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ANALYSIS OF CLIMATE CHANGE RELATED HAZARDS FOR THE RISK REDUCTION, CASE OF FLOODING IN THE CITY OF KIGALI

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Abstract: This study aims to analyze climate change related flood losses toward reducing the resulting risks in the City of Kigali. Secondary datasets on climate change (rainfall and temperature patterns) and flood losses (people killed/injured, destroyed infrastructures (classrooms, bridges, markets, electrical and water lines), cropland damaged and lost livestock) are utilized from1990 to 2020. Annual mean rainfall and temperature (max and min) data were collected from Tropical Applications of Meteorology using Satellite (TAMSAT) and the United States Environmental Protection Agency. Flood losses are collected from Ministry in charge of Emergency Management (MINEMA). The Spatial Analysts Tool of Geographic information System (GIS), Microsoft Excel and Statistical Package for Social Sciences (SPSS) facilitated data analysis and presentation. The results show a 1990 and 2020 fluctuating trend of temperature. The highest record of 27.86 ^{o}C was registered in 2000 while the lowest of 22.77 ^{o}C was noticed in 2010. For the rainfall, the 1990-2020 annual mean rainfall increases from 102.96 mm up to 221.34 mm in 2000 and 2020, respectively. This is attributed to rising number of flood losses also recorded within the considered period. The number of injuries caused by flood rose from 9 over 1990-2010 to 85 across the period 2010-2020. Similar, the number of houses damaged by flood increased from 75 to 3,187 within the period of 1990-2010 and 2010-2020, respectively. In addition, the map of flood over the study area confirms that areas with higher record of losses are similar recording higher rainfall. Although flood results from different factors, only climate change (rainfall and temperature) considered by this research confirm the effect on the growing number of flood losses. This is confirmed by the calculated, small but positive P value (0.028) between climate change and flood losses in the City of Kigali. Relevant recommendations are provided to policy makers and communities for the flood risk reduction and climate change adaptation mechanism which can be adopted in the context of the City of Kigali.

Keywords: Climate change, City of Kigali, Flood, Risk Reduction, Rwanda

1.Introduction

In the past decades, flood and drought along with extreme weather happened as major hydro-meteorological hazards. They generated several losses among people within different parts of the world. Hydrological extreme events and their occurrences and magnitude are increasing due to global climate change(Tripathi et al. 2022). The impact of climate change magnitude can be viewed across numerous sectors like fisheries, livestock, cropping and forestry, ecosystem and biodiversity, economy and health along with increasing the vulnerability of these sectors affected. The primary key to these effects is population growth and unplanned urbanization along with other people's activities across the globe (Kundzewicz et al. 2014; Ranger et al. 2011).

Floods are generally originated from fluvial, pluvial, coastal and storms sources and cause significant economic, environmental, and social effects. Flooding is the main challenge generated by the changing weather and climate (Li et al. 2016). Over the Southeast Asia (China, India, Vietnam, Bangladesh, Indonesia and Thailand), about 237 million people are predicted to be under climate change risk in the year 2050 (Mirza 2011). Flood risk and associated human morality and infrastructure losses are also dominantly localized in these countries due to advanced exposure and low community adaptation abilities (Yan and Alvi 2022; Patel et al. 2020).

In the City of Kigali, rapid urbanization combined with extreme weather, poor drainage system and less infiltration contributes to high runoff and frequent urban floods (Nduwayezu et al. 2016). Several parameters affect the quantity of stormwater runoff quantity including area of the catchment, Slope and shape of the catchment area, porosity of the soil, obstruction in the flow of water as trees, fields, gardens, etc., initial state of catchment area regarding wetness, intensity and duration of rainfall, atmospheric temperature and humidity, count and size of water drainages and culverts present in the area (MoE 2018; Bizimana et al. 2012; Nduwayezu et al. 2016).

Nevertheless, there is still lack of knowledge on the extent to which climate change contributes to the occurrence of flood which both policy makers and local communities would benefit in terms of future planning and safety as well. In addition, as the City records expanding trend, understanding historical climate record in the City of Kigali would contribute to flood loss reduction, resilience building and environmental and well-being benefits. In addition, there is still lack of knowledge on the extent to which climate change contributes to the occurrence of flood which both policy makers and local communities would benefit in terms of future planning and safety as well. In addition, as the City records expanding trend, understanding historical climate record in the City of Kigali would contribute to flood loss reduction, resilience building and environmental and well-being benefits (Burns 2021; Hess et al. 2019).

Despite the fact that recent researches (Li et al. 2022; Nahayo et al. 2019; Mind'je et al. 2019) indicated that climate change mainly rainfall patterns, is among the causes of flooding in the City of Kigali, these studies associated this fact with the location of the city, in the middle of mountains which facilitates the runoff along with poor settlement and high population density. However, there no existing research which was undertaken to show long term climate record and associated losses which could help in the risk reduction. The authors recognized this fact and chose to carry out this research on the Climate change related Hazards for the Risk Reduction with the case of Flooding in the City of Kigali.

2. Methods and Materials

2.1 Description of the research area

This study was conducted in the City of Kigali in Rwanda. The city has a population of 1.63 million people growing at and an average annual growth rate of 4%. This number counts roughly 14% of the total Rwandan population and is one of the fastest growing cities in the region with a high increasing of population (Nikuze et al. 2019). The City of Kigali is subdivided into three districts: Gasabo, Kicukiro and Nyarugenge. Those 3 districts have 35 sectors, subdivided also into 161 cells. The cells also comprise a total number of 1,061 villages. The City of Kigali is surrounded by the Northern Province on the North, Eastern Province on the East and South and Southern Province on the West. The elevation of the lower part is roughly 1400 m and the higher hills are at over 1845 m above the sea (Ntampaka et al. 2021; Bizimana et al. 2012).

The city of Kigali is founded on hills and mountains, with three mountains in the south and west (Mt Rebero, Kigali and Jali), draining a catchment area with a total area of about 730 km^2. The highest hill is Mount Kigali with 1850 m of latitude. Over time, the city of Kigali has evolved by leaps from one hilltop to another. This discontinuity is due to various constraints, namely the existence of flood plains, swamp and steep slopes. The settlements were mostly developed on gently sloping hillsides and on flattened hilltops (REMA 2013). Kigali experiences a tropical climate and receives relatively high annual average rainfall of 1,000 mm. The rainfall regime is bimodal, with seasonal convective rainfall occurring mainly during the months of March to May (main rainy season) and October to December (secondary rainy season) (MoE 2018).

