International Journal of Environmental Planning and Management
Vol. 6, No. 4, 2020, pp. 115-124
http://www.aiscience.org/journal/ijepm
ISSN: 2381-7240 (Print); ISSN: 2381-7259 (Online)

Contribution of Green Infrastructures on Flood Risk Reduction in Kigali City of Rwanda

Uwera Martine, Nsanzumukiza Martin Vincent*, Maniragaba Abias, Mukasekuru Francoise, Mucyo Jean Claude, Ntabugi Marie Claudine, Niwenshuti Emmanuel

Department of Environmental Economics and Natural Resources Management/Faculty of Environmental Studies, University of Lay Adventists of Kigali, Kigali, Rwanda

Abstract

Nowadays, the world is facing many environmental concerns due to the rapid urbanization, concentration of economic activity, competition for space in dense urban agglomerations, unplanned development, environmental degradation and climate change. Thus, leading to an increase in the probability of floods, water, and air pollution, urban sprawl, and lack of waste management occurrence and their risks in urban settings. This study aimed to analyse the contribution of green infrastructures in reducing flood risk in Kigali City, Rwanda. The Geographic Information System (GIS) and Microsoft Excel were the main tools employed by the study. The study utilized secondary data on green infrastructures which revealed that the high possession rate is localized in Gasabo district. Regarding recent flood losses, it was realized that from January 2017 to April 2020, an advanced number of flood losses were registered in 2018. The authors based on these recent events, literature review, and expert opinion to select eight factors that likely contribute to flood occurrence in Kigali City. The flood occurrence was highly attributed to land use and land cover (26.7%), rainfall (21.16%), elevation (16.41%), slope (14.35%), and soil texture (11.37%). The spatial distribution of flood hazards highlighted that residents of Gasabo district are a large extent exposed to flood at 55.4% compared to residents of Nyarugenge and Kicukiro districts, exposed to flood at 25.4%and 19.2%, respectively. The ANOVA test of the relationship between variables generated an average possession value of 0.299. It was concluded that the initiated green infrastructures (mainly wetland) did not contribute to flooding risk reduction in Kigali city. Thus, green infrastructure location suitability is highly recommended.

Keywords

Flood, GIS, Green Infrastructures, Wetland, Risk Reduction

Received: August 31, 2020 / Accepted: October 23, 2020 / Published online: November 27, 2020

1. Introduction

Nowadays, the world is facing many environmental concerns, due to the rapid urbanization, concentration of economic activity, and climate change [1, 2]. Some of them are floods, water, and air pollution, urban sprawl, and waste disposal further resulting from unplanned development, competition for space in dense urban agglomerations, and environmental degradation [3]. Rwanda is counted among the most densely populated country in Africa with 445 inhabitants per square km. The country is currently highly vulnerable to climate change with a temperature increase of 1.4°C since 1970, higher than the global average, and can expect an increase in temperature of up to 2.5°C by the

* Corresponding author
E-mail address: nsanzumumartiv@gmail.com (N. M. Vincent)

2050s [4]. Concurrently, Rwanda's urbanization grows rapidly, which is mainly driven by the population growth together with an increase of migration from rural areas to urban areas and goes with the increase in housing space, need for support infrastructure, and other development activities [5]. The above posed significant pressure on the city's existing green spaces and has led to serious destruction of wildlife biodiversity and the city no longer enjoys the same magnitude of biodiversity and that the city is striving to protect it more in the future [6]. This is associated with other human activities and increasing wetlands degradation which leads to biodiversity loss [7].

The rapid urbanization in Kigali City in combination with extreme weather, a poor drainage system and less infiltration due to that contributes to high runoff is leading to frequent floods [8]. However, there is still a lack of knowledge on the importance of green infrastructure and how to install, which if well installed, would help to ensure that urban growth lies in the innovative development of green infrastructure [9]. This would help in flood loss reduction, resilience building, and environmental and well-being benefits. Besides, it is crucial to integrate these concurrent threats into the development plans for the urban areas to satisfy the component of climate resiliency, which contributes to sustainable growth.

Nevertheless, to the best knowledge of the authors, no study has been conducted to assess the contribution of green infrastructure in reducing flood risk in Kigali city. Therefore, this expresses a definite need to demonstrate a model that shows the potential of green infrastructure to abate flood risk among urban residents. This was recognized by the authors by choosing to conduct this study to examine the impact and potential contribution of green infrastructure to cope with urban challenges by focusing on flood risk reduction in the City of Kigali.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in Kigali City of Rwanda populated by over 1.1 million people with an average annual growth rate of 4% [10]. As indicated in Figure 1, Kigali city is subdivided into three districts: Gasabo, Kicukiro and Nyarugenge. The city is surrounded by the Northern Province on the North, Eastern Province on the East and South and Southern and Western Provinces on the West.

