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Full Length Research Paper

Impacts of Land Cover Change Caused by Urbanization on the Flood Regime of Msimbazi Catchment in Dar es Salaam, Tanzania

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ABSTRACT

The hydrological processes of a catchment are the function of climate, land use and land cover. Changes in either climate or land use or land cover can result in alteration of the catchment's hydrological processes. In the recent past, Msimbazi catchment in Dar es Salaam has undergone drastic land cover changes mainly due to urbanisation. These land cover changes caused changes in the behaviour of river flow resulting in frequent floods. Therefore, this study analyses the impacts of the changes in land cover due to urbanisation specifically with the changes in river flow, surface run-off and base-flows. Previously generated land cover maps of Msimbazi catchment and a combination of spatial and meteorological climate datasets were used to parameterise the hydrological model (SWAT). The model was calibrated and validated using the Sequential Uncertainty Fitting algorithm (SUFI-2) on a monthly resolution. The results show that there is an increase in surface run-off, mean river flow and the reduction of base-flow with the increase in urbanisation within the catchment. These increase in river flows; surface run-off and reduction of base-flow indicates the likelihood of an increase in flooding events in the catchment.

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INTRODUCTION

Climate-related natural disasters such as floods and droughts are on the rise globally increasing by at least 83% from 1989-1999 to 2000-2019 (UN, 2020). In Sub-Saharan Africa, the situation is even worse reported that in the Eastern Africa region overlapping the Nile basin about 6 million people were affected by floods in the year 2020 (World Bank, 2021).

Moreover, the rapid growth of African cities characterised by mass migration from rural areas and urban sprawl have created cities that are vulnerable to flooding disasters.

The explosive increase of population in the Sub-Saharan African cities comes at a point where most of the city's authorities are not prepared to manage the higher population growth. This leads to improper urbanization through uncontrolled establishments of built-up areas and the creation of informal settlements in unplanned areas (Amoako, 2012). Cities such as Dar es Salaam in Tanzania faced urban sprawl with the uncontrolled acquisition of land by the residents in areas in the vicinity of the rivers streams which were perceived as isolated and cheap (Kombe, 2005). Most of these areas became flood-prone areas as they were continuously hit by flooding events (Palela, 2000).

Msimbazi catchment located in Dar es Salaam is among the most affected urban catchment in Tanzania with the increase in cases of flooding events reported recently. In the years 2018 and 2019, 7 flooding events were reported that caused a loss of about 100 million US dollars (World Bank, 2019). These recent increases in flash flooding events within the catchment may be linked to the results of the intensive transformed land cover whereas from the past the catchment was highly dominated by grassland areas to urban built-up dominated recently. The study by (Kibugu *et al.*, 2021) mapped the increase of urbanization in relation to land cover changes in the Msimbazi catchment. This study showed that urban built-up areas have increased by about 26% while grassland has reduced by 36% from 1998 to 2020. The study further projected the increase of urban built-up by 14% and a reduction in grasslands by 36% in the future from 2020 to 2040.

This study utilises the land cover maps produced in the study by Kibugu *et al.*, 2021 to describe the changes in land cover caused by urbanisation in the Msimbazi catchment and the hydrological model SWAT to simulate the changes in land cover to changes in hydrological processes of the catchment. Soil Water Assessment Tool (SWAT) model has been widely used in un-gauged and data-scarce catchments to simulate the hydrological processes with the changing of land cover and the model gave sufficient results (Bahati *et al.*, 2021).

Previous researches on Msimbazi catchment have focused on assessing separately spatial characteristics of the catchment to the flooding events. The studies done such as Igulu and Mshiu (2020) assessed the effects of land use and cover change on the impervious surface as a measure of urbanization together with its driving factors such as population growth and economic development in Msimbazi catchment. Mzava *et al.* (2019), and Igulu *et al.* (2012) researched the spatial characteristics of the catchment and land management by the residents living within the Msimbazi catchment. Valimba and Mahé (2020) assessed the suitability of observation time intervals in the estimation of flood magnitudes and recession of Msimbazi River using daily and 10-minutes climate datasets and concluded that 10-minutes climate datasets were useful but hardly available.

This study aims at establishing the link between land cover transformation due to urbanization and the recent increase of occurrence of flash flooding events in the Msimbazi catchment. This is done through observing the changes that occur on surface run-off and base-flows. Particularly quantifying the changes that have occurred in river flows, surface run-off and base-flows caused by changes in land cover from the past 22 years (1998-2020) and that will occur in the projected 22 years (2020-2042). Through this study, added knowledge will be provided on the causes of flash flooding events within the catchment which will help in flood control and prevention of floods in the future. The study also provides insight on the future behaviour of the hydrological processes of the catchment which can guide the policymakers and associated authorities in generating proper policies that will ensure a sustainable environment towards the future.

METHODS AND MATERIALS

The goal of this study is to assess the impacts of land cover changes on the occurrence of flash floods in the Msimbazi catchment. Specifically simulating monthly hydrological processes with changing land cover maps of the years 1998, 2020 and 2040 and assessing changes that have occurred on the river flows, surface run-off and base-flow. The framework of the study is as shown in Figure 1.

