

Original Research

Road Flooding in Kigali City, Rwanda: Causes, Effects on Road Transportation and Mitigation Measures

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Abstract

Flooding can have an effect on each thing of our lives, including road transportation. This study investigated the causes and the effects of flooding on road transportation in Rwanda, Kigali city and contributed to the mitigation measures. The data were collected by administering 150 questionnaires on the respondents within the study area and by physical survey. The hypotheses were formulated and tested using the statistical method of student's t- test and the data displayed a significant difference ($P < 0.05$). The results of this study revealed that heavy rains, poor drainage systems, illegal disposal of waste in drains, and poor construction and maintenance of roads are the main causes of road flooding in the city of Kigali. The effects of floods on road transportation include traffic jam and increased travel time, damage to road structures, blockage of drains and traffic accidents in the study area. The study recommends green storm water infrastructure practices, good road construction works, controlled dumping sites, the construction and maintenance of drainage systems and an immediate government response to the threat of flooding to address the challenges of flooding on road transportation in the city of Kigali.

Keywords: road flooding, effect, road transportation, mitigation measures, Kigali

Introduction

Flood is a natural phenomenon, and may occur when water accumulates on an impermeable surface and cannot rapidly disappear [1]. In Rwanda, flood is among the main disasters and has had a huge impact on road transportation, infrastructures, human development, and the environment. Flooding, especially

flash flood events that start suddenly due to intense precipitation, is the primary cause of weather-related disruptions to road transportation, and are expected to continue in the course of time [2]. Transportation serves as the lifeblood of the economy, and any effect on the road network can be considered as a potential danger for different traffic flow characteristics [3]. Therefore, it is important to explore potential hazards that may lead to potential network restrictions. Given the capacity of floods to have an effect on vast areas for a long period of time, disruptions to road transportation can cause

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broad knock-on consequences [4]. Floods damage road infrastructure and affect millions of people worldwide annually [5, 6]. The average annual-reported flood losses and deaths between 1980 and 2012 exceeded \$ 23 billion and 5,900 people, respectively [7-9].

The urbanization process is one of the major causes of the continuous increase in floods and associated damages around the world; mostly because of the increasingly impermeable surfaces and the exposure of people and their properties [7, 10]. The increase of impermeable surfaces, houses, roads, and much more without the simultaneous establishment of an adequate storm water drainage system, contributes to the damming of surface runoff, which ultimately leads to flooding [5, 8, 9]. Floods can be one of the main catastrophic natural events since they can gravely damage any transportation system. When floods block part of a road network, the various effects of flooding on the characteristics of the traffic flow can be observed, including disruption of communications, traffic jams, increased traffic volume, reducing the speed limit and increasing travel time. According to Adebayo and Jegede [11], good road construction, construction of flood control works where there is flood menace and controlled dump sites should be carried out to mitigate the problems of flooding on road transportation. Rwanda is prone to a series of disasters, by virtue of its geographical conditions and its climatic profile [5, 12]. Floods are key disasters which mostly affect the country's localized areas and most of those affected lack effective means to deal with natural hazards. The mountainous landscape and heavy annual rainfall, as well as overharvesting of the natural environment, such as deforestation, improper agricultural practices and inadequate housing conditions, accelerate the risk of disasters and lead to the destruction of road infrastructures, loss of life and property damage [13]. The city of Kigali has been vulnerable to flooding since the 1960s [14, 15] and the impact has increased as the city has grown over the years. Floods in Kigali occur mainly during the long rainy season from April to June and from September to December, when heavy rains are recorded [16].

Kigali's population was estimated to reach 1.1 million in 2014. According to the city's master plan, authorities expect this figure to reach approximately 4.2 million population in 2040 [17]. This rapid population growth will lead to changes in land use and require improvements in infrastructures of the city. Due to the developments in natural floodplains, the city's hilly topography, and inadequate drainage systems, different parts of the city experience annual flooding. In 2013, a severe flood occurred in the city of Kigali in the Nyabugogo wetland. The flood claimed the lives of four people through a car thrown into the water, severely damaged road infrastructure, small businesses, households, and disrupted traffic flow and economic activities for many days [18]. Therefore, to reduce the flood impacts in the Nyabugogo flood plain,

the mitigation measures which can include buffer zoning around the river, relocation of infrastructures within the flood plain area, rainwater harvesting and raising public awareness are needed [19].

