2020 and 2018 but decreasing in 2023. Floods resulted in a significant increase in injuries in 2023 compared to previous years. Landslides showed varying impacts, peaking in 2016, 2020, and 2023. Windstorms caused fewer injuries but demonstrated an increasing trend in recent years. Hailstorms caused minimal injuries throughout the period. These findings highlight the diverse impacts of weather events and emphasize the need for tailored disaster preparedness strategies.

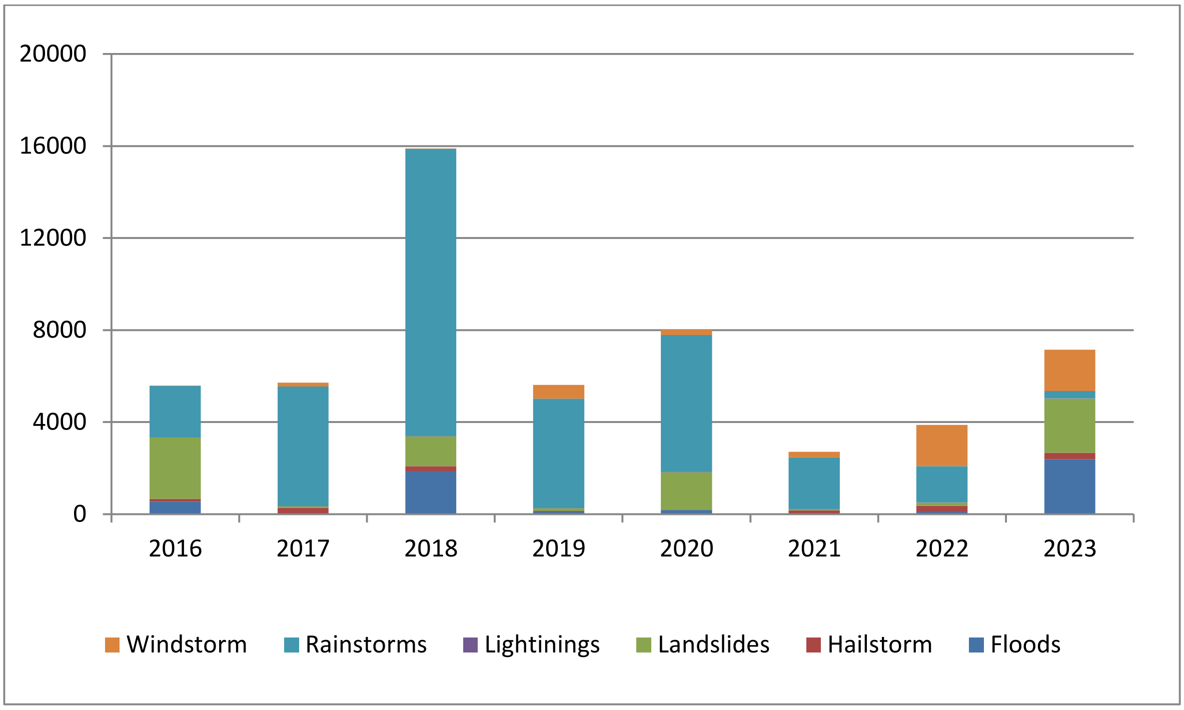
Figure 15: Spatial distribution of climate related house damages in Rwanda for 2016-2023



Source of data: https://www.minema.gov.rw/publications, 2024

The figure 15 illustrates that Rubavu District, notably affected by floods and landslides in May 2023, experienced the highest number of damaged houses (4,576-6,953), impacting 10,381 households across 14 districts with 131 fatalities. Kirehe District, in a drought-prone area, ranked second in house damages (2,192-4,576) from 2016 to 2023, influenced largely by rainstorms and windstorms compared to landslides and floods. Other districts reported varying levels of house damages (1,299-2,192), emphasizing the widespread impact of extreme weather events. This highlights the critical need for effective adaptation measures to mitigate future damages.