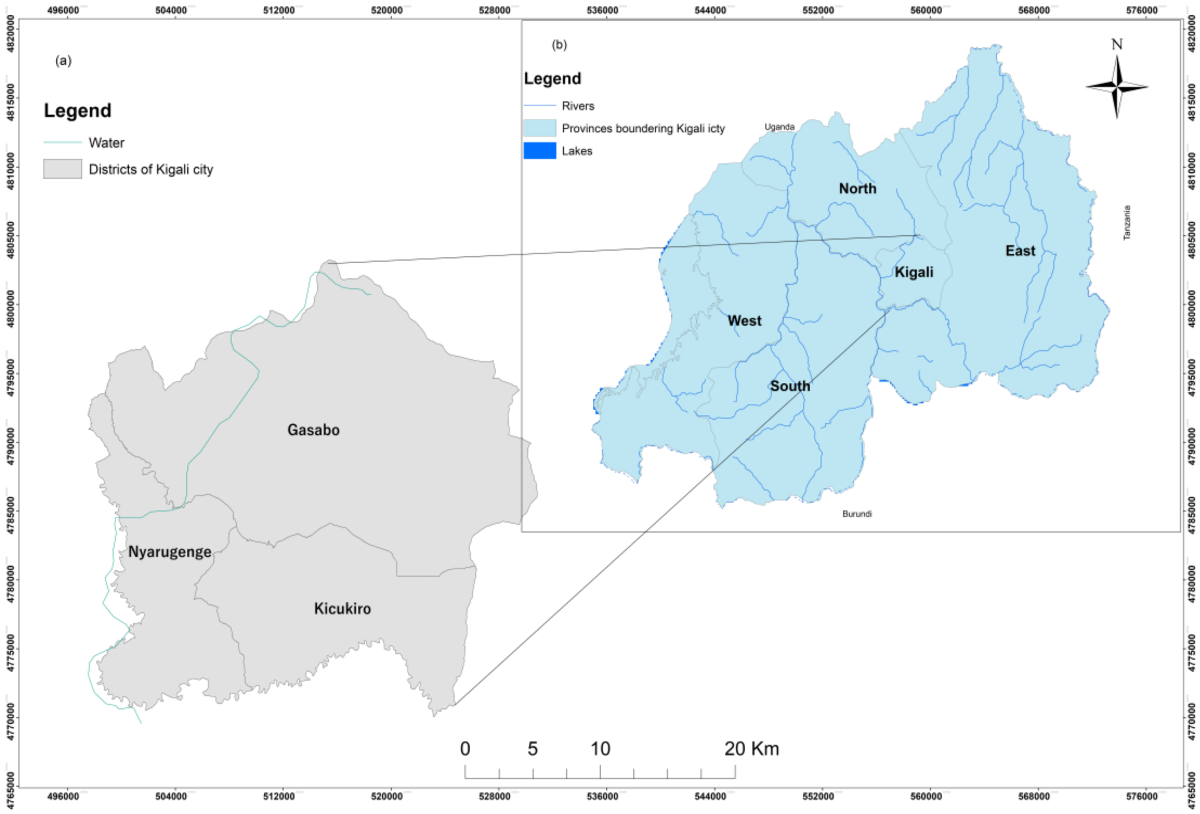

Figure 1: Map of the City of Kigali

Typical rainfall events are characterized by high intensities of short duration with high temporal and spatial variability, which leads to pluvial flooding (REMA 2013). The drainage network of City of Kigali contains a few complex inter-connected networks of small drains. Most of the existing drains are found undefined and not routinely maintained. Major drains are considered based on identified outfalls, engineering survey data and existing drainage network map from the City of Kigali'office. Most of the drainage structures in the City of Kigali are culverts, channels and bridges. In the development of drainage system, normally drainage infrastructure is sized according to the probability of occurrence of an expected peak discharge during the design life of the installation. This is related to the intensity and duration of rainfall events occurring not only in the direct vicinity of the structure, but also upstream of the structure (MoE 2018).

2.2 Data collection and analysis

2.2.1 Data types and sources

This study mainly consists of using secondary data related to climate change record and recent flood losses registered in the City of Kigali. The detailed information of the proposed methodology for this research is provided in Figure.2.

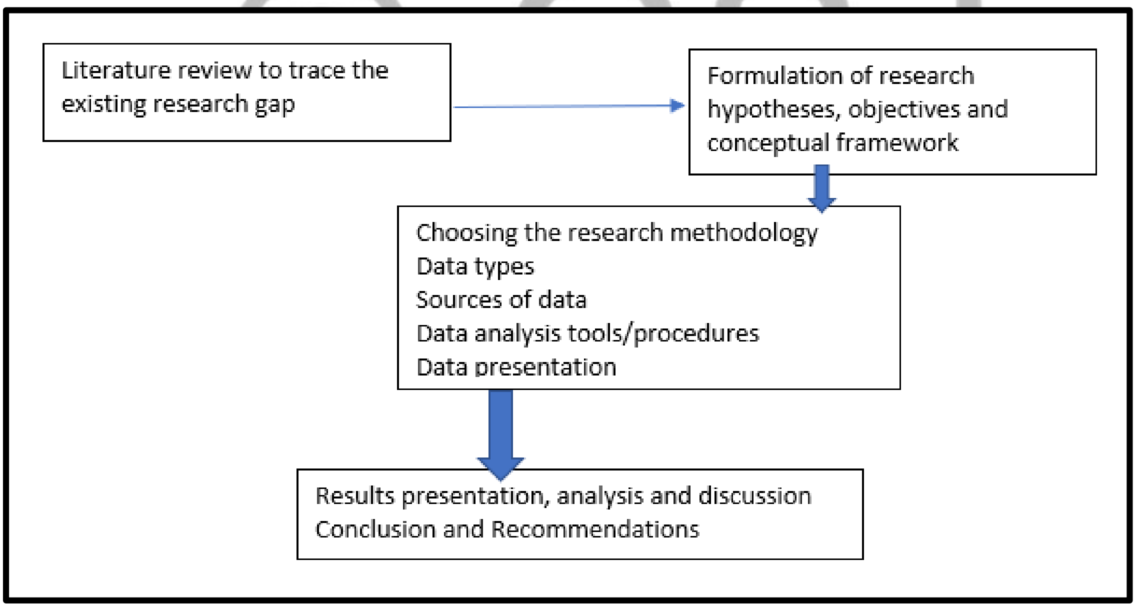

Figure 2: Study methodological flowchart

The authors employed dataset related to climate patterns mainly annual mean rainfall and temperature (maximum and minimum) patterns ranging between 1990 and 2020 as the study period. These datasets were collected from the Tropical Applications of Meteorology using Satellite (TAMSAT) and the United States Environmental Protection Agency. The secondary data on recent flood losses recorded in the City of Kigali were collected form Government reports, researches and Ministry in charge of Emergency Management (MINEMA).

2.2.2 Data analysis

For the climate change, the study uses maps of rainfall and temperature over the study period (1990-2020). The Geographic Information System (GIS) software, its version 10.8 was used to map the above rainfall and temperature patterns across the City of Kigali. Since the maps which were employed are from global scale, the researcher utilizes the Spatial Analyst Tools, specifically the Extraction by Mask technique in order to produce the map relevant to the study area. The Shapefile of the study area was collected from the National Institute of Statistics of Rwanda (NISR). Accordingly, the datasets on flood losses registered (killed/injured people, destroyed roads or bridges, damaged cropland and houses) were analyzed and presented by using the Microsoft Excel into Tables in order to reveal the trend between 1990 and 2020.

Furthermore, Pearson Correlation analysis of the Statistical Package of Social Sciences (SPSS) calculated the relationship between the two-research independent (Climate change) and dependent (flood losses) variables. To estimate this relation, the authors recognized that some researches which assessed/mapped flood hazard in the City of Kigali used several causal factors such as elevation, slope, land use and land cover, lithology, drainage density, distance to road and rivers. However, climate exchange mainly rainfall was selected among the above factors. Hence, for this research only climate change specifically temperature and rainfall were considered.

