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Spatial Relationship Analysis of Urban Expansion and Disaster Risk Exposure in Rwanda

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Abstract: This study aimed to analyse the relationship analysis between urbanization and flood risk exposure in Nyarugenge district in City of Kigali. The authors utilized secondary datasets on urban growth such as population growth and urbanization rate within sectors of Nyarugenge district. The employed datasets on flood causal factors generated the flood hazard distribution over the study area. The study covered a period ranging between 2015 and 2020. These data were collected from United States Geological Survey (USGS), National Institute of Statistics of Rwanda (NISR), Offices of City of Kigali (CoK) and Nyarugenge district. The Geographic Information System (GIS) facilitated to map flood hazard and its causal factors. The Statistical Package for Social Sciences (SPSS) estimated the correlation between urban growth and flood risk exposure.The results show that Muhima, Nyarugenge and Gitega sectors with high urbanization in 2015 changed in 2020. However, in 2020, Kanyinya and Mageragere sectors which were not urban in 2015 registered expanding urbanization in 2020. Also, the mapped flood hazard reveal that the 2020 urban areas are quite exposed to hazard due mainly to rainfall, urbanization through poor land management elevation and slope as major drivers. Finally, the estimated high/advanced P value (0.061) confirms that urbanization growth in Nyarugenge district is among the drivers to flood occurrence and its associated losses. As conclusion, the results of this study localizes zones in Nyarugenge highly that are prone to flooding which can

help policy makers to ensure appropriate land management and urbanization development as well.

Key words: City of Kigali, Flood, Nyarugenge district, Urbanization, Rwanda

1. Introduction

Disaster are gradually causing losses on community lives, livelihoods, properties and environment mainly due to human activities such as poor land management, inappropriate settlement type sand location and the changing climate as well (Smith et al. 2017). Resettlement of population is complex process and if it is not conducted properly can create serious problems for the people involved (Khazai et al. 2013). Hence, it can be noted that the implementation of land use master plan can help to minimize vulnerability and building resilience of poor households from high risk zones, when face poorly planned and executed resettlement program can lead to social, economic and human activities (Paton and Johnston 2001; Osuteye et al. 2017).

Floods are crucial issue to many African countries due to poor or insufficient resources, both financially and technologically, to fight the effects and impacts of flooding (Ayugi et al. 2020). Between 1996 and 2005, floods have posed several devastating and terrifying effects on the continent of Africa. Within that period, there were approximately 290 flood-disasters reported. Over 8,183 people lost their lives, approximately 23 million people were consequently affected in diverse ways. The results of the huge economic losses were estimated at approximately $1.9 billion (Ponte 2014; Ayugi et al. 2020).

In Rwanda, urban areas are increasingly recording space expansion and apart from City of Kigali, other secondary cities are being developed (Nikuze et al. 2020). However, rapid human population growth, improper settlement, cities' location, frequent and intense rainfall are the major challenges to urban development in Rwanda. For example, between 2010 and 2012, there has been longest and most severe rainfall shortage on record which was then followed by two years of unusually excessive rains (Gasasira Higiro 2020). The resulting floods have led to significant economic, environmental, and social damage (e.g. population displacement).

The City of Kigali is reported to be prone to flooding while its inhabitants keep on increasing. This likely expresses the expansion of the urban land for the sake of where to settle and/or locate

other human activities (Michieletto et al. 2019). However, it is also reported that as long as human activities expand, he associated risks may increase as well. For example, Nyarugenge district is highlighted among hotspots of flooding in the City of Kigali due to poor settlement and rainwater management (Bachofer et al. 2019).

The extreme floods in Nyarugenge district have led to the death of dozens of people and have destroyed roads and other infrastructure, leaving many people homeless. Furthermore, the floods have resulted in a significant reduction in agricultural production, with consequences for food security (Isugi and Niu 2016; Nkubito 2016). It is reported that in 2002, the total population Nyarugenge district was 239,660 and reached 284,561 in 2012 with an annual increase of approximately 1.9 percent. As long as human population is predicted to keep on increasing in this area, it is good to ensure that people settle in safe area (Habtu et al. 2017; Gasasira Higiro 2020).

Urbanization is growing rapidly in Rwanda but poses several negative impacts. For example, in Nyabugogo catchment within Nyarugenge district, intense human activities and heavy rainfall has been repeatedly reported to be the major cause of flooding in this area. This is associated with damage to properties, disruption to business and traffic, discomfort to community and in some cases loss of human lives and livestock (Nikuze et al. 2019; Gasasira Higiro 2020). This expresses that conducting a research on how urbanization may lead to flood risk exposure among urban residents would help to facilitate policy makers to ensure low risk among people and properties as well. Therefore, this study aimed to assess the impact of urbanization expansion on disaster risk exposure with the case of flood in Nyarugenge district.

