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THE ROLE OF RAIN FORECASTING IN FLOOD RISK REDUCTION, CASE STUDY OF KIGALI CITY, RWANDA

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ABSTRACT

Floods are recognized as a severe natural disaster influenced potentially by anthropogenic activities. Kigali downstream floods were coming from the drainage system and the flow of streams. The study revealed on contribution of rain forecasting in reduction of flood risk in Kigali city, to show how well forecasted rain used to decrease flood risk among urban residents. The objectives were to carry out a flood risk analysis, determining the potential frequencies rainfall occurred and assessing the contribution of rain forecasting on flood risk reduction. The data was for Kigali city in three districts (Nyarugenge, Gasabo and Kicukiro) from 2016 to 2020, collected from literature review on disaster in Kigali city and Statistical package for social sciences (SPSS) tool and Microsoft excel was used in analysis. The risk analysis factors were based on deaths, injury, infrastructure loss and crops loss per ha, the prone district is Nyarugenge. The Pearson correlation coefficient between variables mostly had positive correlation and in significate range with flood risks in both districts but on different range with such exception of negative relationship. Nyarugenge district precipitation made positive correlation with infrastructure and deaths, $r= 0.138$ in range $0<r< 0.25$ very low correction; $r=0.673$ in range $0.50\leq r<0.75$ high correlation, respectively conclude that the increase of precipitation led to raise both infrastructure loss and deaths. Recommended measures will base on particular features of district (soil type, land use, geology and geomorphology analysis) especially on Nyarugenge district, which is more suspended to the floods to mitigate and adapt flood risks.

Contribution/Originality: The paper contributed in demonstration of the potential frequencies rainfall occurred, had more influence in three districts but reinforcement needed on building resilient, land use and management will be at Nyarugenge district than other districts of Gasabo and Kicukiro districts.

1. INTRODUCTION

The climate change impacts were relating to the extreme weather events, which caused such events as drought, forest fire, heat waves, dust storms, floods and landslides. Globally on flood, from the year 1995 to 2015, 3062 floods disasters were recorded and accounted for 47% of all weather associated with the disasters which include geophysical hazards like volcanoes eruption and earthquakes, hydro-meteorically hazards like storms and climatological hazards like drought [1].

The disasters a raised from water resource such as soil erosion, landslide, floods and water borne diseases can also cause impairment of socio-economic activities, fauna and flora as well as to the human health [2]. The process of urbanization is among the sources of the continuous increase of the floods events and the interrelated losses worldwide, principally due to the upsurge of impervious surfaces and the exposure of people and their properties [3]. The houses, impervious surfaces in urban areas, roads and many more infiltration capacity reduction of the former catchment in rural areas [4].

The floods impacts counted in the economic loss of 666billon united state dollars (USD) and the people affected was 2.3 billion which represented 56% of all the people affected by weather related disasters where 157,000 people died due to the floods [1]. The floods events accounted from 1997 to 2008 for the overpowering majority of monetary disaster damages and accounted for one third of the total of 3.3 million people exaggerated by disasters in African cities [5]. Furthermore, the ended past two decades, the floods and droughts have exaggerated over 2 million persons [6]. The loss in Rwanda from risks of floods predicted in total economic value, it's about 1.4% of the overall gross domestic product (GDP) of 2011-201 of the fiscal year [7].

The events of heavy rainfall in Kigali city, trigger rapid rushes in the flow of streams and drainage systems leading to downstream flooding. The impacts of floods are accelerated with mainly hilly topography included the area physical structure united with the demographic pressure on scarcity resource of land [8]. In 1960s Kigali city was experienced although by floods, but in 2000s the frequency has more significant and the great impacts have been occurring on infrastructures, human development, environment and as well as properties [9].

The flood risk forecasting and analysis requirement probabilistically of floods was mainly dynamics and the floods risk assessment discover the flood process sequence from precipitation, accumulation in the catchment, runoff generation, flood routing in the streams system, inundation to economic damage, probable failure of flood protection measures then after the process of mitigation and preparedness [10] .The study revealed on rain forecasting to reduce flood risks in Kigali City, through analyze the historical data of rainfall and analyze the risks associated with flood and theirs reduction in the study area.

The growth of high population density development and urban area, that triggered higher flood exposure as the greater risks. The natural ecosystems are being affected by human activities including land use, biodiversity and natural loss, air pollution exceeding the required limits, urban flooding, the impervious areas enhanced runoff storm water from decline of retention basin areas ,thus will have numerous effect on economic, social and environment aspects which are useful to achieve the sustainable development goals and when it is coupled with other hazards they are predicted to become more serious, dominant and frequent in the coming year generally in the growing towns [11].

From Rwanda landform that made 20% of inland more probable to flooding in any given year [12]. In Kigali also the flood loss is remarkable, the study done on small and medium sized enterprise around Nyabugogo shows that among 350 surveyed business 81% of businesses affected by floods in 2013 and 2014, the sum of $194000.00 around was direct and indirect damages from floods where, the businesses annual loss costing amounted more than 139,308,500.00 rwf [13].

The role of rainfall forecasting in flood risk reduction study was based on carrying out the floods risks analysis, determining the potential frequencies rainfall occurred and assessing the contribution of rain forecasting on flood risk reduction. Which provided information to Policy and Decision makers like governments, local, regional and international institutions and non-government organizations (NGOs) to which the flood risks will be reduced in the area and be the basis for choosing and implementing flood management measures to reduce economic losses as well as deaths of people in general and also will bring the new knowledge to communities, government, different institutions and NGOs working in Kigali city for understanding the application of weather forecasting in their short term and long-term activities depending on how they can be affected by flood.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

Rwanda country capital is Kigali city with landscape of hills region and valleys and referred as the central plateau. The city composed three districts as follow; Gasabo, Kicukiro and Nyarugenge with 731.4 km square. Those 3 districts have 35 sectors was subdivided into 161 cells. The cells comprised also a total number of 1,061 imidugudu literally known as village. Kigali has the highest population density of the country. It is currently occupied by approximately 1.2 million peoples with 70% rural population, which is comparatively young. The youth make up about 60% and women create slightly more than 50% [14].