Thereafter, in order to successfully perform the Pearson Correlation analysis, the researcher based on the fact that a p-value smaller than 0.05 indicated a statistically significant association (at 5 % level) and a p-value larger than 0.05 reveals no statistically significant association between two variables tested. The researcher refereed to Pearson correlation values (coefficient r) suggested in Table 1.

Table 1: Pearson correlation analysis guideline

	Coefficient, *r*	
Strength of Association	Positive	Negative
Small	.1 to .3	-0.1 to -0.3

Medium	.3 to .5	-0.3 to -0.5
Large	.5 to 1.0	-0.5 to -1.0

3.Results

3.1 Climate change record

For the results on climate change, the authors utilized the annual mean temperature in degree Celsius, relative humidity in percentage and annual mean rainfall in millimeter.

3.1.1 Temperature patterns

In 1990, it is noticed that the annual mean temperature varied across the City of Kigali. As shown in Figure 3, higher temperature of 27.61 degree Celsius was mainly concentrated in the middle of the City of Kigali while the lowest temperature of 23.5 decree Celsius was noticed largely within Gasabo district.

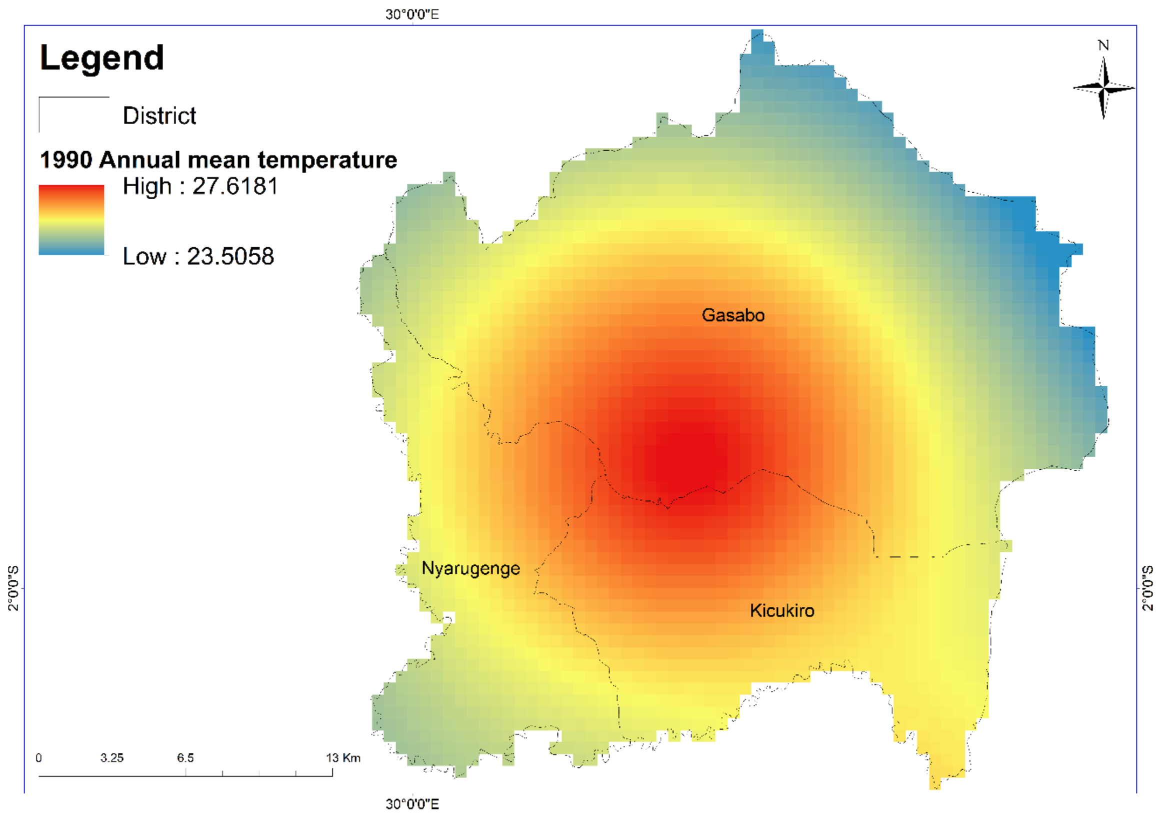

Figure 3: 1990 Annual mean temperature in the City of Kigali

With regard to the recorded temperature in 2000, the results in Figure 4 show that Kicukiro district recorder high temperature than Gasabo and Nyarugenge Districts. However, it is noted that both low and high temperature increased a bit than the record of 1990.

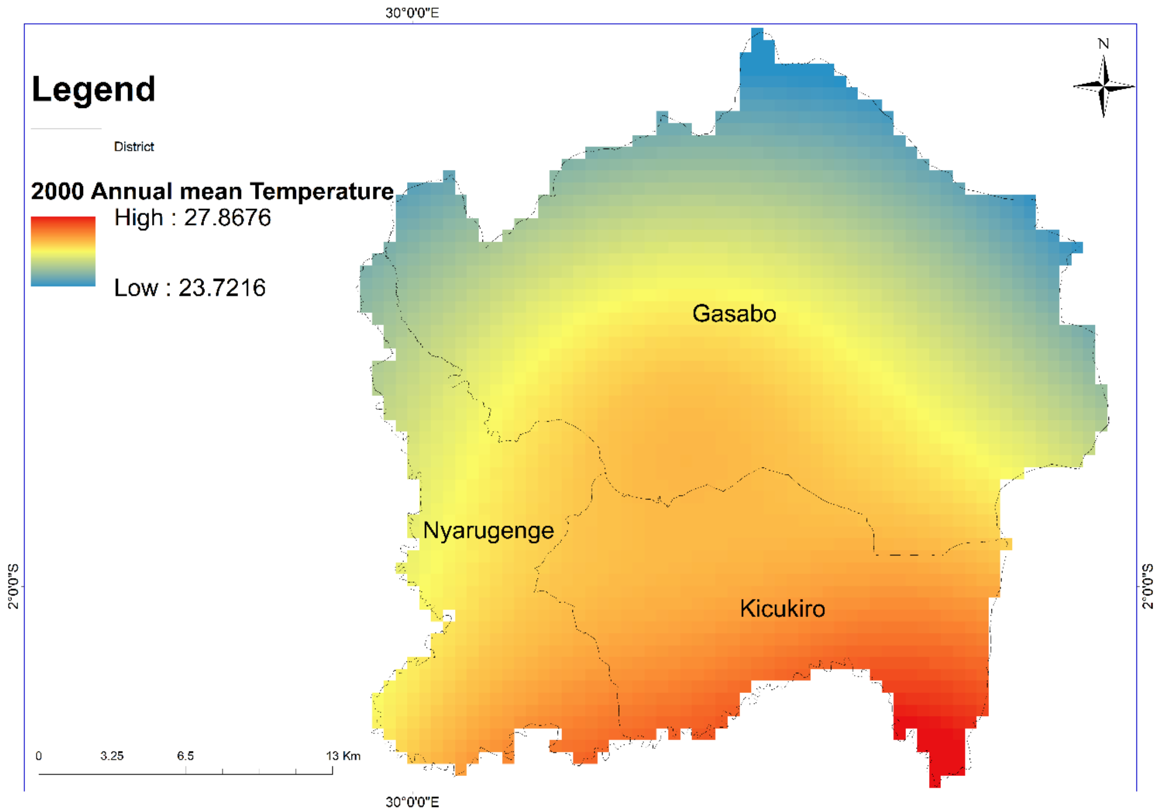

Figure 4: 2000 Annual mean temperature in the City of Kigali

In 2010, the results in Figure 5 show that the distribution of high temperature seized a large part of the City of Kigali. The record of 1990 looks similar to that of 1990.

