International Journal of Social Sciences and Management Review

Volume: 04, Issue: 05 "September - October 2021"

ISSN 2582-0176

ASSESSING THE APPROPRIATE STORMWATER MANAGEMENT SYSTEM FOR KISII MUNICIPALITY, KISII COUNTY, KENYA

JAMES OKINYI MANYARA MEJA* GETABU ALBERT, ONCHIEKU JAMES, OGENDI GEORGE, OKWADHA GEORGE

Department of Natural Resources Management, Kisii University, Kenya

*Corresponding Author

https://doi.org/10.37602/IJSSMR.2021.4505

ABSTRACT

Urban storm drains are crucial in draining water from the city to major water bodies and finally to retention Bonds, lakes and dams. The storm drains Stormwater is a direct result of rainfall, where water flows before it joins the main drainage systems. In urban areas, stormwater is a major contributor of non-point source pollution emanating from urban liquid wastes that are washed down to the main water channels. This study aimed at developing an efficient and effective stormwater management system within the Municipality. The need to study an appropriate design for the Kisii stormwater system was informed by researches that indicated urban flooding was majorly caused by poor drainage systems and unsynchronized water channels with culverts. The study aggregated all data collected from the Kenya Metrological department on rainfall intensity for Kisii Municipality and Field research Data on storm channels alignment, depth, width and formation. The SWMM model used two scenarios Low Impact Development (LID) model and Manning's formula storm channels adjustment. The LID model introduced retention bonds, storage tanks and infiltration within Kisii town while manning formulae was used to adjust culverts levels to adjoining culverts. The study was analyzed using PCSWMM software and it was established that infiltration accounted for 50.4% while storage barrels comprised of 24.3%. The introduction of LID in Kisii town reduced flood water by 28.8%, though this wasn't enough to reduce flooding downstream the introduction of channels realignment and LID simultaneously reduced flooding at Daraja Mbili by upto 66.7%.

Keywords: Storm management, LID, PCSWMM, Urban drainages

1.0 INTRODUCTION

Urban stormwater management systems are critical in reducing urban floods and enhancing water quality. Their art of management of urban stormwater is based on the hydrological processes experienced in the specific areas.

Granata et al. (2016) state that hydrological processes include losses associated with interception, infiltration, evapotranspiration and depression storage; transformation of the resultant effective rainfall into overland flow with the resultant flow entering the drainage system. The design tool for stormwater management systems is the Intensity Duration

Volume: 04, Issue: 05 "September - October 2021"

ISSN 2582-0176

Frequency (IDF) curves which represent the intensity and frequency of maximum rainfall events in different durations (Fadhel et al., 2017).

Urban areas are faced with the challenges of managing stormwater (Sharley et al., 2017). Urbanization typically results in undesirable changes to the flow rates and contaminant loads in urban stormwater (Burton and Pitt 2001). Worldwide, initiatives have been developed to reduce pollutants discharged by storm waters into receiving waters. These include the Flood and Water Management Act (2010), UK, The USA's National Pollutants Discharge Elimination System (NPDES) (1972) and the Australian Guidelines for Urban Storm Water Management (2000).

In the management of urban stormwater channels research by Computational Hydraulics International (CHI) indicates that the management can be approached in two distinct categories which can be community approach by enhancing Low Impact Development (LIDs) and structural approach by altering and realigning the drainage channels and junctions/culverts.

Low Impact Development (LID) includes a variety of practices that mimic or preserve natural drainage processes to manage stormwater. LID practices typically retain rainwater and encourage it to soak into the ground rather than allowing it to run off into ditches and storm drains where it would otherwise contribute to flooding and pollution problems (EPA, 2020)

Flooding and urban storm waters cause infrastructure damage that becomes catastrophic and severe as in the case of Toronto and Calgary in 2013. Human suffering and after-effects caused by both events continue, and these floods represent a harsh reminder for municipalities to refocus their attention on infrastructure sustainability (Miller, 2013). The issues of urban stormwater are widespread and can be derived from social, economic, institutional, technical and related factors; and issues derived from climatic variations (Upadhyaya, 2013). The challenges are vast and vaguely understood and thus the need for a comprehensive study of stormwater challenges and management.

2.0 DESCRIPTION OF THE STUDY AREA

The study was carried out within Kisii Municipality in Kisii County which is approximately 29km2 wide. The County is located (-0.678881 S, 34.774066 E) at the CBD.

It is located in the southern end of the western Kenya highlands at an altitude of 1660 m above sea level.

