PAPER 165 – SUSTAINABLE MANAGEMENT OF STORM WATER GENERATION IN A FAST-URBANIZING RESIDENTIAL AREA OF MALETE, KWARA STATE, NIGERIA

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ABSTRACT
An alteration in the natural land cover characteristics of the environment due to the high rate of urbanization globally has created a large span of impervious surfaces that resist the infiltration rate but encourage runoff from precipitation. This phenomenon affects the natural environment. To mitigate the effect of storm water generation, Low Impact Development (LID) techniques was developed as a means of storm water management. In this study, Storm Water Management Model (SWMM) in conjunction with MAPWindow GIS was used to simulate the effects of selected LIDs embedded in the SWMM to mitigate storm water generated in the study area. The study area was delineated into six sub-basins in the GIS environment and imported into the SWMM to study the effect of some selected LIDs which are green roofs, rain gardens, vegetative swale, and permeable pavement. The results show that the permeable pavement has the highest reduction value of about 50% across all sub-basins while Green Roof has the least reduction value of 0.003%. Outcome of this study can be a decision support tool that can be adopted by different stakeholders and relevant authorities in the selection of appropriate LIDs practices to mitigate the urban impact of storm water generation in the study area.

KEYWORDS*:* Storm water; Mitigation; SWMM; LIDs; Sub-catchment; MAPWindow

1.0 INTRODUCTION

Storm water is the precipitation generated from rain, sleet, or melting snow. In a natural setting, only a small percentage becomes surface run off. This runoff usually flows into the nearest stream, creek, river, lake, or wetland. Due to the rapid urbanization around the world, the natural land covers characteristics are changing into impervious surfaces and degrading the natural environment. These adverse effects include the increase runoff and peak flows that cause flash flooding and water quality degradation and other water related problems (Dientz, 2007). In addition, climate change is another big challenge that is making our towns and cities vulnerable to erosion and incessant flooding. Climatic change and growth in the major cities have altered hydrological pattern and increases runoff volumes resulting into erosion, flooding and degradation of ecosystem. Low impact development (LID)s advocates the design of a decentralized storm water control system above centralized location in the catchment area. The benefit of LIDs is to control the amount storm runoff, improve storm water quality and river, reduced the flood peak, increases the infiltration rate and base flow and to restore water cycle systems distorted by urbanization to their pre-development state Kim et al., (2021).

In the past, the control schemes of urban flooding were focused on the construction of drainage channels to convey the generated runoff. However, construction of drainages in our towns and cities can only achieve a certain effect in the short term but cannot solve the problem fundamentally. In recent time, applications of Low Impact Development (LID) practices have proved as the sustainable solutions to mitigate the adverse effects of urbanization and to retrieve the natural hydrology of urban areas. The impact of various LIDs can be simulated using various hydrological models such as Storm Water Management Model (SWMM) which can simulate the natural hydrological conditions as much as possible.

Malete is one of the fastest growing towns in Kwara State Nigeria and this might not be unconnected with to the recent citing of Kwara State University in the town. In the past ten (10) years of establishing the University, the number of students admitted for different programs has geometrically increased while the academic and non-academic staff of the university has also shot up. Hence, there is a rapid growth in the construction of buildings for student hostels at different locations around the town to cater for the housing need of the student and staff populace. This rapid urban growth has increased the generation of urban storm water runoff, and this may be accompanied by associated effects such as water logging resulting in ground flooding, traffic jams, underground submerging, and interruption of utilities pipeline such as gas and electricity. Urban water logging seriously impacted on people's life and property safety.

Therefore, this research aimed at studying the effect of the application of different Low Impact Development (LID) in managing storm water generation in the study area. Outcome of the study can be an eye opener and decision support tool to develop and other relevant authorities in selection of best alternatives LIDs for storm water management in the area.

2. THEORETICAL ANALYSIS

The modeling tool adopted in this research was Storm Water Management Model (SWMM). It is a comprehensive hydrological and water quality simulation model used for single or continuous events of runoff in urban areas (Rossman, 2005). SWMM comprises four computational blocks, namely RUNOFF, STORAGE/ TREATMENT, TRANSPORT and EXTRAN. Hydrograph and pollutograph were generated by the RUNOFF block. The basic input parameters required to simulate hydrograph were rainfall hyetograph and the sub-catchments physical characteristics. The infiltration loss on pervious area was estimated by Horton equation (Equation 1) because of the availability of soil data. The EPA SWMM is a physically based, deterministic model that simulates water inflows, outflows, and storages within a sub-catchment.

$$F = ff + (fo - ff)\, e - kt \qquad \text{Equation 1}$$

where f_o: the initial infiltration rate (capacity)
f_f: the final rate (almost equal to percolation rate)
k: Constant (depend on soil type and vegetation)
t: time from the beginning of the rain