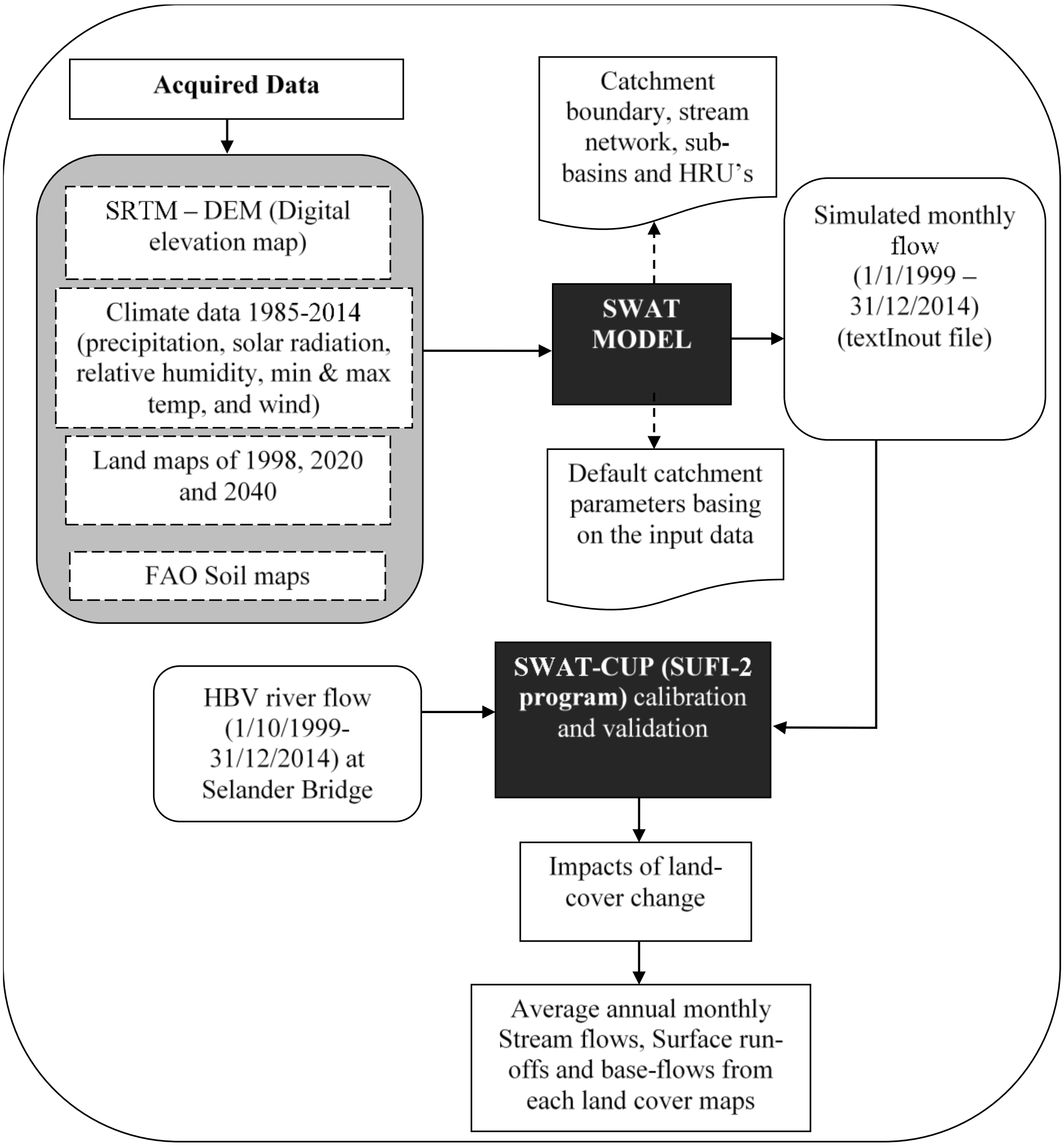


Figure 1: Conceptual framework of the study

Study area description

Msimbazi catchment extends from Pugu hills in the coastal region to the Indian Ocean through the centre of Dar es Salaam region in Tanzania (Figure 2). The catchment has an average area of 266 km^2 which is almost 15% of the total area of the Dar es Salaam region. Since the catchment passes through the centre of the region, makes it highly attractive for settlements establishment compared to other catchments in the region because most of the economic activities are taking place in the centre of the region.

However, the improper establishment of settlements around the catchment and in the vicinity of river streams has led to the Msimbazi River and its tributaries being abused in different ways. Activities such as dumping effluent and other pollutants produced in the city into the river streams have been common. As a consequence of the high levels of pollution, the river's water quality has sharply decreased and is no longer safe for consumption, domestic uses, or even irrigational uses

(Ak'habuhaya and Lodenius, 1988). Soil erosion is also experienced within the catchment mostly in areas in the vicinity of river streams mainly caused by the increase of stormwater with increased suspended coarse particles. The increase of soil erosion led to the local community around the catchment developing local measures to counteract the erosion effect; measures such as the use of sandbags (Mkilima, 2018).

The terrain of the catchment is relatively flat having the highest elevation of 312 m and lowest elevation of 5 m above sea level. Downstream the catchment whereas the terrain is mostly flat there are two separate major tributaries with different large sub-catchments from the main river sub-catchment. This division considers the overflow of the three rivers during extreme flooding, increasing the risks of wider flooding areas downstream of the catchment (Valimba & Mahé, 2020).

The climate of Msimbazi catchment is warm tropical throughout the year having an average temperature of 26°C and having two rainy seasons one short rainy season from October to December with a monthly average range of 75-100 mm and a longer rainy season from March to May with a monthly average of 150-300 mm while having an annual average of 1050 mm (Ndetto and Matzarakis, 2015).