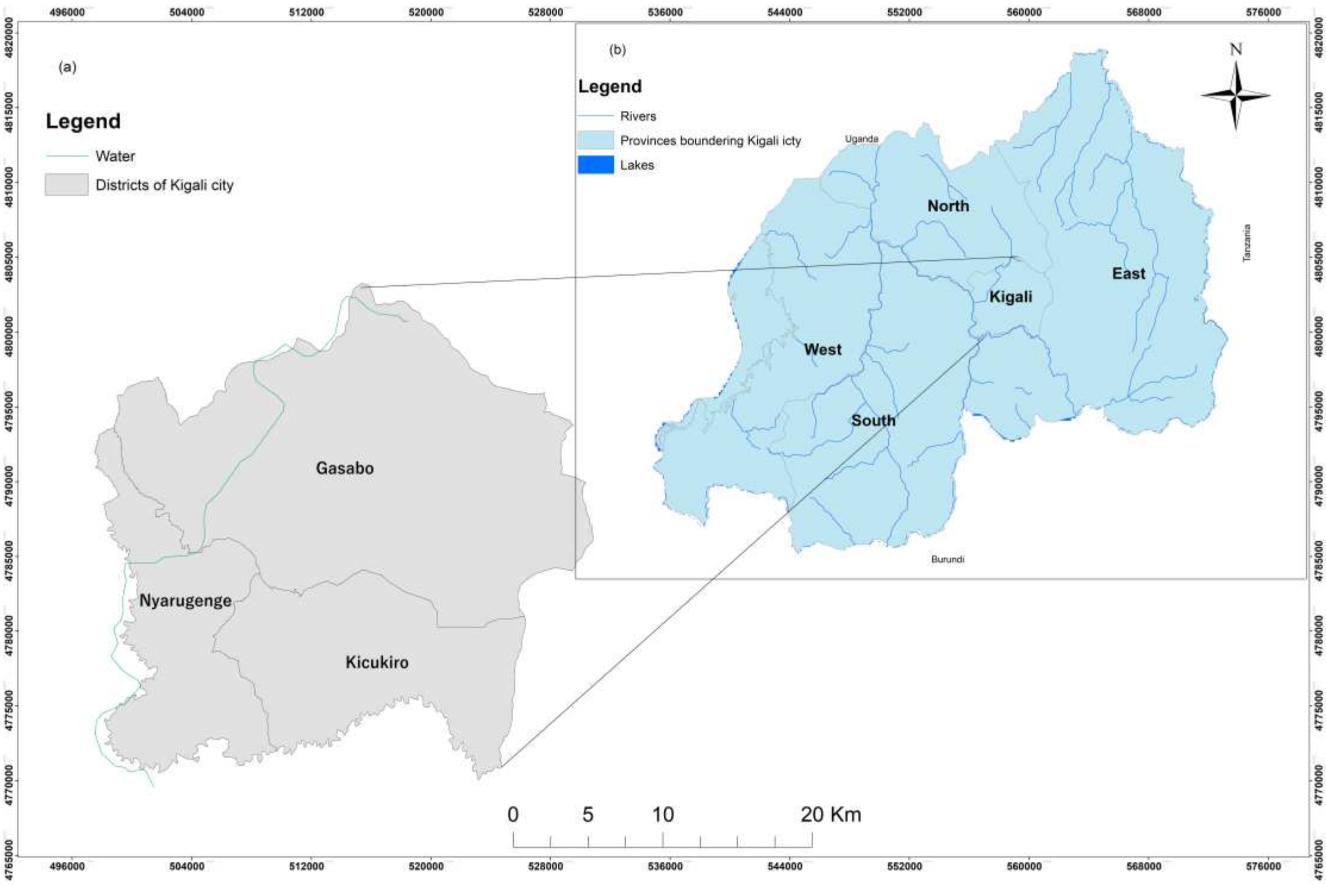

Figure 1. Map indicating the location of Kigali city and its bordering provinces of Rwanda.

The city of Kigali is founded on hills and mountains, with three mountains in the south and west (Mount Rebero, Mount Kigali and Mount 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 [6]. 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). Typical rainfall events are characterized by high intensities of short duration with high temporal and spatial variability, which leads to pluvial flooding [6].

Over the last decades, Kigali City recorded floods on an irregular basis. This frequency of flooding in the capital underlines the importance of floodproofing measures. Therefore, the rapid urbanization which mainly results from unsustainable urban development should adopt the application of green infrastructures that promote Nature-Based Solutions (NBS). This NBS does not only complement flood risk reduction, but also improves the urban quality and strengthens livelihoods and resilience in urban neighbourhoods [11].

2.2. Data Types and Collection Techniques

This method provided the needed information on floods which occurred in the city of Kigali, identify the existing green infrastructures components that had been planned in the City of Kigali; it also helped to review and analyse the gaps, challenges and best practices that happened during the implementation of the green infrastructure. For this study, the authors employed dataset related to green infrastructures which were collected from the Rwanda's Ministry of Environment, Rwanda Water Resources Management, Rwanda Land Management and Use Authority, and the City of Kigali.

The datasets on flood causal factors namely: elevation, slope, rainfall, land use and land cover, distance from rivers, lithology and soil texture, and Normalized Difference Vegetation index were collected from the United States Geological Survey (USGS, 2019) Rwanda's Ministry of Environment and Rwanda Metrological Agency. To develop the maps of the study area and flood causal factors, the Geographic information System (GIS) was used. The data on recent flood losses recorded in Kigali city were collected from the Rwanda's Ministry in Charge of Emergency Management and the City of Kigali. These data ranged from January 2017 to April 2020.

2.3. Data Analysis

For the green infrastructure analysis, the authors employed the Google earth in order to locate the installed green infrastructures in Kigali city. These were then imported into the ArcGIS for better mapping and locating the green infrastructures across the study area. Thereafter, the study analysed and mapped flood causal factors by using GIS and these maps were merged together into ArcGIS, in its Spatial Analyst Tools, specifically the Weighted Overlay technique in order to produce the final flood hazard map of Kigali city.

Furthermore, the data on recent flood events (killed/injured people, destroyed roads or bridges, damaged cropland and houses) were analysed to reveal the trend between January 2017 and April 2020. Finally, to analyse the contribution of green infrastructures contributed to the reduction of flood risk.

3. Results and Discussion

3.1. Green Infrastructures Plans Initiated in Kigali City

Considering different initiative for the beautification of the city, rainwater management, and promotion of green spaces, the list of different Green infrastructure that can address the flood risk occurring in Kigali City is limited to the permeable pavement, Tree & Plants, Park as water retention, terracing, Natural Wetland, Rainwater harvesting, Green ditches, Eco Concrete solutions, Uphill forestation [12]. To better understand green infrastructures in Kigali city, previous works (report/academic studies) completed with a specific focus on wetland as the existing GIs in Kigali city were considered. Table 1 listed the reports related to flood risk for wetland management. The results were adopted from different reports of Kigali city on Green Infrastructures, their location, structure, and contribution as well.

The results in Table 1 indicated several reports on green infrastructures in Kigali city that were consulted. These reports discussed the existing GIs in Kigali city by mainly focused on three parts. The first was to analyse flood occurrence in Kigali city and how green infrastructure could serve as the best solution (policy/plan) for the management of the wetland largely affected by flooding and also serving as green infrastructure. The second part was to develop the tools such as Geo-information technology and flood risk modelling to help in monitoring or analysis of past record of flooding in order to better predict its future occurrence with the purpose of suggesting suitable interventions. The last point but not the least, was to put in place possible mechanisms, plans and strategies to rehabilitate and restore the existing green infrastructure (wetland).

Table 1. Consulted documents on green infrastructures in Kigali city.

