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CASE STUDY

The impact of an urbanizing tropical watershed to the surface runoff

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ABSTRACT

The lack of hydrological data for urbanizing watersheds in developing countries is one of the challenges facing decision making. Msimbazi River is located in the city center of Dar es Salaam and is highly influenced by human activities; this includes dense populations that are characterized by informal settlements. The catchment is currently undergoing flooding, which triggers a dilemma in its surface runoff trending. This study aimed to simulate rainfall-runoff of an urbanizing Msimbazi watershed that will provide an understanding of hydrological data including peak flows and discharge volumes of Msimbazi River. The data used in the study include soil, rainfall, DEM and land use. HEC-GeoHMS and ArchHydro tools in ArcGIS were used to generate hydrological inputs to be used in the HEC-HMS interface. The resulted sub-watersheds have high CN values ranging from 70 to 90 implying the possibility of high runoff potential. Sub-watershed W620 indicates the highest runoff, among others with the highest runoff of 290mm for the year 2015. The peak flow on the river indicates the value ranging from 7.2 m^3/s to 30m^3/s with the highest values being on the downstream. The overall trend indicates an increasing surface runoff and peak flow in sub-watersheds from 1985 to 2015. Simulated results in this study were validated with the observational data of the catchment recorded in 2017. Given that most of the rivers in Tanzania are ungauged, the approach applied in this study can be used to enhance decision making on settlement planning, water resource, and disaster management in the currently observed urbanizing areas.

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INTRODUCTION

In recent years, humankind experiences an increase in an unpredictable flood occurrence contributed by both meteorological conditions and human alteration of the environment. Floods have affected human life, properties, and infrastructures; the situation becomes worse if not well managed (Winsemius *et al.,* 2016). Global disaster studies report tens of billions of US dollars annual losses, and a thousand casualties occur due to flooding (Hirabayashi *et al.,* 2013). The overall global trend indicates that in future floods are likely to increase more (Hirabayashi *et al.,* 2013; Ali *et al.,* 2011). Tanzania, like any other developing country with limited resources, only significant River catchments are gauged and continuously being monitored (Van Dijk *et al.,* 2016). The majority of small and seasonal rivers are ungauged; hence, there is limited hydrological data, which makes computational techniques for designs, planning, and decision making difficult. Dar es Salaam has a total of five seasonal rivers, which are Mpiji River, Mbezi River, Tegeta River, Msimbazi, and Kizinga Rivers. All the rivers are ungauged and lack historical hydrological information that can assist in understanding there hydrology and hydrodynamics within the catchment. Msimbazi River is located in the city center of Dar es Salaam and is highly influenced by human activities, including dense populations characterized by informal settlements (Schofield and Gubbels, 2019). The River is currently one of the vulnerable urban catchments having recurrent flood events (Kebede and Nicholls, 2012; Smiley and Hambati, 2019; Schofield and Gubbels, 2019). Despite the area being identified as hazardous by the 1979 Dar es Salaam city master plan (Armstrong, 1987), severe informal settlements started within the catchment in the early 1980s with a peak development in the 1990s (Kombe, 2005). Population growth might have triggered the need for urban infrastructure construction in the Msimbazi catchment to support demand (Ndetto and Matzarakis, 2013). The population is mostly concentrated in the Msimbazi River catchment due to its proximity to the city center, where most of the socio-economic activities are undertaken. In this current decade, surface runoff estimation for the historical events based on the rainfall is becoming a cornerstone for accurate and reliable hydrological data required for designs of infrastructures and catchment operations as well as response to different activities that may help in floods forecast, water allocation and climate studies (Blöschl, 2006). However, the rainfall-runoff concept in the ungagged catchment can be a challenge due to non-linearity in the hydrological processes (Beven and O'Connell, 1982). In order to fulfil the demand, understanding of the hydrological and hydro-dynamics of the river together with catchment characteristics need accurate assessment. A catchment like Msimbazi undergoes various hydrological and hydrodynamic processes conditions, including precipitation, evapotranspiration, infiltration, groundwater percolation, and finally, surface runoff, each at diverse spatial and temporal scale (Devia *et al.,* 2015). The output interaction of these processes is surface runoff presented by runoff hydrograph. Surface runoff is one of the aspects for a hydrological parameter that indicates a measure of precipitation not infiltrated into the ground and consequently accumulate to a higher surface runoff as a flood. One of the methods to estimate the accumulated surface runoff in an ungagged stream is by using Curve Number (CN). Watershed in this study is defined as a natural occurring hydrological unit that, in a rainfall event, contributes surface runoff to a single unit based on the geographical boundary (Bera *et al.,* 2014). Hydrological Engineering Centre - Hydrologic Modeling System ((HEC-HMS) was used to simulate rainfall-runoff processes for this urbanizing watershed. It is a semi-distributed model that takes into account the spatial distribution of the hydrological units by simulating the hydrological process that includes evaporation, infiltration, and runoff (Scharffenberg and Harris, 2008). Its semi-distribution into hydrological units considers spatial characteristics of each sub-watershed, including land use, soil, and weather as homogenous. All spatial parameters used on HEC-HMS are prepared and imported from HEC-GeoHMS in GIS. Runoff and peak discharges of the catchment are estimated from the Soil Conservation Service (SCS) Curve Number (CN) model. Therefore, the study hypotheses that an increase in urbanization leads to increased surface runoff within a watershed. It aims to simulate rainfall-runoff of an urbanizing watershed by providing an understanding of the watershed hydrological data including peak flows and discharge volumes of Msimbazi River. This is significant for developing countries to generate information useful in informed decision making on settlement construction and disaster-related measures. This study has been carried out in the Msimbazi river watershed located in Dar es Salaam Tanzania in 2019.

MATERIAL AND METHODS

Study area description

Msimbazi River Watershed forms part of the Wami Ruvu basin in the eastern part of the Ruvu sub-basin (Ngana, 2010). The watershed is one of the four river basins available in Dar es Salaam that covers 192km^2 (Fig. 1). The river originates from Pugu Hills flowing through the North of Dar es Salaam city center into the Indian Ocean. Some of its tributaries are Ng'ombe and Kibangu Rivers. Climatically, Dar es Salaam is a tropical city that has a warm climate throughout the year. It has annual minimum, maximum and average temperatures of 16°C, 33°C and 26°C respectively. The average annual rainfall within the region is 1050 mm experienced in two rainy seasons; a short rainy season occurs from October to December at a monthly average of 75 – 100 mm and the more extended season is experienced from March to May, at a monthly average of 150-300 mm (Ndetto and Matzarakis, 2013; Ngailo *et al.,* 2018). The annual total and maximum rainfall characteristic from 1985 to 2015 is indicated in Fig. 2. The watershed is within sedimentary bedrock with coarse-grained sandy soil spreading on a broader area (Mtoni *et al*., 2012).