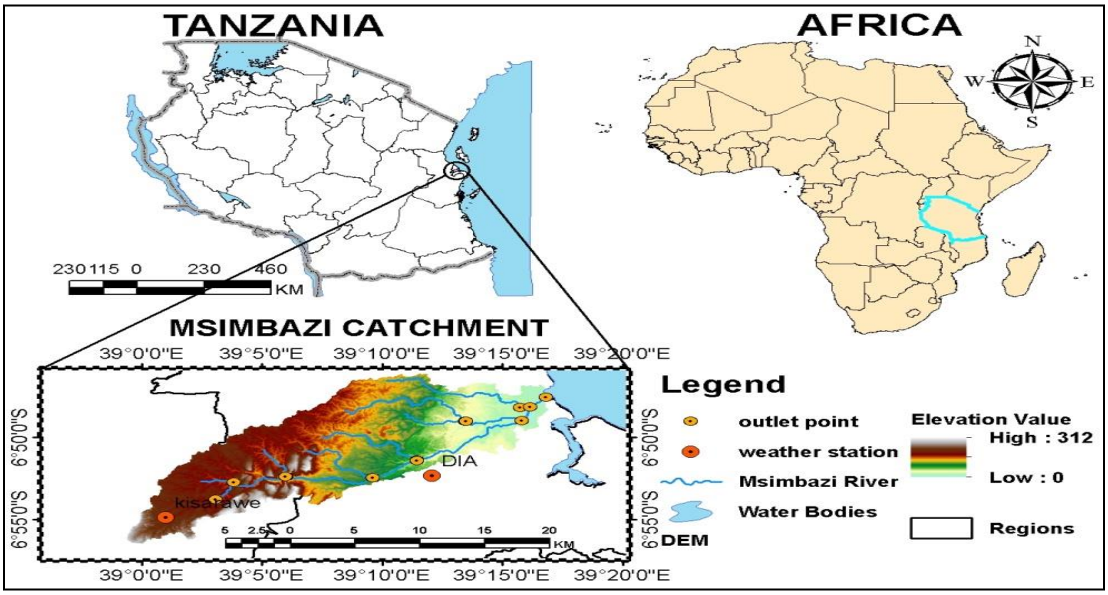


Figure 2: Msimbazi catchment area, location of weather stations and the topography of the catchment.

Data Acquisition and Processing

Climate data

Rainfall, minimum and maximum temperatures datasets from two stations Kisarawe meteorological station and Julius Nyerere International Airport (JNIA) from January 1985 to December 2014 were acquired (Table 1). The quality of this data set was good with less than 5% of the missing data. Other climate variables like solar radiation, wind, and relative humidity were taken from the Coordinated Regional Downscaling Experiment (CORDEX) Africa regional climate models, with a spatial resolution of 0.44°. The CORDEX project has been successful in representing Africa's climate variables with different signatures of rainfall as reported in many studies such as (Näschen *et al.* 2019).

All of the climate variables from the Regional Climatic Model (RCM) were taken as a mean of three historical and Representative Concentration Pathway 4.5 (RCP4.5) regional climate model runs (Table 2). The study chose RCP 4.5

because it represents the increase of greenhouse gases as to what is currently experienced (Thomson *et al.*, 2011). These three models are sufficient as they represent a range of different precipitation signals, with increasing, decreasing, and constant precipitation patterns when comparing the period from 1985 to 2014.

Discharge Data

Due to the Msimbazi river being un-gauged, simulated discharge data from the study by (Valimba and Mahé, 2020) using the Hydrologiska Byråns Vattenbalansavdelning (HBV) model were used to give the continous discharge data for the calibration of the SWAT model simulation results. The water heights of the Msimbazi river from different position were acquired in the study by (Valimba and Mahé, 2020) used in validating the HBV model. The discharges were simulated at the outlet point of the whole catchment near Selander Bridge located at the grids 9248685N and 530492E. Lack of measured discharge data on the city rivers hinders model performance and representation of the actual river characteristics.

Spatial Dataset

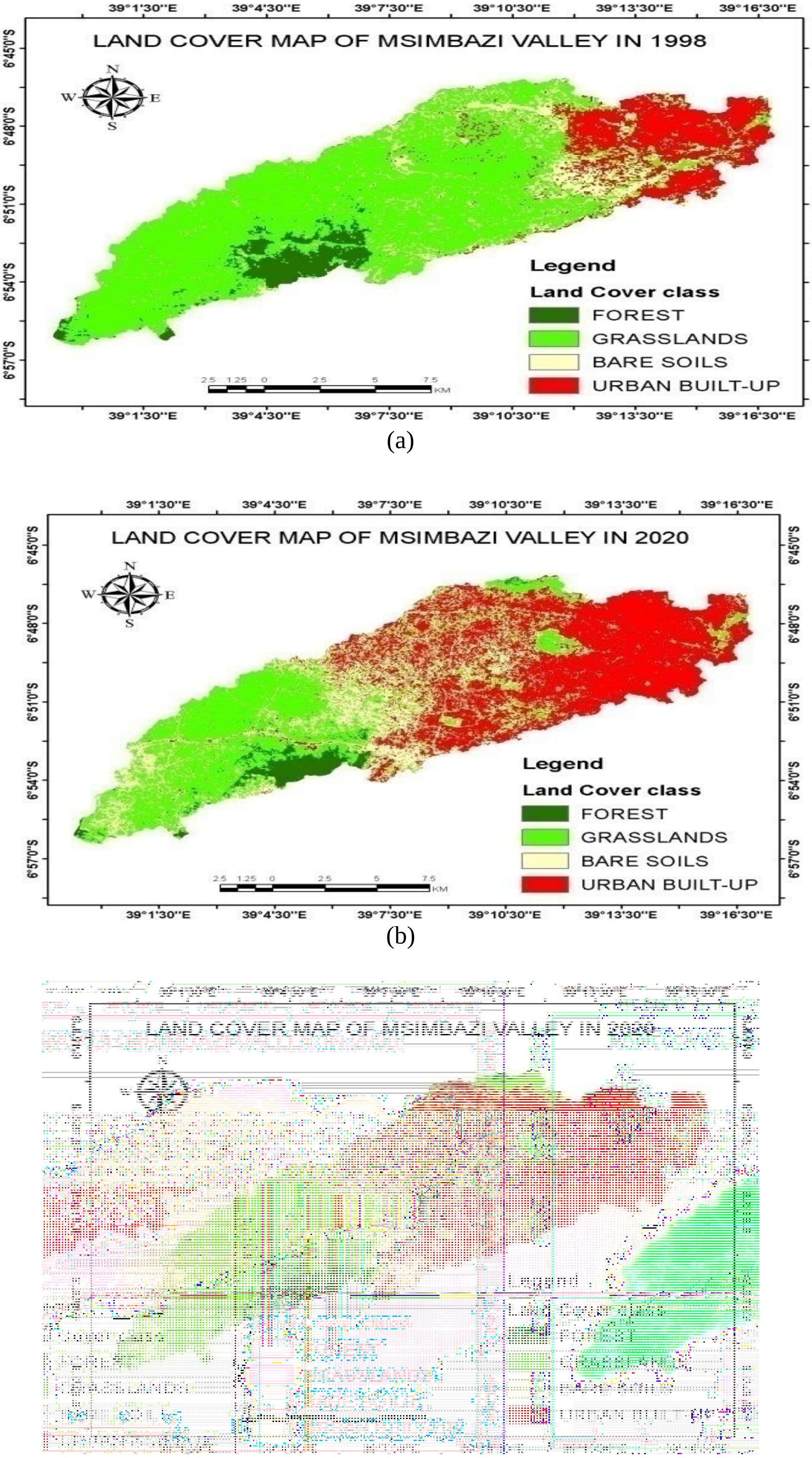
Other spatial data used included the Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) with 30m resolution was used to describe the topography of the catchment. Soil data from the soil database of the Food Agriculture Organisation (FAO) were used in the presentation of the soil characteristics of the catchment. Land cover maps were obtained from the study by Kibugu *et al.*, (2021) (Figure 3) were used in the parameterisation of the model.