Author and year	Title	Status	Summary of content and information used
U.R, (2010)	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.	Completed	The study aimed to improve flood mitigation within Rwanda's rapidly growing Kigali City using Geo-Information Technology (GIT) to identify flood hazard zones, analyse flood exposure and vulnerability, and suggest planning interventions for Nyabugogo area.
REMA (2012)	Establishing Urban Wetland Recreation and Eco-tourism Park in Nyandungu Valley, Kigali City (Rwanda)	Completed	Analysis of Nyandungu wetland conceptual framework for Eco-tourism and wetland recreation and conceptual plan for Urban Wetland Recreation and Eco-tourism Park. Use for analysis planned developments and system analysis.
REMA/NEMUS (2018)	Detailed Sub-Catchment Management Plans for Gikondo and Nyabugogo Wetland Systems	Completed	Plan for wetland rehabilitation, maintenance actions, monitoring programs, plan implementation, cost-benefit analysis of restoration options and recommendations.
MOE (2018)	Assessment of Current Storm Water Management and Flood in the City of Kigali Areas	Completed	General information on flood hazard and impact for CoK flood prone areas including potential measures.
RHDHV (2019)	Assessing flood risks and its potential control and management in Masaka wetland, Rwanda	Completed	Flood risk modelling of Masaka wetland.
SMEC (2019)	Technical Support for Development of Wetland Master Plan for Kigali City	Ongoing	Analysis of current and future situation of CoK Wetlands and development of wetland master plan of the City of Kigali.
World Bank (2020)	Overview of Conceptual Wetland Rehabilitation Design Alternatives: Gikondo And Nyabugogo (Lower) Wetlands, Kigali, Rwanda	Ongoing	Analysis of Gikondo and Nyabugogo wetlands and possible rehabilitation strategies.

3.2. Distribution of Green Infrastructure in Kigali

The results in Figure 2 indicated that natural green infrastructures (wetland) are available within all three districts of Kigali city. The majority of them are located in Gasabo District. Regarding the types of green infrastructures available in Kigali city, the majority of them are national green infrastructures, Figure 2.

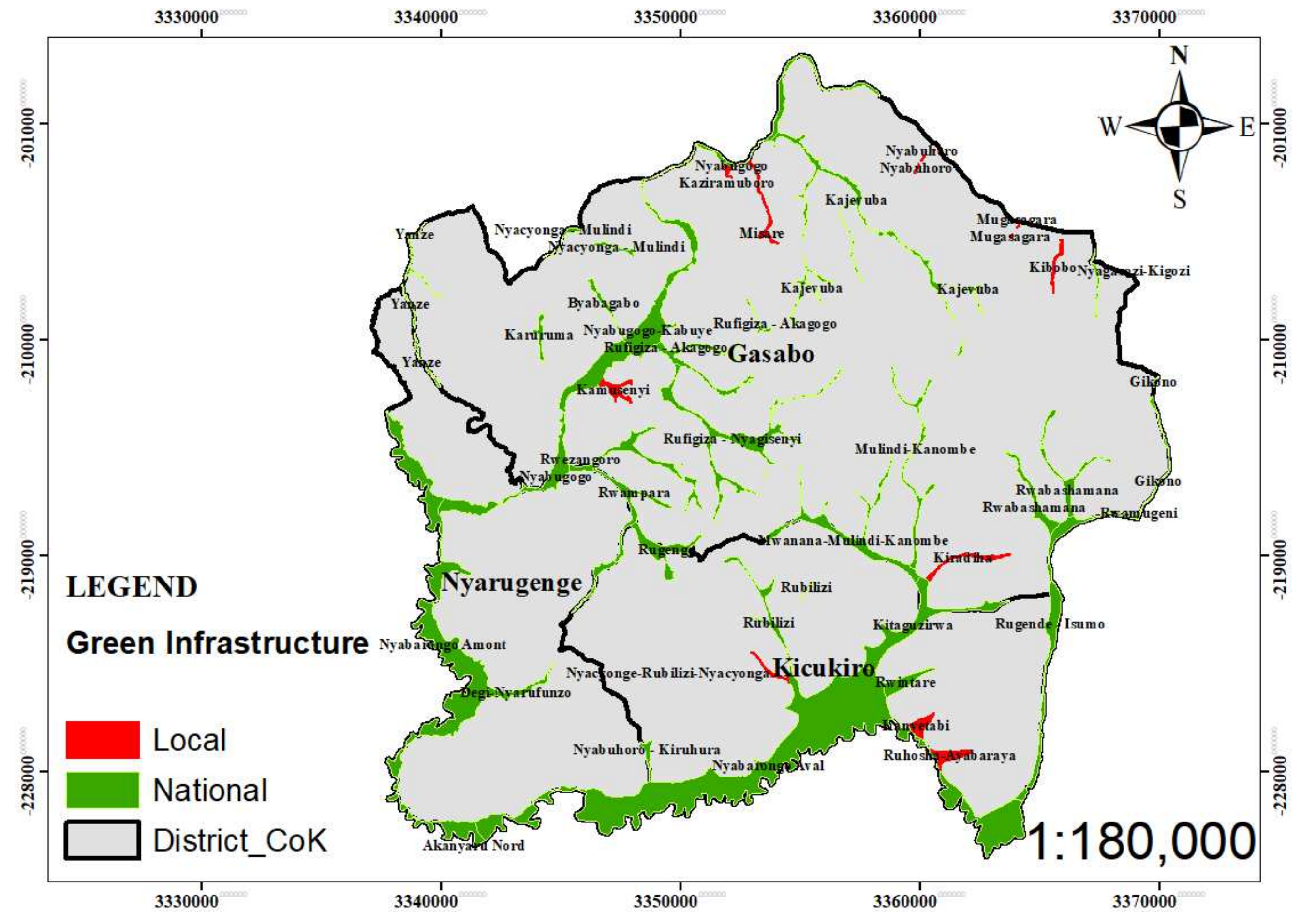

Figure 2. Green infrastructures located in Kigali city.

The results in Table 2 illustrated that the possession rate of green infrastructures in three districts (Gasabo, Kicukiro and Nyarugenge) of Kigali city is not equal. Gasabo District possesses the majority (44.32%) of all green infrastructures available in Kigali city compared to Nyarugenge and Kicukiro Districts, (Table 2).

Table 2. Estimated possession rate of GI in districts of Kigali city.