The area has a bi-modal rainy season with long and short rainy seasons (March to May and October to November), it receives an average rainfall of over 1700 mm per annum distributed almost throughout the year. Temperatures in the area range from 10°C to 30°C with a relative humidity of 88%. The area is densely populated with a population of 103,000 people and a density of 2862 people/km2 (Nyarango et al., 2008).

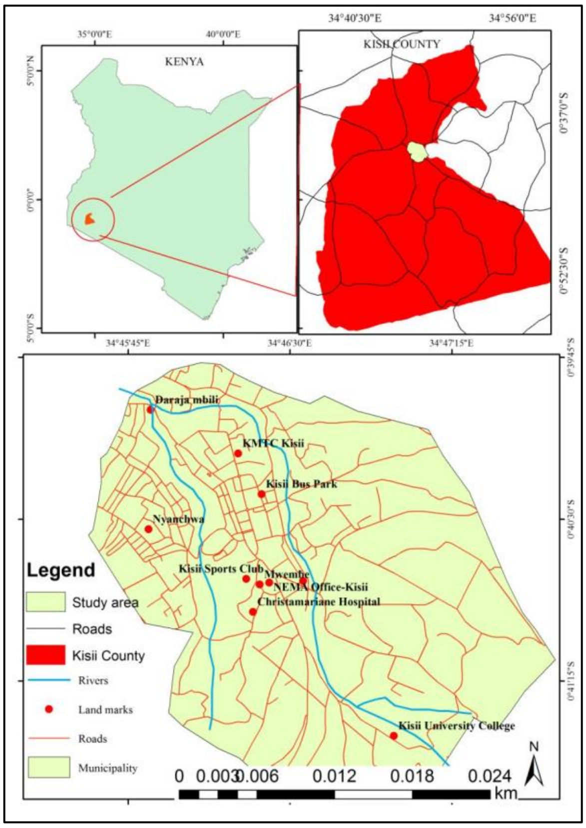


Figure 1: Study area

3.0 RESEARCH DESIGN

The descriptive research design was used in this study to obtain a picture of county plans and management of storm drains systems with relation to open water quality in the Municipality. Design Science Research methods were used to develop a model and a probable storm water management system for Kisii Municipality. This study focused on existing plans, county officials' statements, the public opinion on storm drains and water quality in the municipality.

4.0 DATA ANALYSIS

The simulation of storm water used PCSWMM 2020 and SWMM models of water management. The models comprise of Environmental Protection Agency [EPA] Storm water Management Model [SWMM] version 5.1 and Computational Hydraulic International (CHI) for PCSWMM. SWMM and PCSWMM are some of the top urban rainfall-runoff models that can be utilized to simulate hydrological processes in an urban area.

The study used precipitation intensity data from the year 1999-2019 to simulate the study area as supplied by the Metrological department (Kenya Metrological Department-Kisii and KALRO). The SWMM model requires several parameters to simulate flooding in urban areas, such as topography data, soil data, network data and climate data.

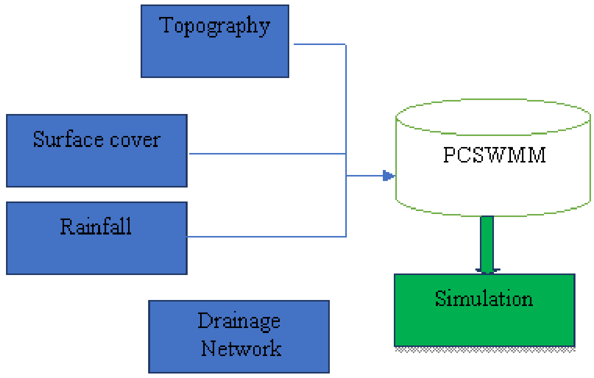


Figure 2: Simulation process

4.1 The SWMM Modeling

Low Impact Development (LID) was used modelling in SWMM 5.1. LID is a decentralized small-scale measure module that is included in SWMM. It is environmentally friendly, easy to construct, small in size, economical, and ornamental as landscape. There are eight types of LID controls in SWMM 5.1: Bio-Retention cell which is documented to hold up to 95% of runoff waters, the bio-retention cell biological mitigation factors such as green vegetation, Rain garden, green roof, infiltration trench, permeable pavement, rain barrel, rooftop disconnection and vegetative swale.

