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Land susceptibility to the stormwater runoff in Nyabugogo river catchment area, Rwanda

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ABSTRACT

In Rwanda, 40% steep slope land and rapid growing urbanization increase susceptibility of land to stormwater runoff. The objectives were to analyze causal factors of stormwater runoff in the study area, to identify the extent to which the study area is susceptible to stormwater runoff, and to generate stormwater runoff susceptibility map of the study area. The study area is Nyabugogo catchment which crosses the districts of the Eastern Province (Kayonza, Rwamagana, and Gatsibo), the Northern Province districts (Gicumbi and Rulindo), and other districts of Kigali city (Kicukiro, Nyarugenge, and Gasabo districts). The authors employed secondary datasets collected from the United States Geological Survey (USGS), ranging between 2017 and 2020. Six triggering factors: Land Use and Land Cover (LULC), Rainfall, the duration of photosynthetic activity (NDVI), soil texture, Elevation, and the Slope were analyzed. The results indicated that poor land use and land management ranked 36.10%, rainfall 28.70%, and NDVI which ranked 16.40% are the main triggering factors. The results proved that Moderate, High and Very High Susceptibility to storm water runoff at large extent are recorded in Rulindo and Gicumbi districts of Northern Province, a large part of Gasabo and Nyarugenge districts in Kigali City, and parts of Gatsibo and Rwamagana districts, in Eastern province. It was concluded that if Best Management Practices (BMPs) are applied, flooding and erosion along with pollution can be minimized. The policy makers are recommended to consider the prone areas identified by this study and assign them the priority for stormwater runoff management plan.

Contribution/Originality: This Study of Land Susceptibility to the Stormwater Runoff in Nyabugogo River Catchment Area shades light to the government entities, stakeholders, decision makers and planners to ensure relevant planning and implementation of localized stormwater management for the sustainability of the community and environment as well in the study area.

1. INTRODUCTION

Natural catastrophes can have serious negative effects on the economy, society, and human beings, and many small, low-income developing nations are particularly susceptible to them. A magnitude 7.8 earthquake that struck areas of Syria and South-Eastern Turkey early on February 6, 2023 is one example of a recent big disaster. In Turkey and Syria, there have been more than 34,000 fatalities and tens of thousands of injuries. During earthquakes, falling masonry and bricks frequently result in fatalities. According to the US Geological Survey,

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many people in Turkey who were affected by the earthquake did so because they resided in unreinforced brick masonry and low-rise concrete frames buildings that were particularly likely to be harmed by shaking [1, 2]. Cyclone Idai (March 2019), which devastated Mozambique and its neighbors' economies and left a high death toll. An additional is Hurricane Maria (September 2017), which caused infrastructure damage and property losses that were projected to be worth approximately 200 percent of Dominica's GDP. Climate change is expected to cause an increase in the frequency and intensity of natural catastrophes over time, which is expected to have negative effects on the economy and society [3].

River floods, flash floods, urban floods, sewer floods, and glacial lake outburst floods are all the results of numerous climatic and non-climatic events such as stormwater runoff, that influence the flood processes. The risk of destruction is increased by human development into flood plains and a lack of flood response and control plans [4].

The stormwater runoff depends mainly on the rainwater which are not harvested for household use and not well drained and snowmelt with poor management under highly exposed landscapes which exacerbate the runoff and associated negative effects among the communities and their wealth [5, 6].

The challenge associated with stormwater is that over land and impervious surfaces including not limited to parking areas, paved places, building rooftops, the runoff doesn't soak into ground, but remain on the top ground and then leads to losses [5, 6]. The findings of the research conducted by Zahmatkesh, et al. [7] indicated that stormwater runoff is at high extent, associated with human activities including agriculture, building without proper rainwater harvesting, lack of industrial wastewater treatment where wastewater goes immediately to wetland and other natural resources [7]. Therefore, in this study, the term "susceptibility" is referred as the likelihood of having stormwater runoff in the study area.

In Rwanda, stormwater are largely caused by the heavy and intense rainfall where places like in the City of Kigali and in Northwestern province register high record of stormwater runoff and this is associated with human activities like poor settlements from which wastewater are immediately loading to rivers and wetland which causes other socio-economic risks [8, 9]. Rwanda's urbanization is rapidly growing [10]. However, Rapid urbanization has various negative effects on stormwater management, including floods, which, for instance, in the Nyabugogo watershed, damage houses, disrupt commerce and traffic, annoy the population, and occasionally result in the loss of human and livestock lives [11].

Furthermore, understanding the contribution of different factors of urbanization to the generation of runoff which may result into flooding is still lacking [12].

Therefore, a loss of 1.4 million tons of fertile soil occurs annually in Rwanda as a result of the country's 16% to 40% of the land being a steep slope susceptible to soil [13]. On May 3, 2020, the Ministry of the Environment and Meteo Rwanda reported that additional heavy rain was predicted for Kigali city, the Northern Province, and the Rubavu, Nyabihu, Rutsiro, Ngororero, Muhanga, and Ruhango districts over the following seven days, raising the possibility of additional floods and landslides [14].

Following that, The Ministry of Emergency Management (MINEMA) said that starting on May 1st, heavy rain rained over the nation, inflicting significant damage. May 2020 saw a number of disaster situations across the nation, including one on May 3rd that resulted in more than 100 houses collapsing, 8 fatalities, 5 injuries, and the closure of roadways. People are therefore urged to take the required precautions [15, 16].

The amount of rainfall measured over Rwanda in January 2020 ranged from 48.6mm to 222.4mm. Gitega and Kigali Aeroport weather stations in Kigali City's center district, respectively, recorded 166.4mm and 128mm of rainfall [14]. Nyabugogo Wetlands experience flooding up to three times year, which has an impact on the wetlands around the maturation ponds, which are accessible from the Nyabugogo International Bus Terminals on the Kigali-eastern Muhanga's border. This road is a major route that is heavily utilized by vehicles entering and leaving Kigali, including automobiles, motorbikes, buses, trucks, bicycles, and pedestrians [17].

On December 6 and 7, 2019, severe flooding along the Nyabarongo River and its tributaries occurred in the

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Ngororero district of Northern Province, causing crop damage in the Matyazo, Muhanda, Shyira, and Kabaya sectors. The maximum recorded rainfall was 60.8mm. Over the past 72 hours, heavy rain has also continued to impact central areas of Rwanda, causing floods and mudslides, especially in Kigali City and the Southern Provinces [18]. Since there was so much rain, numerous rivers across the Country overflew their courses as a result of the intense rainfall [19]. Moreover, the water body may become unfit for swimming, fishing, or even for aquatic life to live depending on the type and quantity of water pollution [20].

Major rivers in Rwanda including Mpazi, Nyabarongo, Rusine, Muvumba, and Nyabugogo, have been noted to be polluted in recent environmental studies. The findings showed that harmful contaminants such as heavy metals present in water and fish provide health risks when consumed [21]. As a result, Colocasia esculenta, Amaranthus spinosus, Ipomoea batata, and soil from industrially active areas of Kigali City, Rwanda, were found to contain heavy metals such as manganese, zinc, copper, iron, nickel, lead, and cadmium [22, 23].