The catchment boundary of the study area is situated in the administrative Kigali City on latitude between 2'00"-1'45" S and longitude 29'50"-30'35" E and elevation ranges from 1,376 to 2,311 m above mean sea level. Nyabugogo watershed cover both Kigali and rural areas and the total area is about 1,647 km sq. The main land use activity in the basin is agriculture, which occupies about 897 km sq or about 54% 0f the basin. Kigali keeps rising by leaps and bounds over the hilly terrain surrounding the center [15].

In the largest part of the zone, the slope varies between 10-45%. The study area within boundary regularly of the thalwegs are commonly middle, large and narrow with both irregular and permanent drainage system. They are just about dry except the part of the wetland situated in the southeast of the study area. Which is flooded throughout the great rain season [16]. Kigali is situated closer to the outlet of the middle part of Nyabarongo watershed; Nyabarongo river on part of Nyarugenge and Kicukiro and their tributaries. The main rivers fed Nyabugogo, Nyabarongo, on part of Kigali city are Mpazi, Katabaro, Nyakabanda, Rwezangoro, Rugunga, Rwampara, Rugende, Karuruma, Mulindi, Gitazigurwa, Gitakuzi, Rufigiza, Ruganwa, Rwanzekwima, Morongozi, Nyacyonga, Yanze and Rwintare.

Kigali has a typical tropical climate, which is characterized by high annual rainfall of up to 1400 mm per annum. The area experienced a bimodal rainfall happening mostly throughout the period from March to May and September to November. High intensity thunderstorms/showers that are generally short lived and cause often flooding in the Nyabugogo wetlands. During the rainy month rainfall may reach 300mm per month. During the dry months from Mid-January to March and from June to August it is about 50mm per month where in some regions experiencing orographic precipitations. Most of flooding events in Nyabugogo area occurred in this high rainy season [17].

The study area experiences seasonal temperature variations with highest temperatures throughout the dry season and the coldest period occurs throughout the rainy season. The average monthly maximum temperature ranges between 22-27oC while the average minimum temperature ranges between 17-20oC. The average sunshine is about 1675 hours per year with high sunshine in the dry season and smaller amounts of rainfall in the rainy season this data provided by the Kanombe International Airport weather station [17].

The expected land use and current Kigali city master plan program displays clearly how the city is developing in terms of built up through commercial, social, residential, government infrastructure and industrial and also agriculture, pervious area and water bodies. The Kigali master plan providing a long-term vision for the city and it sets up important pillars of sustainable urban development such as; slopes, forest areas and protection of wetlands. The current land use typology of Kigali is clustered into urban and rural clusters.

The total area working as urban areas is predicted to be 17% around 124.7 km sq. However, the rural portion take over 83%, around 606.73 km sq. The city is providing with many growth opportunities in relations of available undeveloped land and low density areas with the potential to be developed. The city is current land use was subjected by agriculture around 63.10%, natural areas around 19.40% and residential areas around 9.20%. While, the expected in the future land use distribution for 2040 will be subjected the residential around 43%, open and natural areas around 26%, industry around 5% and commercial and mixed use 3% this study will take into account the master plan of Kigali. Which is currently being realized for evaluating the land use change impact on the city [17]. Figure 1 Illustrates, the administrative map of Kigali city capital of Rwanda, as case study.

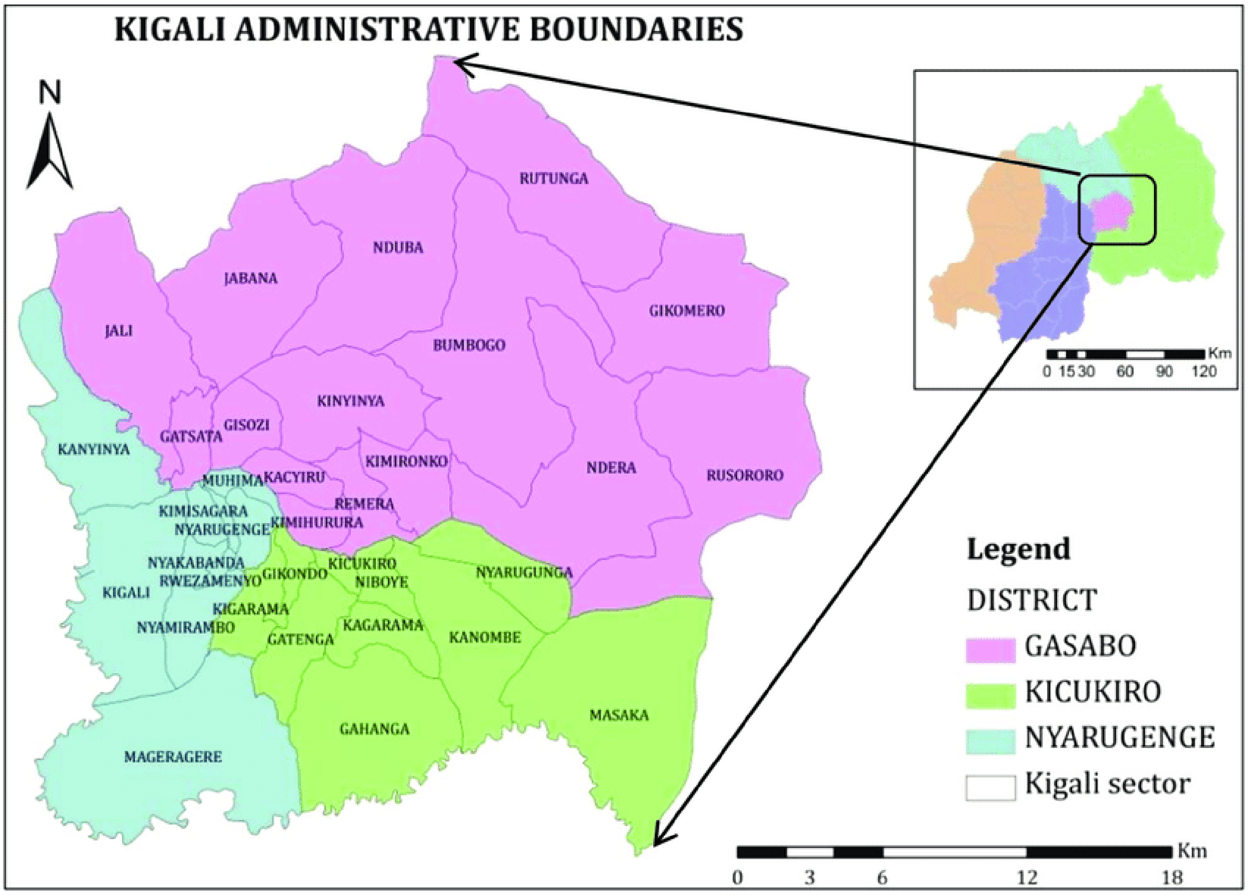


Figure 1. Administrative map of Kigali city [18].