In SWMM, several LID modules are created and then added to the corresponding subarea by changing parameters according to the actual situation. Based on the principle of water balance, the SWMM calculates real-time inflow and outflow of the subarea. Four LID scenarios;

a) No LID technique.
b) LID technique based on infiltration.
c) LID technique based on water barrels
d) LID technique based on the combination of infiltration and water barrels

The SWMM model uses data from the Surface runoff coefficient to simulate total runoff and in turn create overall overflow and retention of water based on the LID parameters. The findings of this study provide some technical support for the construction of drainage systems in urban areas.

5.0 FINDINGS AND RESULTS

5.1 Storm water management system (SWMS)

Stormwater management design used two approaches; the 1st approach was to do a Low Impact Development (LID) model. The model would then be substituted with conduits and junction adjustments based on manning's formulae.

International Journal of Social Sciences and Management Review
Volume: 04, Issue: 05 "September - October 2021"
ISSN 2582-0176

There were 36 infiltration units in the area covering 50.4% of the total study area, 7 permeable pavements and 48 storage barrels. There was 19.6% of uncovered area by infiltration, permeable pavement or storage which amounts to Total surface runoff.

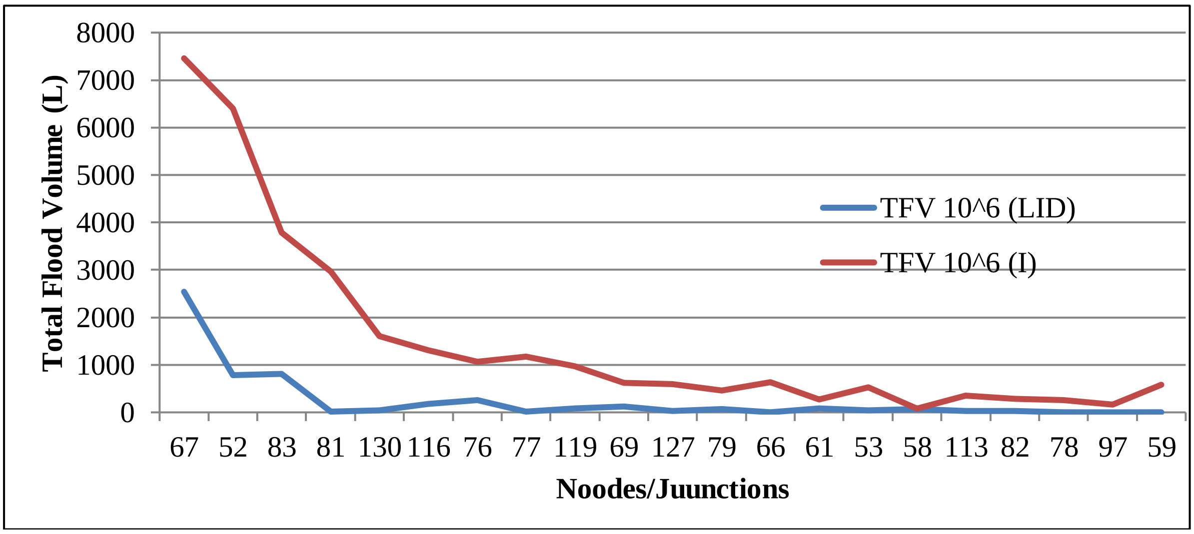
Table 1: LID control summary

LID	No of Units	Area (m^2)	% of Study area
Infiltration	36	1771.83	50.4
Permeable Pavement	7	211.8	6.0
Storage Barrels	48	853.57	24.3
TOTAL	**91**	**2837.2**	**80.6**

5.2 LID on combined

The LID on combined flood control within Kisii Municipality was initiated and it was observed that flooding is mitigated by reducing 281.53 (10*6) litre of water per day. The daily flood rate is 975 (10*6) litres. The No LID technique showed flooding in all the initial flood areas since there were no measures to reduce flooding.

The flooding experienced at the nodes as indicated in shows a comparison between LID imposed sub-catchments and non LID sub-catchments. The LID controlled catchments have high runoff retention and create a high re-routing of water on either storage or infiltration. The significant change is in NODE 67 with a decline of 5000 litres.



Volume: 04, Issue: 05 "September - October 2021"

ISSN 2582-0176

Figure 3: Total flooding Infiltration-Before LID and after LID

The flooding control resulting from infiltration only in the municipality 355.14mm storage on Tanks was 1128mm and 153.77mm were sipped onto permeable walkways grounds. The surface outflow for barrels/storage facility was not available because of instant storage and any spillage was treated as outflow on infiltration.