Figure 16: House damages by extreme weather event in the country (2016-2023)



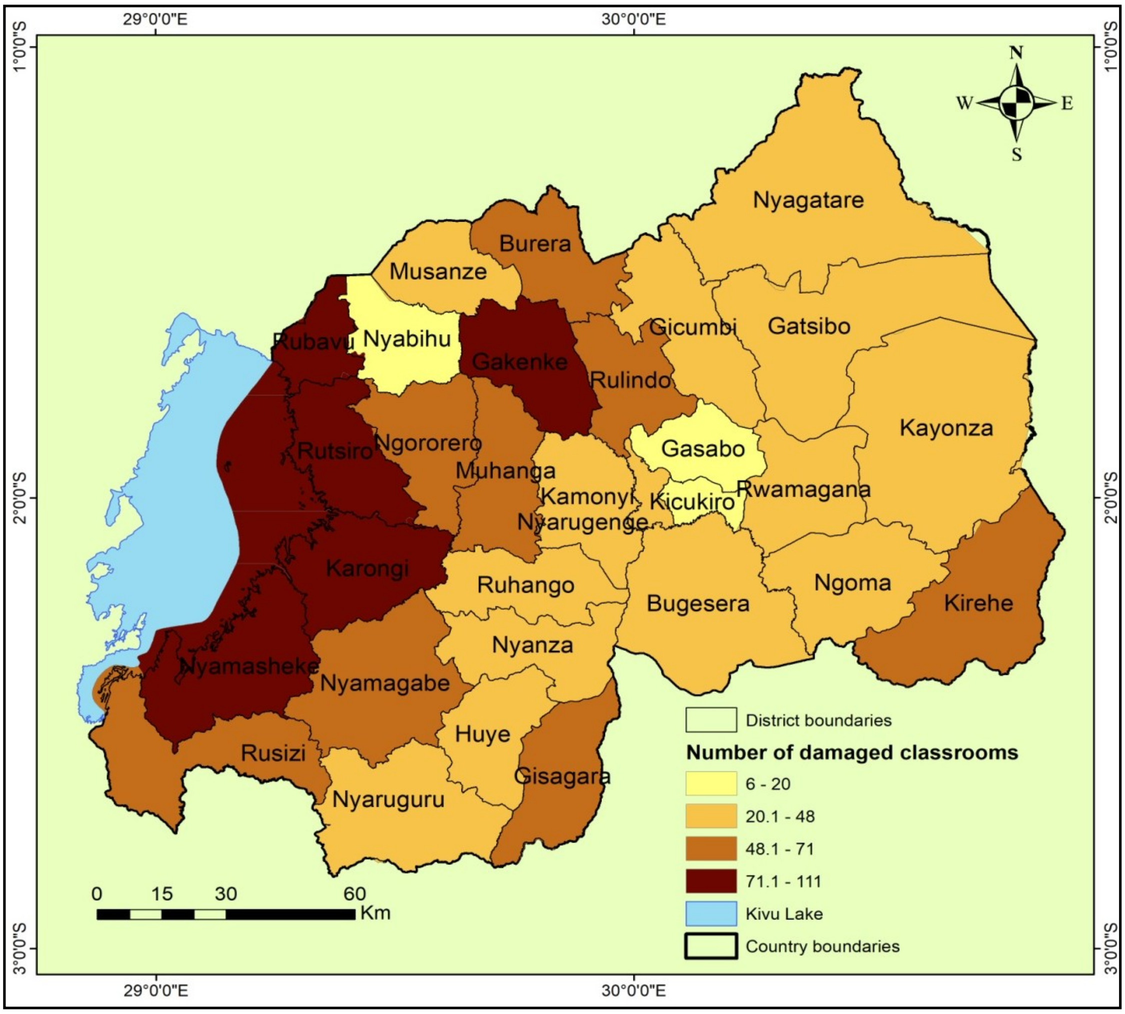
Source of data: https://www.minema.gov.rw/publications, 2024

The figure 16 depicts varying levels of house damage in Rwanda from 2016 to 2023, showing a peak in 2018 with 15,910 houses affected, followed by a decrease in 2019 to 5,691 houses. Subsequent years continued to fluctuate, with notable increases in 2020 and 2023. In total, 54,578 houses were damaged over the eight-year period.