District	Types of Green infrastructures		
	Local	National	Total possession rate
Kicukiro	2.91	13.56	16.47
Gasabo	4.46	39.86	44.32
Nyarugenge	1.16	2.67	3.83
Total	8.53	56.09	64.62

3.3. Distribution of Recent Flood Events in Kigali City

The analysis of recent flood events recorded over the study area illustrated the types of losses triggered by flood throughout three districts of Kigali City between 2017 and 2020. The results in Table 3 indicated that the year 2018 recorded a high number of flood losses. There had been 25 deaths and 27 injuries, along with 2,461 houses destroyed and 584.1 hectares of cropland which were damaged.

The results in Figure 3 showed the recent flood losses recorded from January to April 2020, both deaths and injuries were combined. The second group was of land and/or cropland damaged. The last group entailed infrastructures including houses classrooms, roads, bridges, administrative offices, transmission lines, and markets damaged. Respective to other maps, the year 2018 registered a high number of flood losses than other years considered by this study. The infrastructures and houses were more affected due to the rainfall and storms in Kigali city, which stand as the major factors causing flooding. Similarly, these flood losses (Table 3) were mainly recorded during heavy rains and storm months (March-May and September-December) of each year considered by this study.

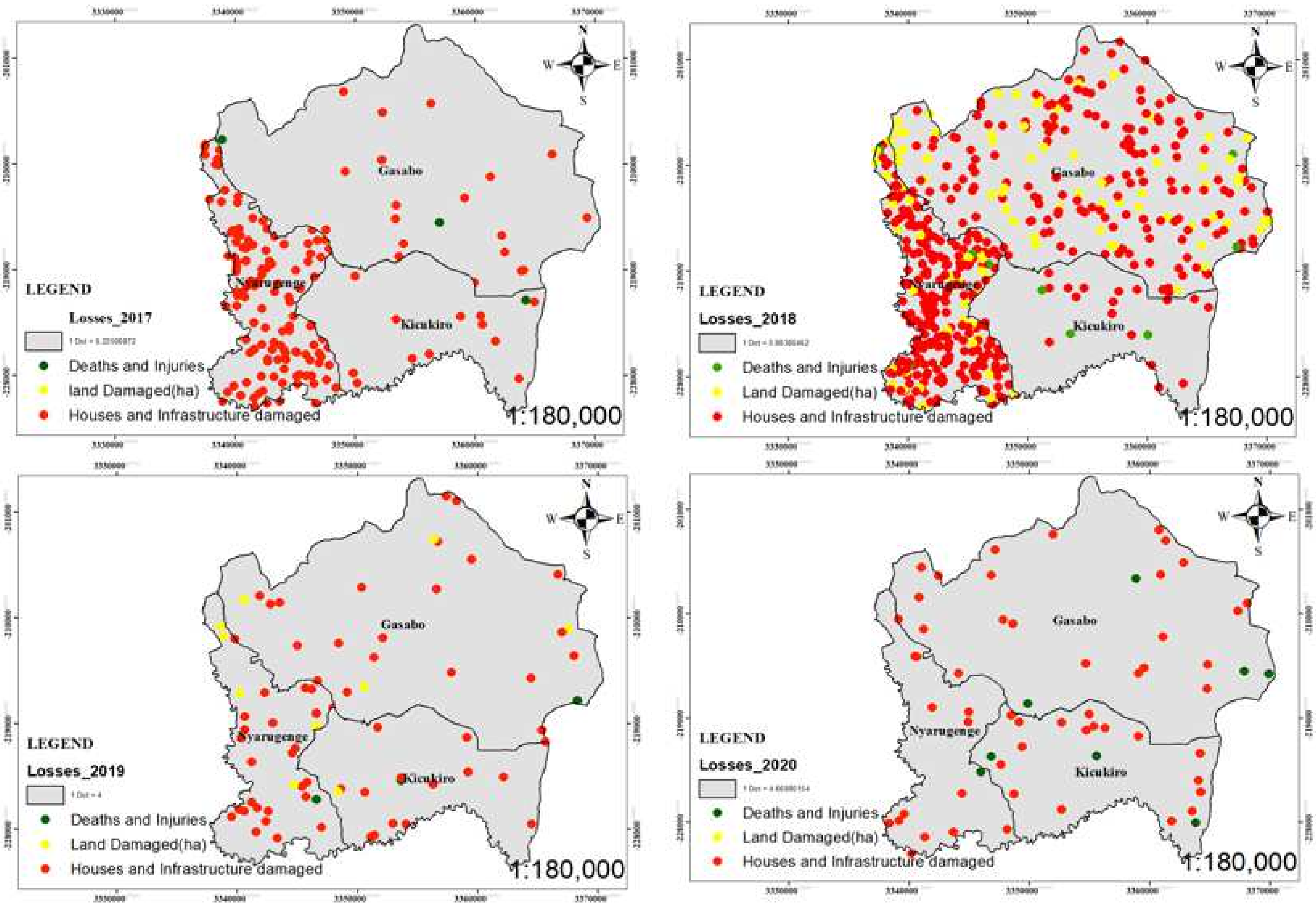

Figure 3. Recent flood events recorded in 2020.

Table 3. Recent flood losses recorded in Kigali city (2017-2020).

Districts	Deaths	Injuries	Houses Damaged	Damaged land Ha.	Infrastructure affected: Classrooms	Roads	Bridges	Administrative offices	Transmission lines	Markets
January – April 2020										
Gasabo	9	9	102	0	0	1	1	0	2	1
Kicukiro	5	8	73	0	0	6	1	0	0	0
Nyarugenge	2	2	53	0	0	4	0	1	1	0
Total	16	19	228	0	0	11	2	1	3	1
January – December 2019										
Gasabo	1	2	75	15	8	2	1	2	1	0
Kicukiro	1	2	56	5	0	0	1	0	0	0
Nyarugenge	1	1	100	20	0	1	1	1	0	0
Total	3	5	231	40	8	3	3	3	1	0
January – December 2018										
Gasabo	8	4	957	377.5	0	0	0	0	0	0
Kicukiro	9	6	111	1	0	0	0	0	0	0
Nyarugenge	8	17	1393	206.6	2	0	0	0	0	0
Total	25	27	2,461	584.1	2	0	0	0	0	0
January – December 2017										
Gasabo	1	2	75	15	8	2	1	2	1	0
Kicukiro	1	2	56	5	0	0	1	0	0	0
Nyarugenge	1	1	100	20	0	1	1	1	0	0
Total	3	5	231	40	8	3	3	3	1	0

3.4. Major Conditioning Flood Occurrence in Kigali City

After recording the total flood losses registered in Kigali city from 2017 to 2020 (Table 3); the major causal factors which led to the flood losses were considered. These factors were selected based on recent flood losses distribution in three districts of Kigali city, literature review and experts opinion on major flood occurrence drivers.

