

Full Length Research Paper

Estimating Flood Magnitudes of Ungauged Urban Msimbazi River Catchment in Dar es Salaam, Tanzania

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ABSTRACT

More often daily climate data have been used in hydrological models to estimate flood flows in small data scarce urban and rural catchments where flow peaking and recession are quick within short periods of few hours. This study assesses magnitudes of error of using daily climate data to simulate flood flow hydrographs of a small urban river catchment, Msimbazi River. Spot discharge measurements were available for Apr-May 2014 and Mar-May 2015 periods. 10-minutes climate records were available at one station, daily temperatures at two stations while daily rainfall records at several stations within the catchment. Visual analysis characterise rainfall events during the 2011, 2014 and 2015 floods, Thiessen-polygon was used for catchment rainfall, Hargreave-Samani model for catchment potential evapotranspiration and flow hydrographs were estimated by calibrated HBV model. Length weighted channel slope was estimated from segment slopes established from available topographical maps and used in estimating time of concentration for the catchment using Kirpich method. Results indicated that simulated flood hydrographs using 10-minutes climate inputs produced higher flood peaks for both December 2011 (peak: 471.6 m³/s) and April 2014 (peak: 393.5 m³/s) and expected hydrograph recession behaviour reproducing the Kirpich estimate of time of concentration of 7 hours. Simulated flood peaks using daily climate inputs were 252.3 m³/s for December 2011 and 205 m³/s for the April 2014 event being 53% and 52% of those simulated from 10-minutes climate inputs. Despite usefulness of 10-minute climate data, these data are required at more stations within the catchment for reliable simulation of fast receding urban floods and therefore more automatic weather stations are needed in Dar es Salaam.

Key words: Flood hydrographs, Hargreave-Samani model, hydrological models, Kirpich method, Thiessen-polygon. flood hydrographs, ungauged urban river.

INTRODUCTION

Riverine floods have been a constant threat to people inhabiting low-lying areas and floodplains, which have either been associated with overflows of water into floodplains and/or exceptionally high

instream river stages. Tanzania has large number of floodplains, which are normally and annually inundated with flood water, and pass exceptionally extreme and rare high flood water in extremely wet years receiving abundant rains. Consequently, several regions of Tanzania have

experienced floods of different magnitudes in the past, events which were rarely documented (EM-DAT, 2008).

The threat of floods is greatest in urban floodplains including Msimbazi floodplain in Dar es Salaam with increasing impacts in Dar es Salaam in the last 10 years. Several floods of different severity level have occurred in December 2011, April 2014, May 2015, April 2016, March 2017, and April 2018 affecting people and properties in various areas. Although floods have been annual events during the Masika (long rains) season in March-May

period in the Msimbazi floodplain, the recent floods have hit many areas in the city some far from the Msimbazi floodplain and some events occurring unusually during the Vuli (short rains) season in October-December period. However, the most frequently affected areas are located in Ilala District of Dar es Salaam (Figure 1) and specifically in the Msimbazi floodplain (Figure 2) into which River Msimbazi is joined by its large tributaries, Rivers Luhanga, Ubungo and Sinza before discharging into the Indian Ocean at Selander Bridge.