Rainstorms caused the most significant damage, totaling 34,799 houses affected, with a peak of 12,505 houses in 2018. Landslides also had severe impacts, reaching peaks in 2016 and 2023, damaging a total of 8,354 houses. Floods affected 5,182 houses since 2016, with notable increases in recent years. Windstorms showed a rising trend in damage from 2020, totaling 4,861 houses affected over eight years. In contrast, hailstorms and lightning strikes caused minimal house damage annually.

This data underscores the critical importance of robust disaster preparedness and resilience strategies to mitigate the impacts of extreme weather events on housing infrastructure and educational facilities in Rwanda.

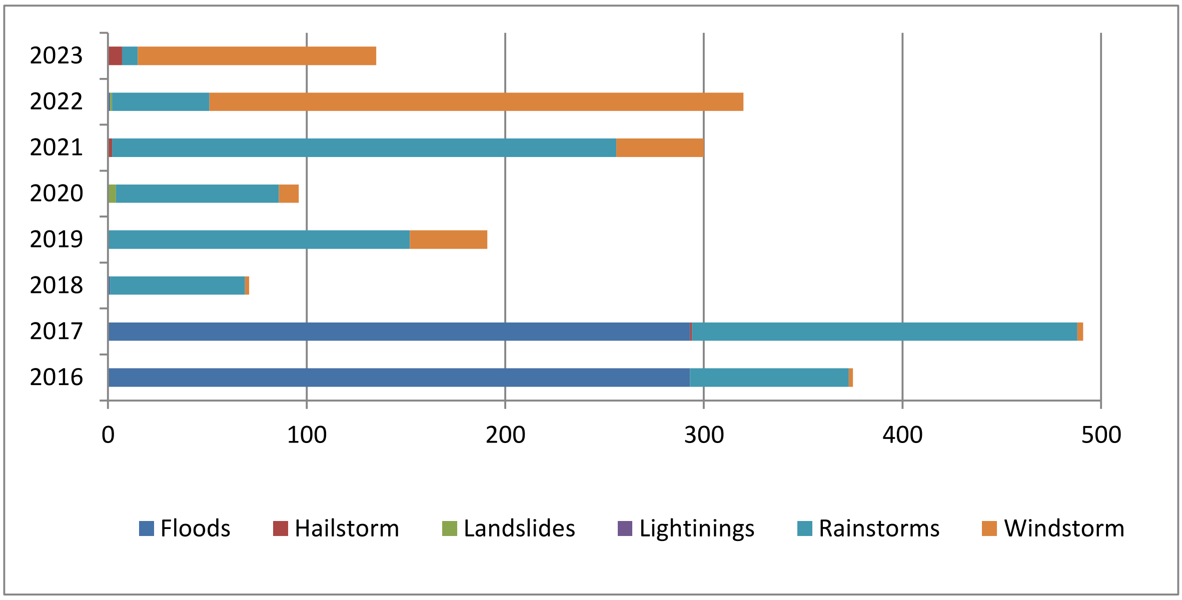
Figure 17: Spatial distribution of climate related classroom damages in Rwanda (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

The highest number of damaged classrooms, ranging from 71 to 111, was recorded in the western region of the country and Gakenke District in the northwest, areas known for their susceptibility to landslides, soil erosion, and floods (figure 17). Additionally, except for Nyabihu District, other districts in the northwest and western parts of the country reported between 48.1 and 71 damaged classrooms. Similar to the trend observed in house damages, Kirehe District, located in a drought-prone area, ranked second in the number of damaged classrooms (48.1-71). This suggests that windstorms and rainstorms significantly contribute to classroom damages, paralleling the pattern seen in house damages. Consequently, an investigation into the correlation between extreme weather events and resultant damages was conducted to confirm this assumption, with the findings summarized in the following figure.