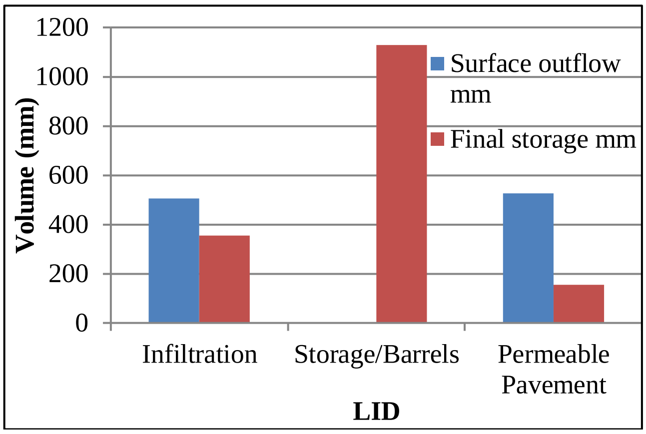


Figure 4: LID performance

Flood control by use of LID on joints was significant on R Riana with water speeds at

Daraja Mbili (67) reducing from 45.26cms to 5.38cms Figure 4.24 below. The Junctions which experienced floods in the initial study area were 34 nodes and on the 1stsimulation-using LID, there were 21 nodes with flooding <6cms. The LIDS efficiency on a research conducted on western Australia by Akhter M, 2016 it was reported that 42% of runoff was retained by LIDs that included retention ponds and infiltration.

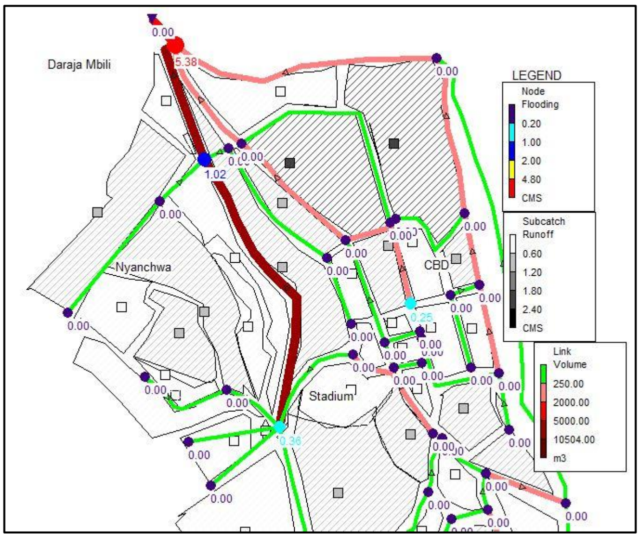


Figure 0.3: Water speeds at Daraja Mbili (CMS)

5.3 Conduits and Joints adjustment

Volume: 04, Issue: 05 "September - October 2021"

ISSN 2582-0176

However, LIDS did not contain the flooding experienced in Kisii town and conduits and joints realignment and was initiated. The flooding downstream after the introduction of adjusted links and junctions to allow more flow resulting from surface runoff.

The adjustment was done for links, conduits (circular using Manning's formula for conduits) while for trapezoidal and rectangular conduits overall adjustments were done. Adjustments were made for six conduits that had a circular profile and three conduits had their base diameter reduced by 10% to merge the inlet and the outlet diameter. This reduced the surcharge level of the conduits 40, 25, 27, 44, 50 and 16respectively for conduits 44 and 50 their diameters were adjusted 5% reducing the inlet and outlet elevation by -0.05m.

Table 2: Adjusted links based on Manning's Formula

Name	Original Diameter (m)	New Diameter (m)	Percent changed (%)	Slope (m/m)	Peak Flow (m^3/s)	New Inlet Elevation (m)	New Outlet Elevation (m)
40	1	0.9	-10	0.0062	1.574657	0.1	0.1
25	1	0.9	-10	0.01273	2.305984	0.1	0.1
27	1	0.9	-10	0.015642	2.135909	0.1	0.1
44	1	1.05	5	0.002406	1.580462	-0.05	-0.05
50	1	1.05	5	0.007758	2.958254	-0.05	-0.05
16	1	1	0	0.009682	0	0	0

6.0 DISCUSSION

Stormwater management system (SWMS)

The stormwater management model SWMM was used to develop a Low Impact Development model (LID) for water management in Kisii Municipality. The LID model used four scenarios to model flooding;

a) No LID technique (maintaining the initial runoff rates without mitigation)
b) LID on infiltration.
c) LID on water barrels/storage
d) LID combination of infiltration and water barrels

Links surcharging was evident after introducing LIDs to the sub-catchments with links surcharging for up to 23.9hrs in link 79

(Mwembe) this indicates a total ponding at Mwembe, this could be caused by the slope and eminent adverse slope at the exit of joint 127 (Mwembe/Christamarianne Mission Hospital Road).