Datasets

The datasets used in the simulation of hydrological processes for Msimbazi River Watershed include soil type, land use, daily rainfall, river discharge data, and ASTER digital elevation model from (ASTER-DEM). The rainfall data used were from two stations, the Julius Nyerere International Airport (JNIA) station and the Port of Dar es Salaam (PD) station, both in the year 1985 to 2015. Daily flow data recorded from Kigogo and Ubungo bridge stations within Msimbazi River for the year 2017 were used for the calibration and validation of the model. The gauge stations within Msimbazi River were installed in 2017 by the World Bank and Tanzania Ministry of Water in the Msimbazi river restoration project.

Methods

The digital elevation model, ASTER-DEM (30 m), of the study area was retrieved from the USGS data source. DEM mimics topographic features of the city was applied in delineating streams, watershed and sub-watersheds (Tachikawa *et al.,* 2011). Based

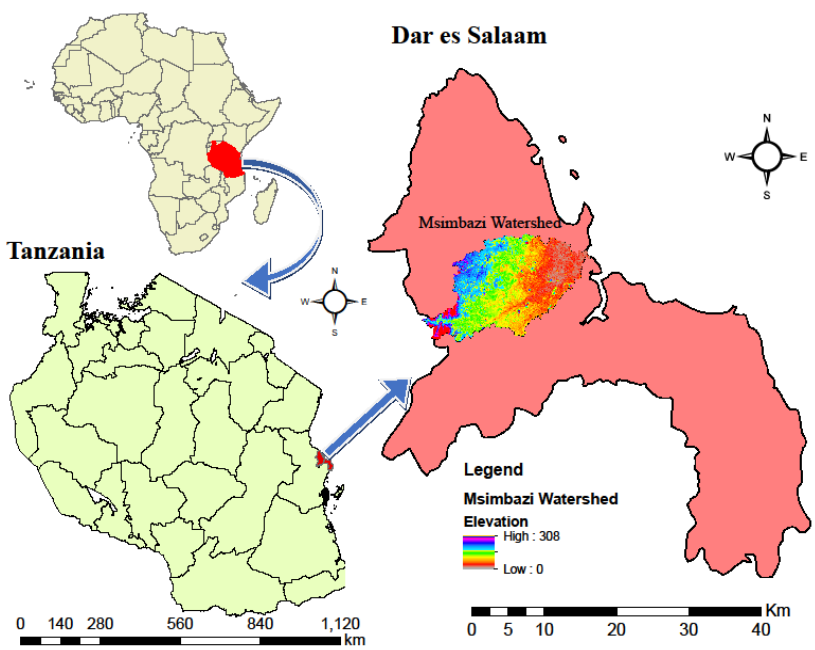

Fig. 1: Geographical location of the study area in Msimbazi River Catchment within Dar es Salaam City covering 15% of the Region in Tanzania

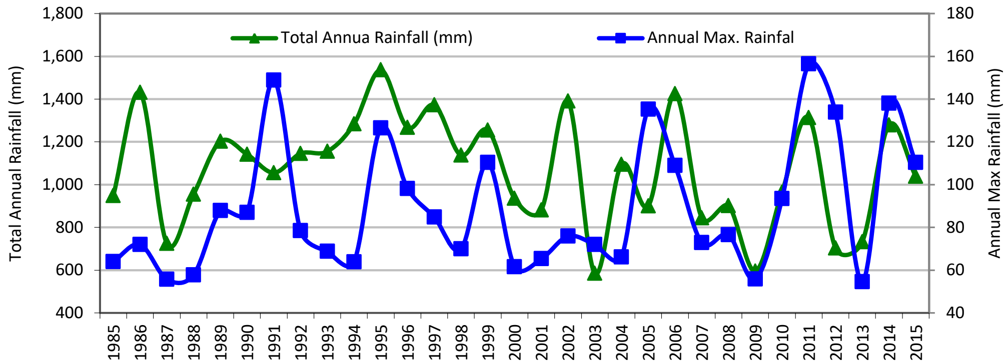

Fig. 2: Annual rainfall characteristic of the watershed from 1985 to 2015

Table 1: Study area soil group showing their texture and respective hydrological properties

Surface texture	Description and infiltration rate	HSG
Sandy clay fine	Low infiltration rates 2.5-12.5 mm/h	C
Clay loam	High runoff and low infiltration rates potentials <2.5 mm/h	D
Sandy	Low runoff and high infiltration potentials >25 mm/h	A

on the literature, the method explained by Fleming and Doan (2010) was applied in the delineation of the watershed. The method makes use of the ArcGIS 9.3 extension tools of Hydrological Engineering Centre - Geospatial Hydrological Modelling System (HEC-GeoHMS) together with ArcHydro extension to generate the data sets and create input files for the sub-watersheds for usage in HEC-HMS. HEC-GeoHMS and ArchHydro area geospatial hydrological toolkits available for ArcGIS generation of hydrological inputs that can be transferred in the HEC-HMS interface (El Alfy, 2016; Satheeshkumar *et al.,* 2017; Zhang *et al.,* 2010).

Soil Types and Land Use

Soil maps indicating the surface layers were prepared from Dar es Salaam Region soil maps that are available at Tanzania Ministry of Agriculture. The maps, most of them being at the scale of 1:7,500,000, were georeferenced, mosaicked, and digitized to extract shapefile polygons of soil groups. Three main soil textures (Table 1) were further classified into their respective Hydrological Soil Groups (HSG) using categories reported in previous studies (Cronshey, 1986; Kumar *et al.*, 1991; Rao *et al.,* 2011). Three HSG of A, C, and D were generated to reflect their soil infiltration property with the assumption that climatic region soil layer will have uniform properties related to runoff potentials (Fleming and Doan, 2010).

Landsat data acquired from Landsat 8, 5 and 4 Thematic Mapper (TM) in 2015, 2009, 1995 and 1989 were accessed from the USGS database already being pre-processed. The data was analyzed, and classified using Linear Spectral Mixture Analysis (LSMA) to obtain land use/cover for the area. Minimum Noise Fraction analysis was performed to generate scatterplots whereby from a combination of different image bands, the endmembers from abundant pixels were collected and used on LSMA. Four land use covers were identified in the study area, including vegetation, bare land, built up, and forest. The data generated from land-use data and soil hydrological groups were used as inputs in the generation of the CN grid in HEC-GeoHMS (Merwade, 2012).