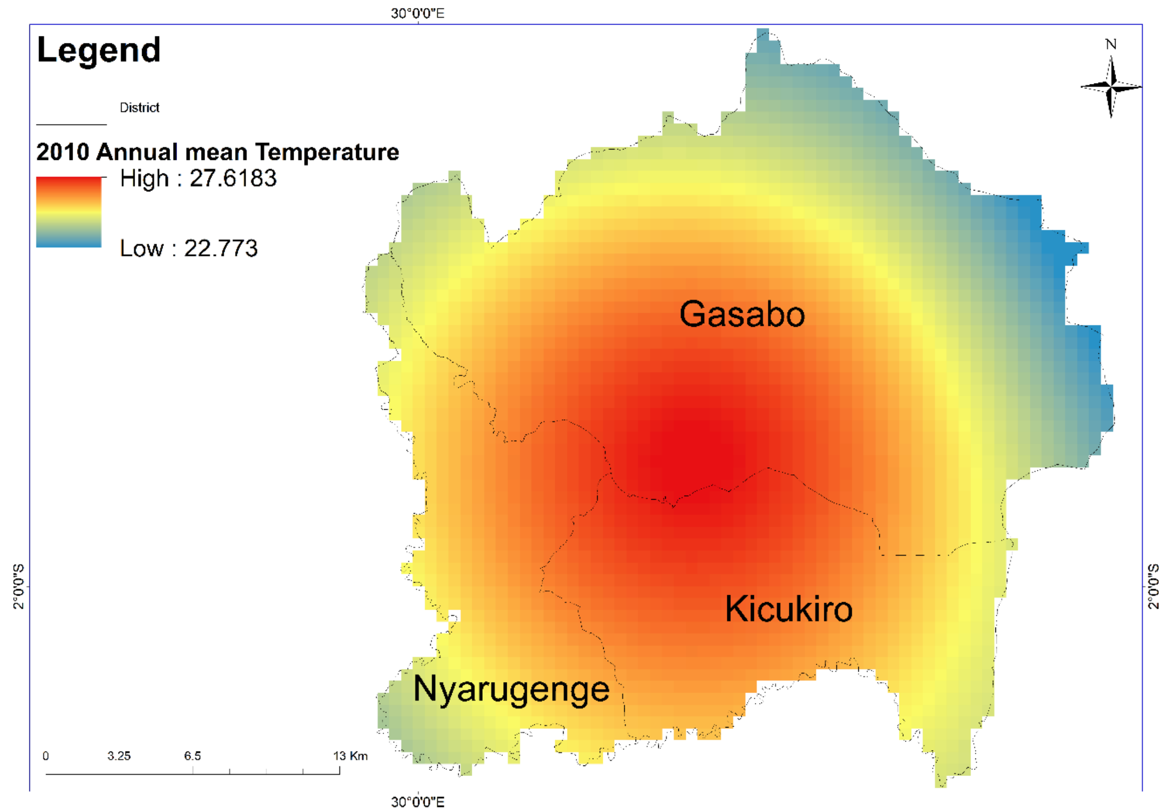

Figure 5: 2010 Annual mean temperature in the City of Kigali

Finally, the distribution of annual mean temperature of 2020, as illustrated in Figure 6 reveals that both low and high temperature recorded decreasing trend. High temperature was 24.99 degree Celsius while the lowest record was 23.31degree Celsius (see Figure 6).

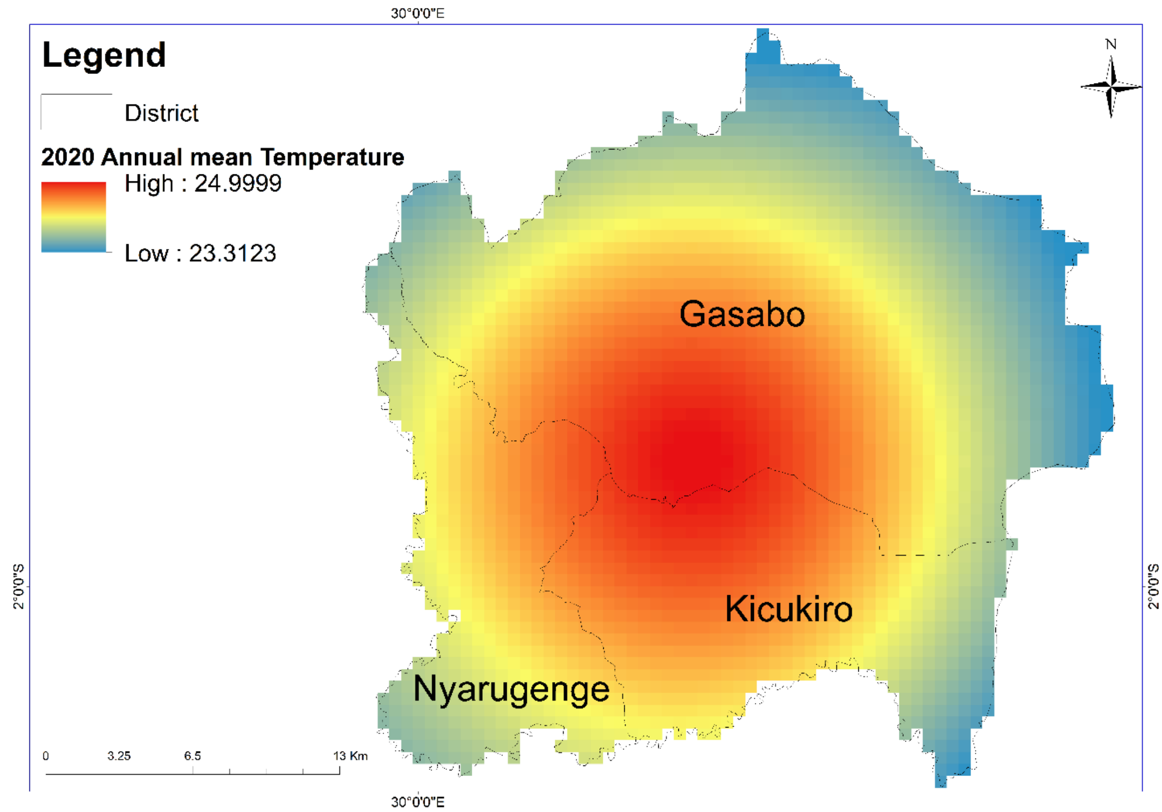

Figure 6: 2020 Annual mean temperature in the City of Kigali

As indicated in Table 2, highest record of temperature of 27.86 was registered in 2000 while the lowest temperature of 22.77 degree Celsius was noticed in 2010. In addition, it can be noted that the recorded temperature is the same range from 1990 to 2020.