The infrastructure magazine on 26th September 2022, stated that the rainwater which runs off impervious or saturated surfaces in the city, such as roofs, roads and pavements, and green spaces, is referred to as stormwater which results in flooding [24]. Natural vegetation and pervious areas facilitate the precipitation to permeate soils in an undeveloped environment, allowing for transpiration by vegetation and evapotranspiration into the atmosphere [24]. In order to manage water resources sustainably, it is important to understand how changes in land use and land cover (LULC) affect surface runoff and groundwater recharge. The rooting system of the vegetation, the canopy's interception, and the pace at which plants transpire all play a significant role in how LULC affects groundwater recharge [25].

Durrans has defined the stormwater as the precipitation such as rain or melting snow and then compares the absorption and surface runoff between natural and urban environment. It was revealed that in a natural environment a small percentage of precipitation becomes surface runoff. However, as urbanization increases, the amount of surface runoff also increases drastically. Surface runoff is therefore created when pervious or impervious surfaces are saturated from precipitation or snow melt [6].

Although earlier studies discussed on Nyabarongo River catchment, none discussed the Land Susceptibility to the Stormwater Runoff in Nyabugogo River Catchment Area.

Therefore, the authors have recognized this gap and chose to undertake this research by considering that Nyabugogo River catchment causes a serous flood followed by socio-economic vulnerability in the City of Kigali which is the capital of Rwanda, in order to take into consideration the sustainable stormwater management strategies for preventing and mitigating related disasters. The objectives of this study were 1) to analyze causal factors of stormwater runoff in the study area, 2) to identify the extent to which the study area is susceptible to stormwater runoff, and 3) to generate stormwater runoff susceptibility map of the study area.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location

This study considered Nyabugogo catchment area, which includes some districts of the Eastern Province (Kayonza, Rwamagana, and Gatsibo), the Northern Province (Gicumbi and Rulindo), and other districts of the City of Kigali (Kicukiro, Nyarugenge, and Gasabo). It is estimated that around 1,135,428 people are living in that area.

2.1.2. Topography

The highest elevation in Nyabarongo River Catchment is 2,280 masl. At an elevation of around 1,360 meters above sea level, Nyabugogo River runs for 46 kilometers down Muhazi lake's discharge to where it joins the lower Nyabarongo River near Kigali City. The main tributaries of the Nyabugogo River are the Mwange, Muyanza, Rusine, Kajevuba and Yanze rivers [26].

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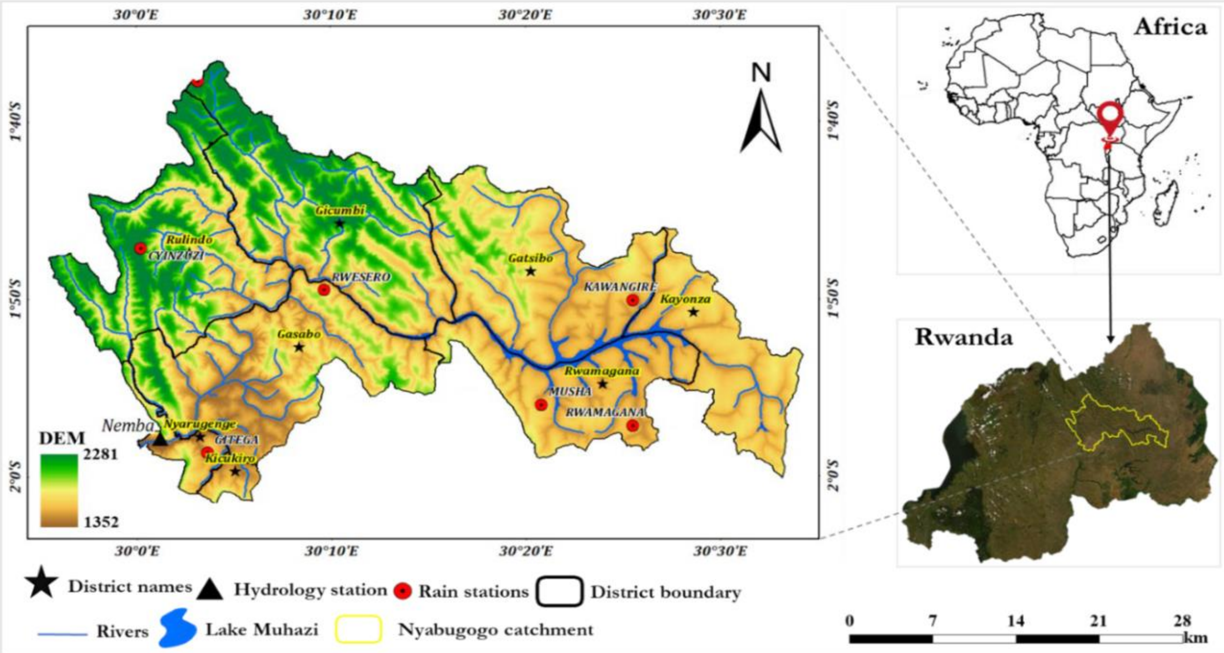

Figure 1. Location map of Nyabugogo River catchment area.

The Figure 1 illustrates the location of Nyabugogo Catchment Area in Rwanda.

2.1.3. Slope

About 17% of the total land area of Kigali City falls under steep slopes of more than 30%. In Nyarugenge District 42%, Gasabo District 32% and Kicukiro District 25% of areas are occupied by steep slopes. The slopes of Kicukiro District are relatively gentle compared to other two districts with 12,520 ha land below 30% slope available for development compared to Gasabo District (29,228 ha) and Nyarugenge District (7,661 ha) [12].

2.1.4. Geology, Soil and Ecology

Shale, granite, pegmatite, and alluvial material are found in Nyabugogo valley bottoms, but the majority of the lithology of the Nyabugogo River Catchment is composed of quartzite and schist/shale foundation aquifers. As quartzite and schist have average storage and transmission properties, it is anticipated that groundwater recharge rates, base-flow, and recession behavior will be typical in these aquifers. The eastern upstream part of the basin has the majority of ferralsol soil types. Due to the fact that they are made of very worn siliceous rocks, they have low fertility, are acidic, and have increased aluminum toxicity. Relative to other severely weathered soils, these ferralsols are frequently deep, easier to work, and less erodible. Nitisol, Acrisol, Alisol, and Lixisol Complexes are more ssignificant [26]. Granitic and meta-sedimentary rocks are found beneath the City of Kigali, which is a part of the study area. The sediments generally underwent very little metamorphism. Schists, sandstones, and siltstones are the main types of rocks found in the City of Kigali. Lateritic soil along the hillsides and alluvial soil along the marshlands make up the majority of the city's surface. The City of Kigali is home to lateritic soils, arkosic sands, colluvium (slope wash), and alluvium, which are the four main types of soil (river deposits). Alluvial (fertile soil deposited in river valleys) and organic soils are found in the lowlands and marshes, whereas lateritic soils, rich in iron and aluminum, predominate on the city's hillside surfaces [26].