Rainfall data

Distribution of the rainfall over the study area in time and space is essential in understanding and planning for hydrological disaster control measures. Thirty-two years daily rainfall data from 1985 to 2017 were acquired from the Tanzania Meteorological Agency (TMA). Two weather stations of Julius Nyerere International Airport (JNIA) and Port of Dar es salaam (PoD) are located within the catchment. Thiessen Polygon method was used to allocate the coverage area of a gauge within sub-watersheds. The method is an area-based weighting scheme analysis that assumes precipitation readings at a particular gauge is constant for the area associated with that gauge (Ali *et al.,* 2011). The data from two gauge stations were used to determine the spatial and temporal variation of rainfall-runoff of the area from HEC HMS based on literature (Ibrahim-Bathis and Ahmed, 2016; Verma et al., 2010). The Soil Conservation Service Runoff Curve Number (SCS-CN) model was applied and accepted for direct computation of cumulative runoff. The model cornerstones are on the amalgamate inputs of land use, antecedent moisture conditions and soil group to generate a runoff factor referred to as runoff Curve Number (CN) of a specific area (Cronshey, 1986; Rao *et al.,* 2017). CN is a constant factor ranging from 1-100 that indicate runoff potential for an area. The higher the CN, the higher the potential runoff. For a water body, CN is approximated to be 100 (Ibrahim-Bathis and Ahmed, 2016). CN grid was prepared and generated from the HEC-GeoHMS CN toolkit in ArcGIS (Merwade, 2012). Geo-HMS superimposes land use and soil hydrological group maps to obtain new polygons of land use soil. The land use soil polygon are estimated area, slope and finally each assigned with a curve number based on standard SCS chat of curve numbers to generate a CN grid map (Satheeshkumar *et al.,* 2017). For sub-watersheds with different land uses and/or soil types, the CN is taken as a weighted sum as indicated in Eq. 1 (Cronshey, 1986).

$$CN = \frac{\sum A_i CN_i}{\sum A_i} \tag{1}$$

Where, Ai and CN_i are areas and CN of each sub-watershed.

Estimation of HEC- HMS model parameters

HEC-HMS model was applied to simulate rainfall-runoff processes where most of the initial data pre-processing were carried in HEC-GeoHMS and Arc Hydro extension tools of GIS software (Gumindoga *et al.*, 2017; Merwade, 2012, Fleming and Doan, 2010). HEC-HMS is applicable in the simulation of single or multiple connected ungauged watersheds. It has empirical and conceptual models, both used for excess runoff simulation and forecast (Scharffenberg and Harris, 2008). HEC-HMS involves the development of three models that are basin model that mimics physical representation of watershed features, meteorological model, and control model for time specification; all are created using the ArcHydro tool and HEC-GeoHMS. The creation of a basin model is based on the terrain processing from the HEC-GeoHMS toolkit available in ArcGIS software. The kit uses topographical information from DEM and stream network to model the basin and sub-watershed and generate initial hydrological data required for modeling (Scharffenberg and Harris, 2008). Terrain pre-processing follows a sequence of steps described by Fleming and Doan (2010) to generate hydrological components from embedding river in the topographic feature to create drainage pathways that are used to delineate watershed basin and sub-watersheds to present a basin network.

The basin model contains all crucial segments of the hydrological system that include rivers, sub-watersheds, and junction. This basin model consists of eight sub-watersheds as seen in the schematic diagram (Fig. 3). The SCS unit hydrograph was used as a transformation method while the recession method was used to account for base flow (Fleming and Doan, 2010). The runoff loss rate was computed by the SCS Curve Number method given in Eq. 2. The algorithm computes excess runoff of a stream after the hydrological loss has taken place as a function of precipitation, soil cover, land use type and antecedent moisture conditions of the soil (Mishra and Singh, 2013; Ponce and Hawkins, 1996). From equation 2, Q represents the surface runoff, P stands for precipitation, Ia is the initial abstraction (loss), and S is the potential maximum water retention after runoff begins.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{2}$$

From the algorithm above, initial stages abstraction I_a takes into consideration the Interception, infiltration, and surface depression storage (Chow *et al.,* 1988). I_a and S have been proven to have an empirical relationship in gauges and ungauged watershed studies Eq. 3 (Fleming and Doan, 2010). Hence, by substituting it in Eq. 2, it gives a relationship of excess surface runoff based on rainfall depth and potential maximum retention.

$$I_a = 0.2S \tag{3}$$

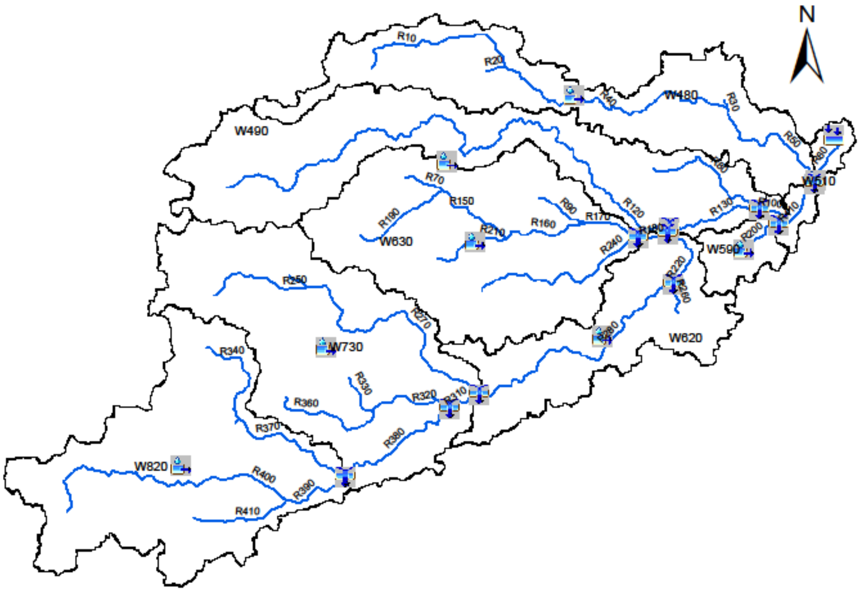

Fig. 3: Schematic diagram of the Msimbazi River watershed together with its sub-watershed

$$Q = \frac{(P - 02S)^2}{(P - 0.8S)} \tag{4}$$

Therefore from Eq. 4, runoff can be estimated from Rainfall (P) and potential maximum retention (S). S in SCS is represented by dimensionless constant derived from the Curve Number (Fleming and Doan, 2010). Bransby Williams Method for Time Concentration Tc (Eq. 5) is used to represent the time of which surface runoff traveled from the remote area to the outlet (Chow *et al.*, 1988). L stands for the length of Main River in km, D represents circle diameter that is equivalent to basin area in km, A is sub-watershed area (km²), and S is river slope (%).

$$TC = \left(\frac{L}{1.5D}\right)\frac{\sqrt[5]{A^2}}{S} \tag{5}$$

Flood Routing Process

Muskingum model which propagates flood routing in the ungauged watershed was applied for river routing (Franchini and Lamberti, 1994). The model is grounded on the assumption that the watershed bedrock is sandy and gravel; hence, the continuation mass balance of inflow and outflow is equivalent to storage rate. Muskingum K value represents the flood wave travel time.

Surface runoff statistical trend analysis

Man Kendall (MK) statistical analysis in Eqs. 6 and 7 were used in the analysis of the surface runoff pattern over the given period (Da Silva *et al.,* 2015). MK test is a non-parametric statistical test used in the hydrological time series analysis of data that lacks normal distribution (Da Silva *et al.,* 2015). Where Tj and Ti represent maximum or total annual values in years j and i. Single tailed Anova was used for a statistical test of the difference between the sub-watersheds.

