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A comparison of flash flood response at two different watersheds in Grenada, Caribbean Islands

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Abstract. Grenada is one of the susceptible areas to flooding. It is due to the high intensity of rainfall in each year and Grenada often hit by hurricanes and tropical storms. Flash-flood often occur in Grenada, specifically in two areas (Gouyave and St. John′s watershed). Both of them have different characteristics. Gouyave watershed represents rural area, whereas St. John′s watershed is an urban area. This paper aims to understand the flash-flood response of Gouyave and St. John′s watershed in different return periods. It is emphasized that urbanization is an important factor related to flash-flood. This paper uses quantitative methods with flood modelling using OpenLISEM software. Input data to develop flood modelling are DEM (Digital Elevation Model), saturated hydraulic conductivity (Ksat), initial soil moisture, surface roughness (Manning's n), and random roughness. The result shows that St. John′s watershed is more sensitive and has higher response to flash-flood than Gouyave. St. John′s watershed is more urbanized which decreases water infiltration. So, it increases the potential run-off and flash-flood events become more massive.

1. Introduction

Flood is one of the most frequent natural disasters worldwide which usually occur in low land areas, near the rivers, coasts, or some areas which have high susceptibility to flooding. One of these susceptible areas is Grenada, Caribbean Islands. Flash-flood events in Grenada are caused by the local heavy rainfall, such as the latest event in 2011. In 2011, the intensity of rainfall in this area is 2.350 mm/year [1]. The high intensity of rainfall in certain areas was also delivered by tropical storms and hurricanes. Grenada's area is called *the hurricane belt* because it is often hit by hurricanes, like hurricane Janet in 1955, hurricane Flora in 1963, hurricane Ivan in 2004, and hurricane Emily in 2005. The hurricane Ophelia in 2011 was one of the most damaging events because it triggered the flash-flood event.

Flash-flood in Grenada usually occurs in two watershed areas, Gouyave watershed and St. John's watershed. In Gouyave watershed, flash-flood hits the downstream area of Charlotte River, while it hits the downstream area of St. John's River in St. John's watershed. Flash-flood event is usually

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triggered by the intensity of rainfall in both of areas. During the rainy season on 2011, the intensity of rainfall in Gouyave watershed is 250-350 mm, while 150-250 mm in St. John's watershed [1].

Both of watersheds have different characteristics. St. John's watershed represents an urban area which is characterized with high intensity of built-up area. St. George, the capital city of Grenada is located in this area and the urban development is growing faster. However, Gouyave is still dominated by natural land-use types, such as forest, mix-trees, bare, and agriculture lands. It seems that Gouyave watershed represents rural area. Flash-flood conditions in these two watersheds are shown at Figure 1 and Figure 2.

Figure 1. Flood condition in Gouyave watershed

Figure 2. Flood condition in St. John's watershed

The different characteristics of those watersheds would influence to the flash-flood response in each watershed. Thus, this paper aims to understand the flash-flood response at Gouyave and St. John's watershed in different return periods which is emphasized that urbanization is an important factor related to flash-flood. The understanding of urbanization factors and their impacts on flash-flood can help to develop the Grenada's disaster risk reduction strategies.

2. Method

This paper uses quantitative methods with flood modelling using OpenLISEM software. OpenLISEM is an event based natural hazard model to simulate runoff, erosion and flash floods for a single rainfall event [2, 5]. It was used to build a flood modelling with generate the land-use change and its impacts to flood events, for example land-use change and its relationship to flood. The data requirements for developing flood modelling were:

