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Quantifying the Effects of Simulated Changes in Land Use/Cover on Flood Reduction: an Insight From Kigali

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Abstract

In the recent decades, the rapid urbanization-induced land use/cover change has strongly altered patterns of surface runoff regimes in many cities in Sub-Saharan Africa's Countries. Yet, few studies have focused on the complexity of the anthropogenic stresses on surface runoff and flash flood in these growing cities. The present study assessed the effects of various land use/cover management scenarios with particular focus on decreasing of surface runoff and flooding in a highly urbanized watershed in Kigali, Rwanda. We used openLISEM hydrological model and the combination of remote sensing and fieldwork to quantify the impact of various land use/cover management scenarios on surface runoff and flash flood reduction. The model simulation results showed that the combined structural and ecosystem-based land use/cover management measures was the most effective technique for reducing surface runoff and flash flood in the study catchment. We observed an average reduction of 63%, 47% and 36% in surface runoff, flood volume and flooded areas, respectively. Furthermore, the implementation of land use/cover management measures would decrease the number of buildings affected by flash flood up to 35%. The results of land use/cover management scenarios could be useful for urban planners and policy makers for adopting suitable strategies to control flood related disaster in the fast-growing cities in Rwanda.

Keywords: Land use/cover change, openLISEM, Surface runoff, Urban flash floods, Buildings

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1. Introduction

Population growth, urbanization and other human activities are causing great challenges to the environment and negatively influencing ecosystem services which act as a buffer to natural hazards (Dosdogru et al., 2020). The situation is worse in many developing countries such as Sub-Saharan African countries where the unplanned urban expansions are replacing forest and vegetation covers and hence results in extensive land use changes (Schütte and Schulze, 2017). The change in land use has a significant impact on catchment hydrological processes by affecting the runoff generation and altering other hydrological factors (i.e. infiltration and interception). This may results in the changes in the intensity and frequency of flooding and negatively affects people inhabiting in those regions (Yang et al., 2015). Therefore, a better understanding of how different anthropogenic activities affect catchment hydrologic processes is vital for predicting and mitigating surface runoff and flood hazard.

The capital city of Rwanda, Kigali has experienced rapid urban development, along with good economic growth in the recent decades. The rapid urban expansion lead to a poorly-planned urbanization in some areas of the city and has generated a number of negative environmental impact such as alteration of the natural drainage network (REMA, 2013). In some catchments, forest and grasslands on steep slope have been cleared and replaced by built-up areas, which increased impervious areas of Kigali City. This has resulted to greater surface runoff in highly urbanized watershed and frequent flash flooding in some downstream areas (Karamage et al., 2017). Moreover, Kigali city lacks adequate drainage systems and households' rain-water collection systems which may aggravate local flash flooding (SHER Ingénieurs-Conseils s.a., 2013). These flash floods have been interrupting business, transport and other development activities for several hours and sometimes cause other damages (i.e. accidents).

A number of studies have shown that forests, grasslands and shrublands play a crucial role in reducing water runoff in a watershed (Huang et al., 2003; Li and Min, 2013; Qin et al., 2013). This protective role of vegetation cover is also relevant in urban areas. For example, Ferreira et al. (2019) demonstrated that afforestation in an urbanized watershed in Brazil reduced significantly overland runoff at different degree. Another study by Li et al. (2017), showed that the storm water control measures such as vegetation cover increases the hydraulic friction of an urban catchment

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and can decrease the runoff velocity in upstream areas and minimize the peak floods in downstream areas. Other measures such as grassed waterways and vegetation buffers have proved to be an effective ways by slowing surface runoff and hence reduce flood in downstream areas (Kalantari et al., 2014; Liu et al., 2017). Another study by Dakhlalla and Parajuli (2016) showed that engineering measures such as water diversion and reservoirs can significantly reduce flash flood in urban watersheds.

There is a gap in scientific research about weather-related hazards (i.e. flood, landslide) in Rwanda (Nahayo et al., 2017). Previous studies focused on the change in land use in the last decades in the city of Kigali (Baffoe et al., 2020; Mugiraneza et al., 2018). Other studies (Bizimana & Schilling, 2010; Karamage et al., 2017; Mind'je et al., 2019) investigated the impact of land use change on surface runoff at bigger scale and mostly used statistical methods. Therefore, there is a need to extend on the previous studies and assess the impact of different land cover management measures on runoff and flash flood in an urbanized catchment in the capital city of Rwanda. The study will help in identifying the measures that can contribute to reduce/ mitigate flash floods in many urbanized watersheds in Rwanda.

The present study examined the effectiveness of various possible land cover management measures on surface runoff and flash flood reduction in highly urbanized Mpazi catchment in Kigali city, Rwanda. The Mpazi Catchment has been pointed as the main sources of surface runoff that cause flash flood in Nyabugogo commercial center located in the catchment outlet. In particular, the specific objectives are: 1) Simulate the impact of the 2012 land use on surface runoff and flooding, and 2) Quantify the effectiveness of different upstream land use/cover scenarios (i.e. reforestation, grassed waterways) in reducing surface runoff and flooding. We used a freely available physically-based hydrological model, openLISEM with series of meteorological data to simulate four land cover management measures in our study catchment. The overall objective was to identify the most effective measures for reducing surface runoff and flash flood that cause damage to downstream commercial center.

2. Data and Research Methods

2.1. Description of experimental site

The present study was carried out on highly urbanized catchment named Mpazi located in Kigali, the capital city of Rwanda in East Africa (1°57'S, 30°3'E) (Figure 1). It has a drainage area of about 8.7 km^2 with very steep topography and an elevation ranging from 1377 m to 1850 m m.s.l. The catchment is located in tropical temperate climate with average annual temperature ranges between 16 °C and 21 °C and an average total annual precipitation is below 1200 mm. The wettest month is April with an average precipitation of 183 mm while the driest month is July with 9 mm precipitation. The catchment has two rainy seasons, which are the long rains seasons from February to May, and the short rains seasons from September to January. The rainiest time of the year is March through May (MAM) in the capital City (Ngarukiyimana et al., 2021; Siebert et al., 2019). The dominating soil types in the study catchments are clay loam acrisols, sandy loam regosols and cambisols. The dominate land use is built-up areas (73%) located mainly in the upper portions and outlet of the watershed followed by forest cover (16%). The watershed has a number of illegal settlements and many of them located in areas that are not suitable for habitation (i.e. steep slope, along riverbanks) (Figure 2) (SHER Ingénieurs-Conseils s.a., 2013).