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(\mathrm{Tj} - \mathrm{Ti}) \tag{6}$$

Where $sign(\mathrm{Tj} - \mathrm{Ti}) = \begin{cases} 1 if\ Tj - Ti > 0 \\ 0 if Tj - Ti = 0 \\ -1 if\ Tj - Ti < 0 \end{cases}$ (7)

RESULTS AND DISCUSSION

Msimbazi River catchment triggered a dilemma on data scarcity for understanding its flood pattern due to its ungauged situation. However, advancement in the integrated use of remote sensing and hydrological modelling technology narrowed the gap (Ibrahim-

Bathis and Ahmed, 2016; Halwatura and Najim, 2013). This study did modelling for rainfall-runoff events from 1985 to 2015 in order to understand the trend of the surface runoff and peak flow within the catchment. The flood modelling has been done to assess the more vulnerable areas which can, therefore, be employed to manage flood in urban areas. Msimbazi River Catchment covers an area of 192 km^2 and river lengths of 70 km, starting from Pugu hills to the Indian Ocean (Fig. 1). The volumetric slope of the watershed is relatively gentle while that of the river bed is sharp, with a range from 0 to 0.8%.

Watershed CN Grid

Land cover mapping for the study area resulted in four land cover types that include forest, vegetation, bare land, and built-up environment (Fig. 4). The larger area under land use indicates significant changes in land cover from 1985 to 2015. Land use indicates a built-up environment to be 11% in 1989, 15% in 1995, 31% in 2009 and 53% in 2015 indicate the magnitude of urbanisation within a watershed. Curve Number (CN) as a salient feature estimated from Geo-HMS based on the soil, land use and digital elevation model (DEM) is highly affected with change in land use. The CN Grid maps generated (Fig. 5) indicates a spatial distributional change in CN from 1985 to 2015. The increasing spatial change in CN value from 1985 to 2015 reflected the change in land use into a built-up environment that is impervious surface. The observed values are primarily indicating the likeliness of Msimbazi sub-basins to have higher surface runoff; this is also supported by Mishra and Singh (2013). Relative distribution of CN values in

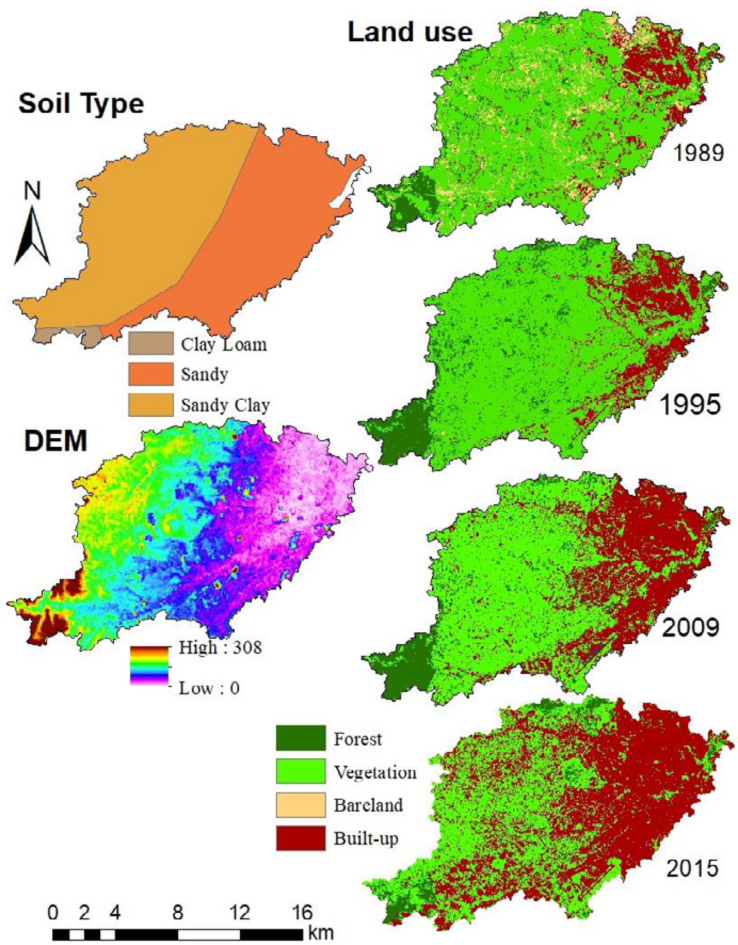

Fig. 4: Msimbazi catchment indicating the change in land use from 1989 to 2015, soil types and topographic

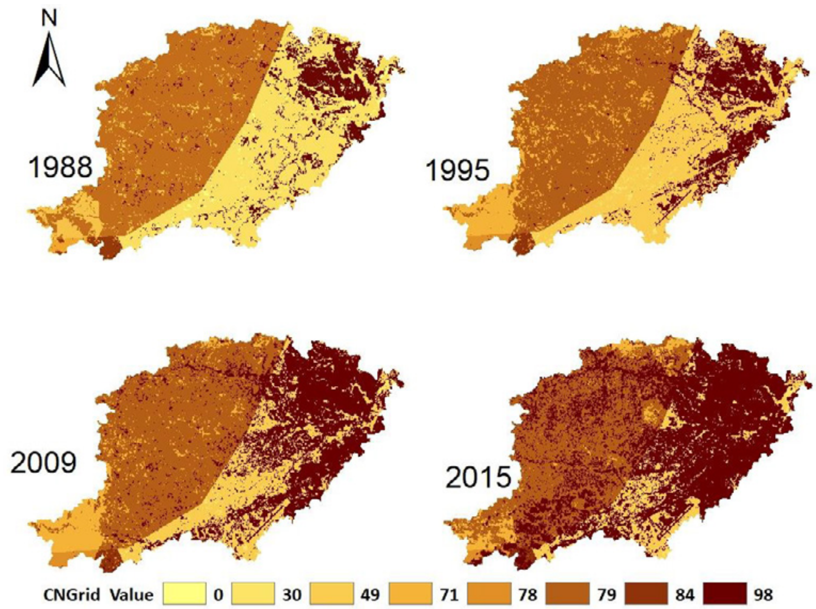

Fig. 5: Spatial distribution of CN Grid of Msimbazi watershed of the years

Table 2: Morphometric characteristic of the watershed

Sub Watershed	Shape length (km)	Area (km^2)	Basin slope	Basin (CN)	T_C (min)	Basin LAG (HR)
W480	57.30	22.07	6.09	89.89	276.02	2.60
W490	57.12	28.16	6.97	90.01	234.80	2.56
W510	13.26	2.25	5.10	78.32	95.94	1.12
W590	13.14	3.25	5.40	90.48	86.54	0.60
W620	38.70	15.38	4.76	88.70	247.33	1.88
W630	35.28	28.44	7.40	86.06	136.46	1.65
W730	40.56	30.26	7.80	81.60	147.83	2.14
W820	43.98	29.80	12.17	82.34	102.98	1.59

the watershed indicates higher values in areas with sandy clay soil when compared to sandy soil (Table 1); this reflects their ability to allow surface water percolation (Daniel *et al.,* 2017).