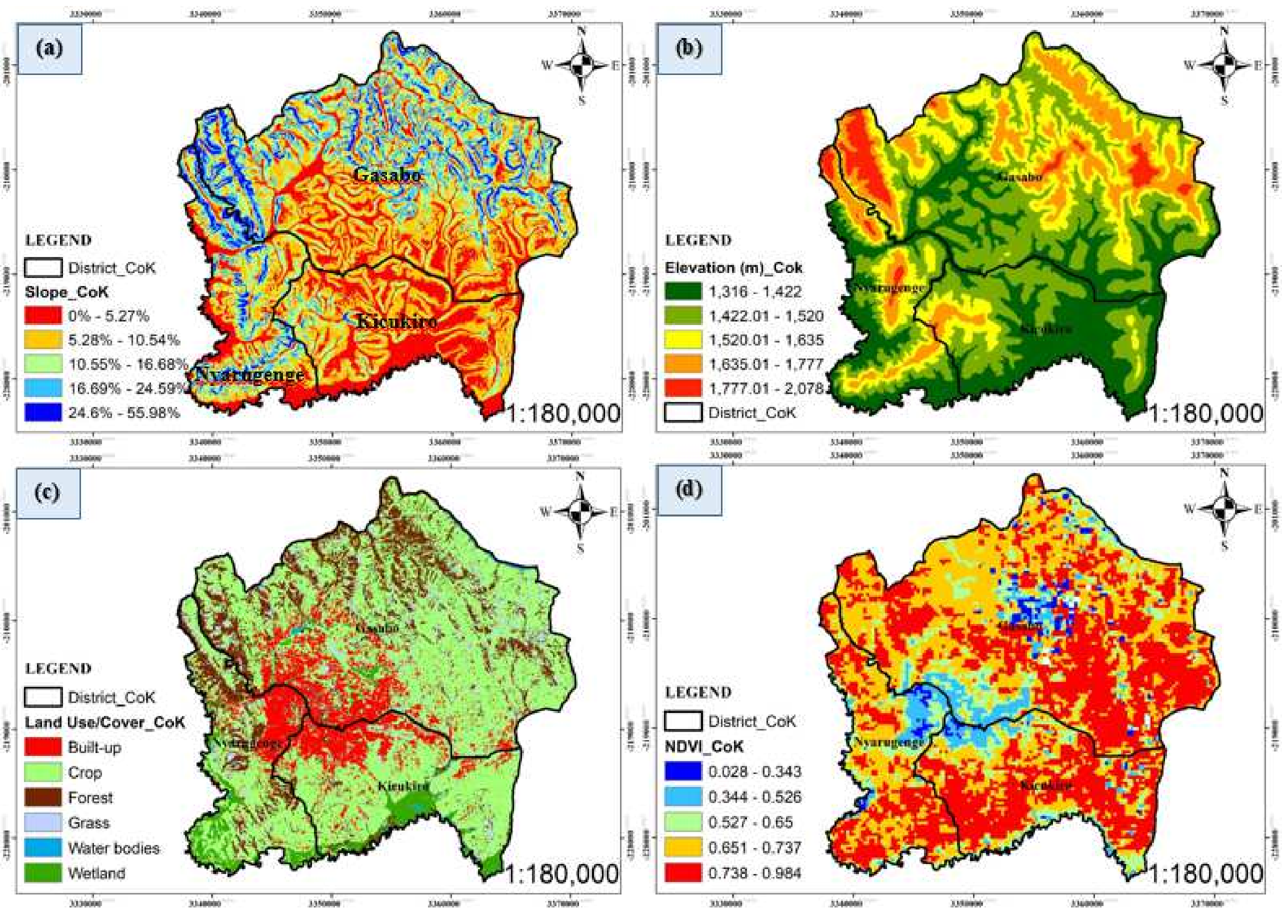

Figure 4. Flood causal factors: (a) Slope, (b) Altitude, (c) Land use/cover and (d) NDVI.

The results in Figure 4 (a) indicated that the slope classes obtained in percentage were 0-5.27%, 5.28 -10.54%, 10.55 – 16.68%, 16.69 – 24.59% and 24.60 – 55.98%. The elevation classes as shown in Figure 4 (b) were namely: 1,316 - 1, 422 m, 1, 423.01 - 1, 520 m, 1, 520.01 - 1,635 m, 1, 635.01 - 1,771 m and 1, 771. 01 - 2, 078 m. Regarding the land use and land cover (LULC) map presented in Figure 4c, the analysis categorized LULC of Kigali city into 6 classes namely: Forestland, Grassland, Cropland, Built-up, Wetland and water bodies. The Normalized Difference Vegetation Index (NDVI) as one of the flood occurrence causal factors in Kigali city was also considered. The NVDI was calculated by using the Equation (1) below.

$$\mathrm{NVDI} = \frac{\mathrm{NIR-RR}}{\mathrm{NIR+RR}} \qquad (1)$$

Where, NIR is the reflectance in the near-infrared portion of the electromagnetic spectrum, and RR is the reflectance in the red portion. The constructed map of NDVI was acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS, 250m resolution) downloaded from an online database (ladsweb.nasacom.nasa.gov/data/html). The obtained NDVI values were provided in Figure 4 (d) as: 0.028-0.343 (very low), 0.344- 0.526 (low), 0.527-0.65 (moderate), 0.651-0.737 (high) and 0.738 -0.984 (very high).