- Catchment characteristics, include local drain direction, catchment boundaries, area covered by rain gauges, slope gradient, locations of outlet and sub-outlets (derived from DEM.map). DEM.map was created based on the interpolating contour line from topographic map with resolution 20 meters. Besides that, it was required rainfall data (from Maurice Bishop International Airport, Grenada).
- Vegetation characteristics, such as leaf area index (LAI), fraction of soil covered by vegetation (PER), and vegetation height (CH), were identified from field observation.
- Soil surfaces, include random roughness (RR) and surface roughness (Manning's n) which were adapted from literature.
- Channel data, including local drain direction of channel network, channel gradient, Manning's for the channel, width of channel scalar, and channel cross section shape.
- Green and Ampt Layer is a physical model to simulate infiltration rates to measurable soil properties**,** such as saturated hydraulic conductivity (Ksat), saturated volumetric soil moisture content (Thethas), initial volumetric soil moisture content (Thethai), and soil depth [8]. There were two layers data. The first layer was derived from field observation and literature and the second layer was obtained from *saxton equations* and field observation. *Saxton equations* is a software for estimating soil water characteristics for water potential and hydraulic conductivity based on soil textures, organic matters, and structures [7].

Flood modelling was derived in two layers to reduce the uncertainty in values of soil properties, such as saturated hydraulic conductivity (Ksat), initial soil moisture, and porosity. The measurement of those soil properties was conducted during field observation in Grenada. The result shows that the top-soils contain much organic materials, specifically roots and leaves, so their values were high. Thus, this paper used two layers; the first layer was obtained from field observation, while the second layers were adapted from literature.

3. Study Area

Grenada is one of the small island states in the Eastern part of the Caribbean region, specifically between the Caribbean Sea and the North Atlantic Ocean. It is located between latitudes 11° 59' and 12° 20' N and longitudes 61° 36' and 61° 48' W. Total area of Grenada's main island is 312 km^2 with total population of 110.000 people [4]. Orientation map of Grenada are shown in **Figure 3**.

Figure 3. Orientation of Grenada's Area

The main island of Grenada has 71 watersheds and 12 of them are large watersheds. From 12 largest watersheds in Grenada, St. John's watershed and Gouyave watershed are selected as study area (**Figure 4**). Most areas at Gouyave watershed are located in the elevation of more than 200 m above sea level, specifically in the eastern parts and southern parts of Gouyave, while, St. John's watershed is dominated by flat area with elevation between 0-50 m above sea level. Both watersheds are dominated by steep-slope (25-55%).

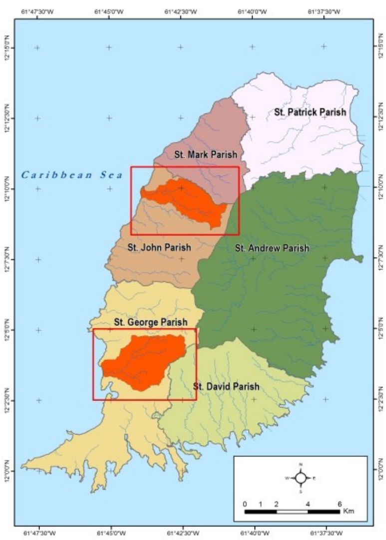

Figure 4. Orientation map of Gouyave and St. John's watershed. Gouyave watershed is located in St. John Parish, while St. John's watershed is located in St. George Parish.

Gouyave watershed is dominated by natural land-use types (**Figure 5**). 56,96% of Gouyave watershed are covered by mixed tree. Besides that, there are also forest, agriculture lands and bare land. The built-up areas can be found in their coastal area (5,53%). Meanwhile, St. John's watershed has higher intensity of built-up areas (**Figure 6**). They cover 23,28% of total area. Moreover, there are many land conversions in this area due to the urban developments and the increasing of urban population.