2.2. Research Design

The approaches used, are quantitative and descriptive approach since methods of collecting data was merely based on secondary data sets and their analysis involved the usage of Microsoft excel for tables and charts. The researcher accompanied a review of the literature with the determination of launching a theoretical framework for more accepting and drawing the standing research gap to be associated. The specific techniques to use in this collection of data include survey, observation, and documentary review. Those methods were involved in collection of historical data of rainfall forecasted associated with flood risks from 2016 to 2020. The data sets include rainfall intensity, which is likely to cause flood risks collected from Meteo-Rwanda. Also flood risks, which were linked with the losses happening on crop production, infrastructure and health domain, thus have been collected from MINEMA, and Kigali city report.

2.3. Data Collection and Analysis

The materials used in this research was the literature review related to the subject. The SPSS 20 tool, using correlation to present rainfall forecasted and corresponding flood risks, to show their relationship and also showing if it was so important in flood risk reduction. The geographical Information System (GIS) tool will be used in this analysis process, through spatial variation of flood basics to be achieved using map presentation.

The researcher was gathered dataset related to historical rainfall and rainfall predicted since 2016 to 2020 which was been collected from Meteo-Rwanda report. The flood risks where, losses counted during the forecasted from past data of rainfall and their risks, recorded from ministry in charge of emergency management (MINEMA) and Kigali city since that time and mechanism used to reduce risks.

The Pearson correlation indicated the influence of rainfall on flood risks in districts of Kigali city. Where at positive both flood risks decrease or increase together while at negative correlation indicated that the impact of rainfall influenced both factors oppositely, one decrease and other increase. The decision will Based on positive and negative of the Pearson correlation coefficient (r) on the contribution of rain forecasting on flood risk reduction analyzed by using correlation conditions as following;

$r=1$; perfect correlation

$0.75\leq r<1$; very high correlation

$0.50\leq r<0.75$; high correlation

$0.25\leq r< 0.50$; low correlation

$0\leq r<0.25$; very low correlation

$r =0$; no correlation

In addition, the P value and Alpha" α "was used to determine where, rainfall had significant impact on the flood risks; respect to the following condition. Whether, at P value>alpha" α" rainfall had significant change on flood risks. While, at P value>alpha" α" rainfall had no significant change on flood risks. The flood forecast issues were used to analyze past data to determine in which district affected by flood than others and at which risk dominant in both districts for advance warning to the future flood hazard about severity on crop production, infrastructure and health domain (injury and death).

After collecting historical data on rainfall and flood risks, the obtained data was exposed to analyze through, SPSS tool using T-test analysis and Microsoft excel. The analysis by SPSS was combined independent and dependent variables in each district of Kigali city to estimate what's extend impacts from any increase of rainfall to conclude on significant of hypothesis. Moreover, the data on recent flood losses (killed/injured people, damaged roads or bridges, impaired cropland and houses) were been also analyzed using the Microsoft Excel in order to reveal the trend between 2016 and 2020 as well as, mapping flood hazard zone in Kigali city via Arc GIS.

This method was providing the needed information on flood due to forecasted rainfall which happened in the city of Kigali. Through, identification of the prevailing flood risk reduction mechanism that had been scheduled in the City of Kigali and also help to review/analyses the gaps, challenges and best practices that were happened during the operation of flood risk reduction by using rainfall forecast.

3. THE RESULTS

This part presented the research findings from historical impacts of rainfall in different districts from meteo stations data of Kigali city. However, precipitation happened from 2016 to 2020 recorded in 3 stations of Kanombe Airport, Gitega station and partly Kabuye station.

3.1. The Flood Risk Analysis in Districts of Kigali City.

The records were taken in five years. In both years, there was a variation of rainfall that led to the variation of the impacts from floods that occurred at different prone areas of Kigali city. Through analysis of data on the goal of flood forecast issues, for advance warning about severity of flood hazard and Also to help authorities to approve the measures. The adaptation/mitigation of adverse impacts of flood was referred on magnitude of flood hazard in three districts to establish risk reduction mechanism.

Figure 2 Shows the potentiality impact of rainfall on flood hazard classes in Kigali city.