Catchment Characteristic

This study investigated the morphometric features of the watershed and their significance in understanding the probable geomorphic effect of flood. The applied parameters include watershed area, perimeter, shape, and slope, which were examined as essential factors to identify the outflow characteristics of the river and factors in determining the arrival time of the flood. The watershed delineation through GIS has been proved to be morphometrically effective for river basin analysis (Mangan *et al.,* 2019; Magesh *et al.,* 2011; Pareta and Pareta, 2011). Sub-watershed W820 has the highest slope of 12% while W620 has the lowest slope of 4.7% (Table 2). The loss and runoff properties of each sub-watershed are shown in Fig. 6. The higher the potential infiltration and the lower runoff per square meter on the sub-watersheds W490, W480, W620, and W590, which could be contributed by the presence of sandy soil conditions, low elevation and the majority of this area being a built-up land cover acting as an impervious surface area.

The concertation times (Tc) from upstream to downstream of the catchment varies in each sub-watershed, higher Tc in W480 and W490 indicate that floods surface runoff takes time to pass along its river system to which surface water continues to pile-up in the existing headwaters of the catchment due to its elongated shape (Sadatinejad *et al.*, 2012). This sub-watershed at downstream has a higher duration lag time compared to others, an indication of a much more slow flow of the surface runoff in the downstream area. The observed shorter duration lag time of the W590 indicates the possibility of earlier flooding than other watersheds.

Model calibration and validation

Simulations of the rainfall-runoff model require observational data for model verification (Rafiei et al. 2012). The simulated results from this study were validated using daily discharge data recorded at three gauges within the Msimbazi River. The three gauges are found in Ubungo, Jagwani and Kigogo under sub-watersheds W620, W630, and W490. The daily recorded data were used for calibration and validation of rainfall-runoff simulated events from 29th October to 31st December 2017. Results from the simulated data were validated to fit the observed data as in Fig. 7, whose correlation coefficient R^2 is 90% and root mean square error (RMSE) 0.4 m^3/s for discharges from simulated and observed data was observed (Fig. 8).

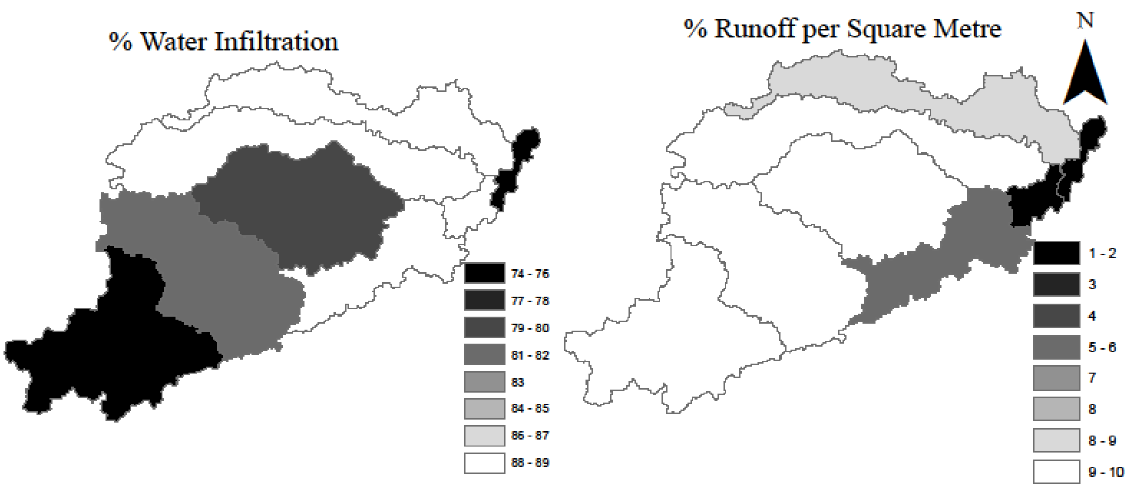

Fig. 6: Water infiltration and runoff in sub-watersheds

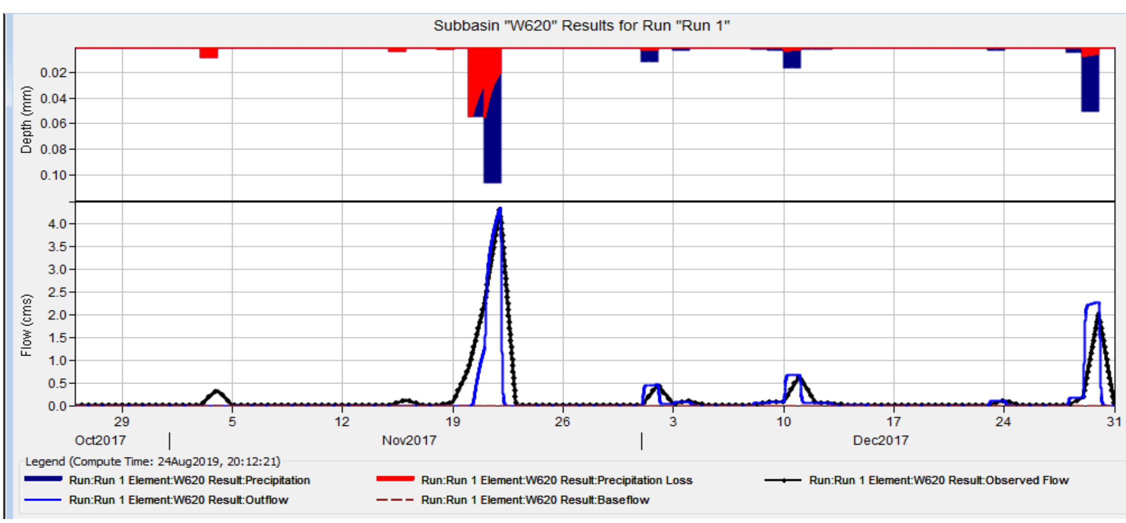

Fig. 7: Msimbazi outflow graphs for observed and simulation discharges 26 Oct to 31 Dec 2017

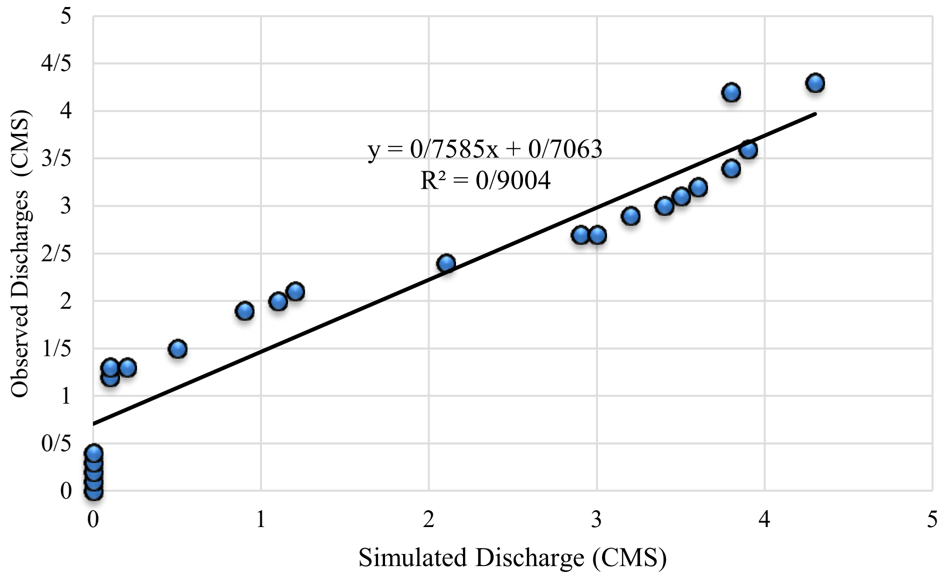

Fig. 8: Hydrological correlation between observed and simulation discharges on 26th Oct to 31st Dec 2017