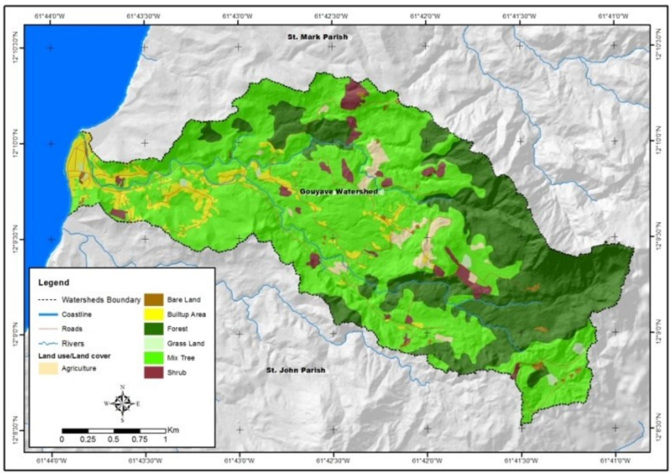

Figure 5. Land-use map of Gouyave watershed

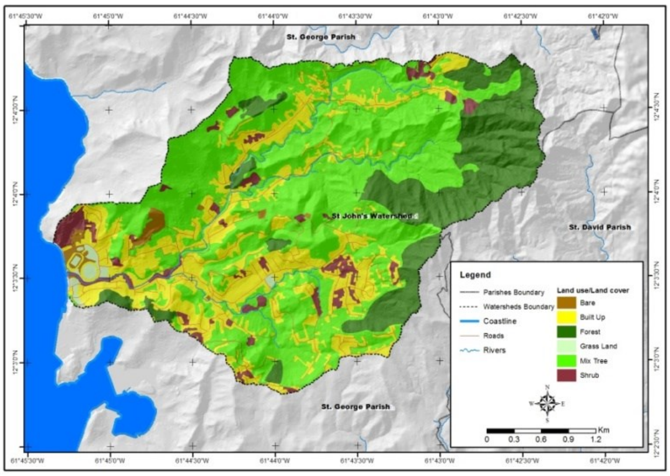

Figure 6. Land-use map of St. John's watershed

4. Method

4.1 Flood Modelling

Flood modelling was conducted in the different return periods. Those return periods were determined from Gumbel Method. Gumbel method is a method to predict the return period of rainfall based on rainfall history data, describe the occurrence probability of extreme rainfalls, and identify the distribution of extreme values [3]. The result of Gumbel Method analysis is shown in **Table 1**.

Table 1 Return periods and maximum daily rainfall

Return Period (years)	Max daily rainfall (mm)	Remarks
2	75.64	Maximum daily rainfall in 2013 (low-categories of rainfall)
5	110.20	It is only used to identify the sensitivity of two watersheds to response flash-flood.
10	133.08	
35	172.42	Maximum daily rainfall in 2011. It is used as an event-based condition and basic data for data calibration and validation

Source: analysis, 2015

Besides the intensity of rainfall, there were some important data that were used for modelling show at **Table 2**.

Table 2 Soil physical parameters and vegetation parameters

Land-use Types	Parameters						
	Ksat (mm/hr)	Porosity	Manning's n (cm)	RR (cm)	PER	CH (m)	LAI
Agriculture	10.714	0.585	0.08	0.2	0.35	4	1.08
Bare land	12.86	0.495	0.023	0.05	0.2	0.05	0.56
Built-up area	10	0.4	0.03	0.05	0.1	3	0.263
Forest	69.643	0.578	0.1	0.5	0.8	13	4.02
Grass land	19.29	0.58	0.023	0.2	0.85	0.5	4.74
Mix tree	42.857	0.554	0.1	0.5	0.7	10	3.01
Shrub	15.96	0.51	0.04	0.2	0.4	1.2	1.28
Road	0	0	0.001	0.05	0	0	0
Water	0	0	0.033	0.01	0	0	0

Source: analysis, 2015

The result of flood modelling is flash-flood depth. The flash-flood depth in both watersheds will be compared to know the sensitivity of watershed response. It is explained in section 5.

4.2 Model Calibration and Validation

Flood model calibration was conducted to minimize the deviation between the result of flood modelling and the observed data. In this paper, calibration was done based on flood depth data which were obtained from Grenada's flash-flood events in 2011.