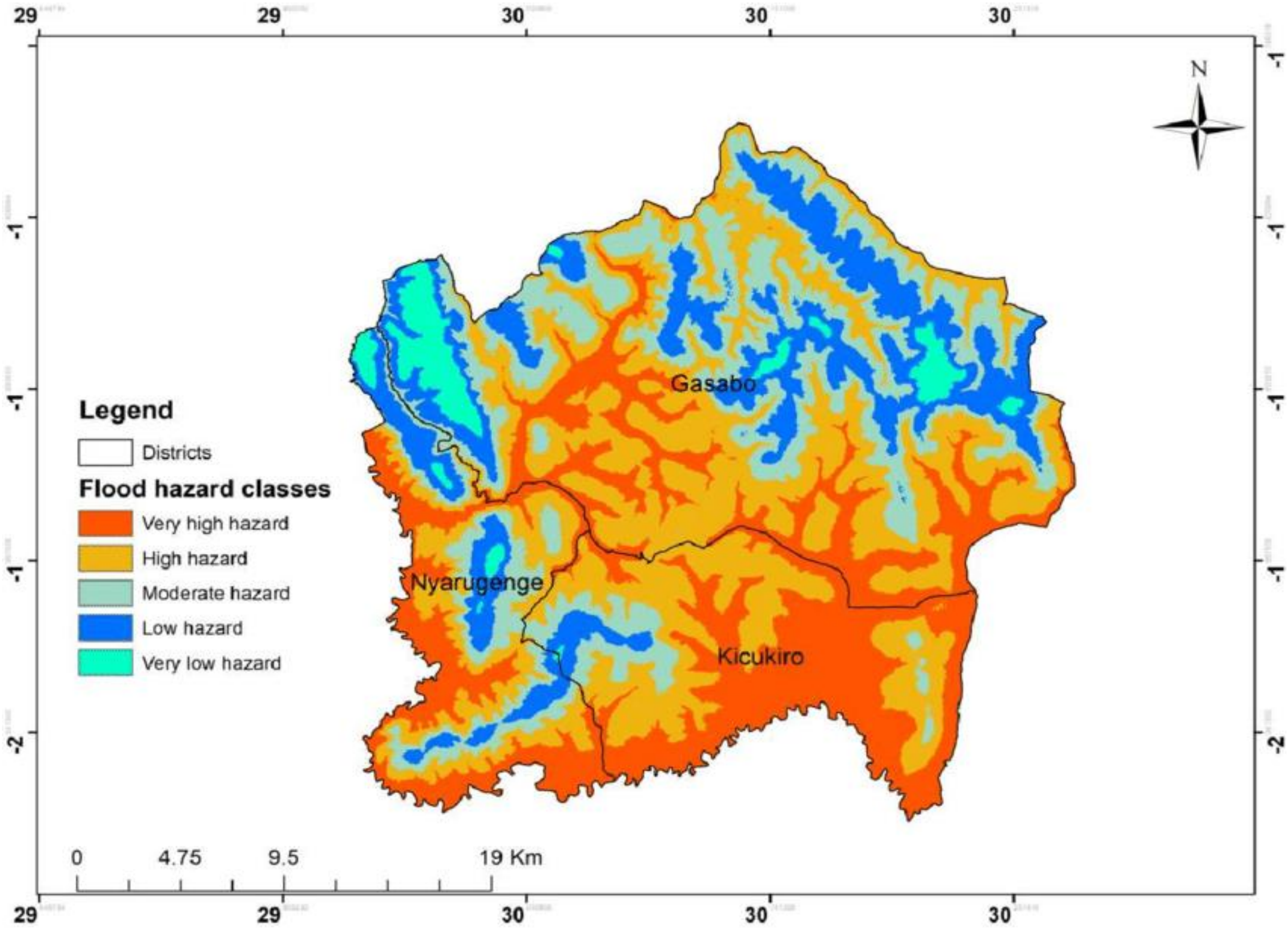
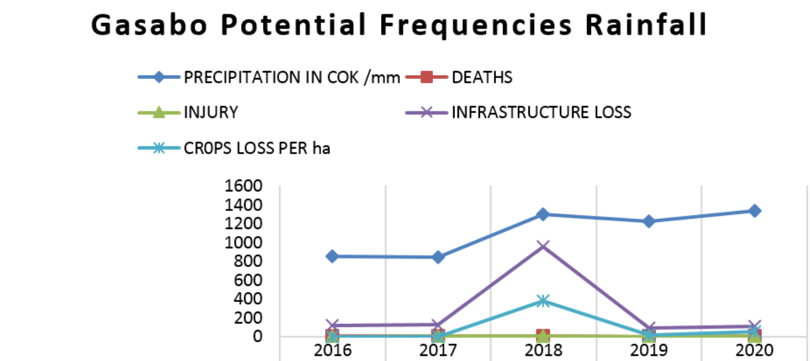


Figure 2. The flood hazard classes in Kigali city [17].



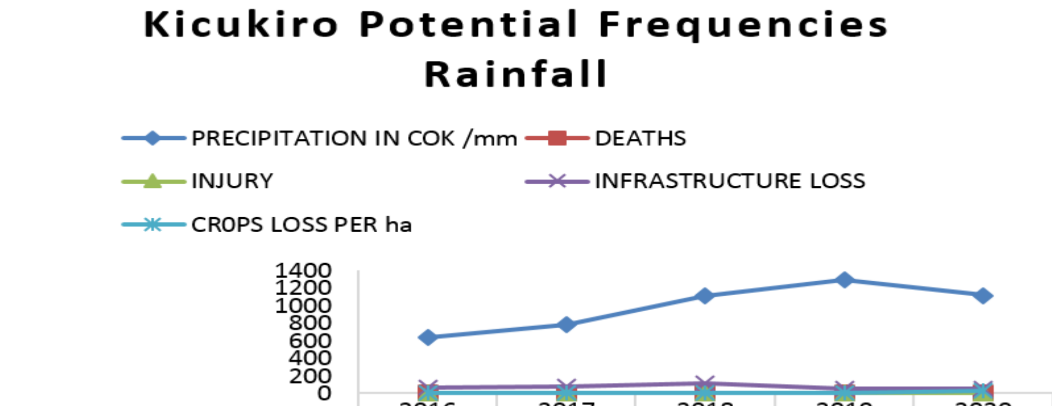
	2016	2017	2018	2019	2020
PRECIPITATION IN COK /mm	850.8	845.7	1300.4	1219.1	1336.1
DEATHS	4	8	8	1	6
INJURY	2	4	4	2	6
INFRASTRUCTURE LOSS	120	121	957	89	107
CROPS LOSS PER ha	0	0	377.5	15	54.4

Figure 3. Rainfall & flood risks variation in GASABO District.

3.2. The Potential Rainfall Occurred in Districts of Kigali City

3.2.1. The Potential Rainfall at Gasabo district

The results of Figure 3, the study showed that precipitation influenced all levels of flood risks at Gasabo district but on different magnitudes. The precipitation had higher potential impact in 2018 at all flood risk factors, including infrastructure losses, crops loss per ha, injury and deaths respectively. While, on consideration of high peak level in 2018 was proportion to increase of risks at different levels divergent in higher peak precipitation of 2020 the increase of precipitation in mm had less effect on flood risks variation. These results obviously demonstrated that the precipitation in GASABO district had partial influence in regards to the increase in mm was not proportionate to the increase of flood risks in each year.



	2016	2017	2018	2019	2020
PRECIPITATION IN COK /mm	640.5	787.3	1113.2	1297.2	1118.1
DEATHS	0	2	9	1	2
INJURY	1	2	6	2	4
INFRASTRUCTURE LOSS	64	79	111	57	52
CROPS LOSS PER ha	0	0	0	5	24

Figure 4. Rainfall & flood risks variation in KICUKIRO District.