Table 1: Acquired Dataset, resolution or scale and the sources obtained

Acquired Dataset	Resolution/scale	Source
DEM	30 m	SRTM https://earthexplorer.usgs.gov/
Soil Maps	1 km	FAO http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/
Precipitation	Daily	Tanzania Metereological Authority (Kisarawe rain gauge, Dar Es Salaam Airport weather station)
Discharge	Daily, Monthly	HBV model simulation (Valimba and Mahé, 2020)
Climate	Daily/0.44°	CORDEX Africa project (Table 1b)
Land Use maps	30 m	(Kibugu & Munishi, 2021)

Table 2: Climate models used in the study

Global Climatic Model (GCM)	RCM	Experiment	Institution	URL link
ICHEC-EC-EARTH	RACMO22T	RCP 4.5, Historical	The Royal Netherlands Meteorological Institute (KNMI)	https://esg-dn1.nsc.liu.se/
ICHEC-EC-EARTH	RCA4	RCP 4.5, Historical	Swedish Meteorological and Hydrological Institute (SMHI)	https://esg-dn1.nsc.liu.se/
CCCma-CanESM2	RCA4	RCP 4.5, Historical	Swedish Meteorological and Hydrological Institute (SMHI)	https://esg-dn1.nsc.liu.se/



(a)

(b)

(c)

Figure 3: Land cover maps of (a) 1998, (b) 2020 and (c) 2040 prepared by Kibugu et al., 2021

Model description

SWAT model was applied to simulate the hydrologic process of the Msimbazi catchment for the chosen period under changing land cover maps. SWAT is a semi-distributed and physically-based hydrological model for continuous simulations of discharge, sediments, nutrients, and pesticides daily (Arnold *et al*, 2012). The model uses remotely sensed and ground observed data (soil, land cover and climate dataset) to describe the land and stream processes that complete the hydrologic water cycle of the catchment through water balance calculation.

These hydrologic processes are controlled by the water demand of the LULC and several parameters specified by the modeler relating to the actual environment. The model divides the catchment into sub-catchments of streams, which are generated from drainage patterns derived from the DEM and by setting a threshold that defines the minimum drainage area to form the stream. These sub-catchments are further discretized into small homogeneous blocks of land use and land cover classes, soil types and slope classes known as Hydrologic Response Units (HRU's) representing spatial features of the catchment at a finer scale.

In these HRU's it is where land processes controlling the amount of water, sediment and nutrients delivered to the mainstream are determined for each HRU providing the basis for water balance calculation (Arnold *et al*, 2012). Water balance calculations are done using the water balance equation below (equation 1).

$$SW_t = SW_o + \sum_{i=1}^{t} (R_i - Q_{surf\,i} - E_{ai} - W_{seep\,i} - Q_{gwi}) \quad (1)$$

where SW_t is the final soil water content on day *i*, SW_o is the initial water content on day *i*, R_i is the precipitation on day *i*, Q_{surf} is the surface runoff on day *i*, E_{ai} is evapotranspiration on day *i*, W_{seep} is the loss to overdose zone and Q_{gw} is the return flow on day *i*.

The stream processes in the water balance equation are climate-driven with daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. Some of these processes *include* the soil processes which are surface run-off estimated using the Soil Conservation Service Curve Number (SCS CN) method infiltration and canopy storage (Baker and Miller, 2013). The soil processes include lateral flow from the soil, return flow from shallow aquifers, and tile drainage, which transfers water back into the river while deep aquifer recharge removes water from the system. Other processes include moisture redistribution in the soil profile and evapotranspiration.

Through these methods, the SWAT model allows the user to quantify the relative impacts of management, soil, climate and vegetation change at the sub-watershed level. Model runs with the same inputs produce the same output, and change of any input variable produces a change in output. This allows the analysis of impacts of changes on the land cover on the hydrological response. A further detailed description of the model and information on the parameters is given by (Arnold *et al*, 2012).

Model Calibration and Validation

For the simulated results to become in agreement with the observed discharge, the model result must be calibrated with the observed data. Calibration is the testing of the model with known inputs and output to adjust the known factors; while validation is the comparison of the model results with known output without further adjustment of any factor. Calibration and validation were performed using the swat-cup software which is a semi-automatic calibration for SWAT output files using the SUFI-2 algorithm (Abbaspour *et al.*, 2015).

This algorithm maps all uncertainties (parameter, conceptual model input, etc.) on the parameters (expressed as uniform distributions or ranges) and tries to capture most of the measured data within the 95%

prediction uncertainty (95PPU) of the model output in an iterative process. The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling.

For the goodness of fit, we are comparing two bands the 95PPU for model simulation and the band representing measured data plus its error in statistical means of Nash–Sutcliffe Efficiency coefficient (NSE) and indices of *p-factor* and *r- factor* were also used (Abbaspour *et al*, 2017). The NSE equation 2 computes model efficiency by relating the goodness of fit of the model to the measured variance which is in the range from -∞ to 1 and efficiency values greater than 0.6 are satisfactory for the model showing good relation.

$$NSE = 1 - \sum_{i=1}^{n} \left(\frac{Q_{obs\,i} - Q_{sim\,i}}{Q_{obs\,i} - Q_{avg}} \right)^2 \qquad (2)$$

where NSE is the Nash-Sutcliffe Efficiency coefficient, Q_{simi} is monthly simulated flow, Q_{obsi} is a monthly observed flow and Q_{avg} is an average observed flow, i is the month of observation and n is the total observation.