The valley of Nyabugogo and Nyabarongo River provide a fertile belt of alluvial soil suitable for agriculture whereas the hilly slopes have undergone soil erosion for a long time, leaving them bare and less productive. Kigali's soil also contains clay deposits that can be exploited for use as local building construction materials. Potential clay zones in Kigali have been identified of which can be extracted as raw materials to manufacture

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bricks for the construction of affordable housing [12].

2.1.5. Hydrology

The main water reservoir in Nyabugogo River Catchment is the Lake Muhazi with about 80 km long and runs east-west [26]. Nyabugogo River, which runs through Kigali, has a number of tributaries, including the Mwange, Rusine, and Marenge rivers upstream. Additionally, it receives water from several rivers in Kigali's urban area, including the Rwanzekuma, Ruganwa, Mpazi, and Yanze River [11].

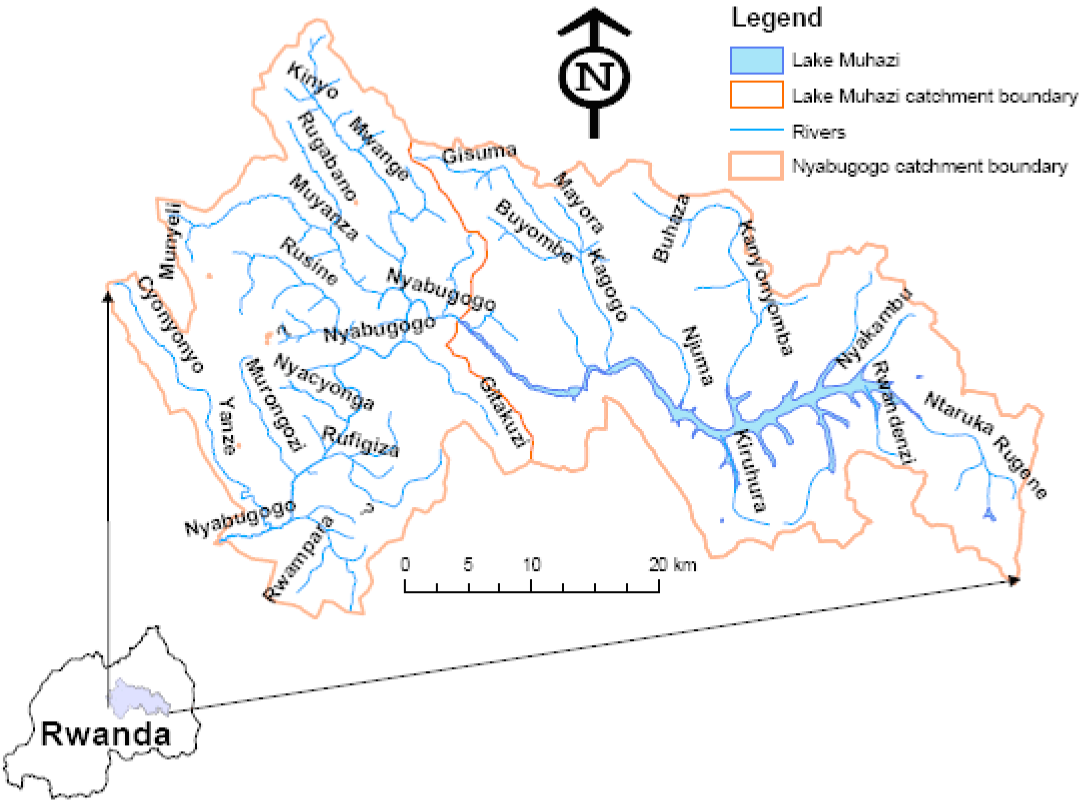

Figure 2. Map of Hydrology in Nyabugogo River catchment area.

The Figure 2 illustrates hydrology in Nyabugogo Catchment Area. Muhazi lake, Nyabugogo river and its tributaries are presented on map.

2.1.6. Wetlands

The Nyabugogo Wetland is situated in the Nyabugogo Catchment and it covers both rural and urban regions, including Kigali, the capital city of Rwanda [27]. It crosses two districts, Nyarugenge and Gasabo, with a combined population of 825,767 people, and drains a total of 1,647 km2 [27]. Between 1094'S and 30004'E, and 1,354m to 2,278m above sea level, is where the Nyabugogo wetland is located [11].

2.1.7. Land use and Climate

Agriculture accounts for about 897 km2 (or roughly 54%) of the catchment's land usage, making it the dominant activity. Depending on the region's altitude, its climate is characterized by a temperature range of 16°C and 23°C [28].

Since 1990 to 2016, Rwanda has experienced an average yearly rainfall of 1116 millimeters, ranging from 805 millimeters to 1725 millimeters [8].

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Rwanda typically experiences four distinct seasons. June to August is the first season, which is followed by a brief rainy season from September to December [29]. With the heaviest rains falling in November, this season receives 30% to 40% of the yearly rainfall [29].

The final season is a brief dry one that lasts from December to February. The fourth seasons, which lasts from March until the end of May, is rainy. 60% of the yearly rainfall falls during this season [29].

The Nyabugogo River's flower farms and the Kabuye Sugar Works are among the main potential sources of pollution in the basin, along with sugar cane plantations upstream, the production of rice and legumes, quarrying, and mining operations. The Ruganwa River receives liquid waste from a large number of other enterprises located in the Kigali industrial region [28].

2.2. Research Design

This study was merely basing on secondary datasets and their analysis involved the usage of Microsoft Excel for tables saved in the format compatible with Geographic Information Systems (GIS), combined with other Environmental Information applications such as ENVI 5.3 for processing and analysis of remotely sensed imagery datasets, ArcGIS 10.3, for analysis and mapping.

During this study, the researcher has reviewed many literatures with the purpose of establishing a theoretical framework for deeper understanding and tracing the existing research gap that needs to be bridged. The other phase involved in this work is the formulation of the research objectives, associated research questions and research guiding hypotheses.

Finally, all sources of information in the preparation of this study were acknowledged through citation in the text and in the reference list. The detailed information of the methodology used for this study is provided in Figure 3.