Flood modelling was calibrated by changing and combining three sensitive parameters, such as Ksat, porosity, and Manning's n [6]. Then, the result of model calibration was evaluated using model Bias and Root Mean Square Error (RMSE). The formula of model Bias and RMSE are:

$$\text{Bias} = \frac{\sum_{i=1}^{n}(\text{y}1-\text{x}1)}{n} \quad (1)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y1-x1)^2}{n-1}} \quad (2)$$

Bias was calculated from the differences of mean values between paired observed and simulated values, while RMSE was measured to show the deviation between resulting values and observed values. The result of model calibration shows that the bias value is 0.123 m and RMSE value is 0.303 m. These values are lowest and both of them are close to zero. Based on this calibration, this configuration is used as model validation in St. John's watershed. The result of model validation is 0.170 m (bias value) and 0.260 m (RMSE value). It is implied that flood modelling has a good performance.

5. Result and Discussion

The comparison of flood modelling conducted to understand how sensitive both of watersheds to response flood. The comparison is shown at Table 3.

Table 3 Watershed response to flash-flood in different return periods

Characteristics	Gouyave watershed				St.John's watershed			
	2 years	5 years	10 years	35 years	2 years	5 years	10 years	35 years
Flood depth max (m)	0.00	0.00	0.21	1.74	0.00	2.75	2.95	3.35

Source: analysis, 2015

Table 3 shows that both watersheds are safe from flash-flood events in 2 years return period. However, in the 5 years return period, flash-flood start to occur in St. John's watershed with maximum flood depth of 2.75 m (**Figure 7**). Meanwhile, there does not occur flash-flood in Gouyave.

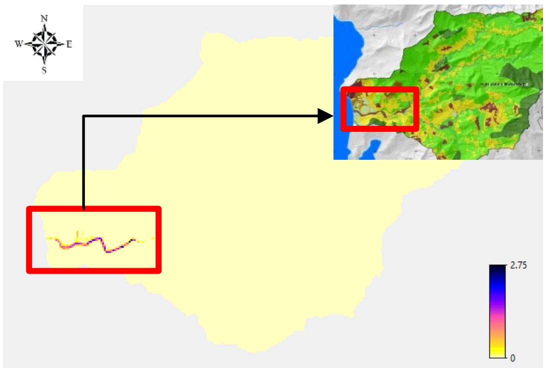

Figure 7. Flood depth of St. John's watershed (m) at 5 years return period

Gouyave watershed starts to respond flash-flood in 10 years return period with 0.21 m of flood depth. It shows that St. John's watershed is more sensitive and has higher response to flash-flood. The flood depth in St. John's watershed is higher than Gouyave (**Figure 8 and 9**).

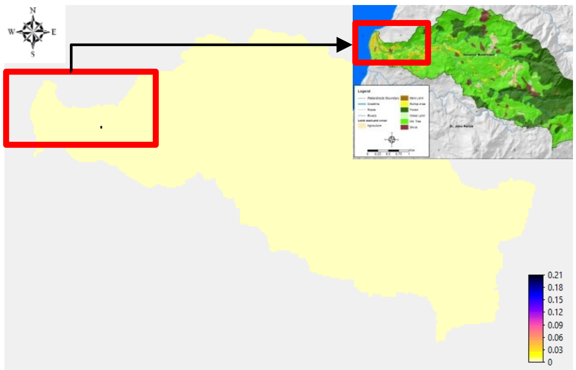

Figure 8. Flood depth of Gouyave watershed (m) at 10 years return period

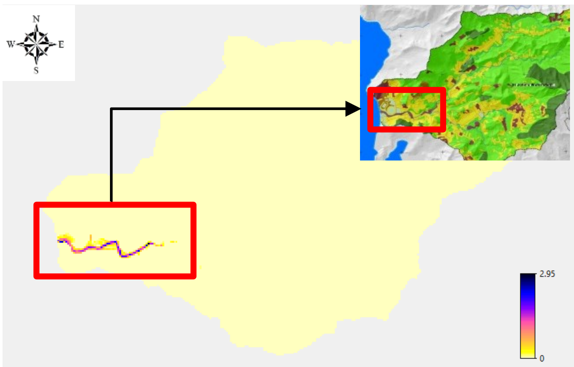

Figure 9. Flood depth of St. John's watershed (m) at 10 years return period

In 35 years return period, flash-flood events in St. John's watershed are more massive than Gouyave. The flood depth of St. John's watershed is also higher (3.35 m) than Gouyave (1.74 m) in the same period (**Figure 10 and 11**).