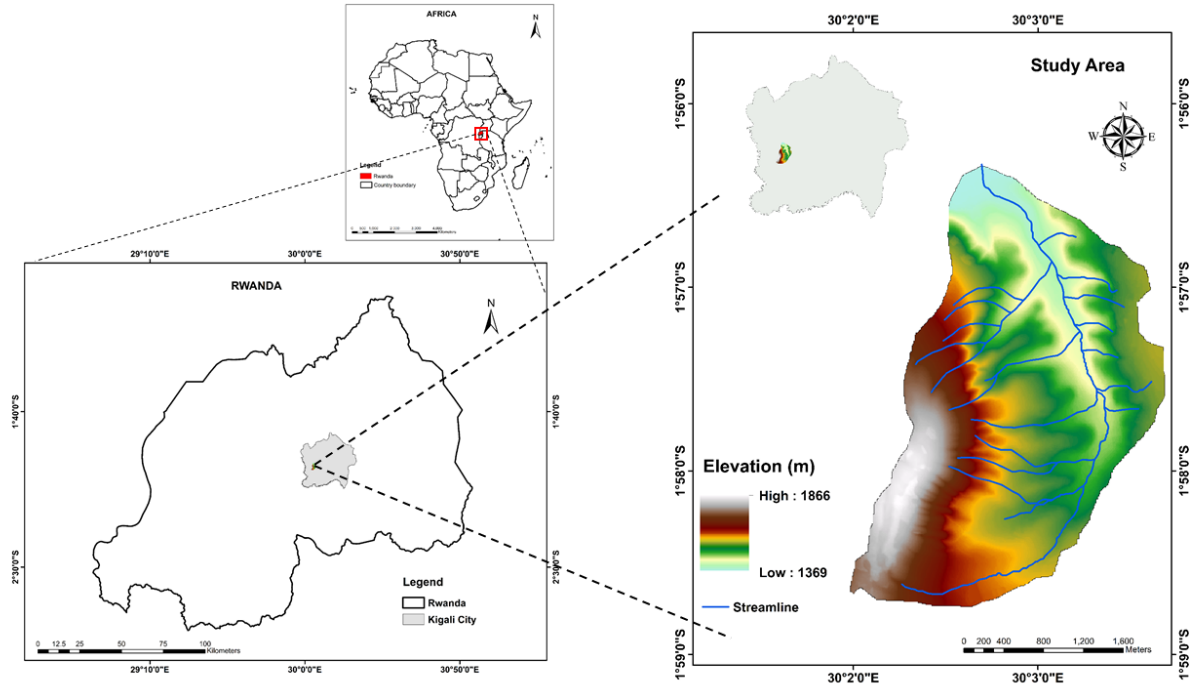

Figure 1: The location map of the study area catchment in Rwanda.

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The catchment has been identified as the main source of surface runoff that cause frequent floods in Nyabugogo commercial center located at the catchment outlet (SHER Ingénieurs-Conseils s.a., 2013). These floods often cause damages on properties, businesses and other infrastructure such as roads networks located at the catchment outlet (Figure 6).

Figure 2: Field photographs from the study catchment: a) Informal settlements on steep slope; b) Poor vegetation cover; c) Illegal occupation in flood risk areas along the riverbank; d) Location of the study catchment outlet.

2.2. Sources of Data

The main dataset used in this study includes spatial data such as land use map, soil data, topography and hydro-meteorological data. These data were obtained from different public and private institutions in Rwanda as shown in Table 1. Moreover, we collected other data including the

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drainage channels dimension and identified traces that were left by previous floods events (Figure 2 and 6). They provided information related to historical floods heights and location at the catchment outlet. Also, the geographical locations of these floods were recorded using handheld Global Positioning System (GPS) devices.

Table 1: The details of data used in the present study.

Data type	Date	Data source
Digital Elevation Model (DEM) Kigali (10m)	2010	Kigali City Council
Aerial photo (0.25 cm spatial resolution)	2012	Kigali City Council
Land use/cover map (30 cm spatial resolution)	2012	Kigali City Council
Soil Map (1:50000)	2006	Ministry of Agriculture and Animal Resources
Roads	2014	Rwanda Transport Development Agency (RTDA)
Daily rainfall data	1980-2015	Rwanda Meteorology Agency
Landsat satellite image	06/2013	http://earthexplorer.usgs.gov/

2.3. Scenarios descriptions for the study watershed

In this study, three different land use/cover scenarios were created with the focus on the land use/cover patterns and other physical measures that can minimize the generation of surface runoff and flash flood in the study catchment. The three land use/cover scenarios were defined based on the 2013 Kigali city master plan (Surbana & International, 2013), Rwanda urbanization policy (MININFRA, 2009), previous researches and other physical factors collected during fieldwork.

2.3.1 *The 2012 land use (SC0)*

Mpazi catchment covers an area of 8.7 km^2 and consists of 73% urban area, 16% forest cover and 11% agriculture land. The SC0 reflected the real land use/cover in 2012 in our study catchment. It was used as the reference scenario (SC0) and compared against other three tested land use/ cover scenarios (described below).

2.3.2. *Scenario 1 (SC1)*

The SC1 used the ecosystem-based land use/ cover measures and consists of conversion of built-up areas on steep slope (>36%) to forestland and grassland in the upstream areas and introducing

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vegetation buffers along the primary and secondary drainage channels in the study catchment. The SC1 scenario also considered the rehabilitation of existing degraded upper forest cover. The vegetation cover has a great impact both on runoff and soil properties as they increase surface roughness and hence has an impact on infiltration processes (Neris et al., 2013) (Fig. 2b).