The study also employed rainfall datasets collected from the Rwanda Meteorological Agency and were interpolated by using the ArcGIS. Figure 5 (a) indicated the rainfall distribution in millimeter (mm) as follows: 44.26 -46.95 mm, 34.96 - 49.64 mm, 49.65- 52.33 mm, 52.34 – 55.02 mm and 55.03 - 57.7 mm. The highest rainfall was observed in Gasabo district contrary to Nyarugenge District which presents the majority of lowest rainfall distribution, Figure 5 (a). The lithological map of the study was prepared using geological data from the Rwanda Land Management and Use Authority and the City of Kigali in Figure 5 (b), it illustrated that lithological classes influencing flood occurrence in Kigali city are mainly Schist and Fluvial.

Moreover, the soil texture and its classification as indicated in Figure 5 (c) are clay, clay loam, sand clay and sandy clay loam soil texture as the dominating classes. Finally, distance from the river was selected due to the reason that is one of the most important factors affecting flooding in adjacent lands. The classification of distance to rivers demonstrated in Figure 5 (d) were five classes in meters (m) namely: 0 - 1,369.4 m, 1,369.41 - 2,738.79 m, 2,738.8 – 4,108.19 m, 4,108.2 – 5,477.59 m and 5, 477.6 – 6,846.98 m.

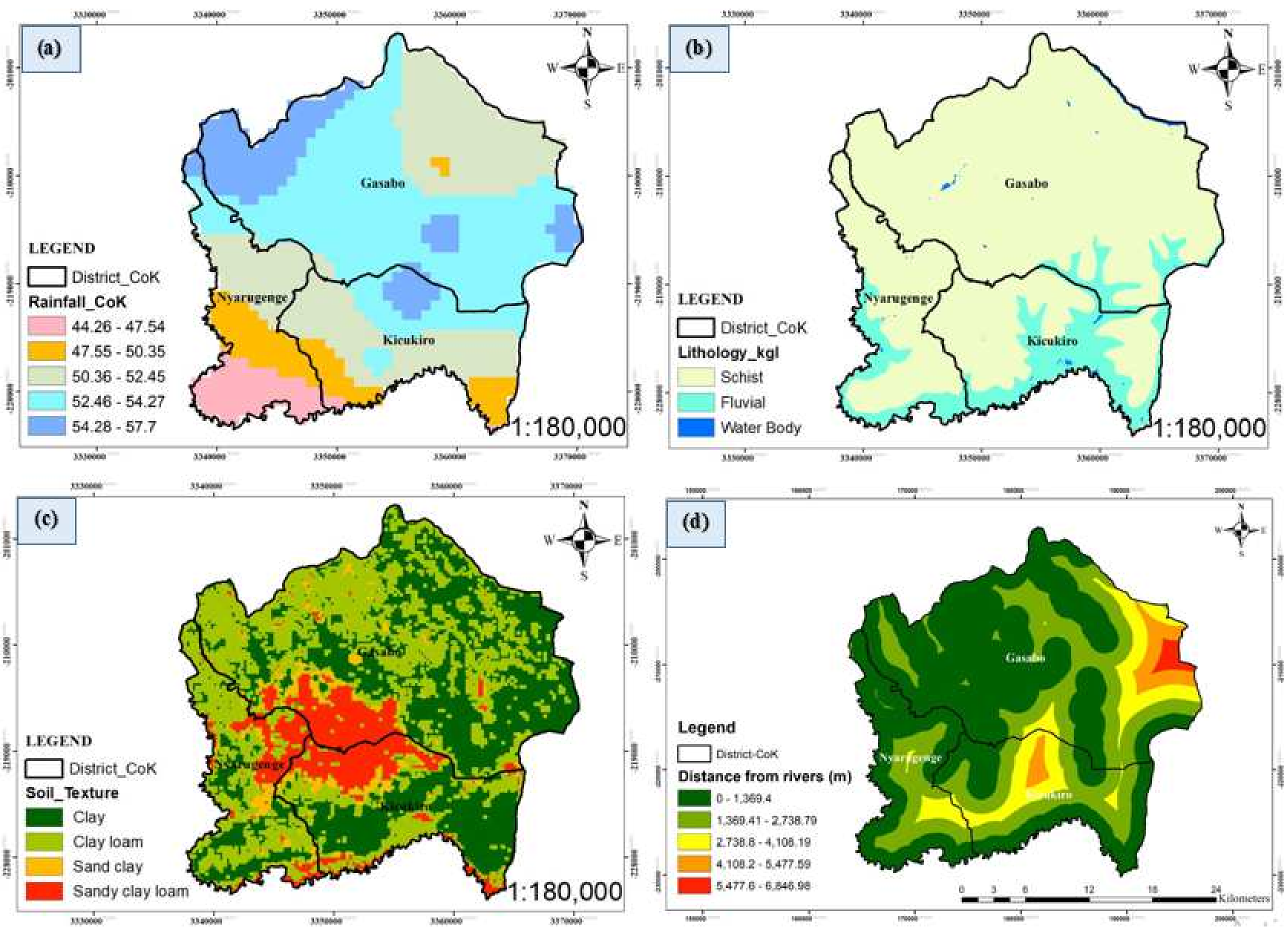

Figure 5. Flood causal factors (2): (a) Rainfall, (b) Lithology, (c) Soil texture and (d) Distance from river.

3.5. Mapping Flood Hazard in Kigali City

The authors combined the above flood causal factors to provide its current hazard map. The exercise was completed by using the Spatial Analyst Tool of ArcGIS. The Figure 6 revealed the five classes of flood hazard in Kigali city such as 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 Kigali city is exposed to flood and Gasabo district records the majority of high and very high flood hazard classes, respectively.

The estimated flood hazard exposure per district, (Table 4) revealed that the residents of Gasabo district are, at large extent, exposed to flood at 5.43% compared to residents of Nyarugenge and Kicukiro Districts, which are exposed to flood at 25.4 and 19.2%, respectively.