3.2.2. The Potential Rainfall in KICUKIRO

The results of Figure 4, the study showed that precipitation influenced all levels of flood risks at Kicukiro district but, on less magnitude compared to the increase of precipitation in mm. The precipitation increase influenced higher potential impact on infrastructure loss with respect to other flood risk factors in 2018, followed by infrastructure losses, crops loss per ha, injury and deaths respectively. While, on consideration of high peak level of precipitation in 2019 was not proportionate to increase of risks at all risk levels, opposing higher peak precipitation of 2018 the increase of precipitation in mm affected flood risks respectively. These results obviously confirmed that, the precipitation in KICUKIRO district had partial effect regards to the increase in mm was not proportion to the increase of flood risks.

3.2.3. The Potential Rainfall in NYARUGENGE

Kigali has a typical tropical climate, which is characterized by high annual rainfall of up to 1400 mm per annum. The area experienced a bimodal rainfall happening mostly throughout the period from March to May and September to November. High intensity thunderstorms/showers that are generally short lived and cause often flooding in the Nyabugogo wetlands at Nyarugenge district, during the rainy month rainfall may reach 300mm per month.

The results of Figure 5, study showed that precipitation influenced all levels of flood risks but mostly influenced in NYARUGENGE district at higher magnitude. The highest precipitation was potential impacts in 2018 year at all flood risks factors, comprised by infrastructure losses, crops loss per ha, injury and deaths respectively. Whereas, on reflection of highest peak level of precipitation in 2018 was proportion to increase of risks at all risks levels and indicated that at any precipitation variation in NYARUGENGE had proportion to flood risks. These results obviously demonstrated that, the precipitation in NYARUGENGE district had major influence regards to the increase in mm was proportion to the increase of flood risks.

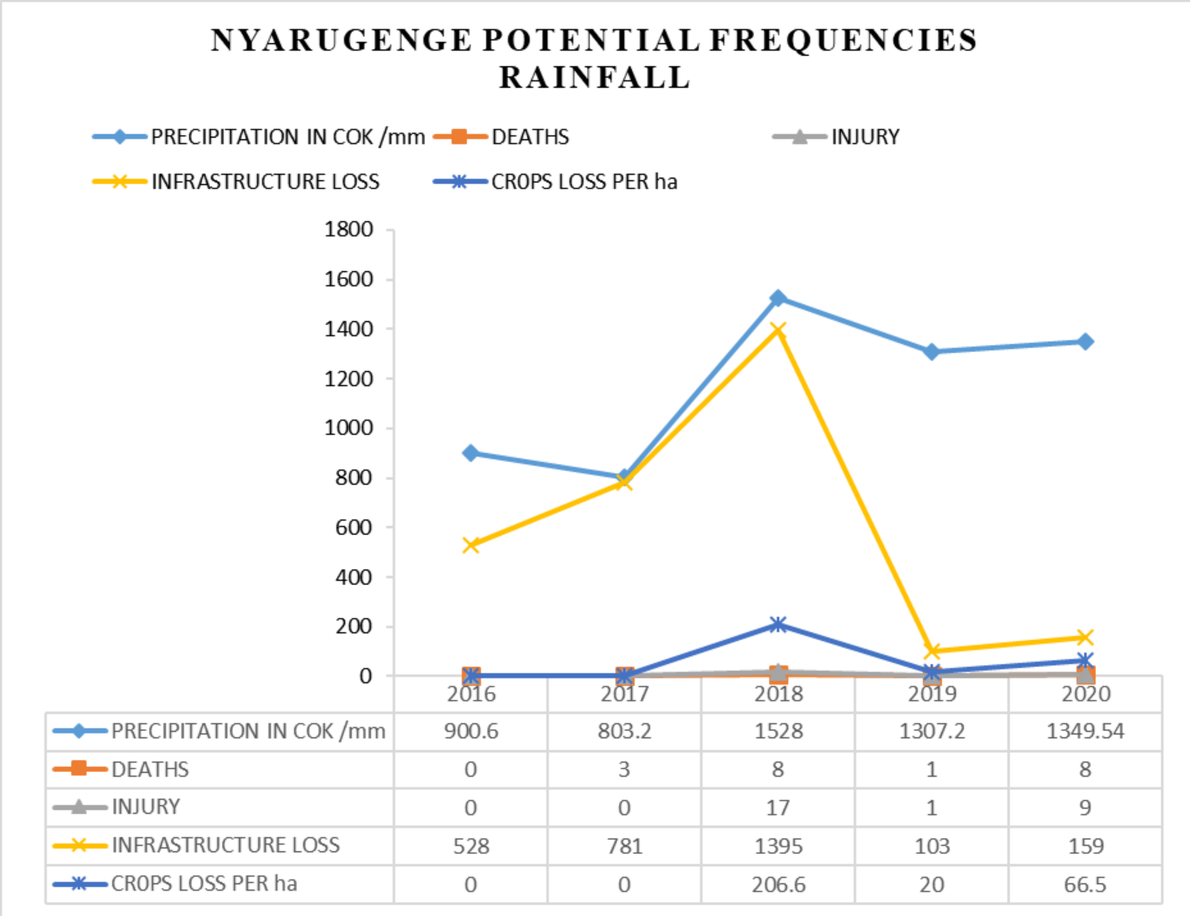


Figure 5. Rainfall & flood risks variation in NYARUGENGE District.

3.3. The Statistical Analysis

3.3.1. The Contribution of Rain Forecasting on Flood Risk Reduction in Gasabo District

The total economic reparations triggered through the natural disaster such water disaster, the losses are probable from deforestation, change of land use, climate change, increasing of population growth and sea levels in the areas suspended to floods, that triggering the citizen's vulnerability to disaster of flood risks [19]. The Pearson correlation coefficient between precipitation and infrastructure losses, crops loss per ha, injury was positive correlation meant the increase of precipitation tend to raise both. While precipitation and death had negative correlation meant the increase of precipitation did not proportionally increase death.