On December 25, 2019, high level flooding occurred in Kigali due to torrential rainfall claimed four lives and causing damage to infrastructures. According to disaster officials, roads were damaged and water and power supply interrupted [20]. High rainfall continued throughout this period considered as the driest, on February 2nd and 3rd, 400-500 mm of rain was recorded in Kigali, causing severe floods resulted in destruction of 15 houses, taking lives of 13 people and two injuries [21]. The records from Rwanda Meteorology Agency (RMA) show how the rainfall have been above the long term mean during this period almost doubling in December and above fifty percent higher in January and February [22]. However, the increase in rainfall intensities will continue into the future due to the climate change.

The climate change, rapid urbanization, and the increased infrastructure interdependence are stressing the society, assets, and the built environment. This is especially apparent in urban areas when weather-related hazards such as floods affect the transport systems [2]. Transport networks support the wealth and safety of the communities, in terms of increasing of the global economy depending on the efficient movement of goods, people and information [23]. Reliable transportation systems can be valued for the consistency of service, travel time, cost and safety [24]. To maintain the volume of traffic flow on the road network, is essential for business, logistics and production [25]. However, Flooding affects this in various ways through both direct and indirect effects [26-28]. Direct damages result to the reduced performance of transport systems, which is the most harmful factor for the society [29], [30]. Meanwhile, studies have revealed that road transportation is one of the leading causes of death in cities during flooding, due to vehicles crossing flooded roads [31-33].

Methods and Materials

Study Area

Kigali city is the capital of Rwanda and it's located in the geographical heart of Rwanda (Fig. 1). The city of Kigali has quickly become an extremely modern city in recent years, and it has become not only the most important commercial center in Rwanda, but also the most important port of entry [34]. Kigali, Rwanda's largest city resides in a hilly region (Fig. 2), with a series of ridges and valleys connected by steep slopes [35].

The largest river that runs through the city of Kigali is the Nyabugogo river. The Nyabugogo river drains into the Nyabarongo river and its watershed contains

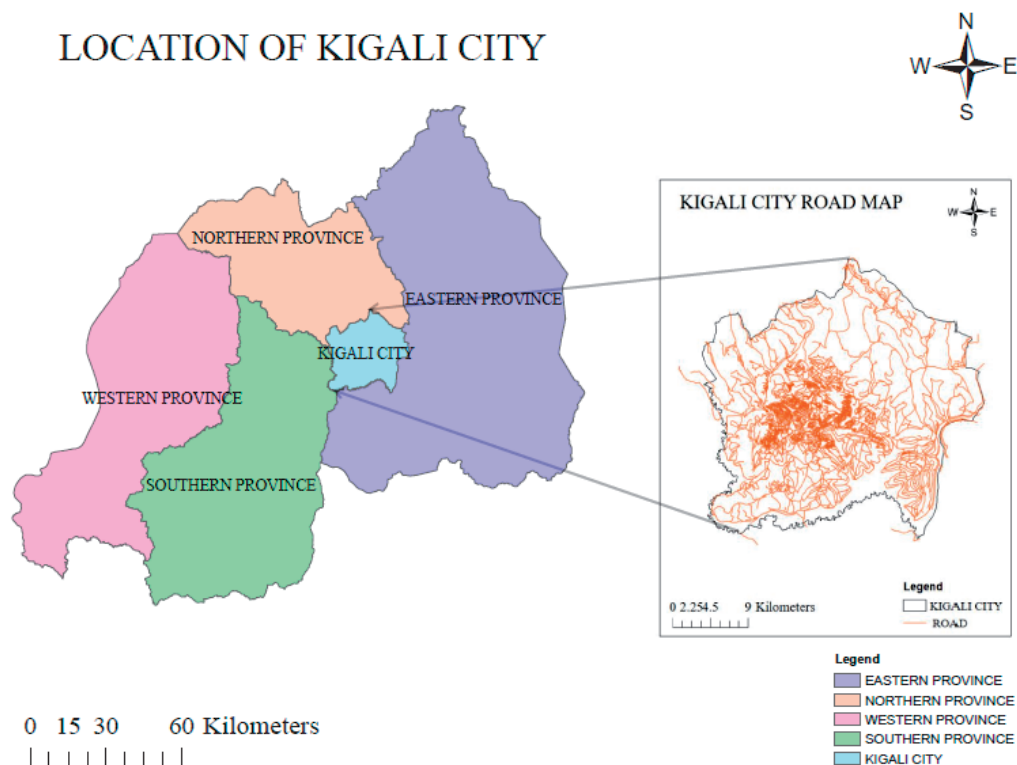


Fig. 1. Location of Kigali city with roads on the administrative map of Rwanda.

most of the city’s territory. The Nyabarongo river forms the southern and western borders of Kigali; however, it is located a bit outside the built-up urban area. The rivers are bordered by wetlands, which serve as water reserves and protection against flood, however, these are in danger due to agriculture and development