2.3.3. *Scenario 2 (SC2)*

The SC2 used the structural land use/ cover measures to decrease the quantity of surface runoff coming from upper areas. We introduced a detention reservoir in the downstream areas close to the study catchment outlet. The location site of detention reservoir was selected based on previous scientific report and other factors such as slope and close location to the study catchment outlet. The size and capacity of the retention pond were based on the estimation of water volume of the flood event that took place in February 2013 (SHER Ingénieurs-Conseils s.a., 2013). Moreover, we considered the increase of artificial channel roughness to reduce the speed of runoff. Structural measures are defined by Mohit and Sellu (2013) as engineering measures used to minimize/ prevent the impact of floods on human properties. During hydrological simulation, the retention reservoir is entered into the model as runoff storage structures, because they impound water coming from upper catchment areas.

2.3.4. *The scenario 3 (SC3)*

This scenario integrates both ecosystem-based measures (SC1) and structural land use/ cover measures (SC2) for surface runoff reduction. The use of combined measures for runoff and floods reduction has been recommended by other previous studies (Hsieh et al., 2006). Various hydrological models are available for simulating surface runoff and flash flood in a watershed. In this study, a free available physical based hydrological model, the Limburg soil erosion (openLisem) was selected and applied to investigate the effectiveness of three land use/cover management scenarios on surface runoff and flash flood reduction. The simulation results from each scenario were quantified and compared to the reference scenario. The model was chosen because it is initial designed for small to medium catchments (1ha-100km^2) (Sanchez-Moreno et al., 2014). Moreover, the openLISEM model was tested in many small catchments of Sub-Saharan Africa (Baartman et al., 2012; Hessel, 2005; Nearing et al., 2005; Sanchez-Moreno et al., 2014). In this study, we used the version 2.03 of openLISEM model.

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2.4. OpenLISEM hydrological modelling

Limburg soil erosion model (openLisem) is a physically based hydrological model initial designed to simulate surface runoff and soil erosion in small catchments (De Roo et al., 1996). The model simulates soil erosion, runoff and shallow floods based on the physical processes of interception by plant leaves, infiltration and surface storage for a rainfall event. It is incorporated in raster format and expressed in term of Geographical Information System command. OpenLISEM combines various hydrological processes to simulate surface runoff and flooding. It incorporates processes such as interception and throughfall, surface storage in micro depression, infiltration (i.e. two-layer Green and Ampt), overland and channel flow during a rainfall event (Nearing et al., 2005). The net precipitation is obtained by subtracting interception storage of leaves and branches. The surface runoff is predicted based on the measured random roughness (RR) of the ground soil surface. The runoff is directed by kinematic wave and manning's equations on the ground and channel flows (de Jong & Jetten, 2007). OpenLISEM has been used to simulate surface runoff for an individual rainfall event. All the model requirements including model inputs, output and mathematical equations are provided in details in De Roo et al. (1996).

2.5. OpenLISEM model input data

OpenLISEM requires a larger number of input variable and parameters. The main inputs data are land use map, soil map and digital elevation model (DEM) and rainfall data (Figure 3). Other model inputs parameters can be extrapolated from existing maps (De Roo et al., 1996). Detailed description of these inputs data are provided below:

2.5.1. Catchments maps

Digital elevation model (DEM) with 10 m resolution was used to delineate the study area catchment using Arc Hydro tools in ArcGIS 10.2.2 (Figure 3c). Thereafter, the DEM was used to create slope angle and local drain direction (Ldd) maps. In addition, the DEM was used to generate other inputs required by model such as catchment outlet and channel local drain direction (Lddchan).

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2.5.2. Land use/cover map

The 2012 land use/cover map of the study catchment was extracted from the land use/cover map of Kigali City of the year 2012 using ArcGIS tools. It was provided by mapping unit of Kigali City Council in our fieldwork. The main land use/cover types in the study catchment are built-up areas, mostly on steep slope occupying more than 73% of the catchment total areas. Other land use/cover types are forest cover (15.8%) in upper catchment areas, agriculture land (10.8%) and water bodies (3%) (Figure 3a). The tree species in the forest are mostly eucalyptus with few native plants. The mixing farming (maize, beans) dominate the agriculture practices.