Figure 18: Schools damages by extreme weather events in the country (2016-2023)

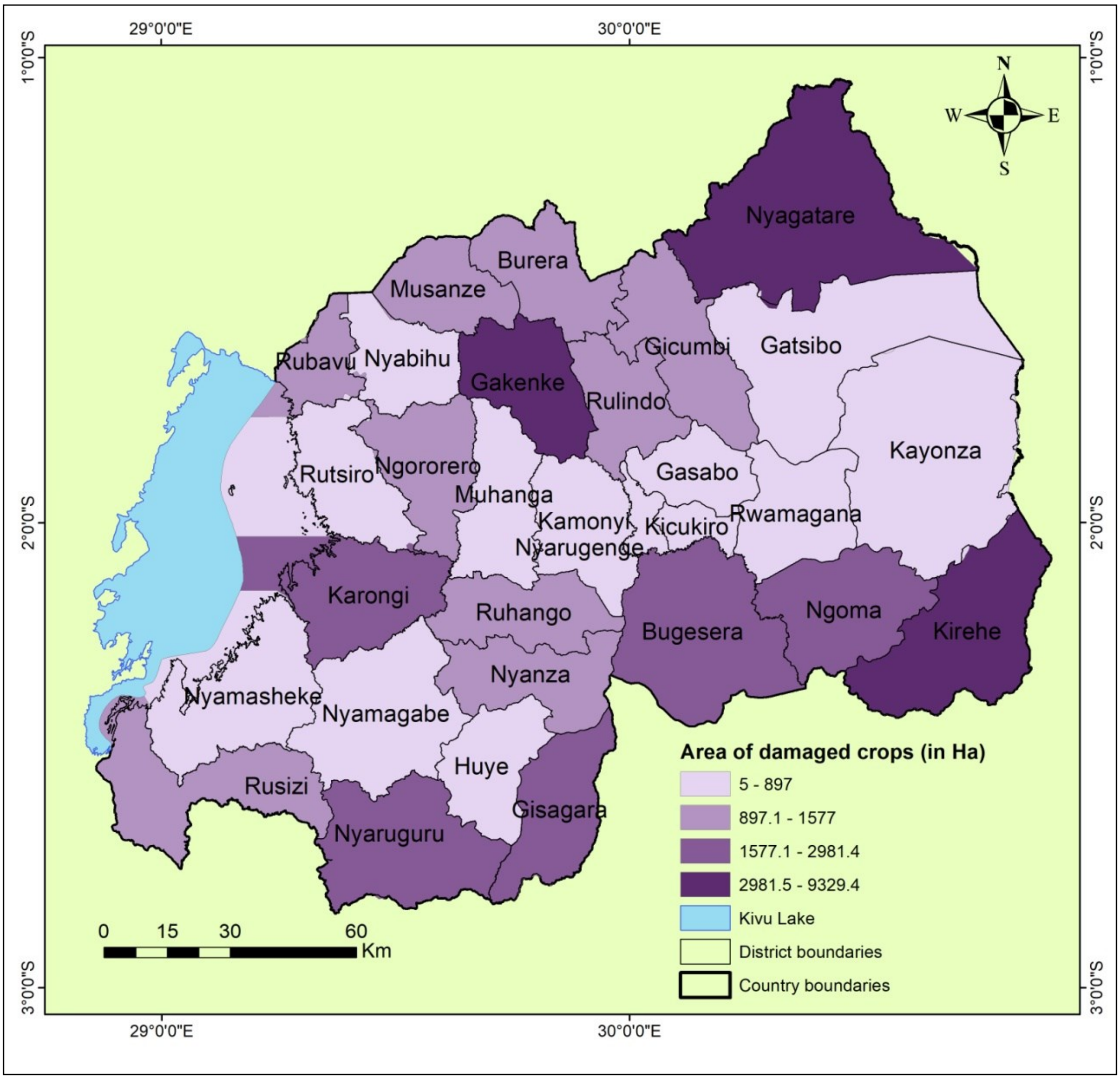


Source of data: https://www.minema.gov.rw/publications, 2024

From 2016 to 2023, floods and rainstorms significantly damaged schools in Rwanda, with floods affecting schools consistently in 2016 and 2017, totaling 293 incidents annually. However, flood-related school damages decreased sharply after 2017, suggesting improved mitigation efforts or milder flood events in subsequent years (figure 18). In contrast, rainstorms showed varying impacts on schools, peaking in 2021 with 254 incidents but declining to 8 incidents by 2023, indicating fluctuating intensity and distribution of rainstorms over time. Windstorms emerged as a notable threat to schools from 2020 onwards, with 269 instances of school damage reported in 2022, highlighting an increasing risk to educational infrastructure in recent years.

Overall, extreme weather events caused 1,979 incidents of school damages during the eight-year period, including 887 from rainstorms, 588 from floods, and 489 from windstorms. This data underscores the vulnerability of schools to diverse weather hazards in Rwanda and emphasizes the critical need for enhancing resilience measures and disaster preparedness strategies to protect educational facilities and ensure uninterrupted education amid climate variability.