Table 2: 1990-2020 Annual Mean Temperature

Temperature (°C)	Year			
	1990	2000	2010	2020
Low	23.50	23.72	22.77	23.31
High	27.61	27.86	27.61	24.99

3.1.2 Rainfall patterns

Regarding rainfall patterns recorded in the City of Kigali, the results in Figure 7 indicates that in 1990, high annual mean rainfall was 231.95 mm while the lowest record was 159.06 mm. The same Figure 6 demonstrates that some parts of both Gasabo and Nyarugenge districts recorded high rainfall than Kicukiro district.

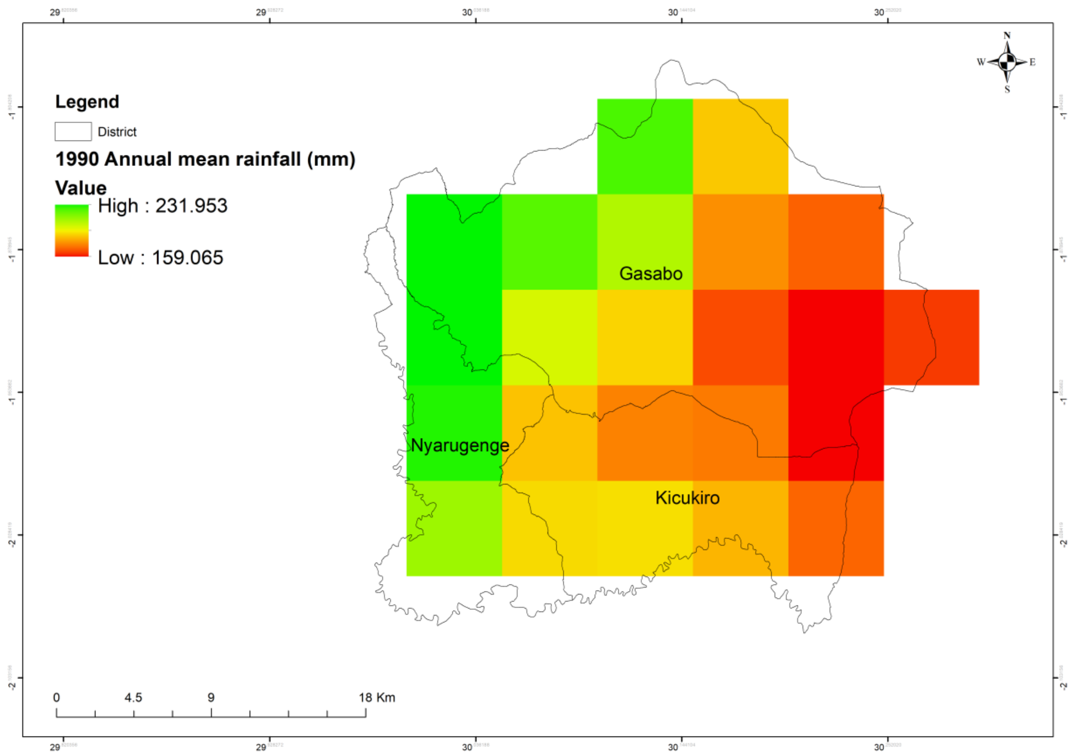

Figure 7: 1990 Annual mean rainfall in the City of Kigali

In 2000, the results in Figure 8 show that in 2000, the recorded spatial distribution of rainfall in the City of Kigali was almost similar within all three districts. Higher rainfall was largely recorded across the City of Kigali at 102.9 mm while the lowest record was 83.7 mm.

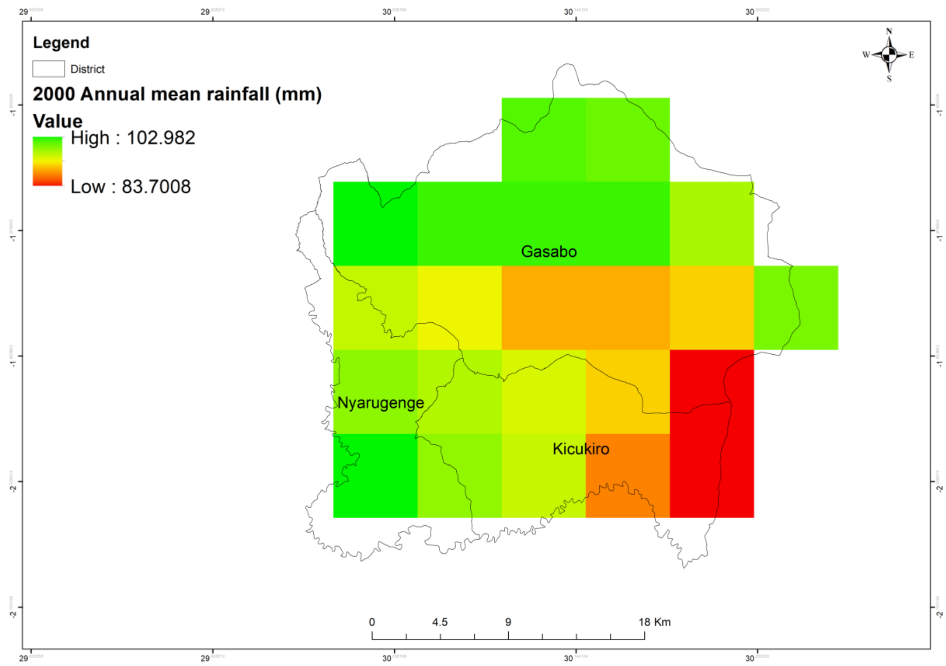

Figure 8: 2000 Annual mean rainfall in the City of Kigali

With regard to the record of 2010, it is indicated that the rainfall was mainly recorded within some areas of Kicukiro district (Figure 9). This was at 123.51 mm and was the opposite of the record of 1990 (see Figure 7) which reveal that higher record of annual mean rainfall was in these parts of the study area. This can express that rainfall intensity records increasing trend within the City of Kigali.