Table 3: Simulated data for the three Sub-watershed

Subwatershed	Rf (mm)	Loss (mm)	Excess (mm)	Direct runoff (mm)	Peak discharge (m^3/s)	Time of peak
W620	75.80	28.53	47.27	47.27	4.3	22 Nov 2017 00:05
W630	75.8	45.91	29.89	29.89	5.6	22 Nov 2017 00:10
W490	78.3	25.76	50.04	50.04	8.2	22 Nov 2017 00:10

Table 4: Msimbazi River main channel simulation result for rainfall events in 2015

Stream	Drainage area (Km)	Length (Km)	Upstream elevation (m)	Downstream elevation (m)	Peak inflow (m^3/s)	Peak discharge (m^3/s)	Inflow volume (MM)	Discharge volume (MM)
R60	157.36	5.38	13.12	6.56	35.20	16.0	255.17	253.89
R100	132.04	0.91	22.97	26.25	30.90	30.2	259.13	257.53
R110	135.29	5.01	26.25	13.12	30.20	29.5	257.60	256.53
R130	103.88	8.66	52.49	22.97	23.20	21.8	264.01	262.35
R140	88.50	0.57	65.62	52.49	22.30	21.2	261.04	259.41
R180	28.44	2.93	98.43	65.62	7.20	7.8	257.47	256.08
R220	60.06	6.46	65.62	65.62	16.00	15.6	264.48	263.39
R280	60.06	23.88	160.76	65.62	15.90	16	266.10	224.48
R310	29.80	3.23	170.60	160.76	8.50	8.3	267.58	265.96
R380	29.80	12.88	213.25	170.60	8.70	8.5	269.20	267.58

This indicates accuracy in the ability of the model to predict runoff in the urban catchments. Table 3 indicates the properties of each sub-watershed on the rainfall event of 29th October to 31st December 2017.

Rainfall-runoff peak discharges

Given the calibration of the simulated rainfall-runoff data, a similar procedure was applied to simulate rainfall-runoff discharges of rainfall peak events for the past 30 years from 1985 to 2015. Table 4 indicates the result of the Msimbazi streams simulated for the event of 2015. The downstream streams have the highest runoff peak flow compared to others due to it being the outlet of the watershed. The runoff peak discharges depend on watershed

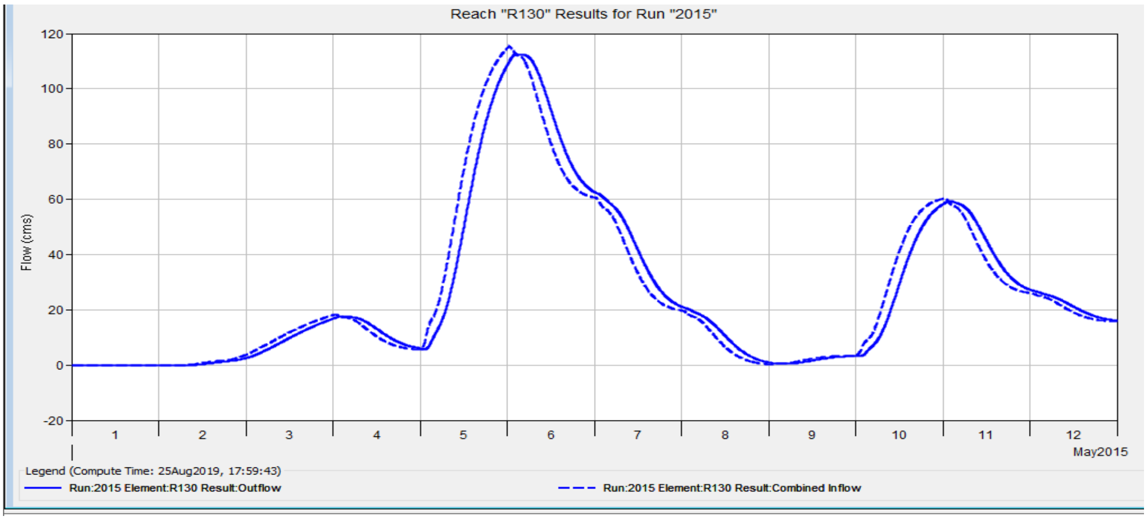

Fig. 9: HEC HMS simulated hydrograph of stream channel R130

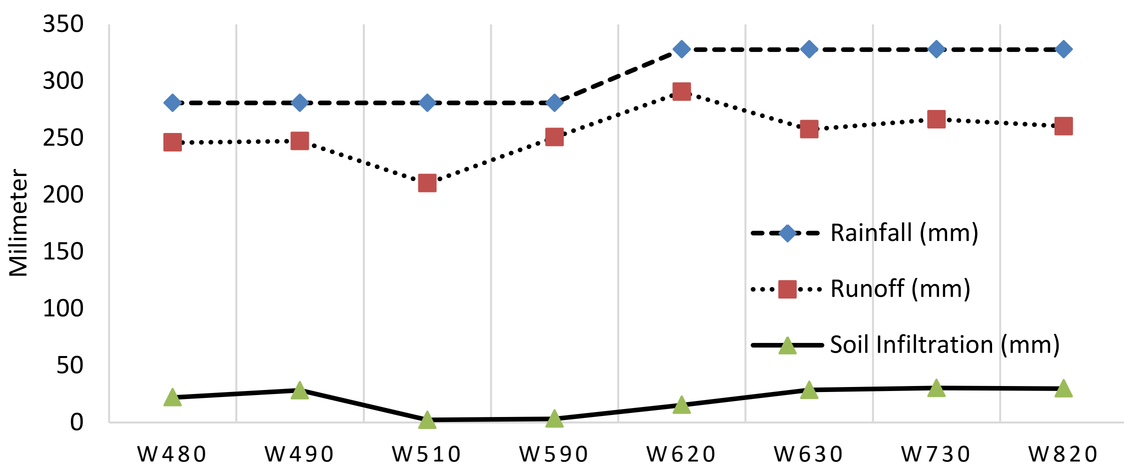

Fig. 10: Simulated result indicating individual behavior of each Msimbazi sub-watershed

characteristics. Fig. 9 is the unit hydrograph of the stream R130, indicating the relationship of its rainfall intensity to the discharge.

The relationship among rainfall, runoff and soil loss variability within sub-watersheds for the year 2015 event is indicated in Fig. 10. Soil infiltration rate is lower in W510 and W590, in which the areas have larger impervious areas compared to other sub-watersheds (Fig. 10). Runoff is seen to be higher in sub-watershed W620.