The P-factor is the fraction of measured data plus its error bracketed by the 95PPU band and varies from 0 to 1, where 1 indicates 100% bracketing of the measured data within model prediction uncertainty whereas when $p > 0.7$ are satisfactory while *R-factor*, on the other hand, is the ratio of the average width of the 95PPU band and the standard deviation of the measured variable. A value of less than 1.5 would be desirable for this index.

Model setup

The SWAT model delineated the catchment and river streams based on the topography of the Msimbazi catchment described by the DEM. The presentation of the SWAT model in the Arcmap version is as shown in Figure 4. The catchment was then divided into 15 sub-catchments and 80 HRU's incorporating two different soil types obtained from the FAO world soil map, four different slope classes from the topography and four different land cover classes which were converted into SWAT land cover classes (Table 3). Daily precipitation datasets acquired from the two stations Kisarawe and Dar es Salaam Airport of 1985-2014 were evaluated for consistency and completeness and used to drive the model with climate variables from the RCM's. The final spatial coverage of the SWAT model is summarised in Table 4. Potential evapotranspiration was calculated using the Penman-Monteith method. The model was run from 1st January 1994 to 31st December 2014 on monthly resolution with 5 years as years to skip to obtain monthly discharge data from January 2000 to December 2014.

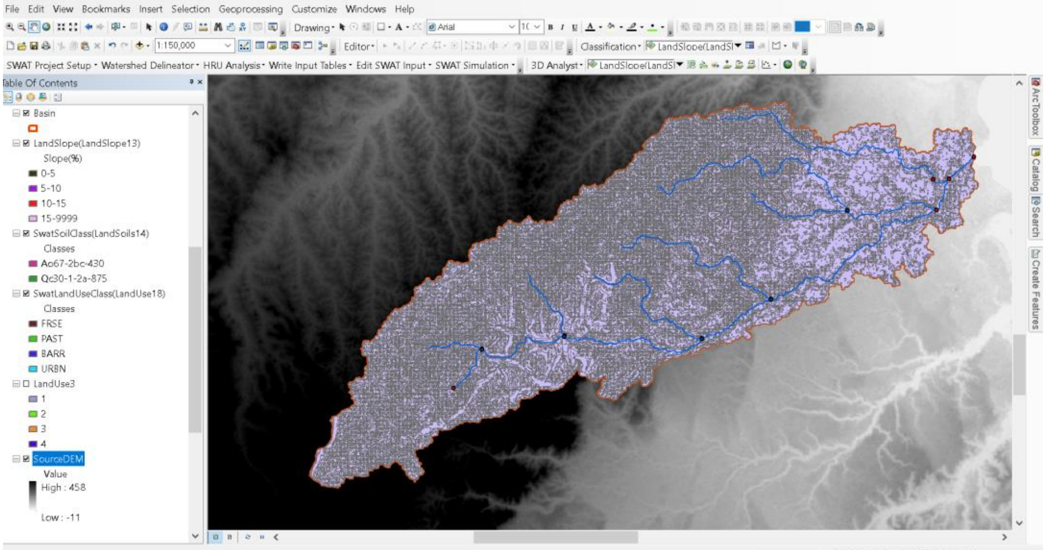


Figure 4: SWAT model as used in the Arc Map Software

Table 3: Land cover re-classification to SWAT database

Land use and land cover classes	Swat land use and land cover classes	Interception (mm/hr)	Canopy (%)
Bare-soils	Barren --> BARR	0.50	10
Built-up areas	Residential --> URBN	2.80	70
Grassland	Pasture --> PAST	1.15	80
Forests	Forest-Evergreen --> FRSE	1.28	65

Table 4: Finals spatial coverage of the catchment within the model

Land use	%Area	FAO Soils	%Area	Slope (%):	%Area
Forest-evergreen	3.42	Sandy clay	72.71	0-5	34.02
Pasture	30.07	Sandy	27.29	5-10	18.52
Barren	25.38			10-15	11.58
Residential areas	41.13			15-9999	35.88

After setting and running the model within ArcSWAT 2012 (revision664), the model was calibrated and validated with data from the study by (Valimba and Mahé, 2020) which simulated discharge of Msimbazi river at the station in Selander Bridge from January 2000 to December 2014. The data was separated into two duration that is calibration period from January 2000 to December 2007 and the validation period from January 2008 to December 2014. These two periods were chosen since they had a minimum difference in their variances and standard deviations.

The SUFI-2 Latin hypercube sampling algorithm in SWAT-CUP (version 5.1.6.2) was used based on the guidelines of (Arnold *et al,* 2012) and (Abbaspour *et al,* 2012) in the parameterization of the model. Sensitivity analysis of the parameters was done to determine the most sensitive parameters and the parameters were ranked in their order of sensitivity (Table 5). The parameters obtained were then adjusted until the simulated flow data are in agreement with the simulated data from (Valimba and Mahé, 2020). The NSE (Equation 2) was chosen as the main objective function with other ancillary criteria to assess the quality of the model with both *P-factor* and *R-factor*. After calibration and validation, different land use maps were utilized to simulate the impact of changes in land cover. The 1998 land cover map was used as a baseline condition for the first model run then 2020 and 2040 land cover maps were used again to run the model. In order to attribute only alterations to the land cover, nothing was modified except for the land cover maps.