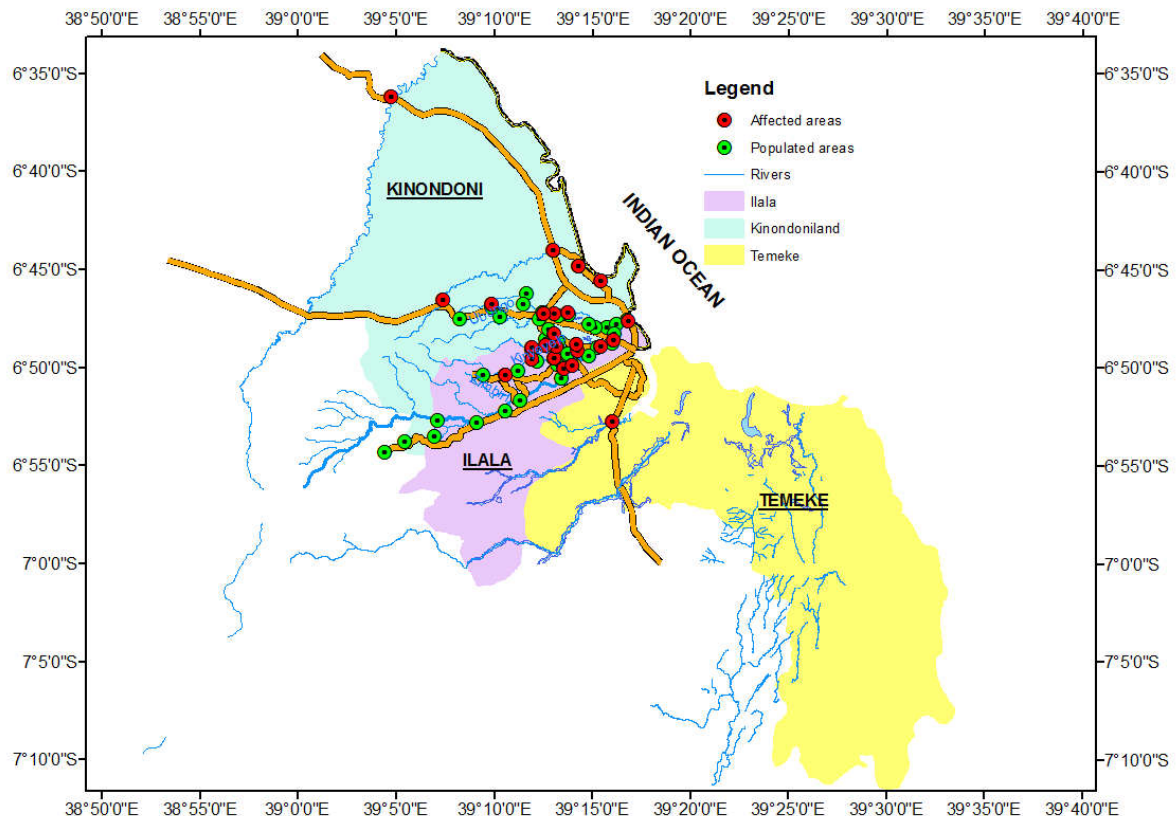


Figure 1: Areas affected by recent floods in Dar es Salaam.

Although floods in Dar es Salaam have occurred in 6 of the last 8 years, they were caused by heavy rains of different patterns occurring as single or multiple events within 24 hours lasting between 1 and 3 days. Consequently, there are similarities and differences between the recent floods in terms of volumetric flows, area extent and duration. The 2011, 2017 and 2018

floods extended for the entire lower Msimbazi flood plain (Vingunguti-Jangwani-Selander Bridge) while the 2014, 2015 and 2016 extended for the Jangwani-Selander Bridge portion of the floodplain. Owing to such variability in the flood characteristics, these floods had different levels of impacts in the natural, social and economic systems of Dar es

Salaam including impacts of inundation on settlements, loss of lives, damages to river cross sections, damages to road infrastructure, damages to buildings and paralysis of transport services.

Management of Dar es Salaam floods is hindered by the lack of hydrographic monitoring network as a few gauges had historically been installed and operated predominantly before the independence in 1961. However, most of them were closed, damaged and/or records missing. As a

result, it is difficult to provide quantification of how large volumes of water have been passing during the recent floods although the floods peaks lasted for some hours before levels receded to low stages. Fortunately, there has been continuous monitoring of rainfall and climate variables at several stations in and around the city with varying observation intervals from minutes to 24 hours, which can be used to estimate quantities of water passed during the recent flood events.

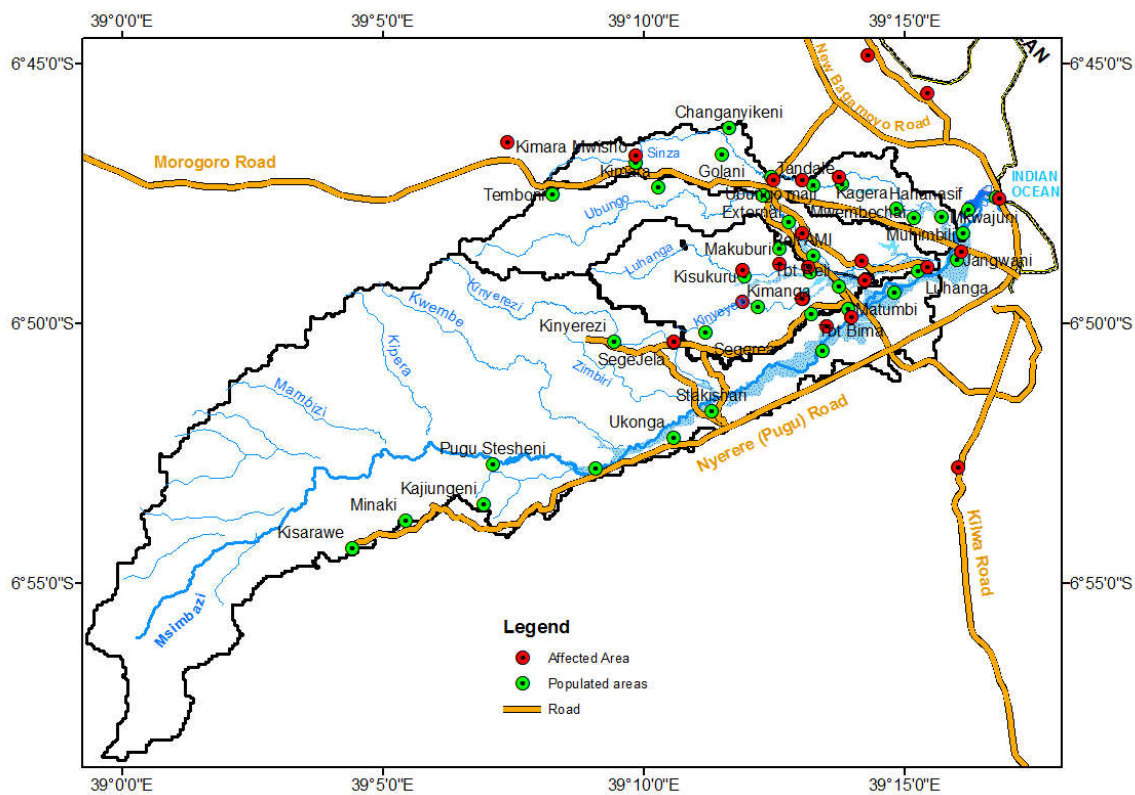


Figure 2: Sub-catchments of Msimbazi catchment showing flood affected areas.