[35]. Kigali has a temperate tropical highland climate and because of its high elevation, it has cooler temperatures than those typical of equatorial countries. It has an average of daily temperature between 15 and 27°C, with little variation during the year. Kigali is located

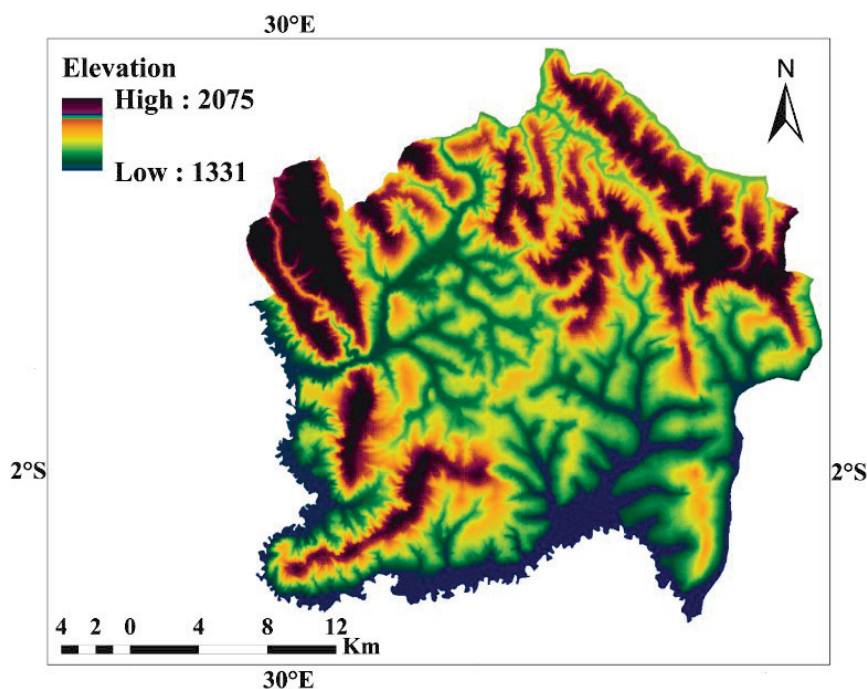


Fig. 2. Elevation Map of Kigali City.

in a region of granitic and metasedimentary, with lateritic and alluvial soils on the hills and valleys, respectively. There are 2 rainy seasons annually; February to June and September to December and in between there are 2 dry periods, the main one from June to September, during which it often doesn't rain, and a shorter one from December to February. April is the wettest month, with 154 mm (6.1 in) as average rainfall, while July is the driest month. However, there is a change in the pattern of the rainy periods as a result of global warming.

Transportation in Kigali is mostly by road. The city of Kigali is considered to be the country's road network center, with paved roads linking other parts of the country, as depicted in Fig. 1. Currently, the city's road network consists of 2,851km of roads, and 16% of which is paved. Most unpaved roads become puddled and dusty during the rainy and dry season, respectively [36].

Data Collection and Analysis

Secondary and primary data were used in the study. Secondary data is data collected from literature review of books, articles, papers, etc. related to the study. To complete the information needed, researchers have acquired with the help of existing literature from available published records (documents) such as textbooks, government official documents and reports and relevant websites from the internet, journals, magazines, manual, etc. This method helped the researchers to have an open understanding of road flooding, causes and effects of flooding on road transportation as well as actions taken to tackle those effects around other parts of the globe. In addition, this method also helped the researchers to get abundant information about flooding effects on road transportation.

Primary data were collected while conducting this research. The site visit has allowed the researchers to get reliable information on the current conditions of the roads and situation of road transportation about

the susceptibility to flooding in the area. The data were collected by administering 150 questionnaires on the respondents within the study area and by physical survey. The data were generated from the use of these 150 questionnaires and physical survey, and based on this information further analysis were done. The physical survey method was carried out in this study to observe the conditions of the roads, existing drainage channels and the present situation of road transportation in Kigali city. Thereafter, the collected data were processed and analyzed by using the statistical method of student's t- test.

Results and Discussion

Road Flooding in Kigali City

Flood Impact on Kigali City Road Transportation

Flooding has bad impacts on road transportation, such as limiting the movement of pedestrians and vehicles and affecting the entire road network, due to some flooded roads are rendered useless and closed. Flooded roads can have a huge impact on businesses, prevent people from getting to hospitals and emergency vehicles from responding, hinder commutes and access to public buses, spreading pollutants, and creating breeding ground for mosquitoes [37]. Due to the developments in natural floodplains, the city's hilly topography, and inadequate drainage systems, different parts of the city experience annual flooding [17]. These floods cause physical damage to transport infrastructure, disruption to traffic flow and the reduction of transport systems performance in general (Fig. 3b).