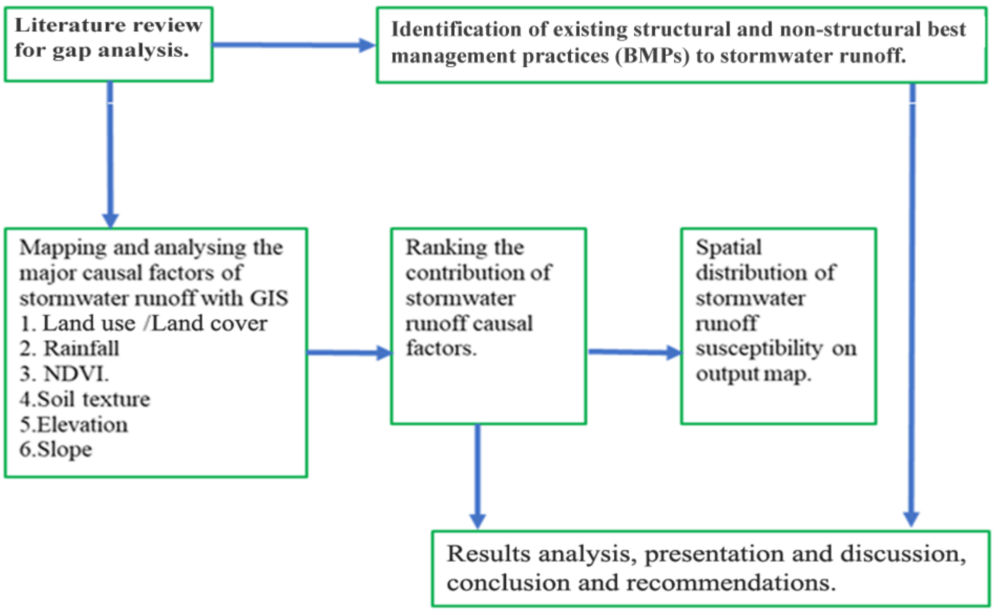

Figure 3. Methodological flowchart of the study.

2.3. Data Collection and Analysis

Data collection methods used for this research include literature research in previous published studies, official reports, satellite imagery datasets coupled with knowledge of the researcher to process, analyze raster data and interpret the output maps.

The desk review activities included the scanning of the literature related to the subject and objectives of this study from available published records or documents such as textbooks, government official documents and relevant

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websites; they also helped during the process of analyzing the collected secondary datasets. The GIS shapefiles of Nyabugogo catchment boundaries and drainage were acquired from Rwanda Water Resources Board.

Furthermore, in this study, the author employed the datasets related to storm water runoff causal factors namely: Rainfall, Elevation, Land Use / Land Cover, Soil texture, Slope, and Normalized Difference Vegetation Index (NDVI) collected from the United States Geological Survey (USGS), and many other raster data providers. The tools of dataset collection were desk consultation of the previous published studies, official reports, and download for acquisition of satellite imagery datasets from raster data providers websites.

Therefore, from the data analysis, Microsoft Excel for Tables and chart making along with Geographic Information System (GIS), combined with other Environmental Information applications such as ENVI 5.3 for processing and analysis of remotely sensed imagery datasets, ArcGIS 10.3, for analysis and mapping were used to complete the study and display the results.

3. THE RESULTS

3.1. Analysis of Causal Factors Contributing to Stormwater runoff in Nyabugogo River Catchment Area

The major causal factors which have been discussed and analyzed in this study are Land Use /Land Cover, Rainfall (mm), the duration of photosynthetic activity (NDVI), soil texture, Elevation (m), and the Slope of the catchment area.

3.1.1. Analysis of Land Use /Land Cover in Nyabugogo River Catchment Area

The land use / land cover in 2020, of Nyabugogo river catchment area have been acquired throughout remote sensing applications and processes performed by the researcher.

The steps for processing and producing land use /land cover for use in ArcGIS are the following:

1. Image acquisition from Earth Observation Satellites.
2. Image pre-processing such as spatial and spectral sub-setting.
3. Perform supervised classification.
4. Preform the accuracy assessment.
5. Produce Land cover/land use classes for ArcGIS use.

Moreover, amongst the considered stormwater causal factors in Nyabugogo river catchment area, there is land use and land cover (LULC). The LULC in the study area was classified into seven classes namely: asphalts, bore land, marshland, cropland, forests, waterbody and built-up area. The analysis in Figure 4 showed that large built-up area and asphalts classes are in Kigali city. The forest is spaced and is very small quantity compared to cropland in the study area, as it is observed on the map.

3.1.2. Analysis of Rainfall in Nyabugogo River Catchment Area

This study used the Enhancing National Climate Services (ENACTS) rainfall data from Meteo Rwanda of Monthly and annual mean for 36 years (1981–2017), with spatial resolution of 0.03mm. The results showed in the Figure 5 indicate that Nyabugogo river catchment area benefits the annual rainfall ranging between 64mm and 113mm. High distribution of annual mean rainfall is mainly recorded within parts of Rulindo, Gicumbi, Gasabo, Nyarugenge and kicukiro districts. Kayonza district record a large portion of low rainfall, and in Rwamagana, Gatsibo, and small part of Gasabo, there were recorded moderate rainfall. The classified rainfall classes were namely very low annual mean rainfall of 64mm to72mm, low annual mean rainfall of 73mm to 89mm, moderate/medium annual mean rainfall of 90mm to 96mm followed by high annual mean rainfall of 97mm to 105mm along with the very high annual mean rainfall of 106mm to 113mm.

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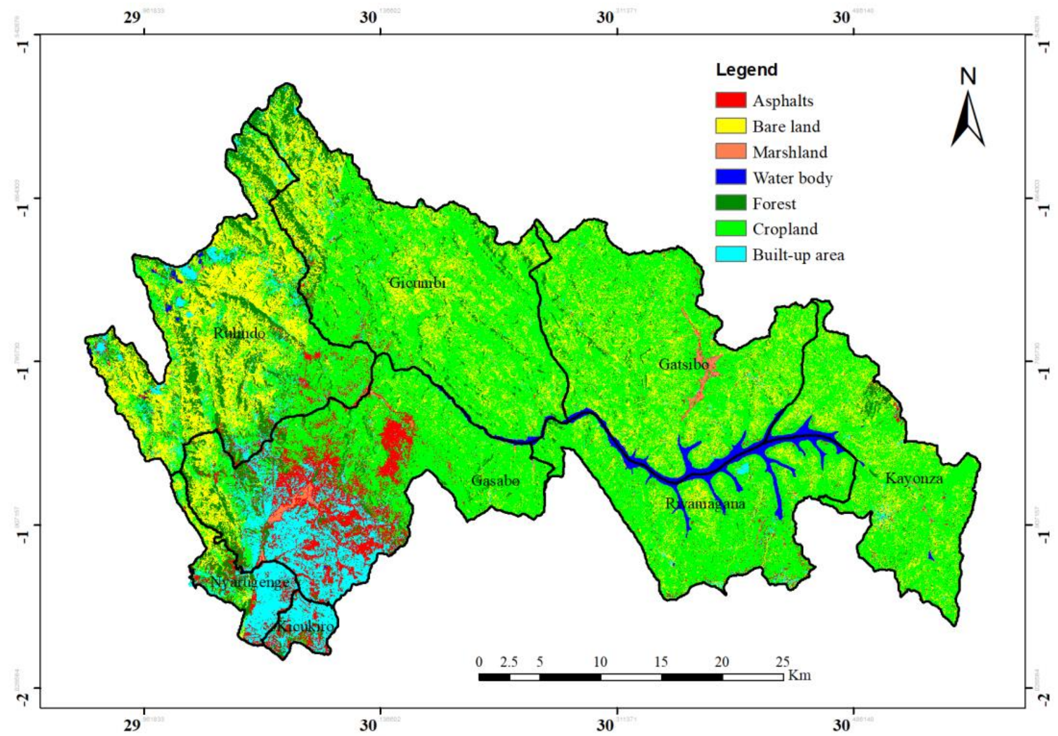

Figure 4. Nyabugogo river catchment area land use land cover map 2020.