Unavailability of continuous flow records at old gauging stations in Msimbazi catchment classifies it as hydrologically ungauged catchment. However, these catchments may have partial or fully available climate records at various locations within and around them. In such cases where data is scarce or unavailable, the hydrologists have developed models and techniques which do not require the availability of long time series of meteorological and hydrological

observations (Loukas and Vasilades, 2014; Blöschl *et al.*, 2013; Botero and Francés, 2010; Nag and Biswal, 2019; Post, 2004). Depending on whether flow hydrographs, statistics or quantiles are the required outputs, several methods can be used including rainfall-runoff modelling using global parameters transfer, quantile estimation from empirical methods and time series summaries from flow duration curves (FDC) regional equation (Swain and Patra, 2017; Valimba, 2016; Loukas

and Vasiliades, 2014). They fall into either statistical, hydrological modelling or stochastic modelling methods (Loukas and Vasiliades, 2014) and more often employed simultaneously.

Unavailability of continuous flow records in Msimbazi catchment have hindered application of rainfall-runoff or routing models in the generation of long discharge records for studying behaviour of flood hydrographs and flooding in the catchment. Anchor Environmental Consultants (2016) have estimated flood quantiles in Msimbazi catchment using statistical methods. No attempt has yet been made to use hydrological and stochastic models in this catchment as have been applied elsewhere where model parameters have been transferred from gauged catchments (Gandry *et al.*, 2013; Valimba, 2016; Valimba, 2019). This approach would provide the entire flood hydrographs as used in Mazvimavi (2003), Deckers (2006), Bárdossy (2007), Perera (2009) and Fionda (2011). They include full transfer of optimum model parameters to target catchment from a nearby catchment (spatial proximity), a similar catchment (spatial similarity or physical reasoning) or used regression-based regionalisation of model parameters. These approaches have their own strengths and weaknesses (Bárdossy, 2007; Bastola *et al.*, 2008).

Lack of stream-flow records in this small Msimbazi catchment result in the catchment being treated as hydrologically ungauged where empirical methods have been used in estimating flood quantiles (Anchor Environmental Consultants, 2016). Despite successes in establishing flood quantiles, it was not possible to study behaviour of the recent floods including peaking time and recession behaviour, which are important in relation to managing impacts of flooding. Availability of few spot discharge measurements at various locations along

River Msimbazi and daily/sub-daily (10-minutes) climate data provides opportunities for the use of hydrological modelling to simulate flood flow hydrographs during the recent floods. Moreover, flood hydrograph behaviour (flow magnitudes and recessions) of small fast draining urban catchments have often been underestimated when daily climates have been used. Therefore, the objective of this study was to assess suitability of observation time intervals in the estimation of flood magnitudes and recession of fast draining urban River Msimbazi in Dar es Salaam.

METHODS AND MATERIALS

The Study Area

The surface water resources within the Msimbazi catchment (268.17 km²) comprise the riverine and palustrine wetlands systems organised within smaller sub-catchments of major tributaries draining into River Msimbazi. The sub-catchments are related to drainage locations of major tributaries with respect to the seasonally inundated Msimbazi floodplain. Consequently, all tributaries draining into River Msimbazi upstream of the floodplain (Kinyerezi, Zimbiri, Kwembe, Kipera, Mambizi, etc) are within the main Msimbazi sub-catchment while tributaries draining directly into River Msimbazi within the main floodplain (Sinza, Ubungu, Luhanga) form separate sub-catchments (Figure 2). This division considers the overflow of the three rivers which, during extreme flooding, contribute directly to floodplain flow before reaching their confluences with River Msimbazi. These sub-catchments are largest main Msimbazi sub-catchment (68.4%), Ubungo sub-catchment (11.4%), Sinza sub-catchment (8.8%) and Luhanga sub-catchment (11.1%). The permanently inundated estuary at Msimbazi Bay is 0.3% of the catchment. Consequently, much of water draining through the

floodplain comes from the main Msimbazi sub-catchment, whose largest area lies upstream of the River Kinyerezi confluence (Figure 2).

River Discharge Records

River Msimbazi had historically been gauged at Stakishari (1J4), whose record is missing. Several other rivers in catchments around Msimbazi sub-catchment in Dar es Salaam had historically been gauged particularly before independence including Sinza at Ubungo (1J2), Mlalakuwa at Colito Barracks (now Lugalo Barracks, 1J3), Mbezi at Bigwa downstream (1J7),

Kizinga at Mbagala/Buza (1J8) and Mzinga at Majimatitu (1J6) and at Kichemichemi (1J9). However, most of them were closed, damaged or missing records hindering estimation of Msimbazi discharge. Consequently, spot discharge measurements were carried out at 5 strategic locations (Figure 3) along River Msimbazi between Stakishari-Segerea Road Bridge and Tabata Matumbi upstream of Railway Bridge (Table 1). The first two sites (MS1 and MS2) are located upstream of overflow sections while other sites are located in the potential overflow locations.