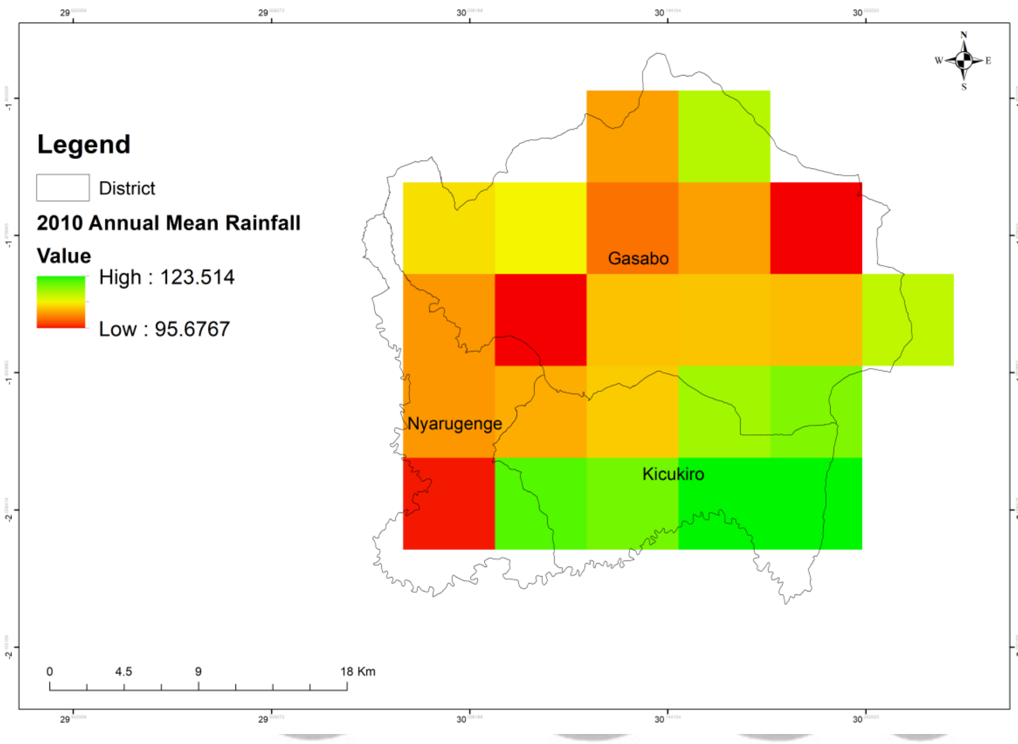

Figure 9: 2010 Annual mean rainfall in the City of Kigali

Furthermore, in 2020, as shown in Figure 10, both Kicukiro and Gasabo districts are localized within low rainfall. A small part of Gasabo district was localized within high rainfall of 221.34 mm.

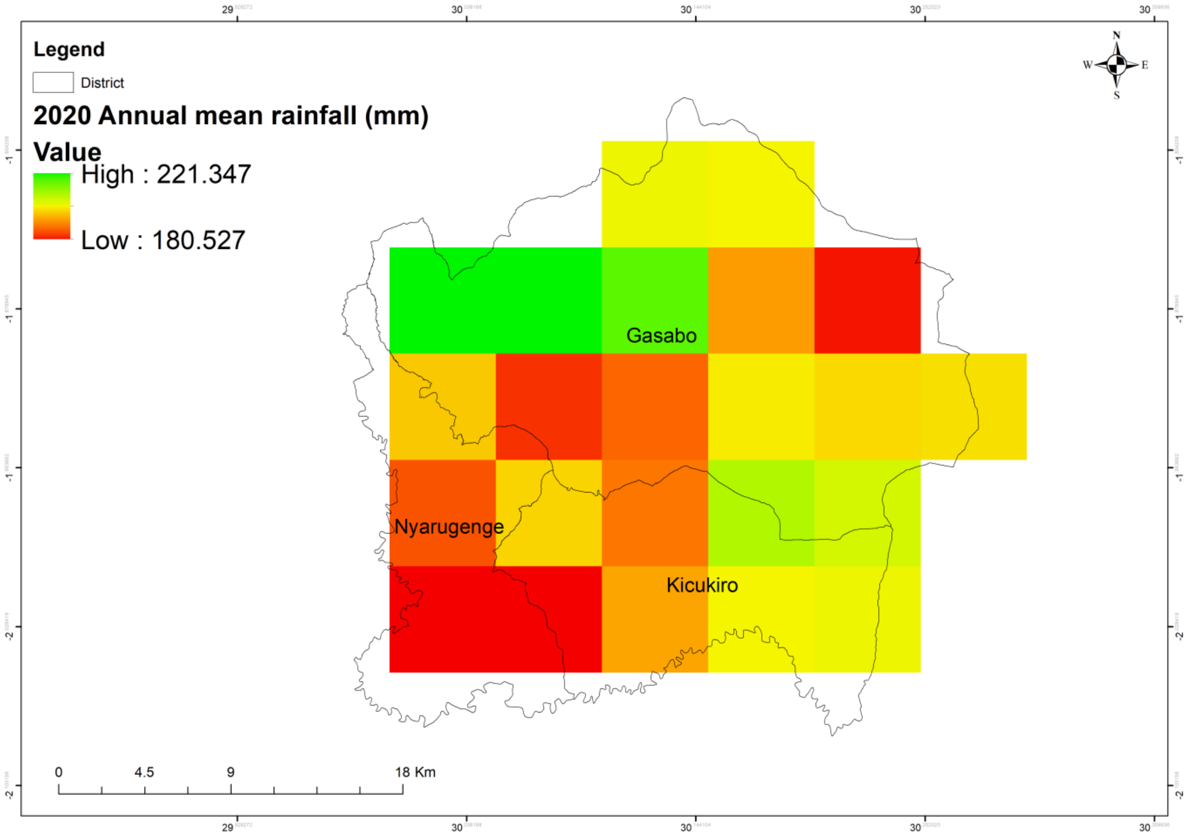

Figure 10: 2020 Annual mean rainfall in the City of Kigali

As indicated in Table 3, between 1990 and 2020, the City of Kigali recorded a variation of rainfall in terms of intensity. The year 1990 recorded highest record of 231.95 mm followed by the year 2020. The lowest record of 83.7 mm was noticed in the year 2020 followed by 2010 with 95.67 mm, respectively. Nevertheless, it is clear that the rainfall record in the City of Kigali is under increasing trend since it increases from 102.96 mm up to 221.34 mm in 2000 and 2020, respectively (see Table 3).

Table 3: Annual Mean Rainfall from 1990 to 2020

Rainfall (mm)	**Year**			
	1990	2000	2010	2020
Low	159.06	83.7	95.67	180.52
High	231.95	102.96	123.51	221.34

4.3 Flood losses

As shown in Table 4, the losses resulting from flooding in the City of Kigali which were recorded between 1990 and 2010 show that the number of people dead form flood were 77 while the damaged houses were 79. There is no record on number of hectares of cropland damaged and infrastructure affected such as roads, bridges, classrooms, markets and transmission lines. The reason can be that there were no sufficient data collection mechanisms which were on place on this time.

Table 4: Recent flood losses recorded in the City of Kigali (1990-2020)

1990-2010			
City of Kigali	Deaths and Injuries	Dead	77
		Injured	9
	Houses Damaged		0
	Damaged Land Ha.		0
	Infrastructure affected	Classrooms	0
		Roads	0
		Bridges	0
		Administrative Offices	0
		Transmission Lines	0
		Markets	0

Source: National Risk Atlas of Rwanda, 2015

Nonetheless, as shown in Table 5, the record of losses caused by the occurrence of flood in the City of Kigali increased tremendously from 2010 to 2020. For example, the number of injuries caused by flood rose from 9 over 1990-2010 to 85 across the period 2010-2020. Similar, the number of houses damaged by flood increased from 75 to 3,187 within the period of 1990-2010 and 2010-2020, respectively (compared Tables 4 and 5).

Table 5: 2010- 2020 flood losses

2011-2020					
		District			
		Gasabo	Kicukiro	Nyarugenge	Total
Deaths and injuries	Dead	26	16	11	53
	Injured	18	18	22	58
Houses Damaged		1229	303	1655	3187

Damaged land Ha.		407	15	246	668
Classrooms		16	0	2	18
Infrastructure affected	Roads	8	6	9	23
	Bridges	4	4	3	11
	Administrative offices	4	0	3	7
	Transmission lines	4	0	1	5
	Markets	1	0	0	1

Source: National Risk Atlas of Rwanda (2015) and MINEMA Annual Report (2020)

The above results on flood losses coincide with the noticed increasing rainfall trend from 2010 to 2020 which can be the reason behind. This results from the fact that in case the intensity and frequency of rainfall increase, the likelihood of recording flood becomes higher as well. In addition, as shown in Figure 10, the 2022 distribution of flood hazard over the City of Kigali confirms its major causes (rainfall), where the areas under high rainfall are similarly under high flood hazard. The results Figure 11 presented five classes of flood hazard in the City of Kigali namely very low flood hazard, low flood hazard, moderate flood hazard, high flood hazard and very high flood hazard. It was noticed that each district of the City of Kigali is exposed to flood and Gasabo district records the majority of high and very high flood hazard classes, respectively (Figure 11).