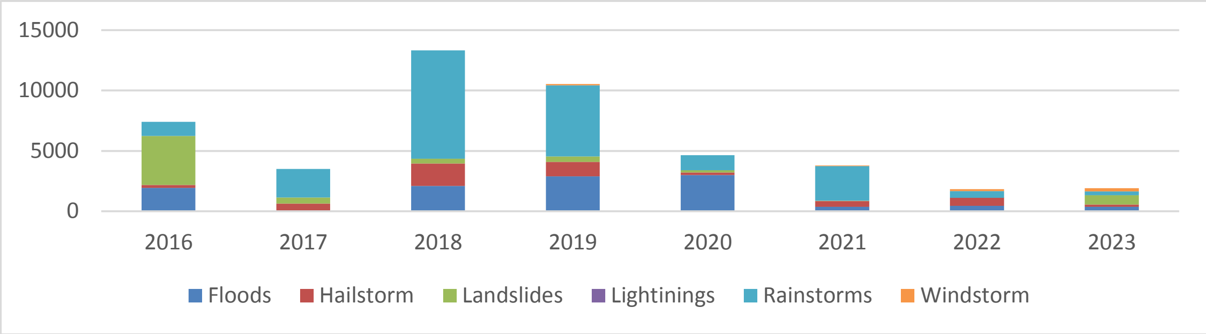
Figure 19: Spatial distribution of climate related area of crops damages (in Ha) in Rwanda (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

Gakenke District in the northwest recorded the highest crop damages ranging from 2981 to 9329 hectares, attributed to landslides, soil erosion, and floods (figure 19). Nyagatare and Kirehe Districts in the east also suffered significant crop losses. Southern districts, particularly in the Amayaga region prone to drought, reported damages ranging from 1577 to 2981.4 hectares, primarily due to long dry spells, droughts, and windstorms. Northern regions, susceptible to landslides and soil erosion, experienced crop damages ranging from 897 to 1577 hectares. Despite lacking official reports on drought impacts, these crop damages negatively affect food security and the economy of the country. Additionally, an analysis of the correlation between extreme weather events and resultant damages was conducted to confirm this assumption, with the findings summarized in the following figure.