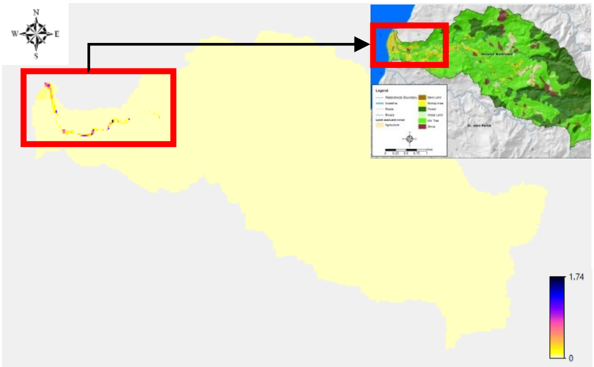

Figure 10. Flood depth of Gouyave watershed (m) at 35 years return period

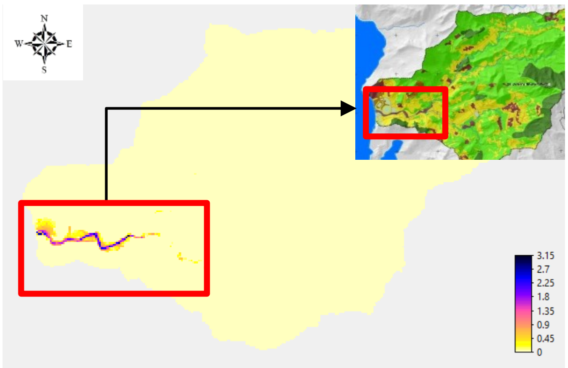

Figure 11. Flood depth of St. John's watershed (m) at 35 years return period

The difference of land-use characteristics affects flash-flood response. St. John's watershed is more urbanized. The urban development in St. George city (capital city of Grenada) increase rapidly, such as increasing the numbers of residential area, commercial area, public facilities, and others. The development of built-up areas in this watershed not only occurs in downstream area, but also in upstream area (**Figure 6**). The increase of built-up areas decreases the capacity of water infiltration into the soil. Thus, run-off will flow down into downstream area and causes flash-flood.

Less water infiltration is influenced by Ksat. The saturated hydraulic conductivity (Ksat) rate of water to infiltrate into the soil. Processes of soil compaction and human interventions with heavy machines in built-up area change the soil pores and make soil more compact, so the Ksat value will decreases. The Ksat value of built-up area is lower than others (10.00 mm/hr). Meanwhile, the natural land-use types, such as forest and mixed-tree have high value of Ksat. Ksat value of forest is 69.64 mm/hr and mixed-tree is 42.85 mm/hr (**Table 2**). If Ksat value decreases, the water infiltration rate will decrease too.

Generally, slope affects the flash-flood response. The greater slope makes the infiltration rate lower. However, slope in both watershed areas are same dominated with 25-55%. It means that slope factor is not a major indicator to determine the flash-flood response.

Besides land-use characteristics, shape and size of watershed also influence run-off [9]. Shape of St. John's watershed is rounder and bigger than Gouyave watershed. Run-off from multiple locations in St. John's watershed flow down and arrive at the same time in downstream areas. It causes the peak flow in St. John's watershed to be is higher than Gouyave watershed and gives the greater impacts to this area.

6. Conclusion

Urbanization is a factor that influences the flash-flood response. The high intensity of built-up areas decreases the water infiltration and increases the potential run-off. It is shown at St. John's watershed. This area responds by flash-flood in 5 years return period, meanwhile Gouyave watershed responds in 10 years return period. The flood depth of St. John's watershed is also higher than Gouyave in the same return period. It means that an area which is more urbanized has a higher response to flash-flood and has greater impact to flash-flood events.

7. References

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