The correlation value in Table 1, meant that in GASABO district precipitation had make infrastructure losses $r = 0.413$ in range of 0.25r0.50, low correlation and $\alpha = 0.01$; p value=0.489 in range of p value $>\alpha$ meant that rainfall had significant change, crops loss per ha $r=0.542$ in range of $0.50 \leq r < 0.75$; high correlation and $\alpha = 0.01$; p value=0.346 in range of p value $>\alpha$ meant that rainfall had significant change, injury $r=0.463$ in range of $0.25 \leq r < 0.50$; low correlation and $\alpha=0.01$; p value=0.432 in range of p value $>\alpha$ meant that rainfall had significant change, while on death had negative correlation $r = -0.06$ in range of $0<r<0.25$; very low correlation and $\alpha = 0.01$; p value= 0.93 in range of p value $>\alpha$ meant that rainfall had significant change.

The study indicated that in GASABO district, the relationship between rainfall and flood risks in significant at which, both flood risks had significant change due to precipitation variation. Refer to past data results correlation, the policy maker in GASABO district predicted that in the rainfall period the crop land was more exposed to flood than infrastructure loss, injury and death during hazard response.

Table 1. The correlation in GASABO district.

The Factors		Precipitation in Mm	Death	Injury	Infrastructure Loss	Crops on Ha
Precipitation in mm	Pearson Correlation	1	-0.060	0.463	0.413	0.542
	Sig. (2-tailed)		0.923	0.432	0.489	0.346
	N	5	5	5	5	5
Death	Pearson Correlation	-0.060	1	0.645	0.513	0.491
	Sig. (2-tailed)	0.923		0.240	0.377	0.400
	N	5	5	5	5	5
Injury	Pearson Correlation	0.463	0.645	1	0.139	0.237
	Sig. (2-tailed)	0.432	0.240		0.823	0.702
	N	5	5	5	5	5
Infrastructure loss	Pearson Correlation	0.413	0.513	0.139	1	0.988**
	Sig. (2-tailed)	0.489	0.377	0.823		0.002
	N	5	5	5	5	5
Crops on ha	Pearson Correlation	0.542	0.491	0.237	0.988**	1
	Sig. (2-tailed)	0.346	0.400	0.702	0.002	
	N	5	5	5	5	5

Note: **. Correlation is significant at the 0.01level (2-tailed).

3.3.2. The Contribution of Rain Forecasting on Flood Risk Reduction in KICUKIRO

The Pearson correlation coefficient between precipitation and death, crops loss per ha, injury was positive correlation meant the increase of precipitation tended to raise the damage both. While precipitation and infrastructure losses had negative correlation meant the increase of precipitation did not proportionally increase infrastructure losses. The disposition of flood on large scale flow arrays might be accredited to multiple drivers such as; land use, river drill and climatic drivers [20].

Table 2. The correlation in KICUKIRO.

The Factors		Precipitation in Mm	Death	Injury	Infrastructure Loss	Crops on Ha
Precipitation in mm	Pearson Correlation	1	0.326	0.508	-0.039	0.409
	Sig. (2-tailed)		0.593	0.382	0.951	0.494
	N	5	5	5	5	5
Death	Pearson Correlation	0.326	1	0.912*	0.891*	-0.190
	Sig. (2-tailed)	0.593		0.031	0.043	0.759
	N	5	5	5	5	5
Injury	Pearson Correlation	0.508	0.912*	1	0.637	0.228
	Sig. (2-tailed)	0.382	0.031		0.248	0.712
	N	5	5	5	5	5
Infrastructure Loss	Pearson Correlation	-0.039	0.891*	0.637	1	-0.579
	Sig. (2-tailed)	0.951	0.043	0.248		0.306
	N	5	5	5	5	5
Crops on ha	Pearson Correlation	0.409	-0.190	0.228	-0.579	1
	Sig. (2-tailed)	0.494	0.759	0.712	0.306	
	N	5	5	5	5	5

Note: *. Correlation is significant at the 0.05 level (2-tailed).

The value of correlation in Table 2, meant that in KICUKIRO district precipitation had make death r=0.326 in range of 0.25≤ r< 0.50; low correlation and α= 0.05; p value=0.593 in range of p value >α meant that rainfall had significant change, crops loss per ha r=0.409 in range of 0.25≤ r< 0.50; low correlation and α= 0.05; p value=0.494 in range of p value >α meant that rainfall had significant change; injury r= 0.508 in range of 0.50≤ r< 0.75; high correlation and α= 0.05; p value=0.382 in range of p value >α meant that rainfall had significant change. While infrastructure losses had negative correlation r=-0.039 in range of 0<r<0.25; very low correlation and α=0.05; p value= 0.951 in range of p value >α meant that rainfall had significant change.

KICUKIRO district correlation results exposed, the relationship between rainfall and flood risks is significant at which; both flood risks had significant change due to precipitation variation. Due to past data results correlation, the prediction in measures taken on the death, crops loss, injury risks mitigation will be that the increase of precipitation tends to raise the damage both, with an exception on vulnerable people who will get first aid.

Table 3. The correlation in NYARUGENGE.

The Factors		Precipitation in Mm	Death	Injury	Infrastructure Loss	Crops on Ha
Precipitation in mm	Pearson Correlation	1	0.673	0.818	0.138	0.780
	Sig. (2-tailed)		0.213	0.090	0.825	0.120
	N	5	5	5	5	5
Death	Pearson Correlation	0.673	1	0.884*	0.375	0.743
	Sig. (2-tailed)	0.213		0.047	0.533	0.150
	N	5	5	5	5	5
Injury	Pearson Correlation	0.818	0.884*	1	0.584	0.960**
	Sig. (2-tailed)	0.090	0.047		0.302	0.010
	N	5	5	5	5	5
Infrastructure loss	Pearson Correlation	0.138	0.375	0.584	1	0.721
	Sig. (2-tailed)	0.825	0.533	0.302		0.169
	N	5	5	5	5	5
Crops on ha	Pearson Correlation	0.780	0.743	0.960**	0.721	1
	Sig. (2-tailed)	0.120	0.150	0.010	0.169	
	N	5	5	5	5	5

Note: *. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

3.3.3. The contribution of Rain Forecasting on Flood Risk Reduction in NYARUGENGE

The Pearson correlation coefficient between precipitation and infrastructure losses, death, crops loss per ha, injury was positive correlation meant the increase of precipitation tended to raise the damage both. NYARUGENGE urbanization tied with population growth upsurge flood risks as in urban areas. Urbanization affected the land through, covered by roads, buildings, drainage networks which change the permeable land into the impermeable land with less infiltration capacity to store rainwater and snowmelt, this impermeable land accelerate runoff, rise peak flow in the drainage channels and ends up by activating flood downstream [21].