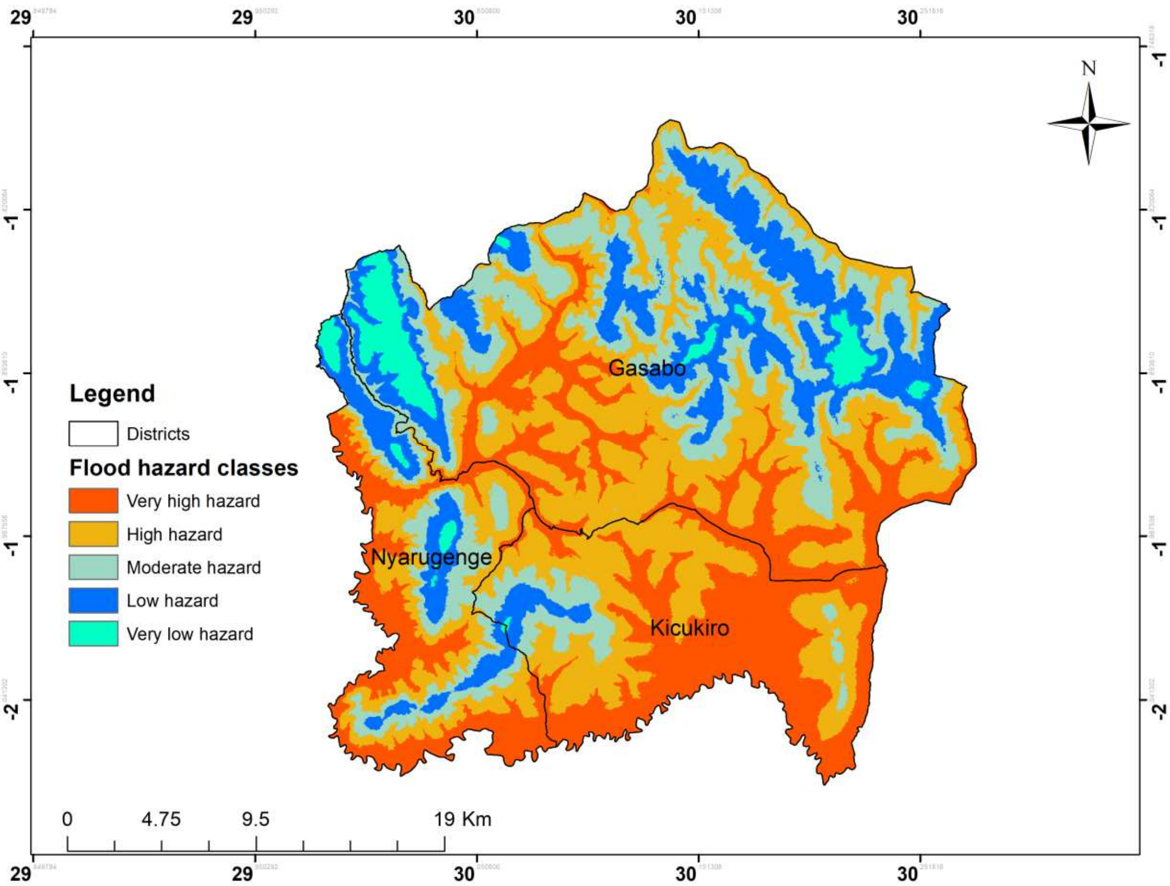

Figure 6. Flood hazard distribution in Kigali city.

With regard to the employed flood causal factors, it was noticed that land use and land cover (26.7%), rainfall (21.16%), elevation (16.41%), slope (14.35%) and along with soil texture (11.37%) were the major parameters conditioning the occurrence of flood in Kigali city (Figure 6).

The occurrence of flood in Rwanda had huge impact on the local community's livelihood since it impacts on natural resources on which people's daily living conditions depend on, and the number of cases of flood occurrence keeps on increasing over time [13-15]. This research applied the Geographic Information System (GIS) to analyse the contribution of Green Infrastructures in reducing flood risk over Kigali city. The results indicated that the majority of green infrastructures are located in Gasabo District at 44.32% compared to Nyarugenge and Kicukiro Districts, Table 2. Accordingly, based on the spatial distribution of flood hazard in Kigali city, the analysis revealed that Gasabo District is at large extent, exposed to flood compared to other districts (Figure 6 and Table 4).

Table 4. Estimated flood hazard proportion per district.

Flood hazard classes						
District	**Very low hazard**	**Low hazard**	**Moderate hazard**	**High hazard**	**Very high hazard**	**Total exposure rate**
Gasabo	0.8	14.3	11.2	23.1	6	55.4
Nyarugenge	2.1	4.6	9.2	7.4	2.1	25.4
Kicukiro	4.6	1.8	3.2	5.3	4.3	19.2
Total	7.5	20.7	23.6	35.8	12.4	100

The study employed the average possession rate of green infrastructures and flood hazard exposure per district, as shown in Tables 2 and 4, respectively.

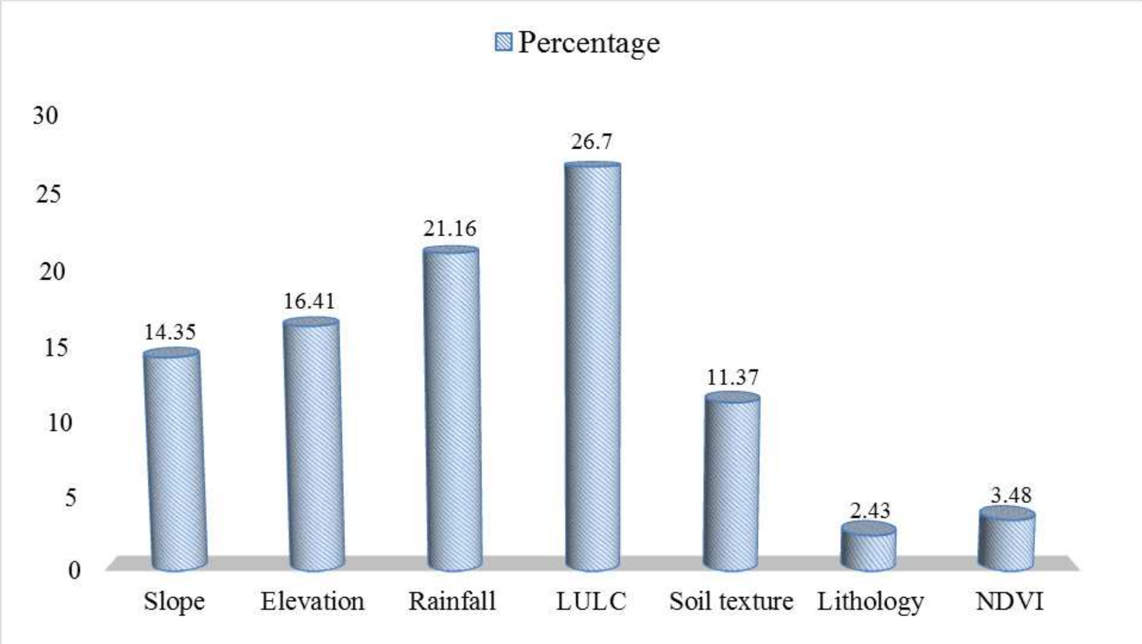

Figure 7. Factors' contribution to flood occurrence.