2. Materials and Methods

2.1 Description of Study area

The current study was specifically conducted by considering the district of Nyarugenge, one of three districts (Nyarugenge, Kicukiro and Gasabo) of City of Kigali. The district of Nyarugenge shared border with Kamonyi district in the western part, Kicukiro and Gasabo districts are localized in the eastern parts of Nyarugenge district. The Rulindo district is located in the northern part of Nyarugenge district (Fig.1). The district of Nyarugenge counts 10 sectors, 47 cells and 350 villages with a total land of 134 Km^2 inhabited by 284, 561 people. Nyarugenge

has the highest population density with 2,149 inhabitants/km and is the least populated district in Kigali city with 284,561 inhabitants (NISR 2012).

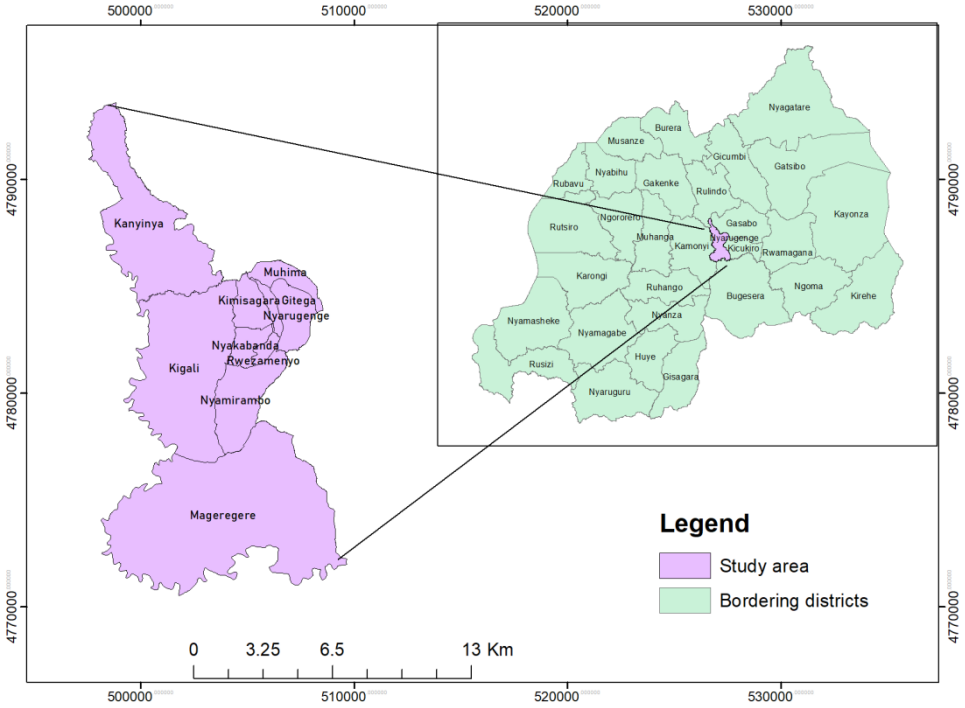

Figure 1**:** Map indicating (a) sectors of Nyarugenge district and (b) its bordering districts of Rwanda

Source: Researcher, (2022)

The topographic analysis of Nyarugenge District identifies 4 distinct features mainly (1) areas of gentle slopes (less than 20% gradient) on the ridges and along the wetlands (2) areas with steep slopes (more than 20% gradient), (3) linear ridges running along the length of the sectors and (4) alluvial plains along the rivers Nyabarongo and Nyabugogo (Gasasira Higiro 2020). The average elevation of Nyarugenge District is 1,000 m above the sea level. Mount Kigali, the highest point in Kigali, has an elevation of 1,853m and the highest spot in Mageragere sector has an elevation of 1,810 m. Due to such hilly topography coupled with large scale deforestation, soil erosion and landslides in the District are key recurrent problems faced by the City. This expresses the need of adequate soil protection measures to address this issue (Nshimiyimana 2015).

The geographic location and topographic features of Nyarugenge district associated with lack of well-planned drainage infrastructure and solutions to increase infiltration and slow the runoff,

exposes the district to frequent flooding as well as landslides. Both hazards lead to destruction of critical infrastructure (energy and transport, commercial buildings) and household property and lives lost. This in turn, limits the mobility of pedestrians, disrupt traffic, and cause accidents and congestion, which presents a high cost to its residents (Bizimana and Schilling 2009; River 2015).

2.2 Data collection

For this study the data on urban land expansion and population density/growth in Nyarugenge district were collected from the National Institute of Statistics (NISR), Office of City of Kigali and Nyarugenge district Statistical Department. These data ranged from 2015 to 2020 as that of flood losses (NISR 2012). In addition, the employed 2015-2020 spatial urbanization in City of Kigali were provided by the Socioeconomic Data and Application Center (SEDAC) managed by the NASA Earth Science Data and Information System (ESDIS) project (Gao and Pesaresi 2021).