Table 5: Order of sensitivity of the parameters used in modeling Msimbazi catchment

Parameters	**Full Parameter Name**	**Order of sensitivity**
R__CN2.mgt	SCS runoff curve number for moisture condition II	1
R__SOL_AWC().sol	Available water capacity of the soil layer (mm H2O/mm soil)	2
V__ESCO.hru	Soil evaporation compensation factor	3
R__SOL_K(..).sol	Saturated hydraulic conductivity (mm/h)	4

V__SURLAG.bsn	Surface runoff lag coefficient	5
V__GW_DELAY.gw	Groundwater delay time (days)	6
V__ALPHA_BF.gw	Base flow alpha factor (days)	7
V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	8
V__GW_REVAP.gw	Groundwater “revap” coefficient	9
R__SOL_Z(..).sol	Depth from soil surface to bottom of layer (mm)	10

RESULTS AND ANALYSIS

SWAT model produced sufficient results on the simulation of the hydrological processes of the Msimbazi catchment. The model simulated flows, surface run-off and base-flows with different land cover maps of the catchment (1998, 2020, and 2040) and established the influence of the changes in land cover on the changes in river flows, surface run-off and base-flows of Msimbazi catchment.

Land Use and Cover Change analysis

The land cover maps of Msimbazi catchment of 1998, 2020 and 2040 by Kibugu *et al.* (2021) identified four land cover classes within the catchment which are urban built-up areas, bare soils, grassland, and forest class. The rapid increase of urban built-up area with a rapid decrease of grassland cover class was mainly observed from 1998 to 2020 and projected to further increase in the future (2040) (Table 6). The study found out that the increase in urban built-up areas was due to the rapid increase of population within the valley attributed by rural to urban migration. The study also pointed out the informal creation of settlements within the vicinity of the Msimbazi River which leads to improper modification of the river streams causing deviation of the natural river regime.

Table 6: Trend in changes of land cover classes within the catchment

Land Cover Class	**Land Cover Map Area**					
	1998		**2020**		**2040**	
	Km²	%	*Km²*	%	*Km²*	%
Bare Soils	33	12	68	25	59	22.26
Built-Up Areas	41	15	110	41	143	53.96
Forest	16	6	10	4	10	4
Grasslands	176	66	79	30	54	20.38
Grand Total	265	100	265	100	265	100

Calibration and Validation of the model

Gauged Rainfall and temperature from the two meteorological stations in the catchment and spatial climate parameters (wind, solar and relative humidity) from the CORDEX Africa project running from 1985 to 2014 combined with the land cover maps, soil dataset from FAO and DEM from SRTM successful simulated hydrological process within the catchment using the SWAT model.

SWAT-CUP program was successfully used to evaluate the goodness fit of the model compared to the HBV model simulation of the Msimbazi River in the study by Valimba and Mahé, (2020) with the sequential uncertainty fitting (SUFI-2) algorithm. The results indicated goodness fit of the monthly discharge from January 2000 to December 2014 which is further explained by the good statistical analysis results of the NSE which was the main function and other auxiliary functions (Table 7). The results were regarded as satisfactory based on the study by Moriasi *et al.*, (2015) stating that model simulation can be judged as satisfactory if NSE > 0.50, $R^2 > 0.50$, and percentage bias (PBIAS) is within the range of ±25% for streamflow.

The calibration period was from January 2000 to December 2007 (8 years duration) while the validation period was from January 2008 to December 2014 (7 years duration) for the simulated discharges of river streams within the Msimbazi catchment.

Table 7: Quantitative model performance analysis for the calibration and validation period

	NSE	R^2	PBIAS	*p*-factor	*r*-factor
Calibration	0.75	0.76	-4.4%	0.58	0.80
Validation	0.77	0.78	-6.4%	0.62	0.78

The validation period gave an improved result with higher statistical values compared to the calibration period as shown in Table 7. Overall, the model shows sufficient agreement in the monthly simulated discharge with the monthly discharges simulated in the HBV model. Although the uncertainty of the simulation represented by the 95PPU band slightly underestimated the peak values from the HBV model and over-estimated the low flow. Generally, the model results coincide and the results are satisfactory.

The flood hydrograph (Figure 5) shows the characteristics of flashy flood hydrographs as the rising and recession limbs are very steep with a small lag time. This indicates that discharge in the river increases rapidly over a short period as rainwater travels much quicker to reach the streams with the higher surface flow and low base-flow contribution. This flash flood behaviour of the catchment explains that the catchment is highly urban built-up dominated since urban areas increase the imperviousness of land which prevents rainwater from infiltrating to the ground.

This instant increase and decrease of flows in the river streams can cause flash flooding on a small burst of rainfall and also cause river streams to remain dry for a longer period as water drains faster with small groundwater contribution.

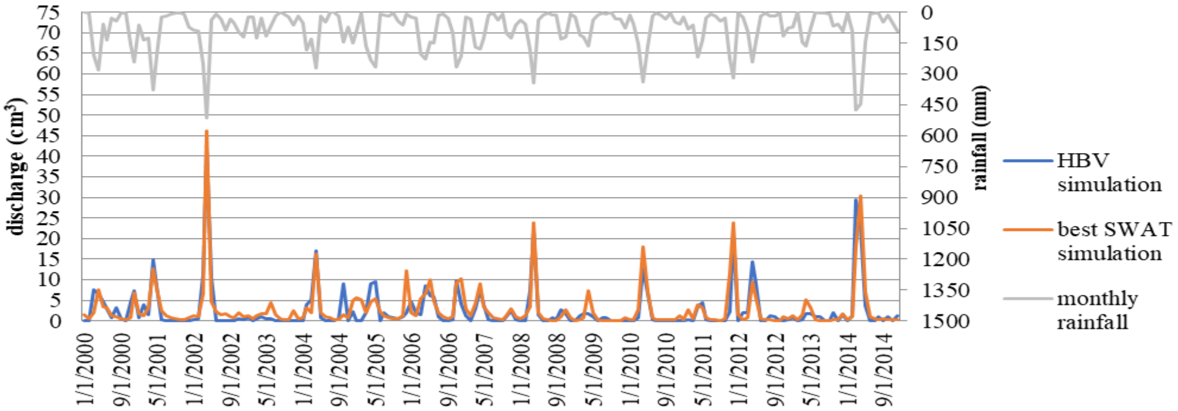


Figure 5: Hydrograph of monthly SWAT simulation and HBV simulation discharges for calibration and validation period

Bandwidth of an Antenna Array with Changing Scanning Angle

The periodic boundary was set in the Y direction to investigate the scanning angle of an antenna. The array performance is shown in Figure 14, whereby an increase in scanning angle affects the antenna bandwidth. The antenna array bandwidth at *Theta* = 0^o was 1.7 GHz, but it deteriorated to 0.98 GHz, equivalent to only 3.5% fractional bandwidth, throughout the $\pm 80^0$ scanning angle. At an angle of 40^0, the antenna array resonance frequency highly deviates from the 28 GHz frequency, decreasing the total antenna bandwidth. This deviation is due to variation of impedance matching with change in scanning angle.