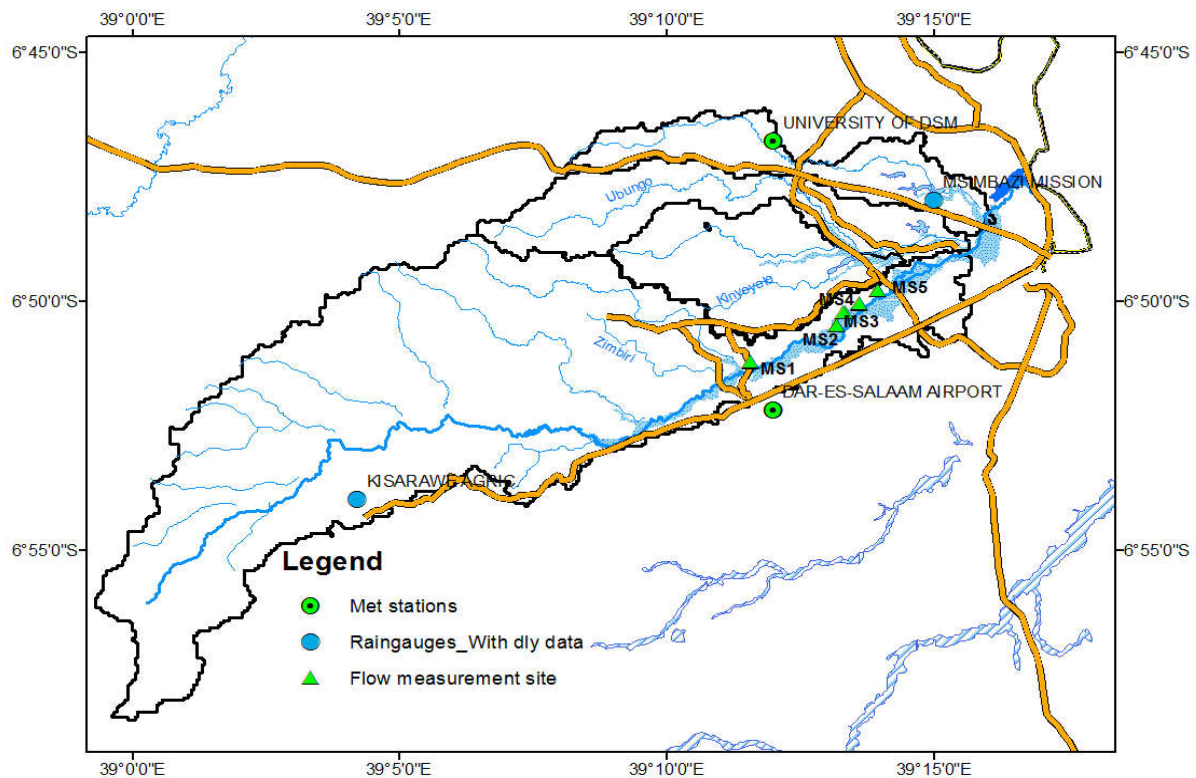


Figure 3: Flow measurements sites, rainfall and climate stations in and around Msimbazi catchment with daily and/or sub-daily data.

During all recent extreme flooding events, water remained in-stream at MS1 while slightly overflow the Vingunguti (MS2) road bridge. This MS1 site has stable cross section of clayey banks and bed with an estimated bankful discharge $603 \text{ m}^3/\text{s}$ at 3.59 m stage of the right bank. Owing to large number of flow measurements and its

location with respect to measurements of flows, MS1 site was selected for quantification of flood discharges. It has 4 spot discharge measurements in the Apr-May 2014 period, 5 measurements in the Mar-May 2015 period and 2 data points in May 2018.

Table 1: Spot measurement sites along river Msimbazi.

Code	Location	N	E	Data points	Dates
MS1	Stakishari-Segerea washed away Road Bridge	9242173.92	521429.3	11	11 Apr 2014 – 17 May 2018
MS2	Downstream Vingunguti Road Bridge	9243584.58	524472.1	5	1 May 2014 – 18 May 2015
MS3	Tabata-Bima	9244996.46	525413.30	4	12 May 2015 – 21 May 2015
MS4	Tabata-Shule	9244554.53	524971.12	4	12 May 2015 – 21 May 2015
MS5	Tabata-Matumbi upstream railway bridge	9244813.91	525896.3	4	12 May 2015 – 21 May 2015

Rainfall and Climate Records

There are two meteorological stations in Dar es Salaam, the Julius Nyerere International Airport (JNIA) and University of Dar es Salaam (UDSM). Several rain gauges existed and few are still existing within and around the catchment with records in various periods of the 1898-2018 period. Only three stations UDSM, JNIA and Kisarawe Agriculture have data available in the recent floods period (December 2011 – May 2018). Daily rainfall records were available at all three stations while daily minimum and maximum temperature records were available at the two met stations (UDSM, JNIA). 10-minutes rainfall/climate records were available at UDSM for the 15 Dec 2011 – 25 Mar 2015 period and sub-daily rainfall/climate data were not readily available for the study. At every 10 minutes interval, minimum and

maximum temperatures were taken as lowest and highest temperatures between any two successive intervals. Hourly minimum and maximum temperatures were taken as lowest and highest of the six temperatures in an hour while hourly rainfall series were accumulations of rainfall amounts received in particular hours.

Catchment Topography and Slopes

The study used topographical maps of Dar es Salaam at 1:50,000 scale covering the entire catchment with a contour interval of 20 m. From topographical maps, lengths of River Msimbazi were measured between consecutive contour lines and slopes were calculated for each river segment between two contour lines (Table 1). Final catchment slope (S) of 0.005165 m/m was computed as a weighted average slope calculated as (UDFCD, 2018).

$$S = \left[\frac{L_1 S_1^{0.24} + L_2 S_2^{0.24} + L_3 S_3^{0.24} + \dots + L_n S_n^{0.24}}{L_1 + L_2 + L_3 + \dots + L_n} \right]^{4.17} \dots\dots\dots(1)$$

where S_i are segment slopes and L_i segment lengths.