For the flood hazard map of Nyarugenge district, the map was produced by the authors and some of the causal factors like elevation, slope, Normalized Difference Vegetation Index (NDVI), land use land cover were collected from the United States Geological Survey (USGS 2020) and lithology type was collected from the Commission for the Geological Map of the World (World et al. 2000). The employed daily rainfall data were collected from the Tropical Applications of Meteorology using Satellite (TAMSAT) data and ground-based observations (Tarnavsky et al. 2014) while the employed soil texture was collected from the Soil Atlas of Africa generated by the European Soil Data Center (ESDAC) (Dewitte et al. 2013).

The above datasets were on global or continental scale and the Extraction by Mask technique of the Spatial Analyst Tools of ArcGIS 10.8 was utilized to extract the respective maps of the study area. Finally, data on recent flood losses were collected from the Rwanda's Ministry in Charge of Emergency Management (MINEMA). These data ranged from 2015 to 2020 (MINEMA 2020).

2.3 Data analysis

For the data analysis, the authors utilized GIS for mapping flood hazard in Nyarugenge district. This exercise will be facilitated by the Spatial Analyst Tool of GIS which indicated the extent of

hazard exposure within each sector of Nyarugenge district. In order to produce the current flood hazard map, the literature review, expert's opinions and field reality contributed in the selection of the major flood causal factors. After mapping current flood hazard, the study indicated the recent flood loses in order to compare them with current flood hazard distribution in the study area.

Furthermore, the urbanization results consisted of urban land, population growth which was presented in terms of Tables or Charts by Microsoft Excel software. The Statistical Package for Social Sciences (SPSS) facilitated the researcher to perform the Statistical correlation between urban growth and flood hazard exposure. To finalize this exercise, the Pearson Correlation test of SPSS evaluated the relationship between urban growth and flood hazard exposure.

In order to successfully perform the Pearson Correlation analysis, the assumed positive and negative statistical significance values were considered. It is assumed that a p-value smaller than 0.05 indicated a statistically significant association (at 5 % level) and a p-value larger than 0.05 will enable to reveal that there is 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 and Discussion

3.1Urban expansion within Nyarugenge district

The results in Figure 2 show that from 2006 to 2012, the total population of Nyarugenge district was increasing and Kimisagara sector recorded high number of total population at 32,699 and 47,411 in 2006 and 2012, respectively.

For Muhima sector, the total population registered a decreasing number from 40,635 to 28,005 in 2005 and 2012, respectively. This can be associated to expropriation of residents in this sector

for settling in other development buildings and/or personal willingness of moving from one place to another mainly in search for cheap land or rent as well.

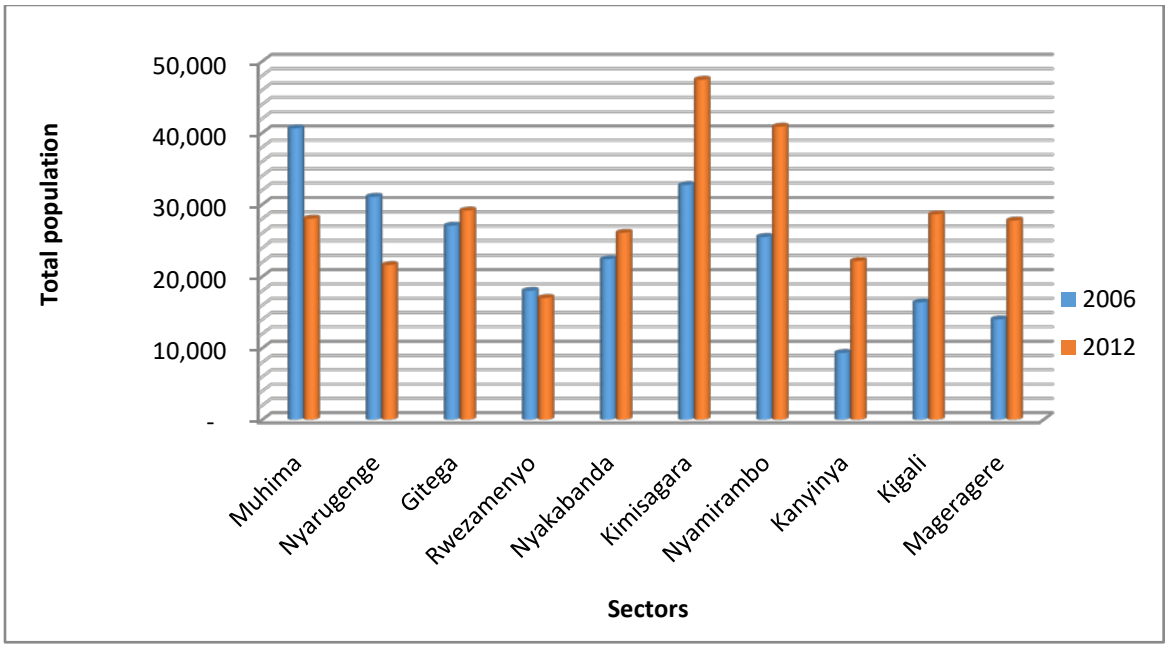

Figure 2**: 2006-2012 total population in Nyarugenge district**

As shown in Figure 3, the results indicated that in 2015, the number of total population recorded in sectors of Nyarugenge district was higher than that recorded from 2016 to 2012 (see Figure 2). The sectors of Kimisagara and Nyamirambo were the highly populated at 51,207 and 44,130, respectively while Nyarugenge and Rwezamenyo sectors recorded low number of total population of 23,331 and 18,360, respectively (Figure 3).