A similar procedure was used to simulate the rainfall-runoff variability of sub-watersheds from peak events from 1985 to 2015 (Table 5 and Fig. 11). Sub-watersheds W480, W490, W510 and W590 are subjected to more rainfall, of which it indicates high rainfall in the western part of the catchment. CN values were updated according to the change in land use with higher values ranging from 70 to 90 in 2015. The result indicates runoff variability in the sub-watershed with 1995 having a higher runoff (Fig. 11). One-way ANOVA indicated a significant statistical difference of the peak discharge among the sub-watersheds (P value<0.000) as is depends on the spatiotemporal distribution of the watershed

Table 5: Simulation result of Msimbazi sub-watersheds indicating the trend analysis

YEAR	W480		W490		W510		W590		W620		W630		W730		W820	
	RF	PF	RF	PF	RF	PF	RF	PF	RF	PF	RF	PF	RF	PF	RF	PF
2015	280.8	23.6	280.8	30.2	280.8	2.2	280.8	3.5	327.7	19.0	327.7	32.7	327.7	35.5	327.7	35.3
2014	319.0	35.0	319.0	44.7	319.0	3.4	319.0	5.2	336.0	24.1	336.0	42.6	336.0	45.9	336.0	45.5
2013	68.7	11.9	68.7	15.3	68.7	0.9	68.7	1.8	100.0	8.0	100.0	10.8	100.0	12.5	100.0	12.8
2012	144.8	15.1	144.8	19.3	144.8	1.4	144.8	2.2	196.4	23.2	196.4	40.5	196.4	43.9	196.4	43.5
2011	222.0	27.5	222.0	35.1	222.0	2.5	222.0	4.1	291.4	16.2	291.4	26.9	291.4	29.5	291.4	29.4
2010	184.3	16.7	184.3	21.3	184.3	1.6	184.3	2.5	267.9	16.0	267.9	27.1	267.9	29.6	267.9	29.4
2009	179.7	15.8	179.7	20.3	179.7	1.5	179.7	2.4	268.1	27.0	268.1	47.9	268.1	51.3	268.1	51.1
2008	109.0	18.2	109.0	23.9	109.0	1.6	109.0	2.8	129.0	12.5	129.0	20.8	129.0	22.5	129.0	22.7
2007	109.8	17.7	109.8	23.9	109.8	1.5	109.8	2.7	195.4	12.2	195.4	20.1	195.4	21.7	195.4	21.6
2006	151.4	12.1	151.4	16.4	151.4	1.0	151.4	1.9	91.8	3.6	91.8	5.4	91.8	5.9	91.8	5.9
2005	291.4	27.5	291.4	35.1	291.4	2.5	291.4	4.1	222.0	16.2	222.0	26.9	222.0	29.5	222.0	29.4
2004	86.4	6.6	86.4	9.3	86.4	0.5	86.4	1.0	249.2	11.1	249.2	19.7	249.2	21.1	249.2	20.9
2003	28.3	1.7	28.3	2.8	28.3	0.1	28.3	0.3	137.7	10.7	137.7	17.8	137.7	19.3	137.7	19.1
2002	541.3	22.5	541.3	29.2	541.3	2.2	541.3	3.4	528.9	11.3	528.9	20.4	528.9	21.8	528.9	21.5
2001	162.5	7.9	162.5	10.4	162.5	0.8	162.5	1.2	195.5	7.4	195.5	13.8	195.5	15.2	195.5	15.8
2000	177.4	12.0	177.4	15.6	177.4	1.2	177.4	1.8	222.0	7.1	222.0	13.3	222.0	14.7	222.0	15.4
1999	127.4	15.8	127.4	20.9	127.4	1.7	127.4	2.4	166.0	13.8	166.0	25.9	166.0	28.3	166.0	29.5
1998	327.7	20.5	327.7	26.9	327.7	2.2	327.7	3.1	326.5	9.2	326.5	17.3	326.5	19.1	326.5	20.3
1997	135.8	20.5	135.8	26.9	135.8	2.2	135.8	3.1	146.0	9.2	146.0	17.3	146.0	19.1	146.0	20.3
1996	177.4	12.0	177.4	15.6	177.4	1.2	177.4	1.8	222.0	7.1	222.0	13.3	222.0	14.7	222.0	15.4
1995	575.9	41.3	575.9	53.2	575.9	4.2	575.9	6.1	600.8	22.0	600.8	40.8	600.8	43.5	600.8	43.0
1994	313.4	37.6	313.4	48.4	313.4	3.9	313.4	5.6	245.0	8.7	245.0	16.1	245.0	17.5	245.0	17.8
1993	351.1	20.6	351.1	26.3	351.1	2.1	351.1	3.0	320.1	9.9	320.1	19.3	320.1	19.6	320.1	20.1
1992	151.5	30.3	151.5	38.6	151.5	3.1	151.5	4.5	172.2	5.5	172.2	11.8	172.2	11.0	172.2	12.2
1991	164.0	24.4	164.0	31.0	164.0	2.5	164.0	3.6	169.1	20.7	169.1	43.6	169.1	41.4	169.1	45.2
1990	121.6	14.2	121.6	18.1	121.6	1.4	121.6	2.1	159.8	8.7	159.8	21.2	159.8	17.6	159.8	21.6
1989	96.1	12.5	96.1	15.7	96.1	1.2	96.1	1.9	102.6	9.3	102.6	22.1	102.6	19.0	102.6	22.9
1988	103.2	13.6	103.2	17.1	103.2	1.3	103.2	2.0	165.5	5.7	165.5	13.9	165.5	11.7	165.5	14.3
1987	152.9	11.0	152.9	14.0	152.9	1.1	152.9	1.6	134.7	7.0	134.7	15.3	134.7	14.1	134.7	15.9
1986	188.0	14.1	188.0	17.8	188.0	1.4	188.0	2.1	243.5	6.4	243.5	14.8	243.5	13.0	243.5	15.3
1985	194.4	13.3	194.4	16.8	194.4	1.3	194.4	1.9	225.0	8.7	225.0	18.2	225.0	17.5	225.0	19.0
Sen's slope		0.14		0.15		0.00		0.02		0.34*		0.4*		0.5*		0.4*
MEAN	201.2	18.5	201.2	23.9	201.2	1.8	201.2	2.8	230.9	12.2	230.9	22.5	230.9	23.5	230.9	24.3

SW=Sub Watershed, RF is Rainfall in mm, PF is Peak Flow in m^3/s, * statistically significant at 95% significant level by Mann- Kendall trend

rainfall and curve number which diverges. The peak flow trend analysis by Mann Kendal indicates a positive Sen's slope indicating an increase of peak flow from 1985 to 2015 in all sub-watersheds. However, some of the Sub-watershed including W620 (p-value of 0.00), W630 (p-value of 0.04), W730 (p-value of 0.00), and W820 (p-value of 0.016), prove a statistical increase in trend as this are watersheds that have undergone significant change in land use from 1985 to 2015. At a 95% confidence interval, the simulated runoffs of each sub-watershed were tested to determine trend analysis from 1985 to 2015(Fig. 9). Surface runoff for the W820 (p-value of 0.03), W730 (p-value of 0.01), W630 (p-value of 0.04) and W620 (p-value of 0.00) indicates a significant increasing trend of surface runoff for a period of 1985 to 2015. Other sub-watersheds such as W590 (p-value of 0.21), W510 (p-value of 0.1), W490 (p-value of 0.10) and W480 (p-value of 0.11) indicated a positive trend based on sin's slope (Fig. 11). However, results were not statistically significant. The positive sins slope among all sub-watershed indicated the runoff has significantly increased in the catchment and may continue to increase as the area is undergoing changes that may be associated with an increase in the flood such as change of the land use to the impervious surface (Ebrahimian *et al.,* 2016; Loch, 2000; Mutayoba *et al.,* 2018).