Figure 20: Crop damages (in ha) by extreme weather events in Rwanda (2016-2023)

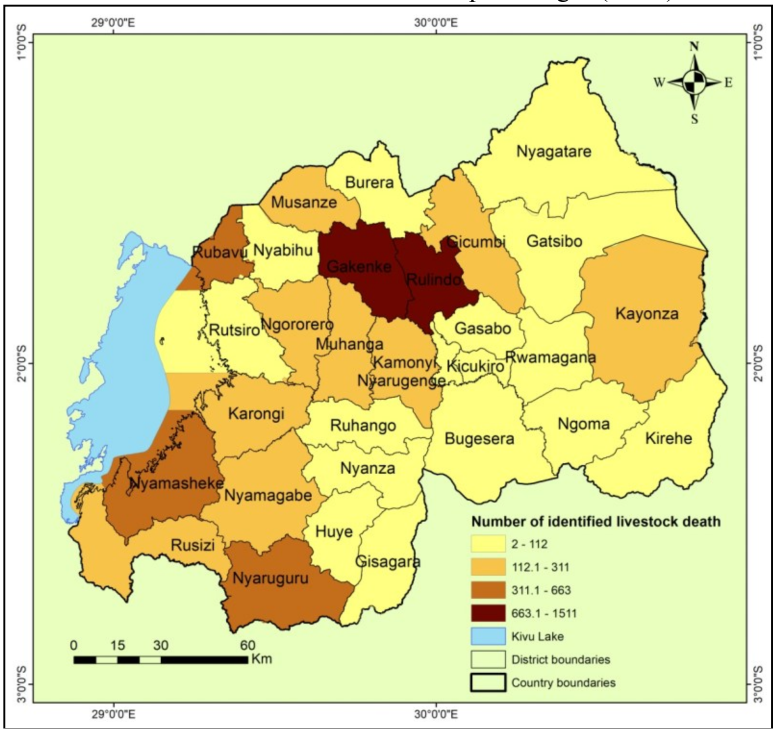


Source of data: https://www.minema.gov.rw/publications, 2024

The data illustrates the significant impact of various climate disasters on crop damage in Rwanda from 2016 to 2023 (figure 20). Rainstorms caused the most extensive damage, totaling 23,413.59 hectares over the eight years, with the highest damage recorded in 2018 (8,977.83 hectares) and a notable peak in 2019 (5,876.2 hectares). Floods were the second most destructive, affecting 11,125.27 hectares, with significant spikes in 2016 (1,927 hectares) and 2018 (2,087.6 hectares). Landslides also caused substantial crop damage, particularly in 2016 (4,083 hectares), contributing to a total of 6,424.59 hectares over the period. Hailstorms resulted in 5,404.51 hectares of damage, with the most severe year being 2018 (1,875.5 hectares).

Windstorms, although less frequent, still impacted crops, with a total of 572.51 hectares, particularly peaking in 2023 (269.905 hectares). Lightning did not record any crop damage throughout the period. This data highlights the diverse and substantial impact of various climate disasters on agriculture, emphasizing the urgent need for effective disaster management and resilient farming practices to mitigate these adverse effects.