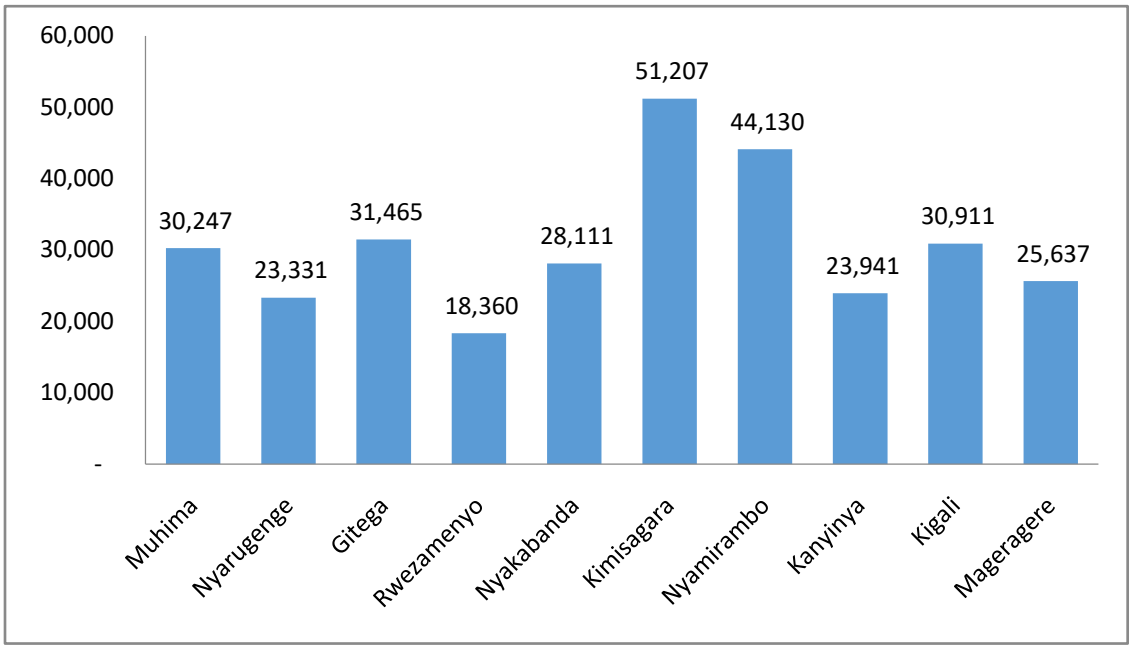

Figure 3**: 2015 Total population of Nyarugenge**

However, as illustrated in Figure 4, in 2020, after five years from 2015 (Figure 3), the number of total population recorded in Nyarugenge district increased at very high number compared to previous years. It is noted that in 2020, the lowest number of total population recorded was 20,217 in Muhima sector and the highest total population number of 102,458 was registered in Kanyinya sector (Figure 5).

The results indicate that Muhima sector recorded decreasing number of total population from 2006 to 2020 while other remaining sectors have an increasing number of their total populations. This expresses that as long as human population increased, it is possible that even the area under settlement and location of human activities like business centers, schools and hospital and recreation centers as well have increased in the same rate as that of human population in Nyarugenge. However, all the above are likely to affecting the natural landscape which leads to its exposure to runoff accelerated by rainfall and then affect people's livelihoods.