The average annual water balance component of the simulated river flow in the baseline conditions of 1998 land cover maps is shown in Table 8. The surface run-off was very high compared to base-flow values which were separated using the web-based hydrograph Analysis tool (WHAT) and gave an acceptable base-flow index value.

Table 8: Average annual water balance components of the Msimbazi catchment by SWAT model

Water Balance Components	**Value (mm)**
Precipitation	1088.1
Actual Evapotranspiration	590
Potential Evapotranspiration	1382.7
Surface Run-Off	386.04
Lateral Flows	6.97
Base-Flows	74.69
Total Aquifer Recharge	106.88

Impacts of Land Use and Land Cover Change on surface run-off and base flows

The impacts of land use and land cover change within Msimbazi Catchment on the river’s surface run-off and base-flows were derived from the comparison of the model outputs with three different land cover maps of Msimbazi catchment (1998, 2020 and 2040). Rainfall and climate parameters (solar, wind, relative humidity, and temperatures) from 1995 to 2014 were constant while land cover maps changed.

The land cover map of 1998 which was the baseline conditions produced an average annual (2000-2014) surface run-off contribution of 386.04 mm, while the land cover map of 2020 produced an average annual surface run-off of 464.00 mm which is 20.19% increase from the 1998 land cover map. Furthermore, the 2040 land cover map also showed an increase in the average annual surface run-off to 466.20 mm on the river which is a further increase of 20.76% from the baseline condition (1998 land cover maps) and 0.52% increase from the 2020 land cover maps.

The difference in the average annual surface run-off generated by the land cover map of 2020 and 2040 was small compared to the 1998 land cover maps, this is due to the changes that have occurred in the land cover maps from 2020 to 2040 were also very small compared to changes from 1998 to 2020. Eckhardt filter method in the Web-based Hydrograph Analysis Tool (WHAT) (Lim *et al*., 2005) separated the base-flow from surface flows and showed the reduction of base-flows from 0.39 m^3 in the 1998 land cover maps to 0.32 m^3 in the 2020 land cover map, and 0.30 m^3 in the 2040 land cover maps which are also reduction of 21.88% from 1998 to 2020 and 23.07% from 1998 to 2040. The average annual monthly surface run-off and base-flow were plotted in figure 6 below to show monthly changes of the surface run-off and base-flow within the three land cover maps.

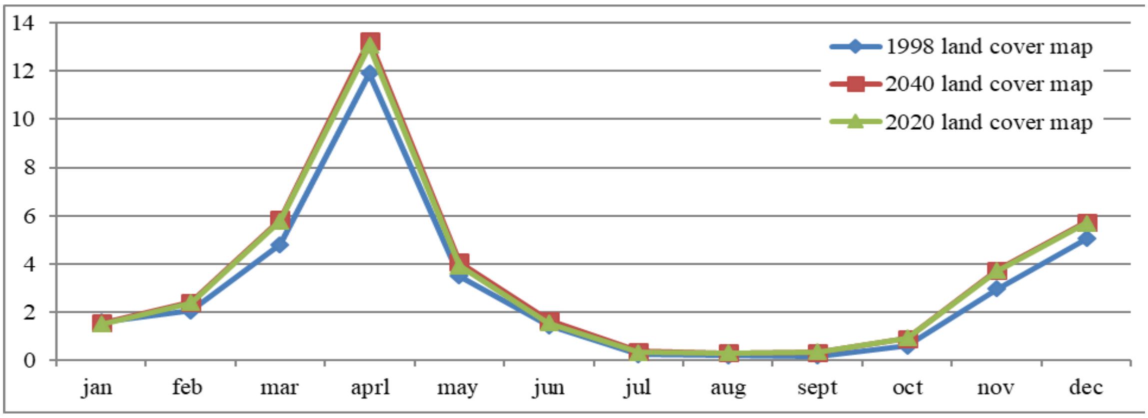


Figure 6a: Average annual monthly surface run-off of Msimbazi River

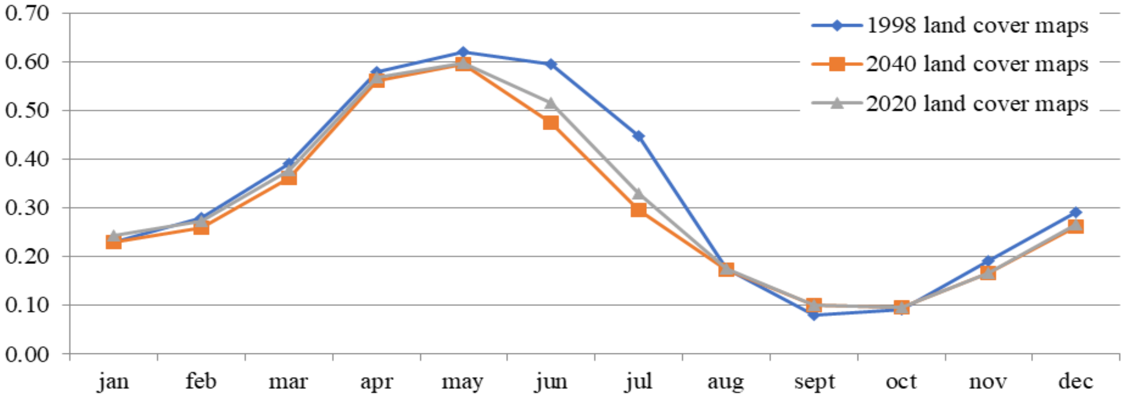


Figure 6b: Average annual monthly base-flow of Msimbazi River

DISCUSSION

Model evaluation

Spatial-temporal characteristics of the catchment were sufficiently represented by the acquired dataset. Specifically, precipitation which is the main driver of the hydrological processes in the model was sufficiently represented by the daily measured precipitation dataset from the two stations that are located within the catchment. Since the elevation difference throughout the catchment is minimal then the difference in the measured precipitation values from the two stations was also small and did not require the use of elevation bands to correct elevation difference.