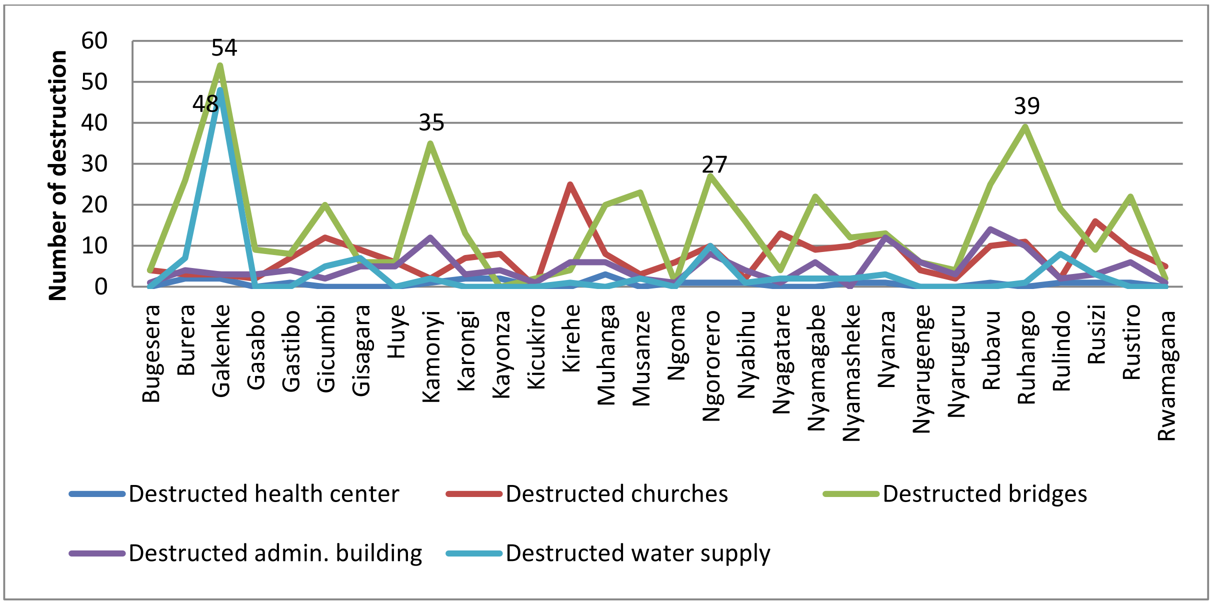
Figure 21: Spatial distribution of climate related area of crops damages (in Ha) in Rwanda (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

Gakenke and Rulindo districts recorded the highest livestock deaths (663-1511) due to landslides and soil erosion from 2016 to 2023, as reported by district-level Key Informants. Following closely were Rubavu, Nyaruguru, and Nyamasheke with losses ranging from 311.1 to 663. Highland districts reported losses between 112.1 and 311, while Eastern Province districts, despite being drought-prone, had the lowest livestock deaths (2-112) due to extreme weather events. This region also faces reduced milk production during long dry seasons, impacting negatively the food security in the country.

Figure 22: Spatial distribution of climate related infrastructure damages in Rwanda (2016-2023)



Source of data: https://www.minema.gov.rw/publications, 2024

From 2016 to 2023, Rwanda faced extensive infrastructure damage across its districts due to severe weather events, impacting vital facilities crucial for community resilience and public services. Health centers bore a significant toll, with Muhanga losing the highest number at 3 centers, limiting healthcare accessibility during emergencies and exacerbating public health challenges. Churches, serving as community hubs and crisis shelters, suffered with Gicumbi losing 12, severely affecting community support networks and safety.

Critical infrastructure essential for transportation and governance suffered substantial damage. A total of 451 bridges were destroyed, with Gakenke notably losing 54 bridges, severely restricting access to essential services such as education and healthcare. Furthermore, administrative buildings crucial for local governance and coordinating disaster responses were impacted, with Kamonyi losing 12 buildings.

Additionally, the destruction of 104 water supply systems, predominantly in Gakenke where 48 systems were destroyed, further exacerbated challenges by compromising access to clean water essential for health and sanitation, particularly in educational settings. This widespread damage has disrupted educational services across Rwanda, emphasizing the urgent need for targeted interventions to enhance infrastructure resilience and ensure continuity of educational activities in the face of future extreme weather events.

IV. Rwanda’s options to avert, minimize and address Loss and Damage

Rwanda has implemented several strategies to mitigate and address Loss and Damage caused by climate change, focusing on risk transfer schemes, social protection, contingency financing, and solidarity funds. The Ministry of Agriculture and Animal Resources launched the National Agriculture Insurance Scheme (NAIS) in 2019, subsidizing coverage to protect farmers from natural disasters impacting crops and livestock. This successful model could be expanded to cover broader economic losses and infrastructure damages, enhancing resilience across various sectors like tourism and business operations.