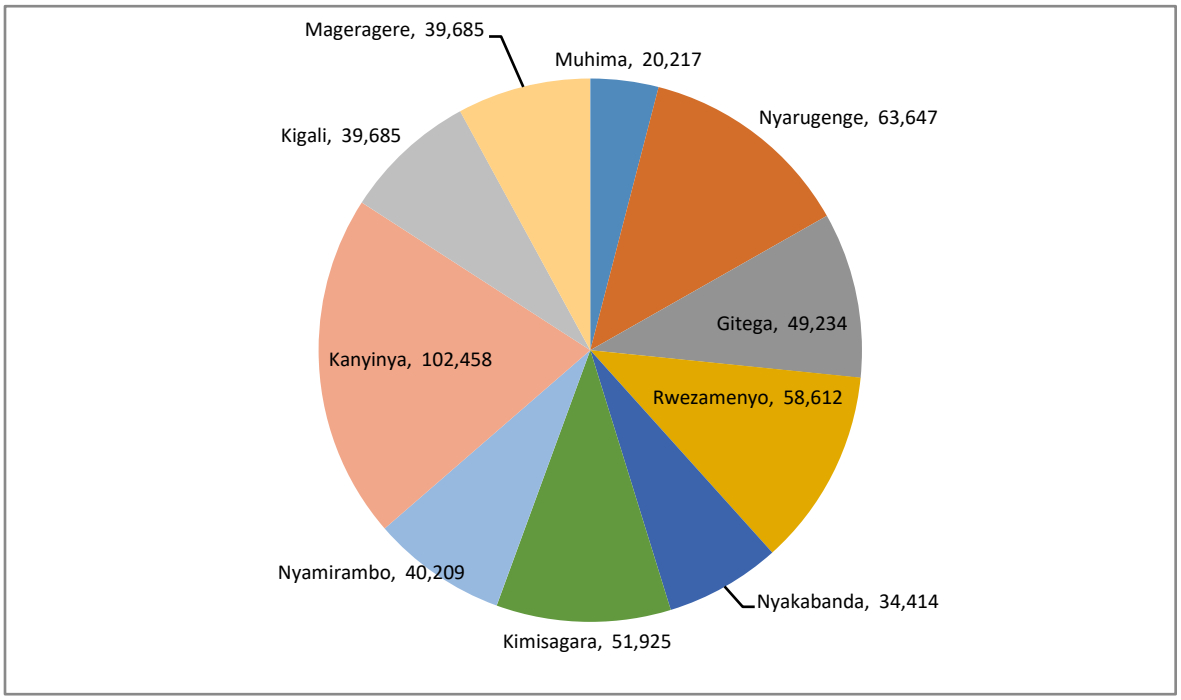

Figure 4**: 2020 total population of Nyarugenge district**

In addition, as shown in **Figure 5 below**, the spatial distribution of urban land in Nyarugenge district reveal the rapidly growing rate within all sectors of Nyarugenge district between 2015 and 2020. This in turn, expresses how the urban land increased since people extended their living areas to rural parts of Nyarugenge and turned them into urban.

However, as shown in Figure 5, the urbanization of 2015 reveal expanding rate and in 2020, the areas covered by urban zones increased compared to that of 2015. This can be associated to the recorded increasing population growth which also shows gradual increase from 2006 to 2020. And as people increase in number, their living area might increase as well together with locating new building and other economic activities which turn on area into urban and/or sub-urban.