The effect of flooding on even a very small part of the route network in Kigali city can cause flood impacts on a much greater part of the route network [38]. Flooding causes substantial changes in the traffic flow characteristics over the whole network, including a decrease in traffic volume, speed limits reduction and increase in travel time. Nyabugogo wetland located



Fig. 3. a) Flooding occurred at Nyabugogo area (Kigali city) on February 23rd 2013, and b) Road Flooding in Kigali city after a torrential rain on 25th December, 2019, Source: <http://www.worldbank.org/>

in Kigali city, is among the most areas in the country prone to floods [18], where almost every year flooding events occur up to three times and affect the roads in Nyabugogo areas (Fig. 3a), Nyabugogo International bus Terminals and the main road which is the major thoroughfare used intensively by busses, trucks, cars, motorcycles, bicycles, and pedestrians leaving and entering Kigali city (e.g. Kigali- Muhanga) [39].

In the worst situations, different parts of the country may be completely isolated from others due to a road closure by floods. In these situations, there are often no other routes available to reach the people in flooded areas, and as a result the community of the flooded area becomes virtually isolated [3].

The Effects of Road Submergence during Flooding on Subgrade Strength

Flooding could result in great damage to road pavements and cause high expenditures for the rehabilitation and maintenance works of roads [40]. During flooding, the subgrade will be affected in terms of its capacity to support the pavement and the subgrade deterioration will cause the failure of the road pavement [41]. Due to this, the resiliency of road pavements in the areas prone to flooding has become a major concern for highway agencies [42, 43].

To the road pavement, water is among the main damaging elements. It negatively impacts the durability and strength of the pavement, especially when water gets trapped in it due to flooding or a poor drainage system. In addition, the subgrade is the important part of the road structural system, and the pavement structure design based on its strength. Therefore, when the roads are flooded for a long period of time, the road pavement materials become waterlogged, and the soil in the subgrade began to shrink and subside as floodwaters drained [44]. The excessive water can drain into the road foundation reducing its load bearing efficiency. Therefore, such situation can lead to loss of strength of pavement systems.

Road Flooding and Its Causes

Road flooding results when the amount of water arriving on the road is higher than the capacity of the drainage channels that take it away. This causes roads to be closed and in some cases for a long time [45]. Heavy rainfall, changes in runoff, a road located in a low-lying area, and rivers overflowing are some situations which can cause road flooding even when drains are adequate. Materials carried by floods may also block the drainage channels. Drainage grills and gratings are mostly blocked when sediments like mud are deposited on the road due to flooding. Road flooding in the city of Kigali, Rwanda is mostly as a result of heavy and persistent rains, and inadequate drainage systems.

According to the physical survey in the study area,

the existing drainage channels in some areas of Kigali city are inadequate and as long as the channel is poor, it can't work efficiently, which is the driving factor of road flooding in the study area. Some places of Kigali city lack drainage channels or have old drainage channels, other places have narrow/Shallow channels and most drainage channels in the city are ineffective and it is recommended to build more effective and rehabilitate old drainage channels.

Heavy rains mostly cause major problems to roads. In East Africa, heavy rains have caused problems to road links for the region. The rains have resulted in roads being washed away in many areas. Many cities in east Africa, including Kigali, Nairobi, etc. have seen roads that are usually heavily congested abruptly resemble rivers, with water washing away vehicles and several structures. A number of key roads links are usually blocked due to floods.

Identification of Respondents

During this research, the judgmental or purposive method of sampling was preferred. In this method the researcher considers target audience as well as the purpose of the study and then select a sample which can provide reliable information. People who are not willing to comply with research objectives are not counted in the analysis. The sample includes 3 types of people: Government institution officers, Investors in Transportation industry and Public car drivers. Other respondents include: Engineers, Chauffeurs, Journalists, University students, Private self-workers, etc. (Fig. 4).

Flooding Issues to the Residents of the City of Kigali and Their Properties

As shown in Fig. 5, from the survey, out of 150 respondents interviewed, 78% of the respondents said that flooding was a problem for them and their properties in the area, which means that flood affected their properties, while only 22% of all respondents who participated in the study said that floods were not a problem for them and their properties in the area, which means that floods did not affect their properties.