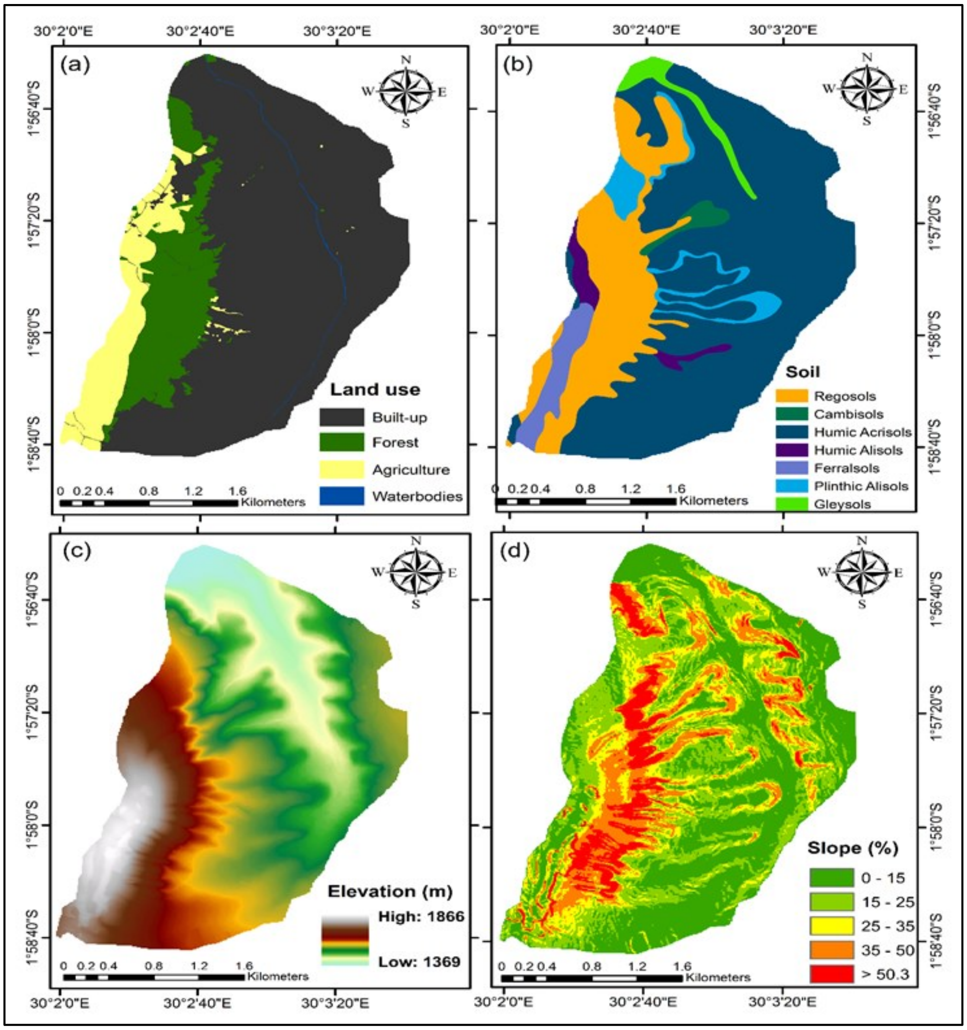

Figure 3: Model input thematic layers: (a) The 2012 land use; (b) Soil map; (c) Elevation map; (d) Slope map.

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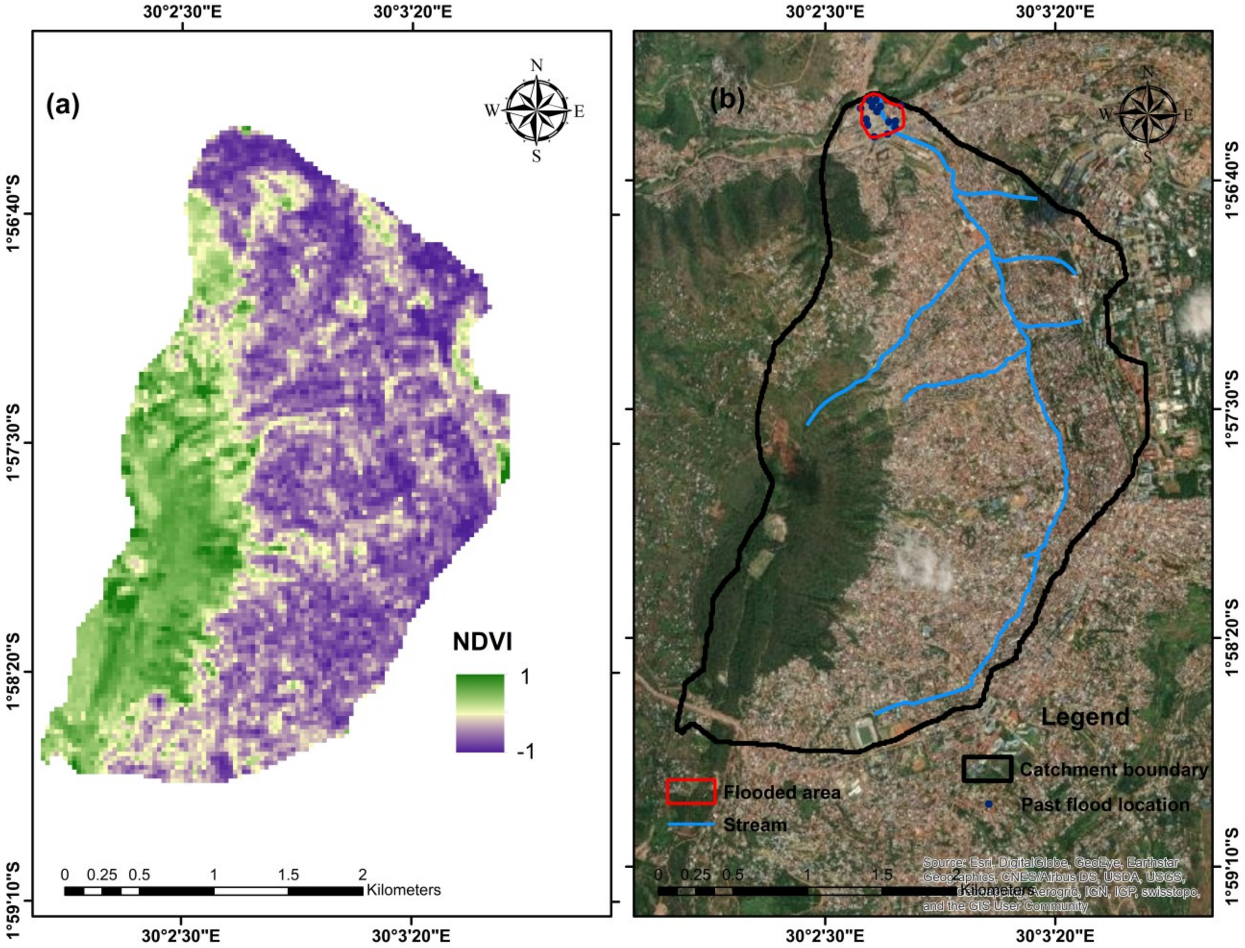
2.5.3. Soil map

The soil map was generated by the Rwandan Ministry of Agriculture and Animal Resources in collaboration with University of Ghent in Belgium (Verdoodt & Van Ranst, 2006) at the scale of 1/50000 (Fig. 3b). The soil map contains all information related to soil type, soil texture composition (silt, sand and clay), bulk density, soil depth and other information related to soil properties. Soil data was used to assess rain infiltration and soil erosion. Moreover, the available soil map was also used to determine saturated hydraulic conductivity (Ksat), porosity (thetas) and initial volumetric soil moisture content (psi). The Ksat, thetas and psi were obtained using the soil water characteristics model (SPAW). The resulting soil moisture contents and saturated hydraulic conductivities served as the model input for assessing surface runoff.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4: (a) The normalized difference vegetation index (NDVI) in the study catchment; (b) Maps showing the flooded locations in the study catchment.