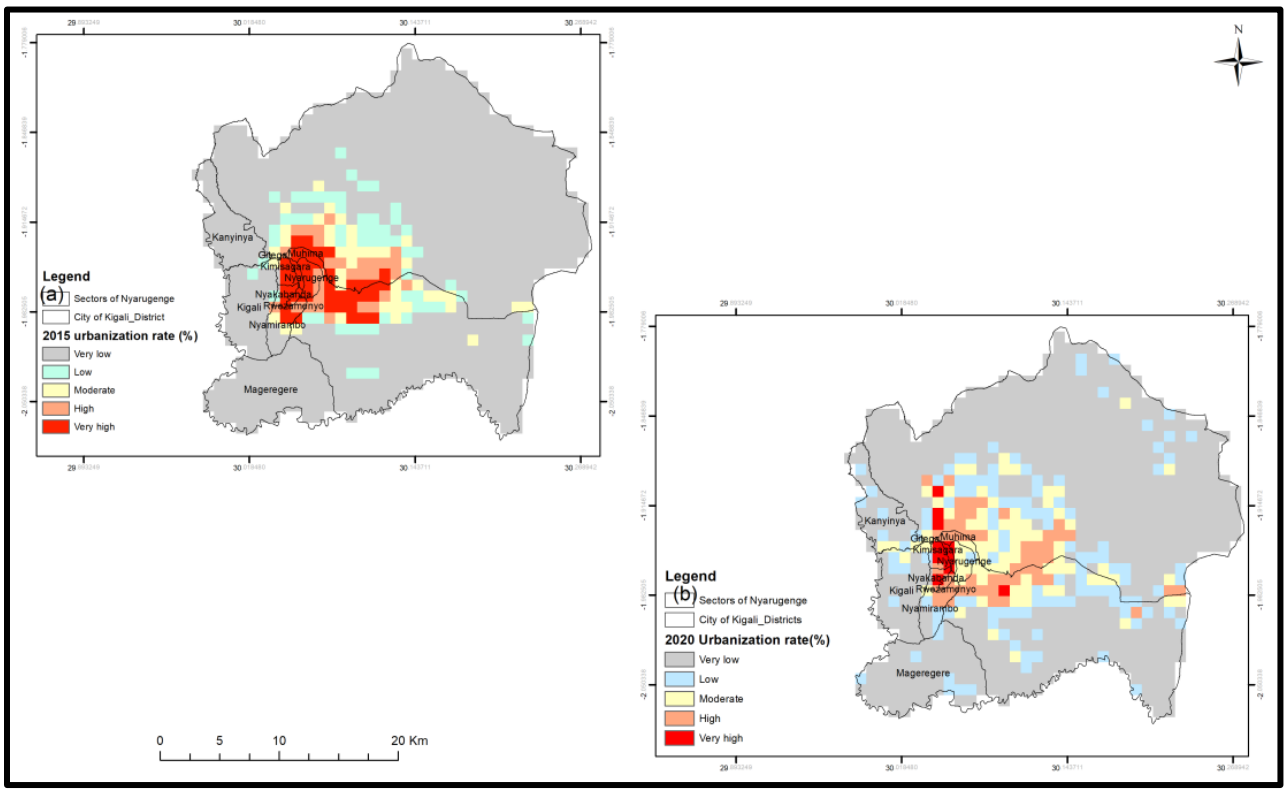

Figure 5: 2015-2020 urban expansion in Nyarugenge district

However, despite the decrease the urbanization percentage mainly the very high urban areas, the results in Table 2 show that the areas which were rural in 2015 become more urban in 2020. This expresses that either people from rural areas migrated to these sectors or those in Muhima, Nyarugenge and Gitega moved to Kanyinya and Mageragere sectors.

Table 2**: Estimated urbanization trend**

	2015	**2020**
Muhima	37	29.72
Nyarugenge	17	14.41
Kimisagara	11.93	10.18
Nyakabanda	9	7.4
Rwezamenyo	5.3	4.91
Nyamirambo	2.4	2.1
Gitega	0.72	1.93
Kigali	0.081	1.37
Mageragere	0	6.7
Kanyinya	0	11.2
Total	83.431	89.92

3.2 Flood risk Exposure

Over time, disaster losses on community lives, livelihoods, properties and environment caused by poor land management, inappropriate settlement type sand location and the changing climate are revealing gradually rise (Eakin et al. 2012). In Rwanda flooding is affecting north-western parts along with City of Kigali and as long as urbanization takes place, losses are likely predicted to increase. Thus, recognizing the extent to which urbanization is causing flooding can help policy makers and urban dwellers to ensure mitigation and adaptation policies (River 2015).

In addition, as recently reported (Evariste et al. 2017; Bento-Silva et al. 2015) in case an area changes from rural to urban, its natural land scape features such as forest and vegetation are damaged while building houses, installing water and electrical lines and settling other urban facilities. It is from the above facts that the authors analyzed the flood causal factors and mapped the current resulting flood hazard in Nyarugenge district. The results in Figure 6 spatially distributed the elevation, slope, NDVI, rainfall, soil texture, lithology, LULC, distance to roads and distance to waters. These factors were considered with reference to literature review on major flood conditioning parameters in the City of Kigali.

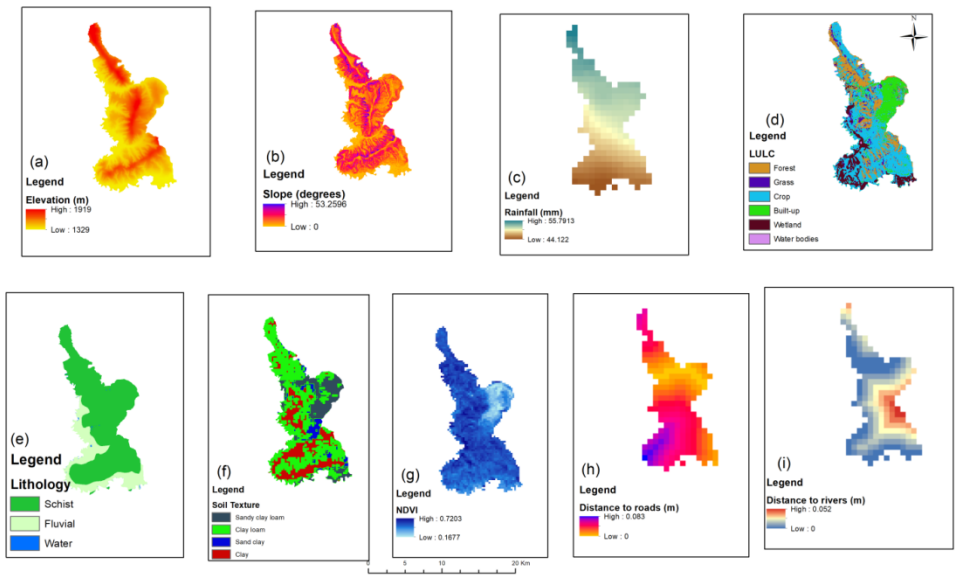

Figure 6**: Selected causes of flood in Nyarugenge district**

The spatially distributed flood hazard over the study area in Figure 4.6, show that the parts of Nyakabanda, Kanyinya, Rwezamenyo, Nyamirambo sectors and small part of Mageragere sector, are classified within very high flood prone zones compared to their counterparts sectors localized in low and very low flood hazard prone. Specifically, it is noted that Kimisagara,

Gitega, Nyarugenge, Nyakabanda, Rwezamenyo, Nyamirambo and Kigali sectors are in the moderate, high and very high flood prone areas (Figure 7)

The flood prone areas record high elevation and slope, and are highly built-up but also, they record moderate to high rainfall. These factors are in most cases, the major drivers to flood occurrence in Rwanda and in City of Kigali where Nyarugenge district is located (River 2015; Mugisha 2015).