Flooding is a large extent, being recorded within urban areas mainly due to the high urbanization rate and inappropriate waste management which easily facilitate the runoff [16]. The proportion of urban dwellers was below 5% in 1600 and increased up to 16% in the 1900s. After 2000, the share of urban population increased considerably within both developed and less developed nations, and today, more than half of the world population lives in the urban areas [17, 18]. This expresses that the growing trend of the population in the urban area is associated with risk if it is not well designed. Among the risks being recorded, disasters are the utmost leading to severe losses and damages among the densely and poorly planned (construction and natural resources management, etc.) urbanized areas [19].

The findings showed that the existing green infrastructures located in Kigali city (Figure 2) are mainly wetland which is located in the downstream while the areas mapped as highly exposed to flood, (Figure 6) were located in the upstream. Hence, regardless of the existing GIs, much flood losses are still recorded and this calls to ensure that the upstream where much runoff comes from, is protected. This would in turn help residents of Gasabo District, highly exposed to flood (Table 4), and possessing a high number of GIs (Table 3) to record low flood losses. According to previous researches [20, 21] relocating the residents from high-risk zones, Figure 7 would help to minimize the losses and ensure that GIs are installed in an appropriate location without any possible harm.

4. Conclusion

This study was conducted to assess the contribution of green infrastructure in reducing flood risk in Kigali City of Rwanda. The data on green infrastructures revealed that the high possession rate is localized in Gasabo district. Regarding recent flood losses, it was realized that from January 2017 to April 2020, an advanced number of flood losses was registered in 2018, being people killed and injured, damaged cropland, etc. land use and land cover, rainfall, slope, and elevation were highlighted among others as the primary parameters influencing flood hazard, highly recorded in Gasabo district than Nyarugenge and Kicukiro districts. However, it was noticed that the initiated Green Infrastructures (mainly wetland) did not contribute to reducing flood risk in Kigali city. Therefore, the study recommends ensuring that GIs locations are appropriate; the upstream of GIs require agroforestry, afforestation, and forestation to minimize the runoff. Accordingly, as the existing GIs are only wetland, it is good to improve the draining system of these wetlands to minimize flooding during heavy rains. There is a need for a community approach and/or training to understand the consequences of residing in flood high-risk zones and community-based disaster early warning is useful to improve people's awareness and preparedness. Future researches suggested to analyse the suitability of green infrastructure locations in Kigali city.

Acknowledgements

The authors would like to express their thanks to all data providers which successfully lead to the completion of this study.

References

[1] Commission, E., The multifunctionality of green infrastructure, 2012. p. 1-36.

[2] EC, Science for Environment Policy, In-depth Report, The Multifunctionality of Green Infrastructure, 2012, Directorate - General Environment-European Commission: UK.

[3] Ahern, J., From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Elsevier: Landscape and Urban Planning, 2011: p. 341-343.

[4] MoE, National Environement and Climate Change Policy, 2019, Ministry of Environment: Kigali-Rwanda.

[5] MININFRA, Urbanisation & rural settlement_sector strategic plan for national strategy for transformation, 2018, Ministry of Infrastructure: Kigali-Rwanda.

[6] REMA, The Kigali State of the Environment and Outlook Report, 2013, Rwanda Environment Management Authority: Kigali-Rwanda.

[7] Fennessy, S. M., Philip and J. Sheila, Wetland restoration for climate change resilience. Ramsar Briefing Note No.10., 2018, RAMSAR Convention Gland, Switzerland.

[8] River, N., Identification of flood prone areas in Kigali City, 2015, UNIVERSITY OF RWANDA.

[9] (Mens et al., 2011, MoE, 2019, Marlow et al., 2013)

[10] NISR, Rwanda Fourth Population and Housing Census. Thematic Report: Population size, structure and distribution, 2012, NATIONALINSTITUTION OF STATISTIC RWANDA: Kigali-Rwanda.

[11] MoE, Assessment of Current Storm Water Management and Flood in the City of Kigali Areas, 2018, Ministry of Environment: Kigali-Rwanda.

[12] Kigali, C. o., KIGALI CITY DEVELOPMENT STRATEGY (2018 - 2024), 2018. p. 1-165.

[13] Mucyo, J. C., Nsanzumukiza M. V, et al., Mapping Landslide Susceptibility and Analyzing Its Impact on Community Livelihoods in Gakenke District, Northern Rwanda. Journal of Geoscience and Environment Protection, 2020. 8(5): p. 41-55.

[14] Mind'je, R., et al., Flood susceptibility modeling and hazard perception in Rwanda. International Journal of Disaster Risk Reduction, 2019. 38: p. 101211.

[15] Munyaneza, O., Y. K. Nzeyimana, and U. G. Wali, Hydraulic Structures Design for Flood Control in the Nyabugogo Wetland, Rwanda. Kigali, Rwanda, 2013.

[16] Douglas, I., et al., Unjust waters: climate change, flooding and the urban poor in Africa. Environment and urbanization, 2008. 20(1): p. 187-205.

[17] Ellis, J. B., Sustainable surface water managementand green infrastructure in UK urbancatchment planning. Journal of Environmental Planning and Management, 2012: p. Vol.56, 24-41.

[18] Adelekan, I. O., Vulnerability assessment of an urban flood in Nigeria: Abeokuta flood 2007. Natural Hazards, 2011. 56(1): p. 215-231.

[19] Popescu, M. E. and K. Sasahara, Engineering measures for landslide disaster mitigation, in Landslides–Disaster Risk Reduction. 2009, Springer. p. 609-631.

[20] Nikuze, A., et al., Livelihood impacts of displacement and resettlement on informal *households-A case study from Kigali, Rwanda*. Habitat international, 2019. 86: p. 38-47.

[21] Bozzano, F., et al., *Displacement patterns of a landslide affected by human activities: insights from ground-based InSAR monitoring*. Natural hazards, 2011. 59(3): p. 1377-1396.