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2.5.4. Vegetation map

First, we calculated the Normalized Difference Vegetation Index (NDVI) using the Landsat 8 image of the June 2013 covering our study catchment. Secondly, the vegetation cover map was generated from the NDVI image using the formula provided by van der Knijff et al. (2000) (Figure 4a). Lastly, the vegetation cover map was used to determine the leaf area index (LAI). The LAI is related to the vegetation storage capacity and is used as an input in the openLISEM model to determine rainfall interception (de Jong & Jetten, 2007).

2.5.5. Built-up area map

The area occupied by buildings are considered as the impervious area (hard surface) in surface runoff modelling. In addition, the roof of buildings contributes to the interception process of rainfall. Therefore, the building footprint for Mpazi catchment was digitized from high-resolution aerial photo (0.25 cm) of the year 2012 provided by the Kigali City Council.

2.5.6. Rainfall data

OpenLISEM model uses detailed event based rainfall to simulate runoff and soil erosion (Baartman et al., 2012). In this study, a rainfall event that took place on the 29th October 2013 during short rainfall season with a total rainfall of 53.3 mm and duration of around 2 h was used for the model simulation. The event was recorded by two rain gauging stations located in the study area. Moreover, daily rainfall data recorded by the Rwanda Meteorology Agency between 1980 and 2015 were used to characterize the storm size and rainfall intensity (for 29th October 2013 event) for specific return period. The return period was determined from the Gumbel method (Chow et al., 1988). The rainfall analysis showed that the 29th October 2013 event corresponded to five-year rainfall event with a total rainfall of 70.88 mm. We selected this storm event for model simulation because it was well recorded by rain gauges and had caused flash flood in Nyabugogo commercial center, located at the study catchment outlet. Figure 5 shows the monthly average rainfall pattern over the study catchment over the period of 35 years.

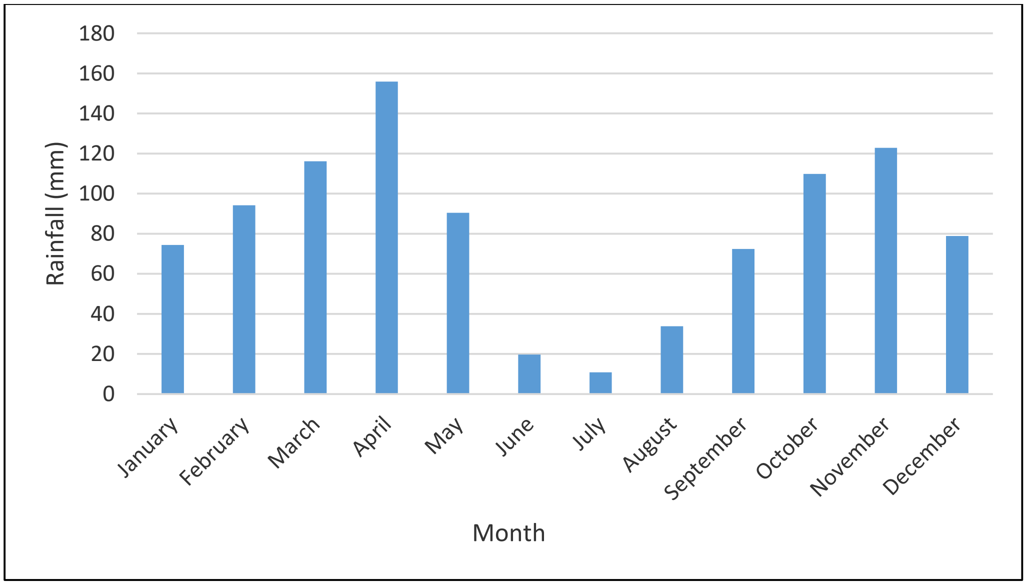

Figure 5: Average monthly rainfall from 1980 to 2015 for the study catchment in Kigali City.

2.6. Modelling surface runoff in openLISEM model

The openLISEM model version 2.03 was used to simulate the surface runoff of the 29th October 2013 flash flood event in Mpazi catchment. All the necessary spatial input data were prepared in the PCRaster, which is an open-source GIS package (Karssenberg et al., 2010). We used a PCRaster script developed by Jetten (2014) to generate a database containing all input maps required to run the model. The spatial input data were resampled at pixel size of 10 meters, the time step length used during simulation was ten second (10 sec) and the simulation length time was set to 150 minutes. The simulation time was set based on the total rainfall event time (2 hours) and additional time required to allow runoff water to reach the catchments outlet (Hessel, 2005). The simulations of the effect of different land use/ cover management measures on surface runoff and flooding were implemented in openLISEM model following the steps described in previous studies (Grum et al., 2017; Hessel & Jetten, 2007; Hessel et al., 2003; Pérez-Molina et al., 2017). The first simulation was carried out by incorporating the database containing all input parameters and the 2012 land use/cover map (SC0) in the model. Thereafter, other simulations were conducted by entering different land use/cover management measures (SC1, SC2, and SC3) in openLISEM model. The effect of the of different land use/cover management measures on runoff and flood reduction, was estimated by comparing the model simulation results (% change) of the reference scenario (SCO) and other tested scenarios (SC1, SC2, and SC3).

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Figure 6: Examples of flash flood impact occurred in the study catchment on: a) transportion service and business; b) Medium sized car swept away by runoff (Source: Kigali Today Newspaper, 2019).

2.7. Model calibration and validation

The present study was conducted in data scarce environment with no recorded historical ground discharge data, as it is the case in many sub-Saharan African countries. A study by Pérez-Molina et al. (2017) suggested that in case of the absence of ground discharge data, the openLISEM model calibration should be conducted based on the field observations and historical flood impacts (i.e. past flood level). Therefore, we used the information collected from fieldwork related to historical flood records including the 29th October 2013 flood event (Figure 4b and Figure 6). We validated our simulation results by comparing the openLISEM model-simulated results with the actual historical ground recorded flood level (Figure 7). Previous studies pointed out that the Ksat and Manning's n values have influence in simulated results, so they can be used for model calibration of surface runoff related studies (Hessel & Jetten, 2007). Therefore, we adjusted the saturated conductivity (Ksat) and manning’s (n) values to match our results with the ground recorded flood level of the 29th October 2013 flood event.