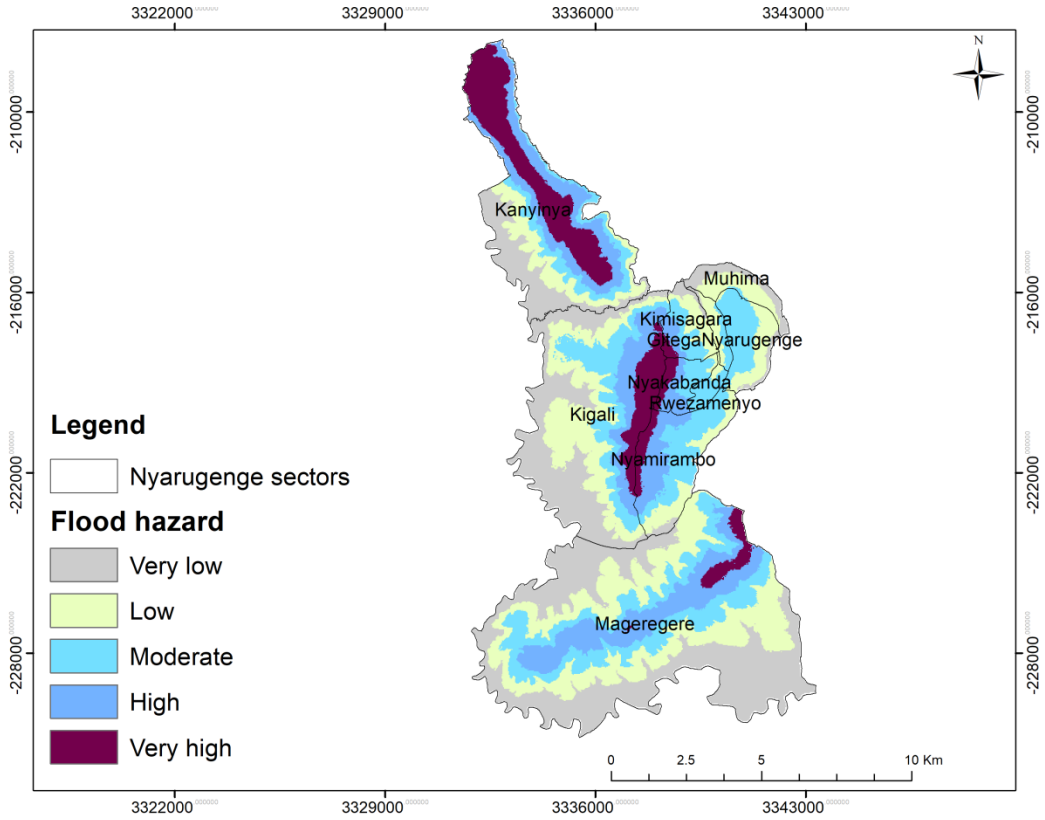

Figure 7**: Current distribution of flood hazard in Nyarugenge district**

In order to better understand how flood distributed in Nyarugenge might have affected people's livelihoods and environment as well, the researcher utilized recent losses caused by flood between 2015 and 2020 (study period).

The results in Figure 8 show that from 2015 to 2017, only one person was recorded as killed by flooding in Nyarugenge district. However, from 2018 to 2020, the number of losses gradually increased where two (2), one (1) injury were recorded together with three (3) were damaged by the occurrence of flooding. This expresses that as long as the urbanization extends in Nyarugenge district (Fig. 5) and the flooding may increase as well with associated loses.