The Pearson correlation value in Table 3, meant that in NYARUGENGE district precipitation had make infrastructure losses r= 0.138 in range of 0<r<0.25; very correlation and α= 0.05; p value=0.825 in range of p value >α meant that rainfall had significant change, crops loss per ha r= 0.780 in range of 0.75≤r<1; very high correlation and α= 0.05; p value= 0.120 in range of p value >α meant that rainfall had significant change, injury r= 0.818 in range of y r=0.818 in range of 0.75≤r<1; very high correlation and α=0.05; p value= 0.090 in range of p value >α meant that rainfall had significant change and on death r=0.673 in range of 0.50≤r<0.75; high correlation and α=0.05; p value= 0.213 in range of p value >α meant that rainfall had significant change.

NYARUGENGE district correlation results showed a significant relationship between rainfall and flood risk at which both flood risks had significant change due to precipitation variation. The past data correlation results, indicated that in NYARUGENGE land use effect was on higher rate influence in rain seasons, meaning that without setting proper measures to mitigate/adaptation of flood risks. The flood will raise its impacts in respective years in the rain period at highest levels.

4. DISCUSSION

The central Regions of Rwanda affected by heavy rain continuously (mostly in Kigali City and the Southern Province), triggering floods and mudslides [22]. The floods magnitude had higher potential impact in 2018 year at all flood risks factors but infrastructure was more prone risk followed by crops loss, injury and deaths respectively. Whereas, in GASABO on different risks over year deaths, injury, infrastructure loss and crops loss were 8 in 2017 and 2018,6 in2020, 957 in 2018 and 377.5 ha respectively; KICUKIRO, infrastructure loss 111, 6 injuries and 9 deaths but, crops loss 24 ha in 2020 and NYARUGENGE floods prone areas had highest potential impact in 2018 year at all flood risks factors where 1395 infrastructure loss, crops loss 206.6 ha, 17 injuries in 2018 and deaths on 8 of 2018 and 2020.

The increase of rainfall tendency in East Africa particularly, to Rwanda and Burundi projection on intensity both in rainy seasons; which is likely to trigger the storms and floods that can resulting to the crop losses, health risks, landslides and impairment of infrastructures, natural ecosystems and rivers overflow [23]. From 1970 to 2050s projections, the average rainfall in Rwanda may increase up to 20% annually [2]. In trends analysis from 2016 to 2020, The precipitation in NYARUGENGE district records was on top rainfall in 2018 with 1528 mm with potential rainfall frequency was in NYARUGENGE with 4 times frequency respect the remains two, followed by GASABO with 4 times compare with KICUKIRO with 1 times potential rainfall. The projection of international monetary fund(IMF) showed that the natural disasters from climate change was actively increased in intensity and frequency respect to their negative impact to the socio-economic activities and also disasters tend to rise moderately [24].

The disasters upstretched from water resource such as soil erosion, landslide, floods and water borne diseases can also cause impairment of humans, flora and fauna as along as to socio-economic activities [16]. In urban area, the problematic of floods influenced by climate change, channel modification and land use have resulted in non-stationary and the hydrologic growing ambiguity. The outstanding risks are always from structural measures subjectively [25]. In all districts rainfall had correlation and in significant range with some exceptions on flood risks. Through correlation results NYARUGENGE indicated that it was powerful affected by flood, by prediction the risks will raise respectively years unless take proper measures to mitigate/ adapt. Whereas, Gasabo district death risks and Kicukiro infrastructure losses had negative correlation in range of $0<r<0.25$ where $r=-0.06$ and $r=-0.039$ in range of $0<r<0.25$ very low correlation, respectively meant the increase of rainfall aren't proportion to flood risks increase. While in Nyarugenge district rainfall increased with the flood risks increases where, it has positive correction on both crops per ha, injury and death on in range of $0.75<r<1$ very high correlation where $r=0.780$, $r=0.818$ and $r=0.673$ in range of $0.50<r<0.75$ high correlation, respectively. To manage those risks required to use alterable mechanisms which is less expensive such as non-structural measures to lessen the flood risks than structural actions [26].

5. CONCLUSION

The results of study illustrated that, at all levels of flood risks had been influenced by precipitation in all districts but, on different magnitude losses and damages. The flood risk analysis on deaths, injury, infrastructure loss and crops loss per ha the highest levels was 8 persons in 2017 and 2018; 6 persons in 2020, 957 in 2018 and 377.5 ha GASABO records respectively. KICUKIRO district records were 9 persons; 6 persons, 111and 24 ha respectively. NYARUGENGE district records were 8 persons; 17 persons; 1395 and 206.6 ha respectively. The outcomes illustrated that in 2018 the precipitation made the highest losses and damages.

The findings from study of the role of rain forecasting on flood risks indicated that the potential frequencies rainfall occurred in KIGALI city was distributed differently in districts within the years from 2016 to 2020. The highest record precipitation with its flood risks as; deaths, injury, infrastructure loss and crops loss per ha in district was 1336.1 mm in 2020; 6 persons; 6 persons; 107 and 54.4 ha respectively GASABO records. KICUKIRO records were 1297.2mm, 1 person, 2 persons, 57 and 5ha respectively. NYARUGENGE records were 1529mm, 8 persons, 17 persons, 1395 and 206.6ha respectively. The results showed that NYARUGENGE district had the highest recorded precipitation with highest prone flood risks.

The assessment of contribution of rain forecasting on flood risk reduction, The Pearson correlation coefficient between precipitation and infrastructure losses, crops loss per ha, injury, deaths mostly had positive correlation and significant range with flood risks in both districts but on different ranges with such exception had negative relationship. The correlation value in GASABO district precipitation had negative correlation with deaths $r=-0.06$ in range of $0<r<0.25$; very low correlation meant that the increase of precipitation was not proportionate to raise the number of deaths. While KICUKIRO district precipitation with infrastructure losses had negative correlation $r= -0.039$ in range of $0<r<0.25$; low correlation meant that the increase of precipitation was not proportionate to raise infrastructure loss. Whereas, in NYARUGENGE district precipitation made positive correlation with infrastructure and deaths losses $r= 0.138$ in range of $0<r<0.25$; very low correlation; $r= 0.673$ in range of $0.50\leq r<0.75$; high correlation respectively meant that increase of precipitation led to raise both infrastructure loss and deaths. The results indicated that, in environmental planning will base on particular case of district, especially the NYARUGENGE district, for future plan on land use and management to mitigate & adapt flood risks.