Catchment Response Time

Observation of recent floods in Dar es Salaam revealed short living flood peaks, which recedes quickly to normal flows. Flow peaks are a result of runoff

contributions from all parts of catchment areas and time taken to contribute to outflows (time of concentration) has been estimated from minutes to a few (< 4) hours in several catchments of Dar es Salaam ranging in size from 1.5 km^2 to 20 km^2 (Msangi, 2017). To understand adequacy of climate records in simulating rapidly receding flood peaks of River

Msimbazi, time of concentration (t_c) in minutes was estimated using a Kirpich (1940) method given by equation (2).

$$t_c = 0.0195 \frac{L^{0.77}}{S^{0.385}} \dots\dots\dots (2)$$

where L is the maximum distance travelled by water (m) and S is the slope along the water path (m/m).

Table 1: Segment slopes of River Msimbazi along the main river course.

Alt (m)	Distance (m)		Slope (m/m)	
	Cumulative	Segment	Segment	$LS^{0.24}$
232	0			
220	173.9	173.9	0.069005	0.002777
200	1271	1097.1	0.018230	0.012730
180	3163.6	1892.6	0.010567	0.019266
160	5882.2	2718.6	0.007357	0.025371
140	9032.1	3149.9	0.006349	0.028374
120	12536.4	3504.3	0.005707	0.030769
100	17291.1	4754.7	0.004206	0.038800
80	22374.7	5083.6	0.003934	0.040824
60	27660.8	5286.1	0.003784	0.042056
40	32492.8	4832	0.004139	0.039279
39.6	32962.4	469.6	0.000852	0.002612
S = 0.005165 m/m				

Establishment of Catchment Climate Series

A Thiessen polygon method gave weights of 0.746 and 0.254 to Kisarawe Agriculture and JNIA stations, which were used in determining catchment daily rainfall series between 1st September 2011

and 30th June 2017 as sum of products of these weights to respective daily rainfall amounts at the two stations. Daily potential evapotranspiration (PET) series was computed from minimum, maximum and mean daily temperatures at JNIA using Hargreave-Samani (1985) method given by equation (3).

$$PET = 0.0023 R_a [T_m + 17.8] \sqrt{(T_{\max} - T_{\min})} \quad [\text{mm/d}] \dots\dots\dots (3)$$

where R_a is extraterrestrial radiation (MJ/m/d), T_m , $T_{\min}$ and $T_{\max}$ are daily/hourly/10-minutes mean, minimum

and maximum air temperatures ($^{\circ}\text{C}$). The extraterrestrial radiation is estimated from equation (4).

$$R_a = 15.392 d_r (\omega_s \sin \phi \sin \delta + \cos \phi \cos \delta \sin \omega_s) \dots\dots\dots (4)$$

where d_r is the relative distance between the earth and the sun given by $d_r = 1 + 0.033 \cos\left(\frac{2\pi J}{365}\right)$, J is the Julian day (1 for 1st January, 365 or 366 for 31st December), φ is latitude (radians: $\frac{\pi \text{Lat} (^{\circ})}{180}$) at JNIA (-6.87°), δ is declination of the sun (radians) given by $\delta = 0.4093 \sin\left(2\pi \frac{J+284}{365}\right)$ and ω_s is the sunset hour angle given by $\omega_s = \arccos(-\tan\varphi \tan\delta)$.

Ten-minutes catchment series (rainfall, evapotranspiration) were established from catchment daily series. Using UDSM 10 minutes data, 10 minutes rainfall and evapotranspiration fractions were computed as the ratio between 10 minutes data to daily data between 15th December 2011 and 25th March 2015. Field experience of spatial occurrences of the 2011, 2014 and 2015 events within the 24 hours period indicated comparable onsets and distributions of the rains between UDSM and JNIA stations. This fact supported the presumption of similar time distribution of sub-daily (10-minutes, hourly) rainfall within the study catchment. The computed fractions were therefore applied to disaggregate daily catchment series into 10 minutes data. Hourly series were established by aggregation of 10 minute series.

Hydrological Modelling

Whilst several rainfall-runoff models may be used, HBV model was selected due to being free, availability of data necessary for deriving its inputs (rainfall, temperature, evaporation) and use experience. HBV model was calibrated for the 1st January 2014 and 31st May 2015 to take advantage of available spot discharge measurements. The model was calibrated separately using daily, hourly and 10-minutes rainfall, average temperature and PET series. An automatic optimisation routine (GAP optimisation) embedded in the HBV Light software was used to

automatically establish optimum values of model parameters. Owing to a small number of spot discharge measurements, model fitting efficacy was assessed by comparing the nine (9) spot discharges against model estimates where deviations were computed and used to classify magnitudes of deviations as provided in the draft EWA guidelines (URT, 2017) as small (< 10%), moderate (10-20%), slightly large (20-30%) and high (>30%).