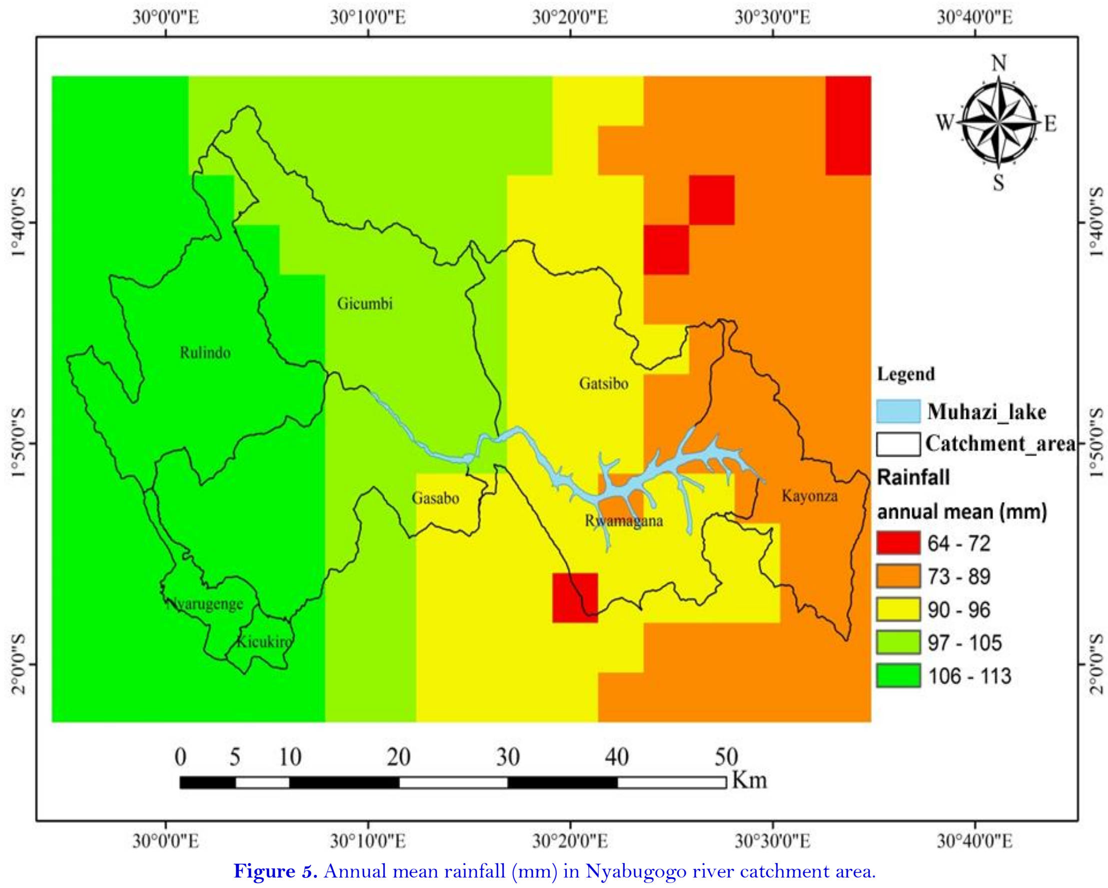

Figure 5. Annual mean rainfall (mm) in Nyabugogo river catchment area.

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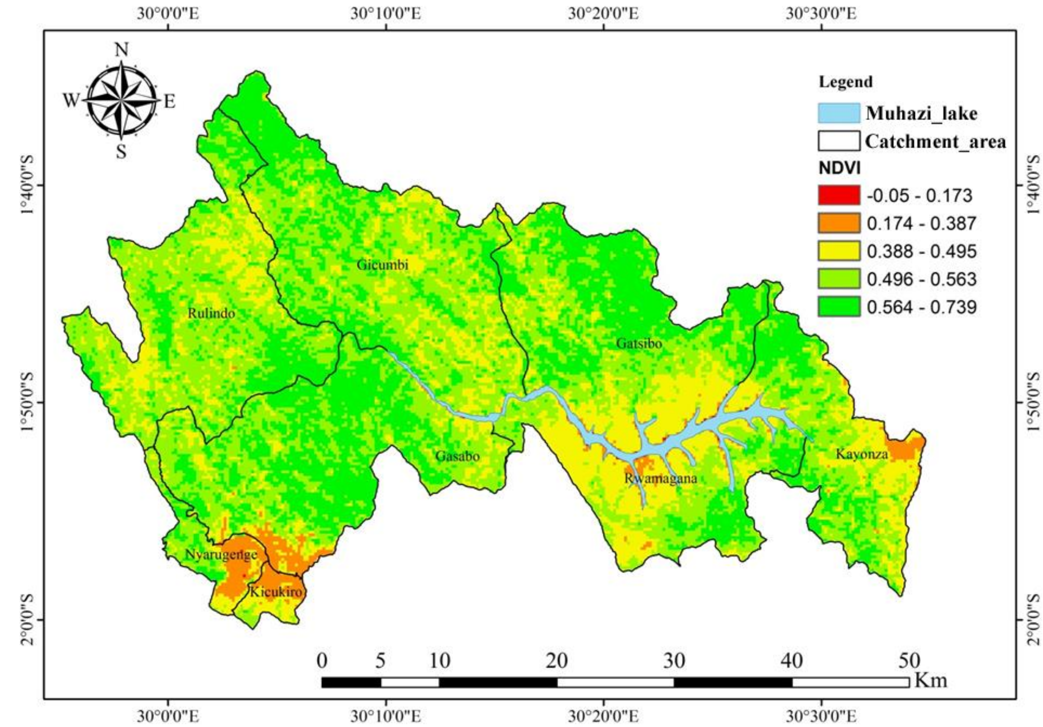

Figure 6. The normalized difference vegetation index (NDVI) in Nyabugogo river catchment area.

3.1.3. Analysis of Normalized Difference Vegetation Index (NDVI) in Nyabugogo River Catchment Area

The Normalized Difference Vegetation Index (NDVI) was considered among the stormwater causal factors for this study. The NDVI was also subdivided into five classes namely very low NDVI at -0.05 to 0.173, low NDVI at 0.174 to 0.387, medium/moderate NDVI at 0.388 to 0.495, high DNVI at 0.496 to 0.563 along with very high NDVI at 0.564 to 0.739 (Figure 6). Very low NDVI is located in Nyarugenge district. Low NDVI is located in cities of Kigali, Rwamagana and Kayonza, in the buil-up areas. A large extent of moderate NDVI is recorded in Rwamaga and Gatsibo districts, followed by Gicumbi and Rulindo districts. A large extent of very high NDVI is recorded in Gasabo and Gatsibo districts also.