Furthermore, Rwanda is pioneering a "Green Bond" through FONERWA to establish catastrophe and resilience bonds, transferring risks to capital markets for broader risk distribution and preemptive financing. The social protection sector, anchored by robust policy frameworks and a strategic plan, supports vulnerable populations through income security, livelihood support, and disaster relief, which could be further developed into an ex-ante financing mechanism for Loss and Damage.

In terms of contingency and disaster relief financing, Rwanda has demonstrated effective use of bilateral development financing, notably during the COVID-19 response. The National Emergency Command Center under MINEMA played a crucial role in coordinating emergency responses, suggesting its potential to evolve into a platform for managing financial instruments aimed at averting, minimizing, and addressing Loss and Damage (UNICEF, 2020, Mwongera, et al.,. 2019).

The solidarity funds, exemplified by the Community Based Health Insurance (Mutuelle de santé), cover over 90% of Rwanda's population, ensuring access to affordable healthcare. This model could be adapted into a solidarity instrument to aid those affected by Loss and Damage, complementing existing social protection efforts.

Looking forward, Rwanda should operationalize the new Loss and Damage Fund (LDF) through COP28, establishing eligibility criteria and technical capacities to access funds efficiently. Strengthening technical capacity within REMA and other relevant institutions will be crucial for developing and implementing effective financing instruments aligned with international frameworks like the Paris Agreement and GCF-DNA functions.

Governance enhancements, including strengthening the National Emergency Command Center and establishing collaborative frameworks with institutions like Meteo Rwanda and REMA, will facilitate robust Loss and Damage assessment and operationalization of financing instruments. Establishing a working arrangement with GCF to develop suitable financing instruments will further Rwanda's capacity to mitigate climate impacts and support sustainable development.

V. Conclusions

Rwanda faces significant challenges and vulnerabilities due to climate change, exacerbated by its geographical and topographical diversity. The country's climate is influenced by its proximity to the Equator and its hilly terrain, which extends from east to west, creating distinct climatic regions. These include the eastern plains, central plateau, highlands, and areas around Lake Kivu, each experiencing varying levels of rainfall and temperature.

The analysis reveals a steady increase in mean annual temperatures across Rwanda from 1981 to 2022, impacting agriculture and livelihoods. Temperature trends show rising minimum and maximum temperatures, particularly during dry spells, which could intensify drought episodes and their adverse effects on biodiversity and human activities. Rainfall patterns exhibit variability across different climatic regions, with the central plateau receiving moderate annual rainfall and the highlands experiencing higher amounts. Extreme rainfall events have increased over the years in certain areas, , leading to risks like landslides, soil erosion, and floods, which pose threats to infrastructure, agriculture, and education services.

Rwanda's vulnerability to climate risks is further underscored by its socio-economic factors, including high population density, dependence on rain-fed agriculture, and limited infrastructure resilience. The northern and western regions are particularly susceptible to landslides, while the eastern lowlands and southeast face heightened drought risks due to low rainfall and high temperatures. Efforts to mitigate climate impacts include the Green Growth and Climate Resilience Strategy, aiming for a climate-resilient, low-carbon economy by 2050. Sectoral policies align with national development goals, emphasizing environmental sustainability and adaptive capacity.

Moving forward, targeted interventions are crucial in high-risk areas to strengthen disaster preparedness, infrastructure, and community resilience. Region-specific adaptation strategies are essential to address diverse challenges faced by local communities and ensure sustainable development amidst climate uncertainties. Overall, Rwanda's proactive approach to climate resilience and disaster risk reduction reflects a commitment to safeguarding lives, protecting natural resources, and promoting sustainable development in the face of evolving climate challenges.

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