CONCLUSION

The study combines the use of a geographic information system and the hydrologic model (HEC-HMS) in examining rainfall-runoff of the flood-prone urbanizing watershed of Msimbazi River to understand the trend of surface runoff. The urbanizing watershed prone to flooding is characterized by a lack of hydrological data to understand its flood pattern. The catchment geomorphological characteristics which were generated using ArcGIS indicated most of the sub-watersheds have high CN values ranging from 70 to 90, implying the possibility of high runoff potential

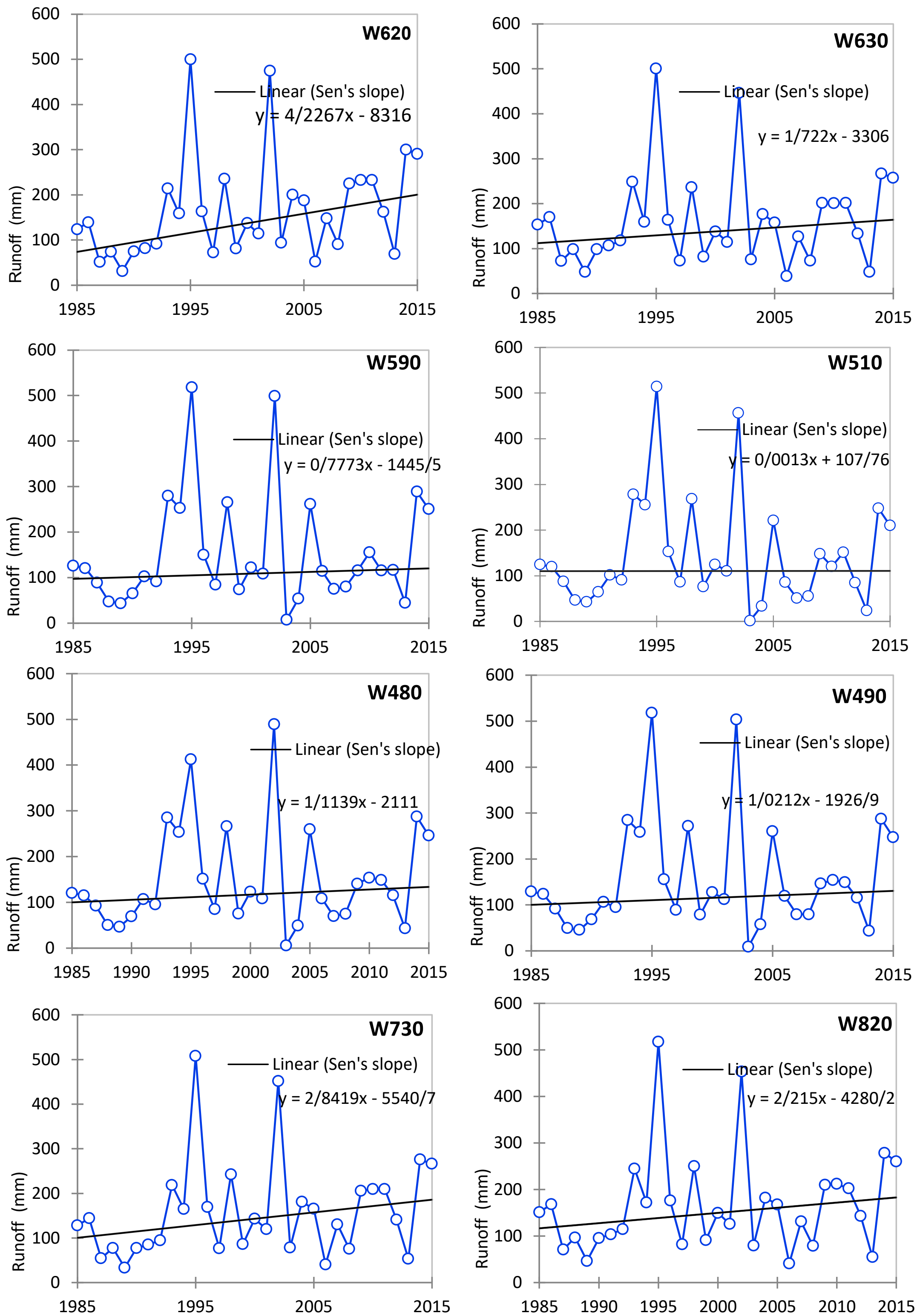

Fig. 11: Surface runoff pattern analysis for the simulated runoff discharges in each sub-watershed

in rainfall events, the surface runoff is estimated to be up to 500 mm. Sub-watershed W620 indicates the highest runoff, among others, with a higher runoff of 290 mm for the year 2015. The simulated peak flow on the river indicates the mean value ranging from 1.8 m^3/s to 24 m^3/s within sub watershed and a positive increase from 1985 to 2015. The result of the surface runoff simulation from 1985 to 2015 indicates hydrological characteristics of the sub-watersheds and peak flow on rainfall events at a specific rainfall. The overall trend indicates a positive Sen's slope with the increasing pattern of the surface runoff over the years. Implying that surface runoff has increased in the watershed as a result of the ongoing urbanization that reduces the surface area for infiltration and increases the concentration-time. Therefore, as the Msimbazi Watershed located in the city center of Dar es salaam, the continuing urbanization will result in the increase of the magnitude of the surface runoff volume and peak flow that will generate more flood events that the ones which are currently observed threatening the urban population. Given that most of the rivers are ungauged countrywide, this approach can be used to enhance decision making on settlement planning, water resource, and disaster management in the currently observed urbanizing areas.

AUTHOR CONTRIBUTIONS

B. Igulu performed data collection and provided environmental science expertise, also worked on the interpretation of GIS and remote sensing data used in this study, and participated in the writing of the manuscript. E. Mshiu provided remote sensing expertise and geology in spatial analysis of remote sensing data sets for enhancement of land use signals, he also participated in writing the manuscript.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
^0C	Degree Celsius
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
ASTER	Advanced space borne thermal emission and reflection
CN	Curve number
DEM	Digital elevation model
Eq	Equation
Fig	Figure
HEC-HMS	Hydrological Engineering Centre - Hydrologic Modeling System
HSG	Hydrological soil groups
ID	Identification
JNIA	Julius Nyerere International Airport
km	Kilometre
km^2	Kilometre square
m^2/s	Metre square per second
mm	Milimiter
PoD	Port of Dar es salaam
RMSE	Root mean square error
SCS	Soil conservation service
Tc	Time of concentration
TM	Thematic mapper
TMA	Tanzania Meteorological Agency
US	United State

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