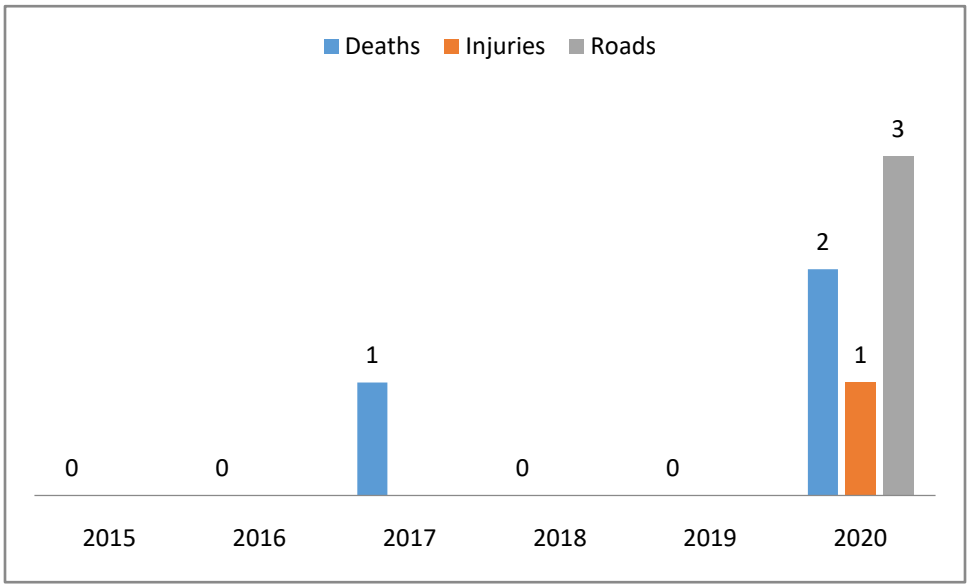

Figure 8: 2015-2020 recorded flood losses in Nyarugenge district

Source: MINEMA, 2022

3.3 Relationship between urbanization on flood Risk

It is reported that flooding stands among the glob threat especially within the urban areas. This results from the reason that as long as buildings are made and the surface soil is covered, in case of rainfall, the runoff water is not having its way to infiltration and then leading to leading to flooding (Munyaneza et al. 2013; Marchi et al. 2010). This occurrence affects the buildings by destroying them, kill people and others become injured along with immense cropland damages and livestock loss.

There is also water quality pollution and infrastructure damages such as classrooms, electrical lines (Khan 2011; Ignacio et al. 2015; Marchi et al. 2010). In Rwanda, more flooding is recorded in the Northwestern parts and City of Kigali due to frequent and heavy rainfall, poor land management under highly elevated land and slope as well (Bizimana and Schilling 2009; Munyaneza et al. 2013; River 2015; Mugisha 2015).

The results of this study in Figures 3 and 4 show that between 2015 and 2020, the population growth registered a growing trend within all sectors of in Nyarugenge district. It is noted that up to 2020, Kanyinya, Rwezamenyo, and Kimisagara are the sectors highly populated than other (Figure 4). However, in term of urbanization, Muhima, Nyarugenge and Gitega sectors record low urban growth compared to Kanyinya and Mageragere sectors (Table 2).

In order to estimate the relationship between urbanization and flood risk in Nyarugenge district, the researcher utilized the Pearson correlation analysis between the research independent variable (urbanization) and dependent variable (flood risk exposure), the estimated P value was 0.061 (Table 3). This value was considered as positive, at very high/large extent.

Table 3**: Relationship urbanization and flood risk exposure**

		Urbanization	Flood risk exposure
Mining practices	Pearson Correlation	1	.061
	Sig. (2-tailed)		.341
	N	3	3
Forest degradation	Pearson Correlation	.061	1
	Sig. (2-tailed)	.341	
	N	3	3

Accordingly, based on the spatial distribution of flood hazard exposure in Nyarugenge district, it is noted that Kanyinya and part of Mageragere sector are highly prone to flood. This likely explain that the higher population growth, the higher people become more exposed to flooding in the Nyarugenge district. Furthermore, the results in Figure 8 indicate that in 2015, the number of flood loses was low than that of 2020, which again expresses that in case of high population growth, more land will be turned into urban, and that losses can be expected. Hence, appropriate eland management in Nyarugenge district is of great importance to minimize the flood risk exposure.

4. Conclusion

This study was conducted in order to evaluate the impact of urban expansion on disaster risk exposure with the case of flooding in Nyarugenge District, City of City. The authors utilized secondary datasets on urban growth such as population growth and urbanization rate within sectors of Nyarugenge district. The study also employed datasets on flood causal factors and distributed flood hazard over the study area for which recent flood losses were also analyzed. The research covered a period ranging between 2015 and 2020. The Microsoft Excel, GIS and SPSS software were utilized to analyze the collected data. The results show that from 2015 to 2020, population growth in Nyarugenge district registered the growing trend and the spatial urbanization indicates that areas Muhima, Nyarugenge and Gitega sectors with high urbanization in 2015 changed in 2020. However, in 2020, Kanyinya and Mageragere sectors which were not urban in 2015 registered expanding urbanization in 2020. Accordingly, the mapped flood hazard

reveal that the 2020 urban areas are quite exposed to hazard similar to loses of flood which indicate the growing number from 2015 to 2020. Furthermore, in order to reveal the extent to which urbanization contributes to flood hazard risk exposure, the correlation analysis test was performed and the obtained P value (0.061) which is high, it is noted that urbanization growth in Nyarugenge district is among the drivers to flood occurrence and its associated losses. Appropriate urbanization, control of population growth and land management are suggested.

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