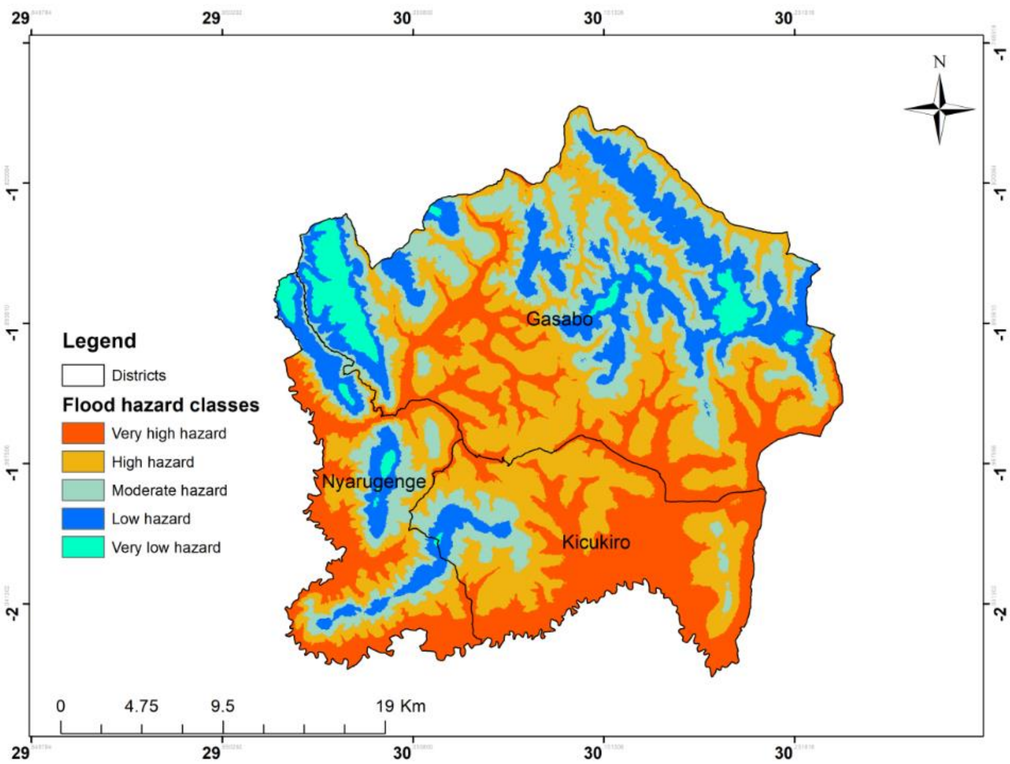

Figure 11: Flood hazard distribution in the City of Kigali
Source: Martine et al., (2020)

The estimated flood hazard exposure per district (Table 6) revealed that the residents of Gasabo district are, at large extent, exposed to flood at 5.43 percent compared to residents of Nyarugenge and Kicukiro districts, exposed to flood at 25.4 and 19.2 percent, respectively.

Table 6: Estimated flood hazard proportion per district

Exposure	Districts		
	Gasabo	Nyarugenge	Kicukiro
Very low hazard	0.8	2.1	4.6
Low hazard	14.3	4.6	1.8
Moderate hazard	11.2	9.2	3.2
High hazard	23.1	7.4	5.3
Very high hazard	6	2.1	4.3
Total exposure rate	55.4	25.4	19.2

Source: Martine et al., (2020)

4. Discussion

Floods are moong the global hazards being recorded under the changing climate, mainly rainfall and temperature patterns which lead to some areas recording higher intensity while other are facing decrease of frequency and intensity as well (Glago 2021). It is reported that, in most of cases, poor countries and their communities are the most affected by flood due to the fact that their adaptation capabilities are limited/not available at all (MoE 2018; Manuta and Lebel 2005).

The changing climate is happening and its associated losses on livelihoods, food security and aggravating conflicts on resources. Across the western and Central Africa, heavy rains caused flooding which claimed hundreds of lives and livelihoods (Singh et al. 2022; Tramblay et al. 2021). However, it is reported that lack of strong early warning system and poor recognition of the major cause of flood also leads to increasing number of losses among the communities. Among other, heavy rainfall and poor land management practices are being highlighted by several researches that they contribute to frequent flood losses (Manuta and Lebel 2005; Singh et al. 2022; Mirza 2011).

In Rwanda, the City of Kigali along with the North-Western part re heavily affected by flooding. Despite the fact that several studies covering these are have been conducted, there is still occurrence of this hazard mainly due to the location of these are in the middle of mountains in which the turnoff is very easy during rainfall (Subramanian et al. 2020; Bizimana and

Schilling 2010; Nikuze et al. 2019). This is predominantly accelerated by the changing climate also being recorded over Rwanda, which affects the distribution and frequency of rainfall along with poor water draining and rainwater harvesting systems in place (Ntakiyimana et al. 2021).

This study considered a long-term relationship between climate change and flood losses in the City of Kigali. The results confirmed that in this area, climate change is real mainly rainfall patterns recorded between 1990 and 2020. It is specifically noticed that from2010 to 2020, the record of annual rainfall increased (see Table 3). In addition, the recorded flood losses increase simultaneously with flood losses within the same period (see Table 3). The results of this research agree with the recently reported (Ngarukiyimana et al. 2021; Nahayo et al. 2019; Mikova et al. 2015) increasing effects of climate change in Rwanda mainly in the City of Kigali. It is reported that under climate change, more rainfall patterns are disturbing people's livelihoods and destroying infrastructures.

In addition, some researches (Rugema et al. 2022; MoE 2018; Taremwa et al. 2016; Nsengiyumva et al. 2019)indicate that rainfall among some causal factors of flood, is the major driver which expresses how rainfall will keep on leading to losses if climate change is not well mitigated and adapted to. Furthermore, the results of this study (see Table 7) confirm the effect of climate change on increasing flood losses within the City of Kigali as proved by the calculated P value of 0.028 on the relationship between climate change (independent variable) and flood loses (dependent variable).

Table 7**: Relationship between climate change and flood losses**

		Climate change	Flood losses
Climate Change	Pearson Correlation	1	.028
	Sig. (2-tailed)		.972
	N	4	4
Flood losses	Pearson Correlation	.028	1
	Sig. (2-tailed)	.972	
	N	4	4

Although this extent on how climate change contributes to flood losses in the City of Kigali is small, it is positive and significant as well. This, as previously reported (Pall et al. 2011;

Bhattacharjee and Behera 2018), can be associated to the reason that rainfall and temperature patterns are not contributing to flood occurrence alone but in association with other factors such as soil type determining the soil water retention capacity, elevation of the area and its slope facilitating the runoff, land management practices exposing the land and/or covering the land with vegetation, etc.