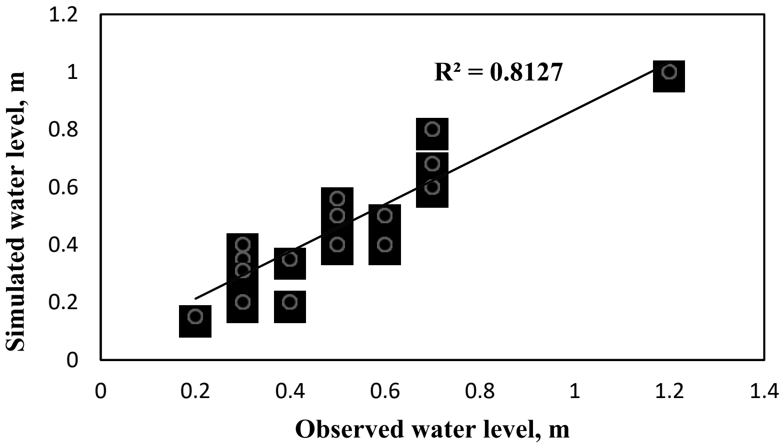

Figure 7: Scatter plot of the observed and simulated water levels.

3. Results and discussion

3.1. Simulated surface runoff and flash flood

The Figure 8 shows the simulated surface runoff from the 2012 land use/cover scenario (SC0) for Mpazi catchment. Under the SC0 scenario, OpenLISEM model simulated successful the flash flood event of the 29th October 2013 in the study catchment. From the figure, it can be seen that surface runoff coming from high densely populated upper areas of the study catchment, are causing flash floods in Nyabugogo commercial center located at the catchment outlet. The maximum flood depth reached one meter at the catchment outlet (Figure 8). The flood volume, flooded area and runoff simulated at the catchment outlet were 57116m^3, 203300m^2 and 51mm, respectively. The number of properties affected by flood depth and flood duration during this event was approximately 71 (Table 2). The number of properties affected is closed to the number of properties counted during our fieldwork survey and from ancillary data availed by Kigali city and the Rwanda Ministry of Disaster Management and Refugee Affairs, which was 65 properties. Also, the model-simulated results showed that the Nyabugogo commercial center stays inundated for almost four hours (Figure 9). This cause damages to transportation infrastructure and disrupt business operations in the area. As discussed by Ward et al. (2016), the duration of flooding is one of the important indicators in evaluating the impact of flood on element at risk. Moreover, the model-simulated results showed that surface runoff are coming from upper highly built-up areas and are the main cause of flash flood at the catchment outlet.

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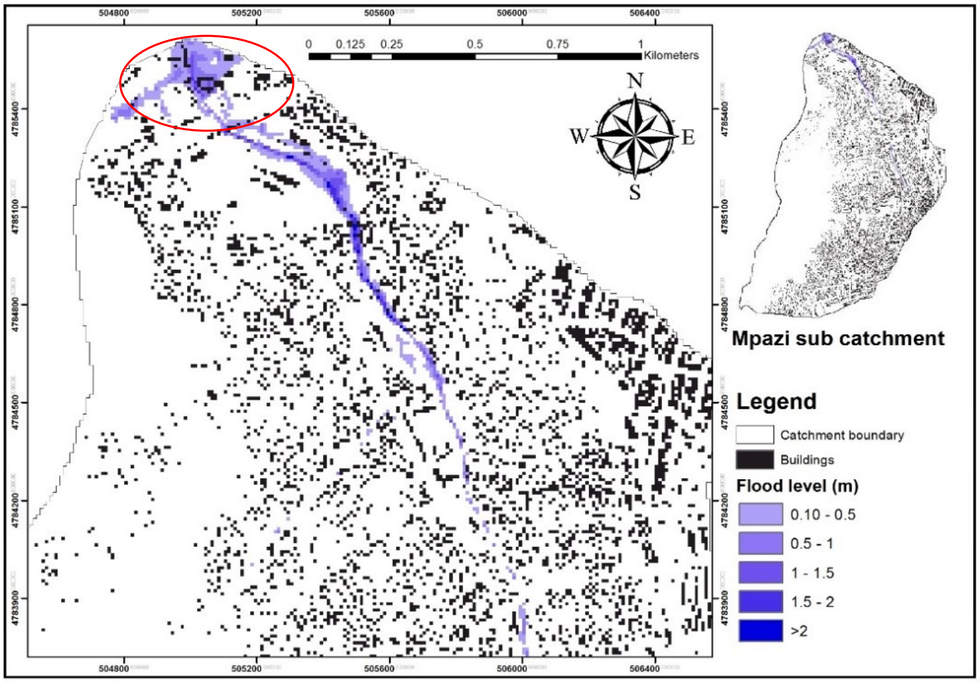

Figure 8: Model Simulation results showing runoff and flash flood in the study catchment (Red circle shows the flooded commercial center).

In addition, during our fieldwork we observed the absence of rainwater harvesting system in most of households in upper areas of the study catchment, which are probably aggravating the floods situation at the catchment outlet. The increase of unplanned settlement in some catchments of the Kigali city was discussed by Mugiraneza et al. (2018). Other studies (Zhou et al., 2013) found a big correlation between the amount of runoff generated and the rate of urban development.

Table 2: Effectiveness of different land use/cover scenarios for the Mpazi catchment.

Criteria for evaluation	The 2012 land use/cover	Land use/cover management scenarios		
	SC0	SC1	SC2	SC3
Flooded volume (m^3)	57116	42452	35179	30320
Flooded area (m^2)	203300	155200	149100	131100
Runoff (mm)	51	40	28	19
Buildings affected (number)	71	62	53	46

SC0: Reference scenario. SC1: ecosystem-based land use measures. SC2: structural measures. SC3: ecosystem & structural measures.