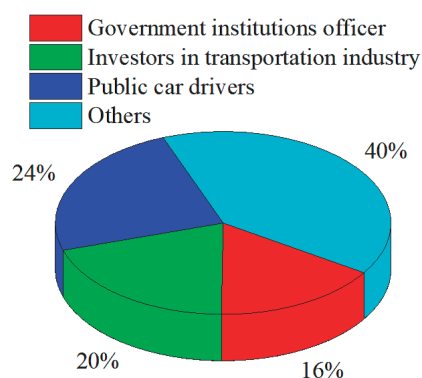


Fig. 4. Identification of respondents.

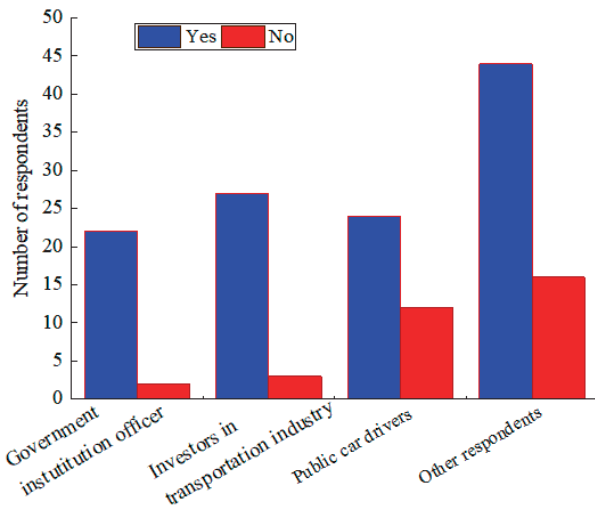


Fig. 5. Number of respondents agree/disagree that flood is an issue to them and their properties.

This therefore suggests that most of the residents within the study area suffered from the problem of flooding owing to its high occurrence in the area.

Major Causes of Flood in Kigali City

As shown in Fig. 6, 18% of the respondents mentioned heavy rainfall (too much rainfall) as the cause of flooding in the study area. 26% stated that flooding in the city of Kigali was due to the absence or ineffective drainage channels. 46% observed that it was due to storm water runoff, and 10% of the respondents noted other flood causes in the area including: narrow/shallow channels, lack of protection of Kigali urban wetlands (Nyabugogo wetland, etc.), illegal disposal of waste in drains (poor waste management) and increase in urban impervious surface. As a result, the problem of flooding was greater in the area where it

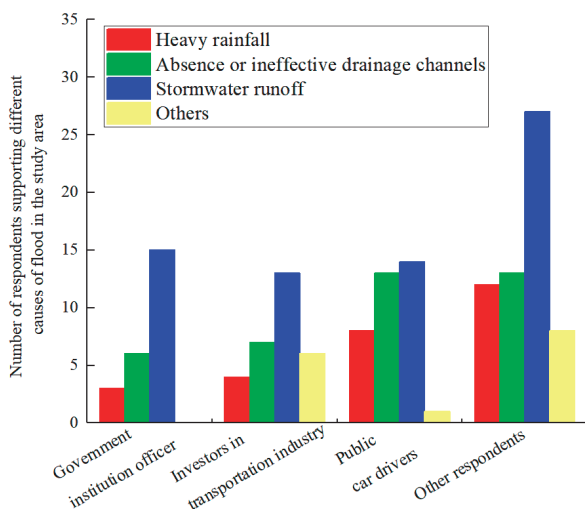


Fig. 6. Causes of floods in the study area.

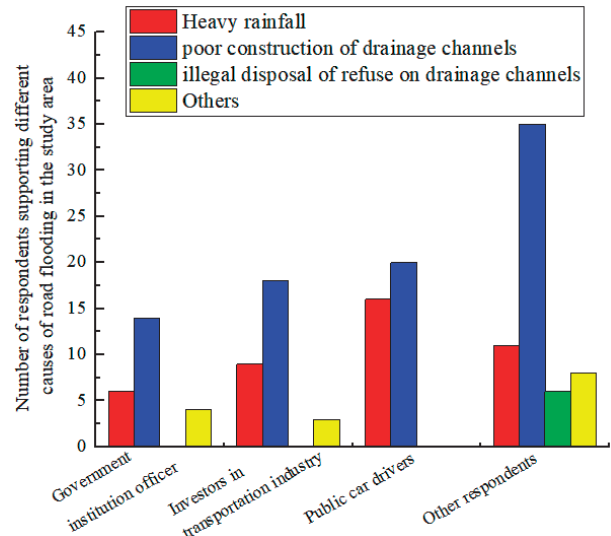


Fig. 7. Causes of road flooding in the study area.

was due to storm water runoff.