3.1.4. Analysis of Soil Texture In Nyabugogo River Catchment Area

The soil texture of Nyabugogo river catchment area was subdivided into four soil texture types including sandy clay loam, clay loam, sandy clay, and clay. The findings in Figure 7 revealed that both sandy clay loam and sandy clay are located in Kigali city, in Gasabo, Kicukiro and Nyarugenge districts. A large part of Rulindo, Gicumbi and Gasabo district are Clay Loam. And, a large part of Gatsibo, Rwamagana and Kayonza are Clay Loam clay soil textures occupy most soil types localized in the City of Kigali. The sand clay and sand clay loam are found, at large proportion, in Kicukiro and Nyarugenge districts.

3.1.5. Analysis of Elevation in Nyabugogo River Catchment Area

For the elevation distribution in Nyabugogo river catchment area (Figure 8), high elevation (over 1,784 m) is at large extent, distributed across Northern Province Gicumbi, Rulindo districts and a part of Gasabo district in Kigali and low elevation (between 1,525 and 1,642m) is localized among all districts of catchment area, and very low elevation (below 1,524) in Kigali city, Gasabo district at large extent, Rwamagana and Gatibo districts and along Muhazi lake low land as well. The results obtained in Figure 8 showed five elevation classes namely: very low elevation: 1,287m-1,524m; low elevation: 1,525m-1,642m; moderate elevation: 1,643m-1,783m; high elevation: 1,784m-1,949m and very high elevation: 1,950m-2,296m.

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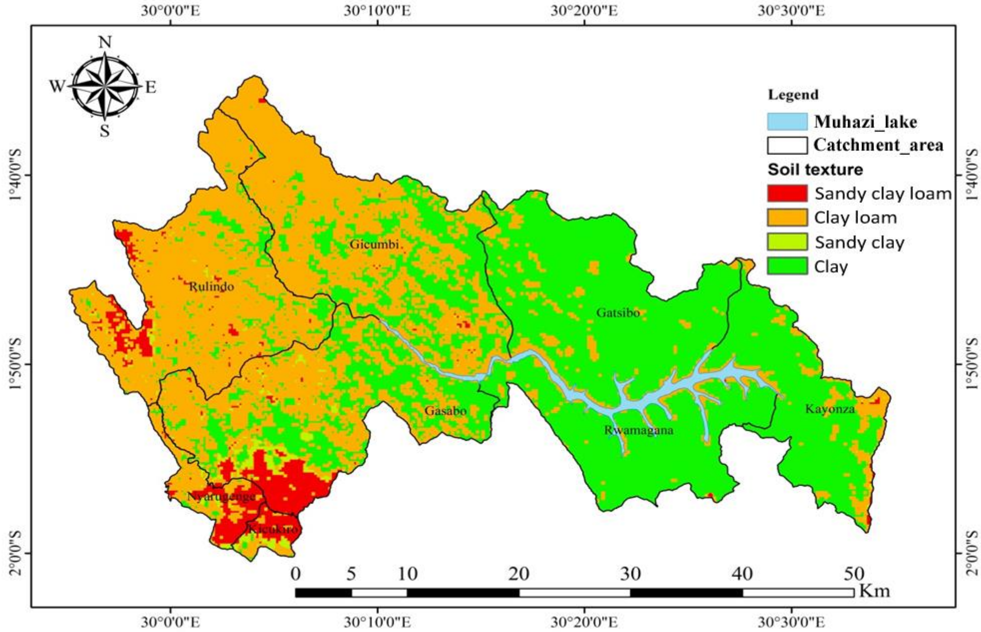

Figure 7. Soil texture classes with the City of Kigali.

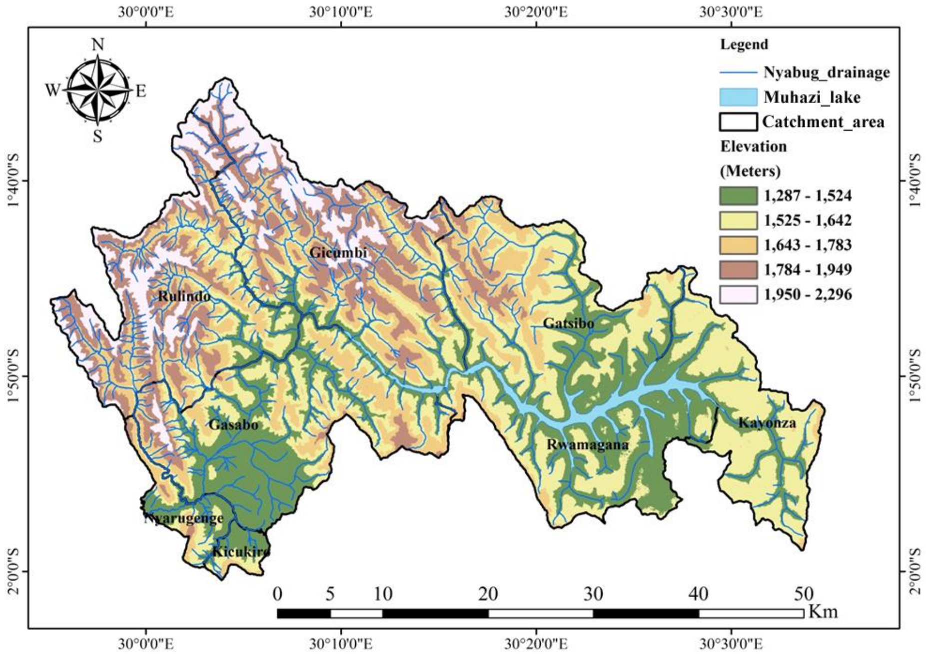

Figure 8. Elevation classes in Nyabugogo river catchment area.

3.1.6. Analysis of Slope in Nyabugogo River Catchment Area

The results showed in the Figure 9 showed five classes of slope namely very low slope at 0% - 6%, low slope at 6% - 8%, medium/moderate slope at 8% - 14%, high slope at 14% - 33% and very high slope at 33% - 100%. Low and very low slope is extended in Eastern province in Gatsibo, Kayonza and Rwamagana districts, large part of Gasabo district of Kigali City as well as small parts of Kicukiro and Nyarugenge districts.

3.2. Identification of the Extent to Which Nyabugogo River Catchment Area is Susceptible to Stormwater Runoff

In order to better indicate the extent to which the selected factors contribute to stormwater in the City of Kigali, the researcher, as detailed in the methodology section, utilized the Analytical Hierarchy Process (AHP) Model. The results in Table 1 showed that poor and/or inappropriate land use and land management ranked first at 36.10 percent followed by rainfall at 28.70 percent along with NDVI which ranked third at 16.40 percent

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followed by Soil texture with 10.20 percent whereas the slope was the last factor at 3.30 percent Table 1.