3.0 METHODOLOGY

3.1 Description of the study area

The study area is in Malete Town which is located between latitude $8^0$36' and $8^0$24' North and Longitudes $4^0$36' and $4^0$10' east. Its total area is 1230.0 km^2 and it is a small town in Moro Local Government Area of Kwara State. The headquarter of the town is in Bode Saadu, a town situated along Jebba road, Moro Local Government is made up of five districts namely Lanwa, Ejidongari, Olooru, Malete and Ipaye. The topography of the area is a fair representative of surrounding plains which can be described as undulating with very broad and gentle slopes. The town is characterized with combination of open storm water drainage system and earth drain for the conveyance of generated storm water from the environment. The town is the custodian of the Kwara State University which was established in 2009. The main occupation of Malete inhabitant are farming, trading and hunting. Figure 1 shows the Google Earth imagery of Malete Town while Figure 1 shows the location of Malete Town in Kwara State Map.

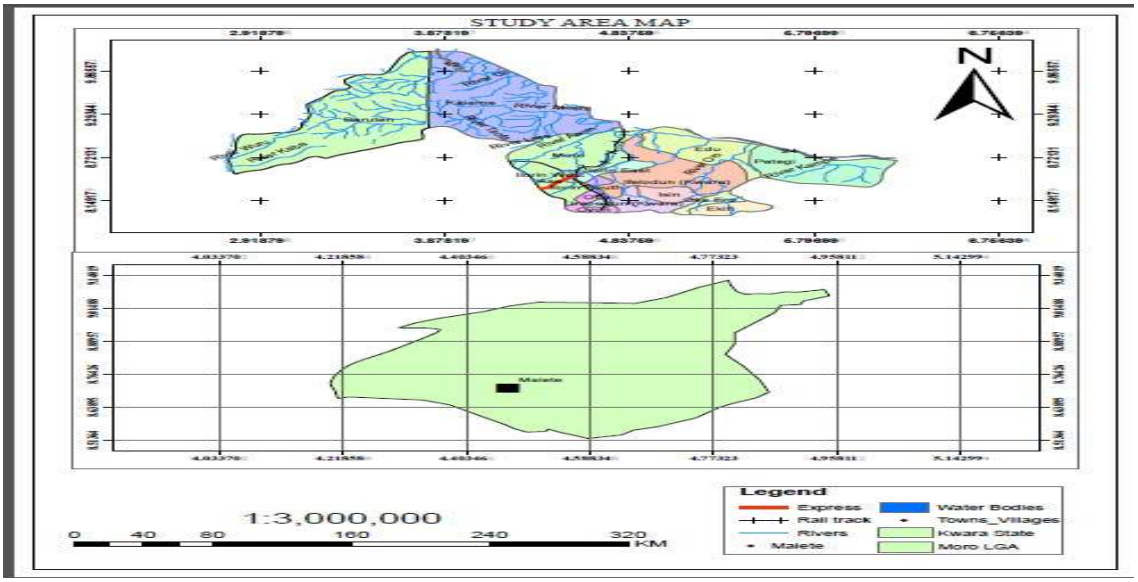


Figure 1: shows the location of Malete Town in Mooro Local Government of Kwara State

3.2 Model Selection, Data Requirements and Geoprocessing of Spatial Data

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Spatial data required for the modelling exercise include the Digital Elevation Model (DEM) of the study area. The DEM of resolution 90 m x 90 m was extracted from online database of Shuttle Radar Topographical Mission (SRTM) website of United State Department of Agriculture (CGIAR, 2012). The DEM was geo-processed using the Automatic Watershed Delineation (AWD) dialogue box from the Mapwindow GIS interface (Leon, 2011). AWD was prepared by setting the elevation units, threshold size and creating an outlet for the watershed. Other spatial data used in the delineation of the watershed into subbasins include the land use map which was extracted from Global Land Cover Characterization (GLCC) database and used to estimate parameters such as vegetation representing the study area. The land use database was prepared by United States Geological Survey (USGS) and has a spatial resolution of 1km. The soil data required for the study was obtained from harmonized digital soil map of the world (HWSD v1.1) produced by Food and Agriculture Organization of the United Nations (Nachtergaele et al., 2009). The daily weather (precipitation, wind, solar radiation, relative humidity and daily minimum and maximum temperature) data of the study area were obtained from Nigerian Meteorological Agency (NIMET) Ilorin and were prepared in the appropriate file format by the model and imported into the model. The study area was divided into six subbasins and 11 Hydrologic response unit (HRU). The HRU is the smallest spatial unit of the model. The total catchment includes 6 sub catchment, 10 junctions, 10 conduit links, 1 outfall, and 1 rain gage station (Figure 1). SWMM was used for obtaining quantity of runoff generated within each sub catchment and the flow rate, flow depth, in conduit during a stimulation period and comprised of multiple time step.