Causes of Road Flooding in the City of Kigali

The result of the study as shown in Fig. 7, revealed that 28% of all respondents mentioned heavy rainfall/too much rainfall as the cause of road flooding in the area, 58% stated that it was due to the poor construction of drainage channels, 4% observed that it was due to illegal disposal of waste in drains, and 10% stated that road flooding in the area was due to other causes including: poor river drainage systems (Nyabugogo river located in the city of Kigali and Nyabarongo river), and inadequate drainage channels. As a result, the main cause of road flooding was the poor construction of drainage channels in the study area.

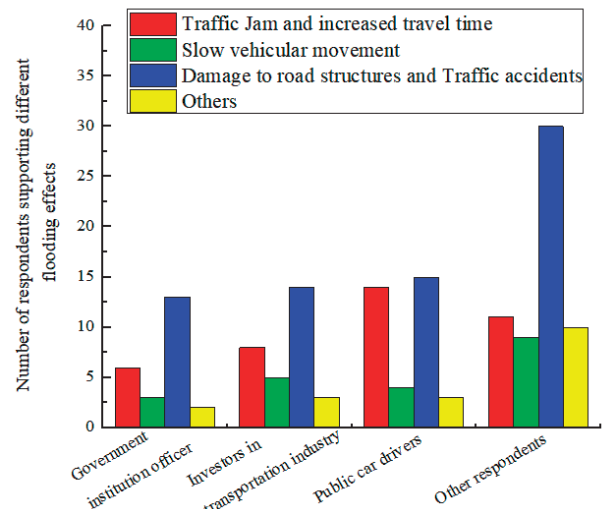


Fig. 8. Effects of flooding on road transportation.

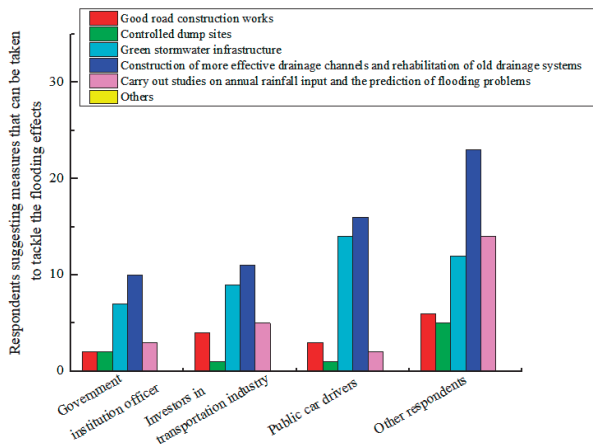


Fig. 9. Measures to control the flooding effects on road transportation.

Main Effects of Flooding on Road Transportation

Fig. 8 shows that 26% of the respondents said that the effect of flooding on road transportation was traffic Jam and increased travel time in their area. Furthermore, 14% stated slow vehicular movement, 48% stated damage to road structures and traffic accidents and 12% stated other effects including: few vehicles on the road and blockage of drains (clogged drainage). As a result, the impact of flooding on road transportation caused damage to road structures and traffic accidents in the city of Kigali, resulting to the transportation blockage and lack of other routes available to reach the people of other parts due to the damage of road infrastructure and also traffic accidents result to loss of lives and damage of vehicles.

Suggestions to Tackle the Flooding Issues on Road Transportation, Especially in Kigali City

Fig. 9 shows that 10% of the respondents noted that the suggestion to tackle the flooding issues on

road transportation in the city of Kigali is good road construction works, 6% stated that Controlled dump sites would be a good solution, 28% suggest green storm water infrastructure as a solution, 40% stated that the better solution to the flooding issues on road transportation in the area is to build more effective drainage channels and rehabilitate old drainage systems, and 16% think that conducting annual rainfall studies and predicting flood problems can be a good solution. According to the results, most of the respondents suggest two possible measures that can be taken to address the effects of flooding on road transportation in the area which are: to build more effective drainage channels and rehabilitate old drainage systems and green storm water infrastructure practices.

Testing of the Hypotheses

As shown in Fig. 10, the significant difference ($P < 0.05$) was observed between the number of respondents. This implies that flood is a great problem in the area and has a big impact owing to its high occurrence. The flooding causes in the area include heavy rainfall, absence or ineffective drainage channels, storm water runoff and others. The storm water runoff displayed a significant difference ($P < 0.05$) compared to heavy rainfall and others.

Fig. 11 shows that, the main causes of road flooding in Kigali city include heavy rainfall, poor construction of drainage channels, illegal disposal of waste in drains and others. Poor construction of drainage channels displayed a significant difference ($P < 0.05$) compared with illegal disposal of waste in drains and others. Furthermore, the flooding effects include traffic jam and increased travel time, slow vehicular movement, damage to road structures and traffic accidents as shown in Fig. 11. The damage to road structures and traffic accidents displayed a significant difference ($P < 0.05$) compared with slow vehicular movement and others and it is the most effect of flooding on road transportation in the area.