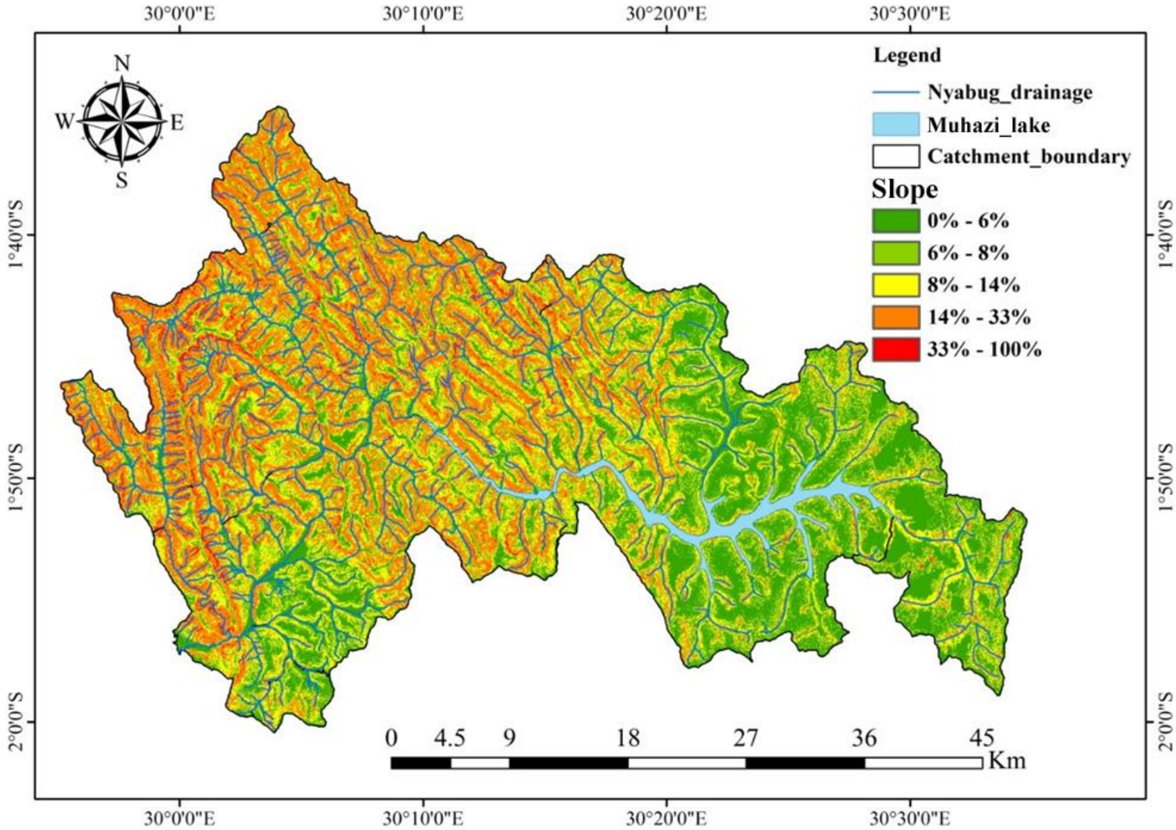

Figure 9. Slope classes of Nyabugogo river catchment area.

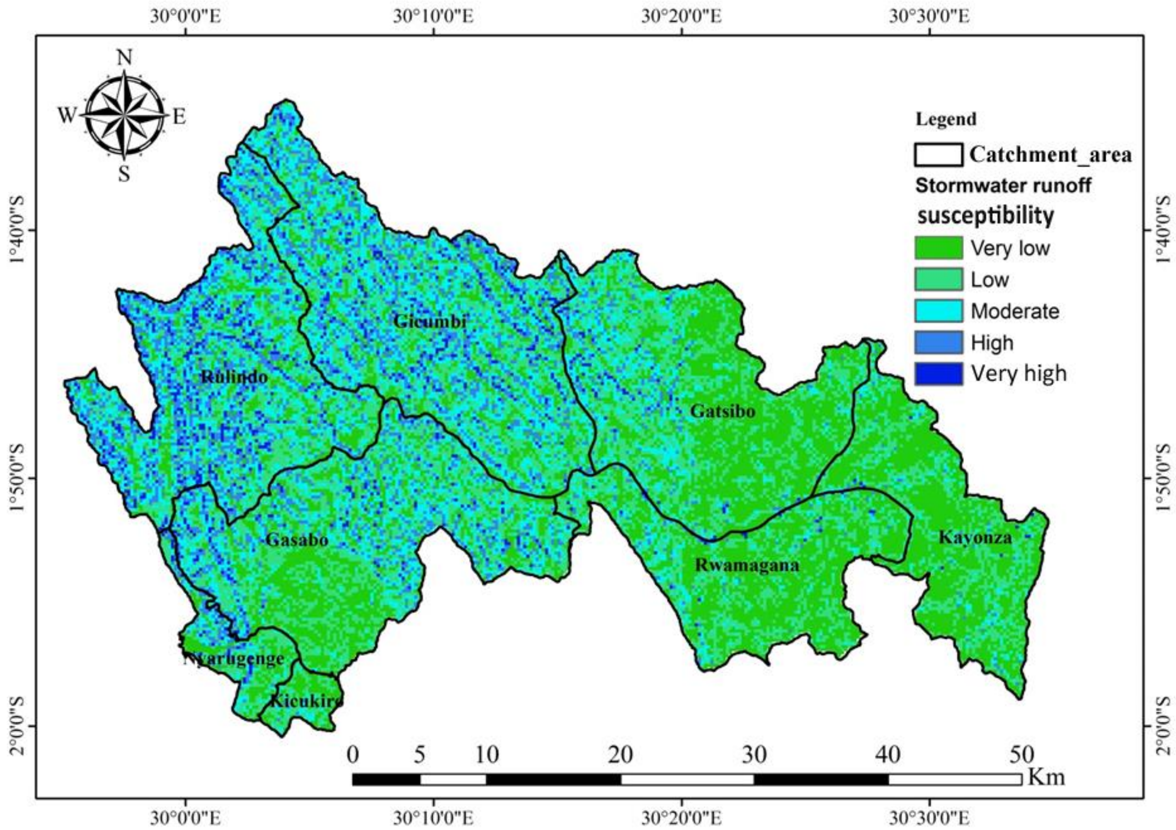

Figure 10. Stormwater runoff susceptibility in Nyabugogo river catchment area.

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Table 1. Stormwater causal factors ranking.

Cat		Priority	Rank	(+)	(-)
1	Land use/ Land cover	36.10%	1	13.20%	13.20%
2	Rainfall	28.70%	2	11.50%	11.50%
3	NDVI	16.40%	3	5.70%	5.70%
4	Soil texture	10.20%	4	4.40%	4.40%
5	Elevation	5.20%	5	1.30%	1.30%
6	Slope	3.40%	6	1.50%	1.50%

These are the resulting weights for the criteria based on the pairwise comparisons using Analytical Hierarchy Process (AHP) Model.

Table 2. Decision matrix.