Flood hydrographs and the statistical model performance indicate satisfactory results of the simulation by the SWAT model. Even though in some years the model underestimated the peak flow values and overestimated low flows with a smaller difference but generally the model coincided with the HBV simulation results done by Valimba and Mahé (2020). Most of the sensitive parameters determined and used in the calibration of the SWAT simulation results controlled the overland flows; parameters such as CN2, SURLAG and SOL_AWC indicated the catchment to be surface run-off dominated with a small base-flow contribution. This is also highlighted in the study by (B. Igulu & Mshiu, 2020)who found out the possibility of high run-off potential in rainfall events in the Msimbazi catchment.

High surface run-off potential catchments are most likely to encore flooding since most of the rainfall is transferred on the surface with very low infiltration. Based on the high run-off potential that was identified in this study and other studies within Msimbazi catchment calls for awareness of the risks of an increase in overland flows which might result in flooding events therefore effective measures such as the proper design of stormwater drainage systems with the capacity to transport effectively surface run-off generated and also maintaining of the available drainage systems within the catchment which currently some are poorly maintained that they are blocked with either sediment or solid wastes.

Impacts of Land Cover Transformation to Flood Regime

Land Cover change of Msimbazi Catchment was sufficiently represented by the land cover maps produced by Kibugu *et al.* (2021). Specifically, the maps were able to identify the extent of increase in urbanization from 1998 to 2020 and also projecting future scenario at 2040 of Land cover of Msimbazi catchment. The Maximum likelihood technique used in the preparation of these land cover maps and the post-classification comparison method used to detect the changes in Land Cover maps was quite satisfactory.

Land cover maps identified four major classes Grassland, Urban built-up, Bare-soils and Forests. Grassland cover class was the most affected land cover class as in the 1998 land cover map, grassland class dominates a large part of the catchment area with 66% coverage while in the 2020 and 2040 land cover maps urban built-up areas dominates a large part of the catchment covering at least 41% of the whole catchment areas in each of the land cover maps. This type of change contributes to the observed increase in river surface run-off and reduction in base-flows observed in the simulations done by the SWAT model.

SWAT simulated surface runoff volumes with a modification of the SCS curve number method whereas a high curve number signifies high surface run-off and low infiltration rate (Mishra and Singh, 2003). The grassland class had an average curve number of 84 while urban built-up area had an average curve number of 95. This is also explained in the study by Palamuleni *et al.* (2011) that used the SCS curve number method to simulate flows and found out the increase in curve number from the forest class which had 79 to agricultural land which had 86 contributed to the increase in the run-off with the reduction of infiltration rate in the upper shire river catchment in Malawi.

The increase of surface run-off in Msimbazi catchment with the changing in land cover maps is also validated in the study by Mkilima, (2018) who studied the changes in the surface run-off with the changing in land cover maps of Msimbazi catchment from 1998 to 2018 using HEC-HMS model and found that the increase of low, medium and high urban areas at about 35% leads to an increase of surface run-off by at least 23.08% in the catchment.

The impacts of the effects of flooding are more severe recently as areas that could be inundated in 1998 had wetlands and reverie vegetation that contributed to the eco-system balance of the catchment but in 2020 the areas are over-populated with human settlement. Measures have been undertaken to relocate residents in areas that are termed as flood-prone areas but these measures did not have a positive output as most of the residents remain in those settlement areas. This anthropogenic influence on the Msimbazi river streams such as dumping of wastewater to river streams increases the quantity of water to be transported by streams, dumping of solid wastes in streams destructs the river regime and block drainage facilities such as culverts and bridges also improper deviation of natural river streams for settlement creation.

These activities have direct impacts on the hydrological process of the river and contribute largely to the observed increase in reports of flooding events. This study and the other aforementioned studies on the Msimbazi catchment have identified the importance of proper land cover transformation and conservation of riverine features explaining that the improper land cover transformation observed within the catchment can be linked to the increase of flooding events in the catchment. Flooding events increase through the increase in peak river flows observed in the average annual monthly flows, the increase of surface run-off and the decrease of base-flows observed in the 1998, 2020 and 2040 land cover maps. The potential increase of surface run-off calls upon proper design, operation and maintenance of the drainage facilities within the catchment and prohibition of solid waste disposal into the river streams.

CONCLUSION

Managing floods within a catchment requires an intensive understanding of the factors that contribute to flooding occurrence and the inundation extent. Land cover is one of the factors contributing to flood occurrence and through this study, the quantification on the impacts of changes in land cover to flood occurrence within Msimbazi Catchment was successfully established. Major land cover changes were from grassland areas to urban built-up areas and bare soils. These changes caused an overall increase in peak discharges of Msimbazi River by at least 30%. Specifically, surface run-off increased by at least 20% while base-flow reduced by about 22%. This increase in river flows and most especially the increase in overland flow attributes to the flood occurrence within the catchment as more water flows on the surface with less infiltrating.

The study recommends gauging the rivers in urban areas so as to monitor the change of hydrological characteristics. Also, the study recommends the proper design and preservation of the drainage facilities in the catchment most especially downstream the catchment where there is high-density settlement. The study further recommends the sustainable preservation of the natural river streams prevention of dumping of wastes into the stream as they contribute to altering the hydrological processes of the catchment.

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