RESULTS AND DISCUSSION

Flood Hydrographs

Hydrographs from daily climate inputs

An HBV model calibrated with daily climate closely reproduced well spot discharge measurements (Figure 4) capturing both measured low and high flows at MS1. Comparison of estimated and observed indicates predominant underestimation of discharges by the model (Table 2) with deviations being small (< 10%), slightly large (20-30%) to large (> 20%). Moreover, the daily climates produced the peak daily discharge of 205 m³/s on 11 April during calibration period. Generated daily discharges for the 1st December 2011 – 31st June 2017 period using the calibrated daily model simulated the highest daily discharges of 252.3 m³/s on 21st Dec 2011, followed by 205.0 m³/s on 11th Apr 2014, 202.8 m³/s (12th Apr 2014), 169.4 m³/s (6th May 2015) and 65.6 m³/s (7th May 2015).

Hydrographs from 10-min. climate inputs

Similarly, HBV model was calibrated with 10-minutes series for 1st January to 31st May 2014 period. Simulated discharges almost reproduced the April and May 2014 spot measurements with very small ($\leq 3\%$) magnitude deviations (Table 2). Similar small deviation (1.5%) between simulated and measured discharges was obtained for the 25th March 2015 event and the

calibrated model was considered suitable for simulation of flood hydrographs during the 2011 and 2014 flood events.

Simulated 10-minutes discharges using calibrated HBV model between 9:00 hours of 10th April 2014 (before flood) through flooding days (11th and 12th April 2014) indicated 6 peaks, three with discharges exceeding 300 m³/s and another two exceeding 150 m³/s (Figure 5). These peaks exceed 124, 81 and 149 m³/s being capacities of River Msimbazi at Tabata-Bima (MS3), Tabata-Shule (MS4) and Tabata-Matumbi (MS5), respectively. The hydrograph indicates short-lived overflows occurred as early as on morning of 10th April at Tabata Shule (localised overflow), repeated on the morning of 11th April and became long-lived covering the entire Tabata Bima-Tabata Matumbi reach by evening of 11th April 2014 (Figure 5). The 222 m³/s measured discharge at 17:40-18:30 hours of 11th April was part of this longer event of 11th April 2014, which peaked at 19:40 hours with a discharge of 307 m³/s. However, the longest overflow event is simulated between 10:00 hours and 19:00 hours of 12th April with the highest discharge of 393.5 m³/s simulated at 10:40 hours.

Simulated 10 minute discharges on 20th and 21st December 2011 indicate two distinct high peaks of 289.8 and 471.6 m³/s, respectively (Figure 6). In fact, the peaks are broad with discharges exceeding 150 m³/s lasting between 06:10 and 08:30 hours on 20th December and 07:00 and 10:50 hours on 21st December 2011. Whilst simulated highest daily (252.3 m³/s) and 10-minute (289.8 m³/s) on 20th December are not very different, the highest 10-minute discharge of 471.6 m³/s on 21st December could not be simulated by daily inputs. However, this was the day of December 2011 floods which observed the most severe flooding to hit Msimbazi Valley in the recent decades (Manyangu 2011; Mujwahuzi, 2011). This further

suggests inability of daily climate inputs in generating flow magnitudes of flash floods typically occurring in small urban catchments of Tanzania during flooding events.

A comparison of flood peaks simulated from 10-minute and daily climate inputs indicates significant underestimation of flood flows when daily series are used. The 10-minute simulated peaks of 307 and 393.5 m³/s on 11th and 12th April 2014 were significantly underestimated by simulations at daily time intervals as 205 and 201.8 m³/s, respectively. This has significant implications in the design of hydraulic structures to protect against and pass the flood flows.

Rainfall Patterns During Flooding

The April 2014 events were isolated multiple events lasted for 16-17 hours. Six (6) events of 11th April occurred between 06:40 and 22:40 hours (16 hours) with the main event occurring for 150 minutes between 17:20 and 19:50 hours (Figure 5) contributing 61.1% of recorded daily amounts, during which the discharge measurement was taken between 17:40 and 18:30 hours when a small rainfall pause before rain restarted at around 18:35 hours. The 5 events of the 12th April occurred between 03:20 and 20:20 hours (17 hours) with two main events, the 110 minutes (08:50-10:40 hours) and 300 minutes (12:40-17:40 hours) events contributing respectively 39.3% and 34.4% of the daily amounts or a total of 73.7% in 410 minutes (6 hours, 50 minutes). With these fractions, the highest amounts on 11th April were 54.1 and 84.4 mm at Kisarawe and JNIA, respectively, and 37.3 and 36.5 mm on 12th April 2014. Rainfall analysis further indicated that the December 2011 events were single continuous events lasted for 250-330 minutes (Figure 6) receiving 83% of rainfall amounts in 70 minutes (20th December 2011) and 81%

amounts in 160 minutes (21st December 2011).