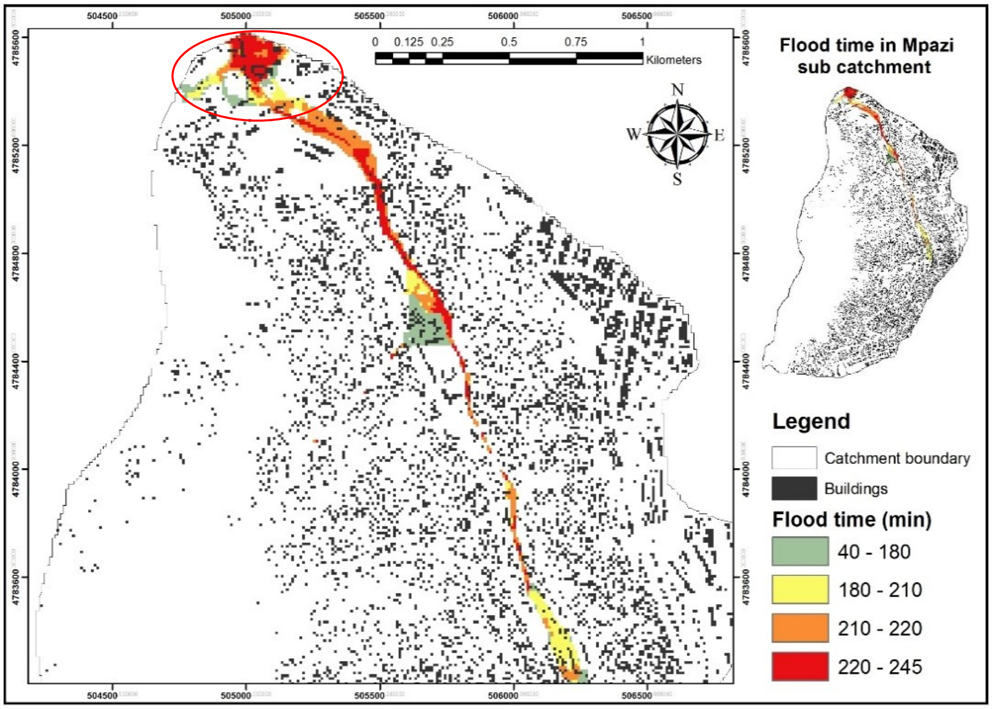

Figure 9: Model Simulation results showing the flash flood duration in the study catchment (Red circle shows the flooded commercial center).

3.2. Effects of simulated land use/cover management scenarios on surface runoff

Surface runoff varied considerably for each of the applied land use/cover management measures. The model simulated results showed that in all three land use/cover management measures (SC1, SC2 and SC3), surface runoff decreased considerably when comparing with the reference scenario (SC0) (Figure 10, Figure 11 and Table 2). The ecosystem-based measures combined with structural measures (SC3) was the most effective technique for reducing runoff. We observed an average reduction of 63%, 47% and 36% in surface runoff, flood volume and flooded areas, respectively. Similarly, the number of buildings affected by flash flood decreased considerably under three land use/cover management measures (SC1, SC2 and SC3) as shown in Table 2. The ecosystem-based measures combined with structural measures (SC3) was the most effective in reducing the number of building affected by flash flood where the number of buildings affected decreased by 35% compared to the reference scenario. Other land use/cover management measures (SC1 and SC2) also showed a decreasing trend where the number of buildings affected by flash flood decreased to 13% and 25%, respectively. The highest decrease in properties affected by flash flood under different flood depths in downstream areas was observed between 0 and 0.5 m flood depth as shown in Figure 11b. The flood depth is an important factor in flood modelling as it increases the severity of the flood damage to the properties (i.e. buildings) under consideration (Ootegem et al., 2015).

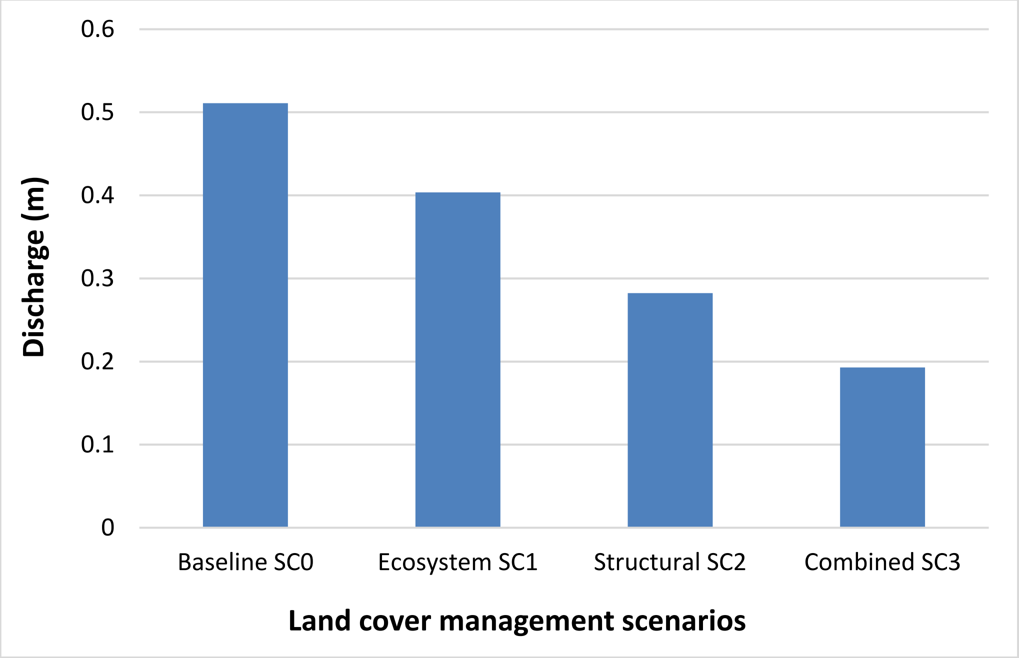

Figure 10: Change in surface runoff reduction per land use/cover management scenarios.