The results of this study on correlation analysis (Table 7) facilitated the researcher to judge on the formulate research hypotheses. Since, there is positive correlation between climate change and flood losses in the City of Kigali, the authors conclude that the risk of flood risk resulting from changing climate is predominantly increasing in the City of Kigali.

For flood risk reduction, the authors designed a conceptual framework on flood risk reduction and/or strategic measures which can be applied, mainly in Gasabo district in which the hazard reveals growing trend. However, we recommend that these measures be extended within all other parts of the City of Kigali to ensure flood risk reduction at equal extent.

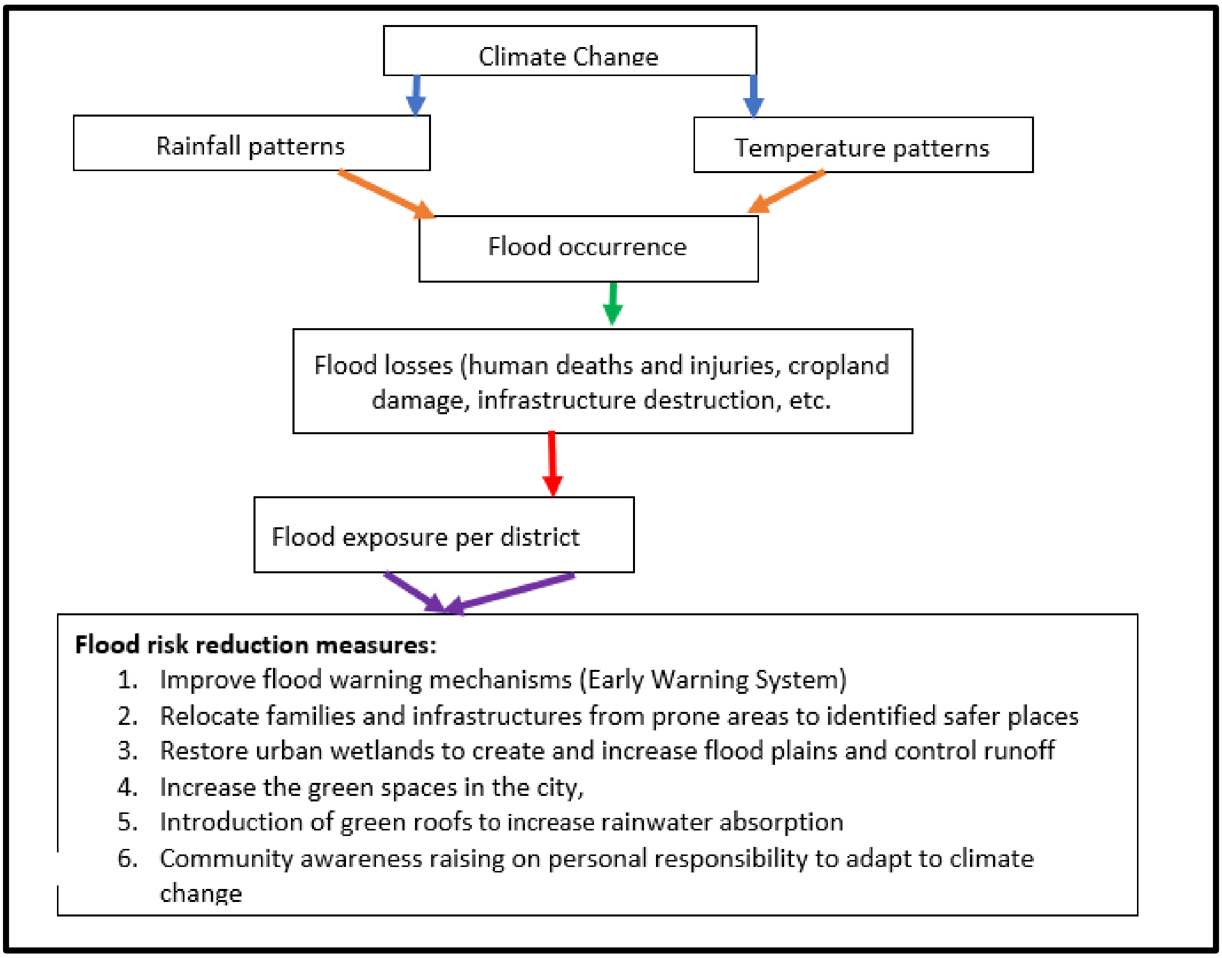

Figure 4. 10:Suggested flood risk reduction framework

5. Conclusion

This research aims to analyze the trend of Climate Change related Hazards for the Risk Reduction with the case of Flooding in the City of Kigali from 1990 to 2020. Secondary data related to climate change indicators mainly rainfall and temperature along with flood losses are utilized by the researcher. The Spatial Analysts Tools of GIS, Microsoft Excel and SPSS facilitate the researcher to collect and analyze the data. The research findings show that between 1990 and 2020, there has been a fluctuating trend of temperature record over the City of Kigali. The highest record of temperature of 27.86 was registered in 2000 while the lowest temperature of 22.77 degree Celsius was noticed in 2010. For the rainfall, the 1990-2020 annual mean rainfall reveals an increasing trend since it increases from 102.96 mm up to 221.34 mm in 2000 and 2020, respectively. As a result, this is attributed to the growing number of flood losses also recorded within the considered period of study. The number of injuries caused by flood rose from 9 over 1990-2010 to 85 across the period 2010-2020. Similar, the number of houses damaged by flood increased from 75 to 3,187 within the period of 1990-2010 and 2010-2020, respectively. In addition, the map of flood over the study area confirms that areas with higher record of losses are similar recording higher rainfall. Although flood results from different factors, only climate change (rainfall and temperature) considered by this research confirm the effect on the growing number of flood losses. This is confirmed by the calculated, small but positive P value (0.028) between climate change and flood losses in the City of Kigali. There need of considering these results in policy planning in terms of food risk reduction. In addition to the conceptual framework proposed by the researcher for flood risk reduction, the following are recommendations which can help the City of Kigali to deal with the floods.

Recommendations to policy makers:

- As long as climate change is real and happening, more flood losses will be recorded; policymakers have to consider this fact and build strong early warning systems toward strengthening People's awareness and preparedness.
- Policymakers have to recognize the effect of climate change and conduct housing suitability studies within the City of Kigali to minimize the communities, environment, and infrastructures' exposure to flooding Strong climate change adaptation mechanisms (e.g., community awareness, education, and strong and resilient properties in safe areas) should be envisaged in the City of Kigali to reduce losses associated with the changing climate.

Recommendations to the residents of the City of Kigali:

- As long as flood hazard-prone areas are known through mapping, the residents of the City of Kigali should consider the use of available information and ensure they build in the safe zone areas for their own safety and for the protection of their investments.
- Although the City of Kigali is becoming more and more urban, the residents are encouraged to expand the areas under trees and green spaces which can facilitate the reduction of runoff and consider adaptation to climate change as personal responsibility.

Recommendations to the researchers:

- Assess the community awareness and preparedness to flooding.
- Predict the likelihood of flood occurrence under climate change.
- Expand the scope of this research to other areas in Rwanda that are prone to flooding.
- Facilitate the policymakers to have updated information needed to make informed decisions and development of master plans.

Acknowledgements

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