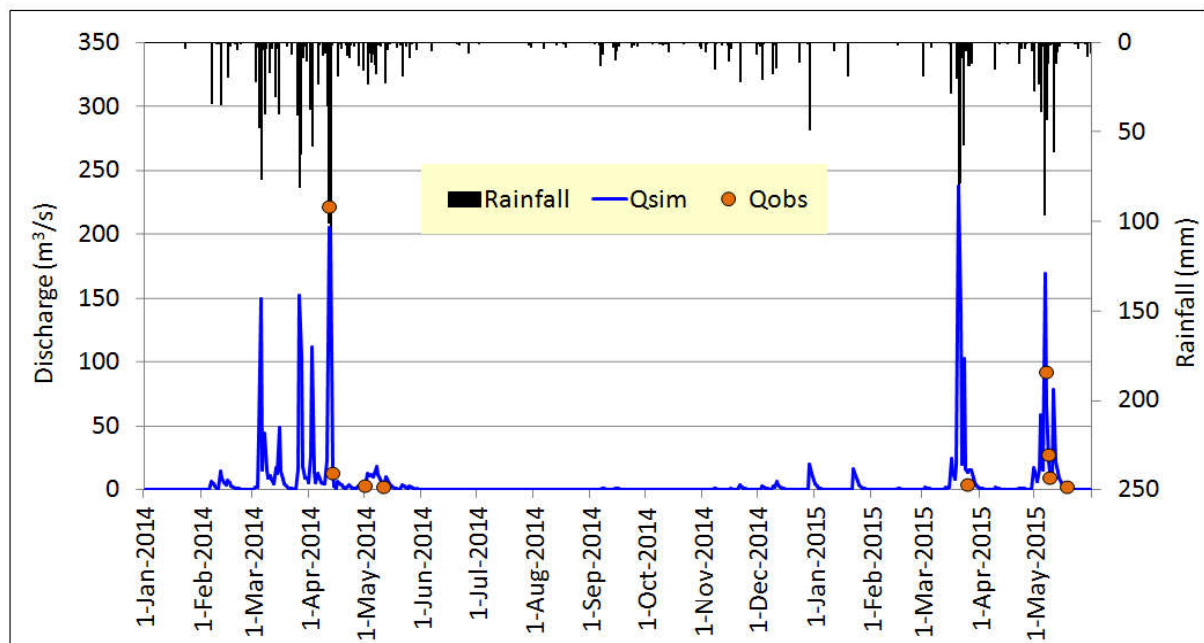


Figure 4: Simulated (Q_{sim}) and measured (Q_{obs}) discharges at MS1

Table 2: Measured and simulated discharges of River Msimbazi at Old Stakishari-Segerea Steel Bridge.

Date	Observed (m^3/s)	From daily climates		From 10 minutes climate	
		Value (m^3/s)	Deviation	Value (m^3/s)	Deviation
11-Apr-2014	222.01	205.01	-8%	222.27	0.1%
13-Apr-2014	12.56	13.55	8%	12.69	1.0%
1-May-2014	3.13	2.91	-7%	3.21	2.5%
11-May-2014	1.87	2.30	23%	1.93	3.0%
25-Mar-2015	4.14	13.33	222%	4.20	1.5%
7-May-2015	92.38	65.57	-29%	No climate data available	
8-May-2015	27.61	21.37	-23%		
9-May-2015	9.15	12.27	34%		
18-May-2015	1.89	0.70	-63%		

Flow Recession

Kirpich formula yields a time of concentration (t_c) of 7.09 hours, which is less than 9.79 hours of a slightly larger Msimbazi catchment upstream of its River Luhanga confluence obtained by Anchors Environmental Consultants (2016). Although Anchors Environmental Consultants (2016) estimated t_c using the Giandotti formula, the difference in t_c of 2.69 hours was slightly longer than

expected. The two sites are only 7.333 km apart and using this information and elevation difference (232 m – 12.8 m) in Kirpich gives a t_c of 8.5 hours shortening the difference to 1.4 hours, which could approximate the actual duration of a flood wave to travel from Segerea site to Jangwani site. However, the computed total t_c from aggregation of segments t_c using segment slopes and river lengths yielded a total t_c of 12.6 hours, much longer than even for a large Msimbazi

catchment upstream of River Luhanga confluence.

Simulated 10-minute discharge series (Figure 5) captured well rapid flow recession of River Msimbazi between rainfall events. The isolated rainfall events on 11th April 2014 resulted into two main

peaks with the first peak receding within 6 hours and 10 minutes and the second within 7 hours and 10 minutes, which are comparable with estimated time of concentration (7.09 hours) at the outlet location (MS1) of the modelled catchment. This feature could not be reproduced by daily series.