The implementation of various land use/cover management strategies would increase surface area covered by grassland and forest and may contribute to the reduction of surface runoff coming from upper areas as showed by model simulated results. Therefore, the SC3 scenario decreased the amount of runoff reaching the retention basin and the reduction of flash floods in Nyabugogo commercial center at the catchment outlet. The use of combined effect of structural and non-structural measures were emphasized by Hsieh et al. (2006) as an effective measure for flood management.

Comparison of simulated results for the ecosystem-based land use/cover measures (SC1) and reference scenario (SC0) showed a decrease in flood volume, flooded area and runoff by 26%, 23% and 22%, respectively. There is a decrease in 13% of the number of properties affected in this scenario (Figure 11 and Table 2). The SC1 would expand of vegetation cover and rehabilitation of existing degraded forest on steep slope in upper portion of the study catchment. This land use

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measures could led to an increased in surface roughness and infiltration, which shall help to reduce the overland flow (Neris et al., 2013).

The simulation result for the structural land use/cover measures (SC2) indicated that detention reservoir would decrease the flood volume, flooded area and runoff up to 44%, 27% and 45%, respectively (Figure 11 and Table 2). The use of structural measures decrease the properties affected by flash flood in downstream commercial center up to 25% compared to the reference scenario. The introduction of detention reservoir close to catchment outlet would collects most of the runoff coming from upper areas and hence reduce the amount of water reaching the commercial centre located at the outlet. The SC2 measures were the second most effective measures in terms of reducing runoff and properties affected by floods. The use of structural measures such as river diversion work and detention pond were proposed by Hsieh et al. (2006) as another solution for flood management in urban areas. Other studies (Lanckriet et al., 2012; Nyssen et al., 2010) in some sub-Sahara African also reported the decrease in surface runoff and flood disasters due to the implementation of land use/cover management strategies.

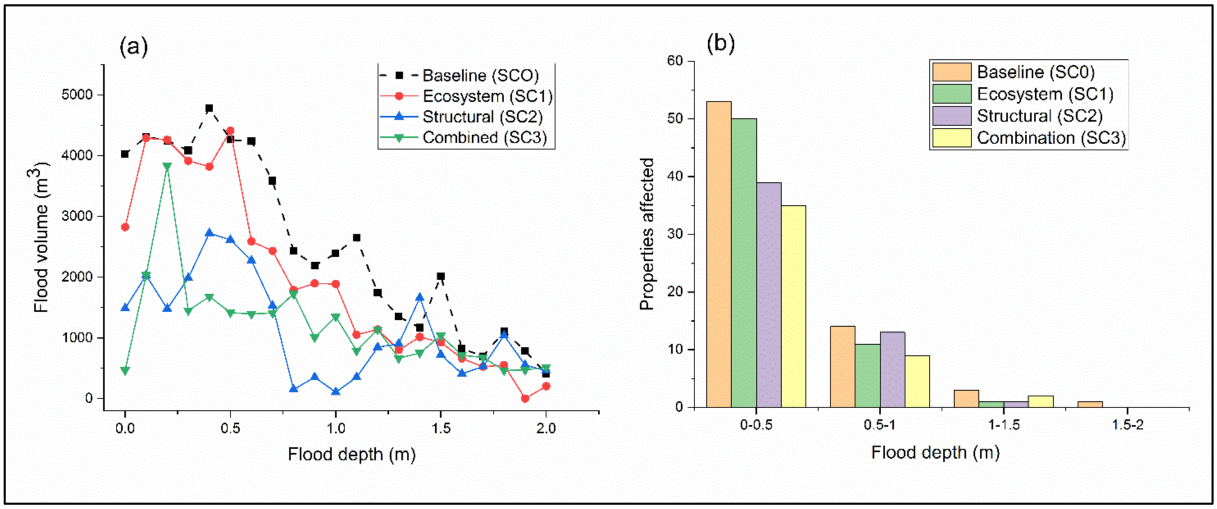

Figure 11: Comparison of simulated results between the 2012 land use land use/cover change scenario (SC0) and different land use/cover change management scenarios (SC1, SC2, SC3). (a) Change in flood volume per land use/cover management scenarios at different flood depth; (b) Change in number of properties affected per land use/cover management scenarios at different flood depth.

3.3. Implications of the proposed land cover management measures

We used the openLISEM model to analyse the impacts of possible land use/cover management measures to reduce runoff and flash flood in our study catchment. The model simulation results indicated that the proposed land use/cover measures would reduce the surface runoff and flash floods in Mpazi catchment. However, the implementation of these land use/cover management measures would not have been completely effective in reducing runoff, because there are still few flooded area in Nyabugogo commercial centre. These measures are not enough to eradicate flood risk caused by runoff coming from upper catchment areas, more studies considering the use of water harvesting technique at household level shall be examined in future research works. Moreover, this study did not consider the implementation cost of the proposed land use/cover management measures, which also is an important factor that shall be considered in future.

The present study was conducted in a data scarcity environment with limitation on historical ground discharge and flood data of the studied catchment. For example, the openLISEM model was validated based on the historical recorded floods level, flooded area and number of affected properties collated during our fieldwork (Figure 7). Therefore, the model results should be interpreted with caution.

4. Conclusions

In the present study, openLISEM hydrological model was successful applied to test the effects of possible land use/cover management measures to reduce runoff and flash flood in Mpazi catchment in Kigali, Rwanda. From a comparison of the model-simulated results with and without the implementation of remedial land use/cover measures, it can be seen that the employment of combined effect of structural and ecosystem-based measures (SC3) was the most effective and would reduce surface runoff, flood volume and flooded areas up to 63%, 47% and 36%, respectively. Similarly, the ecosystem-based land use/cover measures (SC1) decreased surface runoff up to 22%, whereas the structural land use/cover measures (SC2) further decreased the surface runoff up to 45% compared to reference scenario. These findings showed that the implementation of various land use/cover management measures would significantly reduce surface runoff in upper areas and flash floods in Nyabugogo commercial center located in downstream areas. The present study contributes to the literature by investigating the advantages

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and disadvantages of contrasting land use/cover management measures in terms of surface runoff and flash flood reduction. The modelling assessment framework used in the present study can be applied in other sub-Saharan African cities as a tool to support in the development of sustainable urban planning policies.

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