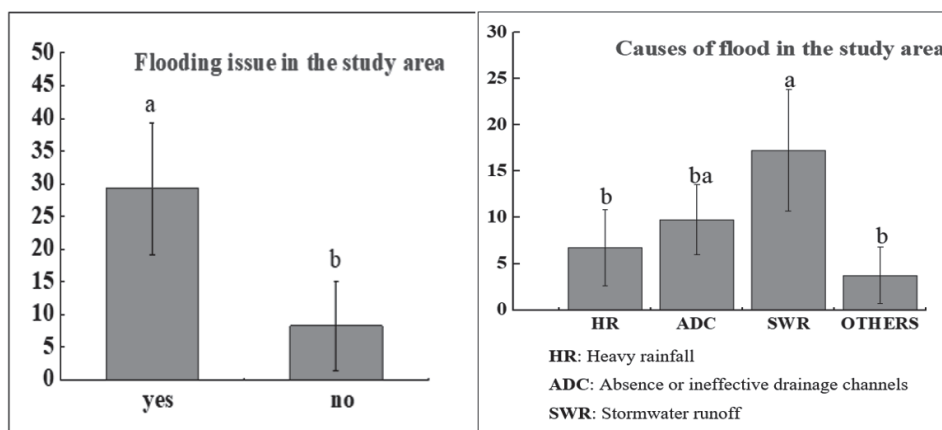


Fig. 10. Flooding issues and causes of floods in the study area. All data presented are mean and standard deviations ($n = 4$). According to the HSD test ($P < 0.05$), the letters used above the bar stated that a significant difference is observed between the two groups.

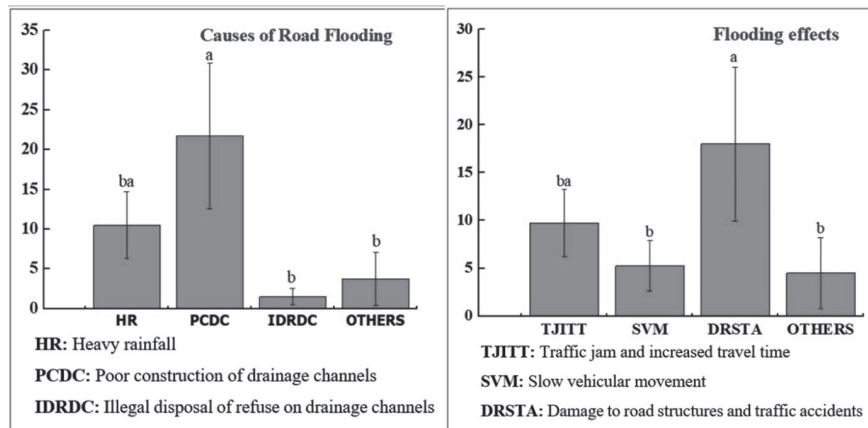


Fig. 11. Causes of road flooding and flooding effects. All data presented are mean and standard deviations (n = 4). According to the HSD test (P<0.05), the letters used above the bar stated that a significant difference is observed between the two groups.

As illustrated in Fig. 12, flood mitigation measures are significantly different where P<0.05. The results show that, the flooding problem was highest in the area where it was due to the poor construction of drainage channels. Therefore, the major suggestion to address the flooding issues on road transportation in the area is to build more effective drainage channels and rehabilitate old drainage systems.

Recommended Mitigation Measures

Based on the findings of this study, floods have huge impacts on road transportation. Flooding causes severe disruptions to the transportation system, damage of road structures and high expenditures for the rehabilitation and maintenance works of roads. Those have had negative impacts to livelihoods and economy of the country. Here are the mitigation measures recommended:

1. More effective drainage channels should be designed and constructed, as well as maintenance and rehabilitation of old drainage systems within the study area. This will help in reducing the occurrence of road flooding in different parts of the city.
2. Regular information on rainfall, stream flows and water levels should be gathered. This will effectively contribute to flood prediction, control and mitigation.
3. Cleaning the drains more frequently and provide controlled dump sites in order to discourage the dumping of waste into drains. Also, the construction of soakaway pits is recommended as a solution to standing surface water.
4. River drainage systems, which can sometimes affect river flooding when there is heavy rainfall, and the creation of buffer zones along river channels must be well designed to reduce susceptibility to floods. These rivers are namely Nyabarongo, Nyabugogo and many others.
5. It is suggested to prepare and provide training and awareness programs on environmental matters to people. This would help to reduce dumping waste materials in the drains and different canals (Ruhurura) in the neighborhoods which result into flooding when clogged up.
6. Protection of the urban wetlands of Kigali mainly by protecting the surrounding mountains of the wetland from runoff, which is believed to be one of the main causes of flooding. Downhill runoff is good at picking up anything that comes in contact on