Factors	[1]	[2]	[3]	[4]	[5]	[6]
[1] LULC	1	2	3	4	5	6
[2] Rainfall	0.5	1	3	4	5	6
[3] NDVI	0.33	0.33	1	2	5	6
[4] Soil texture	0.25	0.25	0.5	1	2	6
[5] Elevation	0.2	0.2	0.2	0.5	1	2
[6] Slope	0.17	0.17	0.17	0.17	0.5	1

Note: Consistency ratio CR = 5.8%.

The Table 2 presents the consistency of the comparison matrix assessed by using the Consistency Ration.

3.3. Stormwater Runoff Susceptibility in Nyabugogo River Catchment Area

The results in the Figure 10 presented Stormwater runoff Susceptibility in Nyabugogo river catchment area.

The results of Stormwater runoff Susceptibility were subdivided into five classes namely very low Susceptibility, low Susceptibility, medium/moderate Susceptibility, high Susceptibility and very high Susceptibility (Figure 10). Very low and low Susceptibility is located in Eastern Province in the districts of Kayonza, Gatsibo and Rwamagana. In cities of Kigali, very low and low Susceptibility are recorded in Kicukiro district and parts of Nyarugenge and Gasabo districts. Moderate, High and Very High Susceptibility to storm water runoff at large extent are recorded in Rulindo and Gicumbi districts of Northern Province, a large part of Gasabo and Nyarugenge districts in Kigali City, and parts of Gatsibo and Rwamagana districts, in Eastern province (Figure 10).

4. DISCUSSION

Stormwater runoff depends on rainwater which are not harvested for household use and not well drained and snowmelt with poor management under highly exposed landscapes which exacerbate the runoff and associated risks among the communities and wealth [5, 6].

The infrastructure magazine has stated that the rainwater that runs off impervious or saturated surfaces in the city, such as roofs, roads and pavements, and green spaces, is referred to as stormwater [24].

The study conducted by Wang, et al. [25] argued that for sustainable water resource management, the effects of land use and land cover (LULC) on groundwater recharge and surface runoff, as well as how these are impacted by LULC changes, are of interest. The LULC's influence on groundwater recharge is primarily influenced by the vegetation's rooting system, canopy interception ability, and transpiration rates of plants [25].

The challenge with stormwater is that over land and impervious surfaces including not limited to parking areas, paved places, building rooftops, the runoff doesn't soak into ground but remain on the top ground and then leads to losses [5, 6].

The findings of the research conducted by Zahmatkesh, et al. [7] indicated that stormwater runoff is at high

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extent, associated with human activities including agriculture, building without proper rainwater harvesting, lack of industrial wastewater treatment where wastewater goes immediately to wetland and other natural resources [7]. In this study, the term "susceptibility" is referred as the likelihood of having stormwater runoff in the study area. In Rwanda, stormwater are largely caused by the heavy and intense rainfall where places like in Kigali city and in Northwestern province register high record of stormwater runoff and this is associated with human activities likely poor settlements from which wastewater are immediately loading to rivers and wetland causing other socio-economic risks [8, 9].

Among these risks of stormwater in Rwanda, there are erosion, pollution and stream bank erosion. The flooding is nowadays posing a significant threat to the City of Kigali due to high runoff. This leads to making some parts of city more exposed to many environmental hazards and risks [12].

This study findings agreed with the above studies on the causes of stormwater runoff, were it ranked the assessed causal factors in the Table 1: poor and/or inappropriate land use and land management ranked first at 36.10 percent followed by rainfall at 28.70 percent along with NDVI which ranked third at 16.40 percent followed by Soil texture with 10.20 percent whereas the slope was the last factor at 3.30 percent.

This study results indicated that the study area which is Nyabugogo River Catchment drains the total area of 1,661 km². This is closer to the data of National Institute of Statistics of Rwanda, 2012 which states that Nyabugogo wetland drains a total area of 1,647 km² [30].

This study results agreed with the studies of Ministry of Environment of land use and land cover classification in Nyabugogo river catchment area in 2018, stating that, about 10% is considered sparse forest. It was observed that the forest is spaced and is very small quantity compared to cropland in the study area on the map of land use and land cover produced in this study. This emphasizes on the study findings of Wang, et al. [25] which revealed that the influence of land use and land cover on groundwater recharge is mostly driven by the vegetation rooting system, interception capacity of the canopy, and transpiration rates of plants [26].

The cropland class observed on this study LULC map supports the findings of the study conducted by Nhapi in 2011, stating that the major land use activity in Nyabugogo river catchment area is agriculture that occupies about 897 km2 (about 54%) of the catchment [28]. Furthermore, the Government of Rwanda (GoR) through Ministry of Environment (MoE), stormwater runoff management plan developed by taking into consideration national orientations as articulated in National Transformation Strategy (NTS1), vision 2050 and the Nation's Green Growth and Climate Resilience Strategy [26]. Nyabugogo Catchment Management Plan (2018-2024) and Sebeya Catchment Management Plan (2018-2024) have been reviewed and referred in this study.

In addition, some policies were recommended including not limited to plant native trees and plants to increase evaporation and transpiration, minimizing impervious areas to facilitate water soaking in the ground, managing stormwater drainage structure, etc.

However, more efforts are still needed such as community mobilization and awareness strengthening on the causes of stormwater and minimization approaches, regular cleaning of roadside drainage and proper wastewater treatment/management. This can then lead to minimizing the occurrence likelihood of stormwater and its associated risks mainly flooding in downstream of the Nyabugogo River Catchment Area, specifically in the City of Kigali.

5. CONCLUSION

This research employed secondary data on causal factors of stormwater runoff susceptibility in Nyabugogo River Catchment Area. These factors were mainly Land Use and Land Cover (LULC), Rainfall (mm), the duration of photosynthetic activity (NDVI), soil texture, Elevation (m), and the Slope of the catchment area, and were selected with reference to the field observation, literature review and experts' opinions as well. The GIS applications were the main tools of data collection and analysis. It was noted that poor land management, rainfall

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intensity, and the duration of photosynthetic activity (NDVI) are the primary parameters causing the occurrence of stormwater occurrence in Nyabugogo River Catchment Area. Moderate, High and Very High Susceptibility to storm water runoff at large extent are recorded in Rulindo and Gicumbi districts of Northern Province, a large part of Gasabo and Nyarugenge districts in Kigali City, and parts of Gatsibo and Rwamagana districts, in Eastern province. The findings lead to the conclusion that if appropriate stormwater management measures including Best Management Practices (BMPs) are applied further consequences such as flooding and erosion along with pollution can be minimized in downstream of Nyabugogo River Catchment Area, specifically in the City of Kigali.

To policy makers and local leaders were recommended to consider the prone areas within catchment districts composed by the land with high and very high susceptibility to storm water runoff identified in this study and assign them the priority while developing and implementing stormwater runoff management plan and projects. Future studies were suggested to assess socio-economic impacts of stormwater runoff in the wetlands located in the study area, more specifically, Nyabugogo and Kabuye wetlands are highly recommended.

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