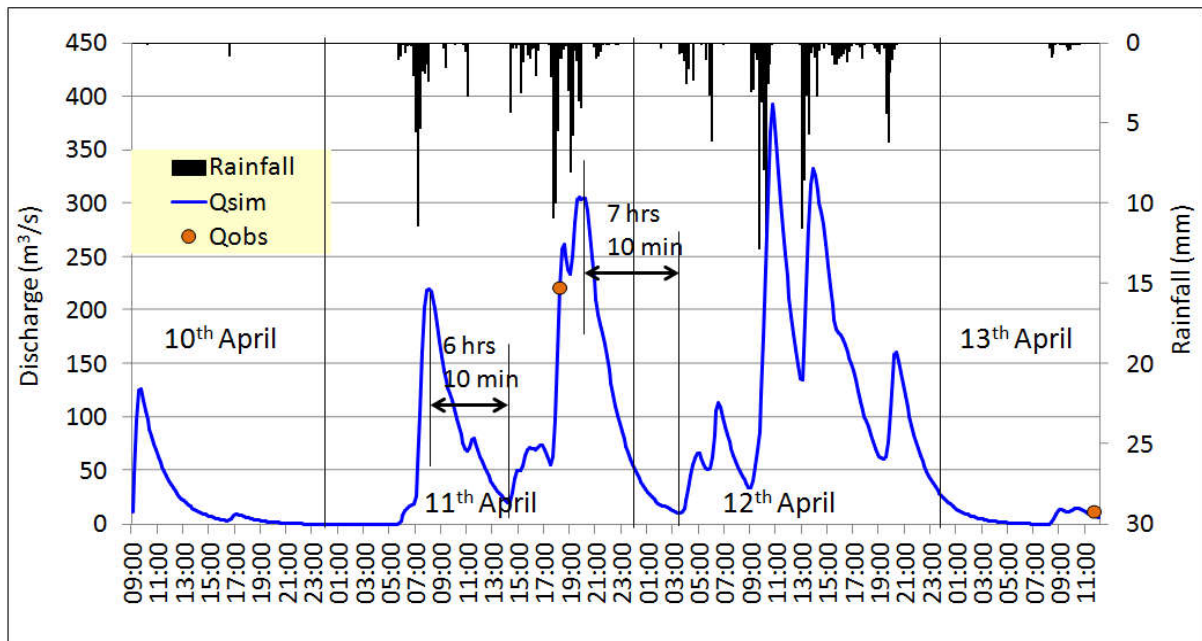


Figure 5: Simulated (Q_{sim}) and spot measured (Q_{obs}) discharges at MS1 between 10th and 13th April 2014.

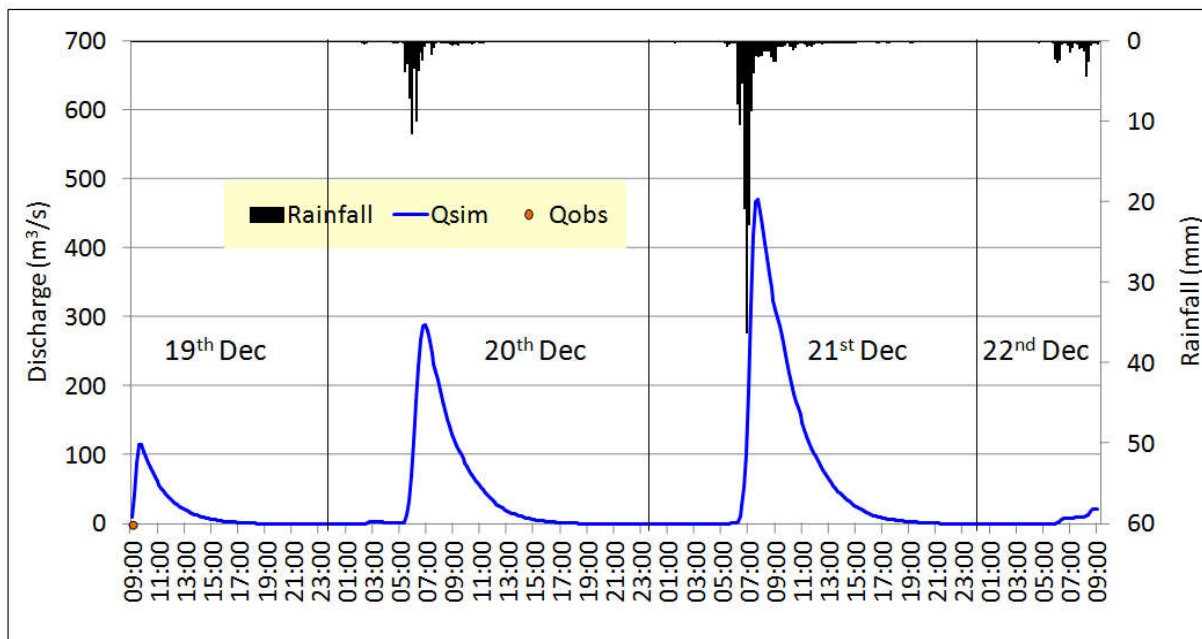


Figure 6: Simulated discharges at MS1 between 10th and 13th April 2014.

CONCLUSIONS

This study was able to quantify inability of a hydrological model to simulate flood hydrographs (magnitudes and recession behaviour) of fast draining urban Msimbazi catchment using daily climate inputs. Simulation results indicated significant underestimation of flood peaks by daily climate inputs compared to 10-minutes and hourly inputs while elongating the base time of flood hydrographs. Simulated daily flows gave a December 2011 flood peak of 252.3 m³/s and a April peak of 205 m³/s whereas 10-minutes simulated flows indicated peaks of 393.5 and 471.6 m³/s for the December 2011 and April 2014 floods respectively. The daily peaks were about 52-53% of 10-minutes simulated peaks. Whilst the Kirpich method estimated a time of concentration of 7 hours, the 10-minutes simulated hydrographs captured the quick flood flow behaviour with recession durations closely matching this estimated time of concentration.

Despite usefulness of 10-minute climate data in simulating magnitude and recession behaviour of flood hydrographs in a small urban Msimbazi catchment, data for only a part of the study period were available at one station (UDSM) and missing at the other two stations (JNIA met and Kisarawe Agriculture), which contribute about 74% of catchment area in the Msimbazi catchment. This unavailability of sub-daily climate data hindered the study of the 2015, 2016, 2017 and 2018 floods. It is therefore recommended to install automatic weather station at Kisarawe Agriculture, rehabilitate the UDSM automet station and record sub-daily (preferably hourly and less) weather data at JNIA and the former two for flood assessments in small and medium sized catchments in Dar es Salaam.

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