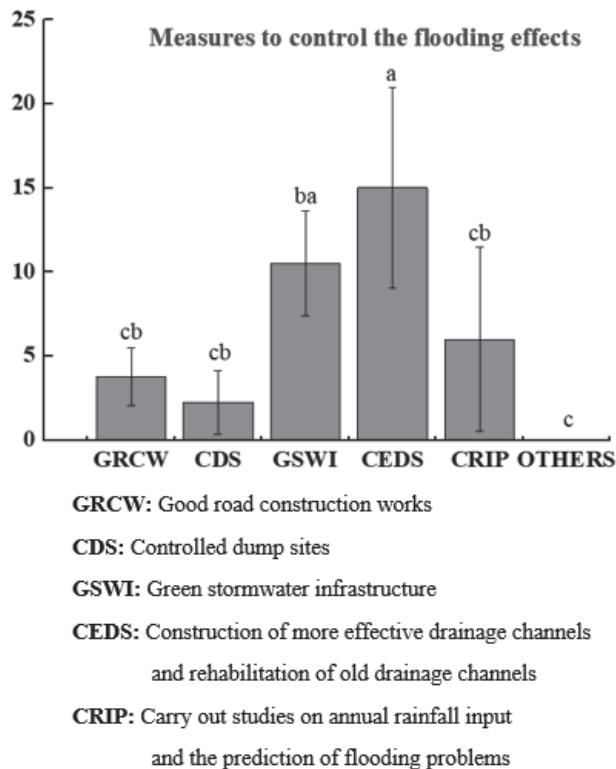


Fig. 12. Measures to control the flooding effects. All data presented are mean and standard deviations (n = 4). According to the HSD test (P<0.05), the letters used above the bar stated that a significant difference is observed between the two groups.

its way to the lower elevation, thus carrying sediment and depositing it on the river bed, which is a factor of flooding in wetlands (for example, Nyabugogo wetlands) and their surroundings. Therefore, local authorities should take appropriate wetland protection measures to protect the urban wetland ecosystem and its surroundings (human property and road infrastructure) from flooding.

7. Sustainable storm water management is recommended to decrease the volume of storm water runoff. The recommended storm water management techniques which can be applied to mitigate the impact of floods in Kigali city are: construction and maintenance of roadside storm water drains, construction of storm water drainage systems across the hillside to collect storm water flowing downhill and green storm water infrastructure practices such as, rain gardens, green roofs, permeable pavements, grass paver parking lots, infiltration trenches, urban tree canopies, a rooftop (downspout) disconnection, vegetative swales and rainwater harvesting (rain barrels or cisterns). Rooftop rainwater harvesting is the most sustainable method of rainwater harvesting which is recommended in the area and if properly collected and managed, it should be used for potable. This method of collecting roof rainwater (water flowing off the roof during the rainfall) by using plastic tanks or underground cisterns depending on households' financial capabilities is currently being practised in some households of the city of Kigali. Nevertheless, as a sustainable technique of storm water management, every household must own at least one plastic tank to collect rooftop rainwater.
8. Other responses to flood hazards that the study recommends to be undertaken include, regulatory approach like forestation of side hills (due to the geographical features of Kigali) where agriculture is no longer practiced. When it rains, the water runoff flowing downhill (for example, from mount Kigali) picks up trash, sediments and other waste into the roads which cause the blockage of drains and sometimes damage road infrastructure. Therefore, forestation alongside hills is recommended.

Conclusions

The results of this study lead to the conclusion that the risk of flooding in the city of Kigali, Rwanda, has become an annual phenomenon. The communities and authorities have to find means to mitigate damage, protect roads from flooding and allow life to return quickly to normal after floods, rather than rebuilding the road infrastructure after every flood. One domain of change is road construction. The techniques of protecting roads by building embankments that withstand washing out during floods have to be developed. The government agencies responsible for disaster management have to carry out an immediate

response to the threat of flooding to address the challenges of flooding on road transportation in the area. Flooding leads to damage of road structures and repairing the same road or half-mile stretch of road every year is too costly and hinders the movement of people as they wait for the roads to be repaired after a flood. One way to fix this issue would be paying attention to the measures recommended. Successful mitigation measures would contribute to the transport systems performance and save public funds, allowing for other important projects rather than repairing the same roads every few years.

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Conflict of Interest

The authors declare no conflict of interest.

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