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REFERENCES

[1] UNISDR, "United nations office for disaster risk reduction (UNISDR). (2015) report.Retrieved from: https://www.unisdr.org/we/inform/publicatins/46796," 2015.

[2] MINEMA, *Green growth and climate resilience-national strategy for climate change and low carbon development*. Kigali-Rwanda: Republic of Rwanda, 2011.

[3] S. Muis, B. Güneralp, B. Jongman, J. C. Aerts, and P. J. Ward, "Flood risk and adaptation strategies under climate change and urban expansion: A probabilistic analysis using global data," *Science of the Total Environment*, vol. 538, pp. 445-457, 2015.Available at: https://doi.org/10.1016/j.scitotenv.2015.08.068.

[4] Y. Li and M. Shao, "Effects of rainfall intensity on rainfall infiltration and redistribution in soil on Loess slope land," *The Journal of Applied Ecology*, vol. 17, pp. 2271-2276, 2006.

[5] World Bank, *World band group,striving toward disaster resilient developement in Sub-Saharan Africa,strategic framework 2016-2020*. Washington D.C: World Bank, 2015.

[6] MIDIMAR, *The national risk atlas of Rwanda*. Kigali: Government of Rwanda Publication, 2015.

[7] REMA, *Kigali state of the environment and outlook report*. Kigali: Rwanda, 2013.

[8] J. B. Schilling, *Geo-information technology for infrastructural flood risk analysis in unplanned settlements: A case study of informal settlement flood risk in the Nyabugogo flood plain*. Kigali City, Rwanda: Springer Science+Business Media B.V, 2010.

[9] J. Nsengiyumva, *Disaster high risk zones on floods and landslides*. Kigali: MIDIMAR, 2012.

[10] V. Herve and J. P. Habimana, *Integrated flood modeling for flood hazard assessment in Kigali City*. Rwanda: GeoTech Rwanda, 2015.

[11] M. Nduta, "Flash flood hazard and coping strategies in urban areas: Case study in Mpazi catchment, Kigali Rwanda," Master of Science, the Faculty of Geo-Information Science and Earthobservation of the University of Twente, 2015.

[12] A.-S. Samuel, R. Patrick, M. J. Herath, and A. O. Phebe, "Situational analysis of flood and drought in Rwanda," *International Journal of Scientific & Engineering Research*, vol. 6, pp. 960-970, 2015.Available at: https://doi.org/10.14299/ijser.2015.08.013.

[13] J. S. Hess, A. Tsinda, R. Mugisha, C. Kind, and A. R. Bizoza, "Estimating damage costs of flooding on small-and medium-sized enterprises in Kigali, Rwanda," *Accident: Journal of Disaster Risk Studies*, vol. 11, pp. 1-11, 2019.Available at: https://doi.org/10.4102/jamba.v11i1.755.

[14] R. A. MIDIMAR, *National progress report on the implementation of the hyogo framework for action (2013-2015).* Kigali: Rwanda, 2015.

[15] E. A. D. Rukundo, "Assessment of climate and land use change projections and their impacts on flooding," *Polish Journal of Environmental Studies*, vol. 25, pp. 2541-2551, 2016.Available at: https://doi.org/10.15244/pjoes/63781.

[16] MINEMA, *National policy for water resources management.* KIGALI-Rwanda: Republic of Rwanda, 2011.

[17] NCEA, *Quick scan (Review) of the ESIA of the Kigali waste water project.* Kigali: The Secretariat of the Netherlands Commission for Environmental Assessment, 2016.

[18] D. Niyonsenga, "Assessing public transport transport supply for Kigali, Rwanda. Retrieved: www.researchgate.net: https://www.researchgate.net/figure/kigali-administrative-boundaries_fig4_265275132. [Accessed 6NOV,202]," 2022.

[19] R. M. Vogel, C. Yaindl, and M. Walter, "Nonstationarity: Flood magnification and recurrence reduction factors in the United States 1," *JAWRA Journal of the American Water Resources Association*, vol. 47, pp. 464-474, 2011.Available at: https://doi.org/10.1111/j.1752-1688.2011.00541.x.

[20] F. F. Hattermann, Z. W. Kundzewicz, S. Huang, T. Vetter, F.-W. Gerstengarbe, and P. Werner, "Climatological drivers of changes in flood hazard in Germany," *Acta Geophysica*, vol. 61, pp. 463-477, 2013.Available at: https://doi.org/10.2478/s11600-012-0070-4.

[21] D. Mukherjee, "Effect of urbanization on flood-a review with recent flood in Chennai (INDIA)," *International Journal of Engineering Sciences & Research Technology*, vol. 5, pp. 451-455, 2016.

[22] IFRC, *Rwanda: Floods-final report-DREF No.MDRRW018.* Kigali: International Federation of Red Cross and Red Crescent Societes, 2020.

[23] M. E. Shongwe, G. J. Van Oldenborgh, B. Van Den Hurk, and M. Van Aalst, "Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa," *Journal of Climate*, vol. 24, pp. 3718-3733, 2011.Available at: https://doi.org/10.1175/2010jcli2883.1.

[24] D. A. IMF, *Building resilience in developing countries vulnerable to large natural disasters.* Kigali: International Monetary Fund, 2019.

[25] S. K. Jain, P. Mani, S. K. Jain, P. Prakash, V. P. Singh, D. Tullos, S. Kumar, S. Agarwal, and A. Dimri, "A Brief review of flood forecasting techniques and their applications," *International Journal of River Basin Management*, vol. 16, pp. 329-344, 2018.Available at: https://doi.org/10.1080/15715124.2017.1411920.

[26] F. K. N. Di and D. D. Tullos, "Flexibility in water resources management: review of concepts and development of assessment measures for flood management systems," *JAWRA Journal of the American Water Resources Association*, vol. 50, pp. 1527-1539, 2014.Available at: https://doi.org/10.1111/jawr.12214.