The links surcharging was reduced by increasing lateral and vertical design of the culverts the major adjustments on links in Nyanchwa was recommended for a complete rerouting and comprehensive route of LIDS with an increase of Rim elevation of Daraja Mbili conduit to reduce surcharging.

The juxtaposing of the existing stormwater drainages in Kisii Municipality and the new drains simulated by SWMM it indicated a reduction in surcharge hours on major surcharged conduits in Mwembe and Daraja Mbili.

Figure 6: Ponding in Mwembe as a result of adverse slope

The limitations of LID in Kisii municipality could be linked to land ownership modes. The land ownership and designated land use which is majorly high, medium residential limits the introduction of LIDs. The residential and urban areas limit the use of LIDs since they need to maximize build-up area for maximum returns. The use of storage tanks can therefore not be effective since its effectiveness is less than 20% in mediating surface runoff. The residents were asked if they preferred a LID method and 87.1% preferred water storage as their major LID method. The storage tanks were smaller than the anticipated runoff and needs upgrading to bigger barrels. Infiltration was less favoured by the resident with 10.5% preferring it.

Table 3: Existing LID methods

	Frequency	Percent
Tank	340	87.0
Infiltration	41	10.5
None	10	2.6
Total	391	100.0

Kisii municipality storm drains are overwhelmed due to design and increased runoff from land use in the study area. The introduction of LIDs in Kisii municipality especially to catchment areas and estates shows a reduction of up to 20% of surface runoff and flooding is still experienced at conduits and junctions. The mitigation measure resorts to aligning waterways by increasing their overall depth and adjusting the inflow and outflow of culvers to synchronize with the conduits. Links at Mwembe and Daraja Mbili are very unstable due to design and slope causing increased surcharging and flooding.

7.0 SUMMARY

The management of storm drains in Kisii was conducted by using an SWMM model. The model used two scenarios Low Impact Development (LID) model and Manning's formula storm channels adjustment. The LID for Kisii created three instances of surfaces to sink or store water on the grounds. The lids covered a total of 80% of the land but their efficiency of retaining water and infiltrating was 30% thus initiation of the adjustment mode of culverts.

The culverts were adjusted to reduce surcharging in all waterways. The major change was done at node 67 with all dimensions increased to accommodate the waters from Nyakomisaro. The circular channels were adjusted to fix the offset links with adjoining links.

REFERENCES

Granata, F., R. Gargano & G. de Marinis, 2016: Support vector regression for rainfall-runoff modeling in urban drainage: A comparison with the EPA's storm water management model. Water, 8, 69.

Fadhel, S., M. A. Rico-Ramirez and D. Han, 2017: Uncertainty of Intensity–Duration–Frequency (IDF) curves due to varied climate baseline periods. Journal of hydrology, 547, 600-612.

Sharley, D. J., S. M. Sharp, S. Marshall, K. Jeppe & V. J. Pettigrove, 2017: Linking urban land use to pollutants in constructed wetlands: Implications for stormwater and urban planning. Landscape and Urban Planning, 162, 80-91.

Burton Jr, G. A., & Pitt, R. (2001). Storm water effects handbook: A toolbox for watershed managers, scientists, and engineers. CRC Press.

EPA, 2020, Urban runoff: Low impact development. Available on: https://www.epa.gov/nps/urban-runoff-low-impact-development Accessed on 4/4/2021 10:32 am)

Miller, G. 2013. Climate change threatens our infrastructure. Windsor Star, 19 July 2013.

Upadhyaya, J. K., Biswas, N., & Tam, E. (2014). A review of infrastructure challenges: Assessing stormwater system sustainability. Canadian Journal of Civil Engineering, 41(6), 483-492.

Nyarango, R. M., P. A. Aloo, E. W. Kabiru and B. O. Nyanchongi, 2008: The risk of pathogenic intestinal parasite infections in Kisii Municipality, Kenya. BMC public health, 8, 237. Open Access Library Journal, Vol.1 No.9, December 17, 2014

Volume: 04, Issue: 05 "September - October 2021"

ISSN 2582-0176

Akhter, M. S., & Hewa, G. A. (2016). The use of PCSWMM for assessing the impacts of land use changes on hydrological responses and performance of WSUD in managing the impacts at Myponga catchment, South Australia. Water, 8 (11), 511.