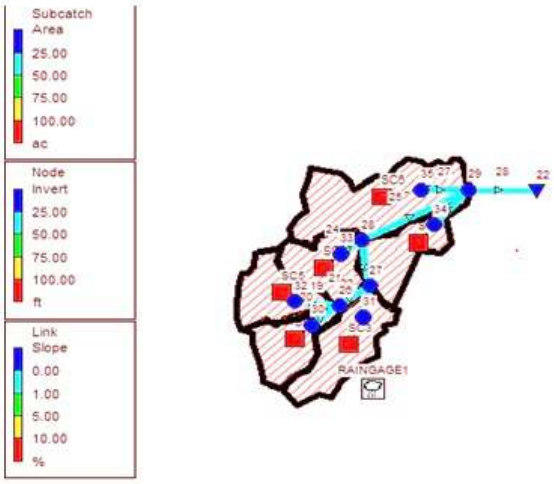


Figure 2: Delineation of the Watershed into Sub basins

3.3 Selection and Modelling of Low Impact Developments

There are different LID components that can be simulated in SWMM model. However, LIDs simulated in this research are (i) Rain Garden (ii) Permeable Pavement (iii) Vegetative Swales and (iv) Green Roof. Different scenarios were created for simulations which include the combination of LIDS to evaluate their efficiency in the reduction of the amount of total runoff from each of the sub catchment area.

4. RESULTS AND DISCUSSION

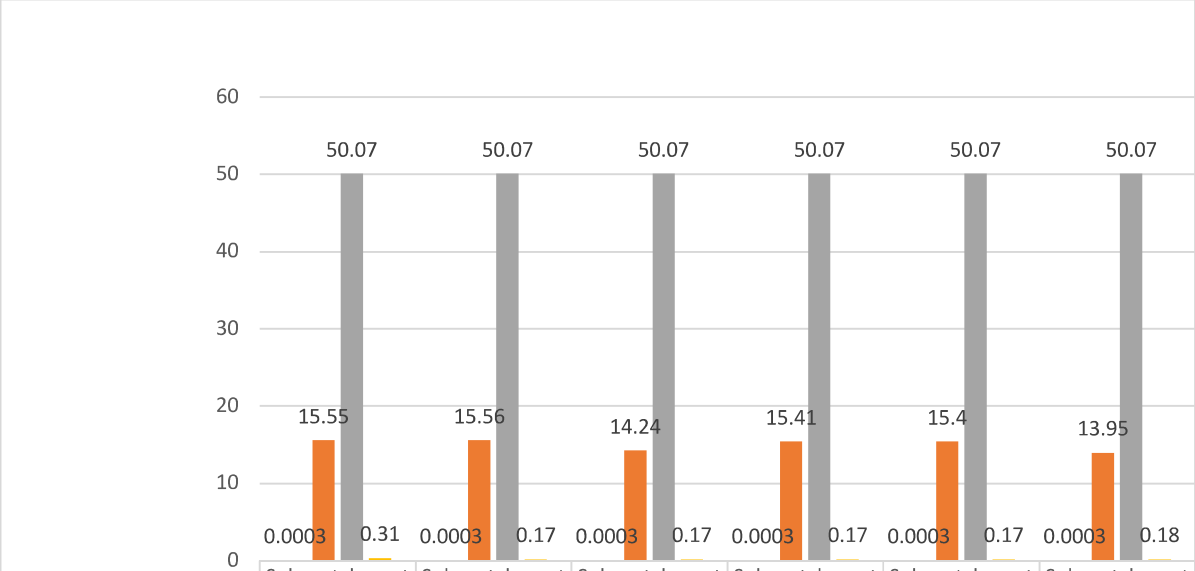
The outcome of the study is as presented in Table 1 and figure 3. The result shows that all LIDs modelled reduced the storm water generation across the sub basins of the study area. However, the percentage runoff reduction using permeable pavement as LID in the six sub-catchment of the study area was highest among the other LIDs considered to reduce surface runoff, flood peak and delay peak flow with average storm water reduction of about 50 %. This result is higher when compared with the results obtained by Arora, et al (2023) that investigated the effectiveness of permeable pavement at the basin scale under a variety of design rainfall and land-use situations. Their results indicated that the incorporation of permeable pavements in urban settings is effective in reducing storm water in a developed catchment by decreasing the peak flow by 7–16%.

The application of vegetative swale has a runoff reduction percentage in the sub-catchment between 13.95% - 15.56% which makes it to be the second most effective in storm water management in the study area. This outcome is lower than the result obtained by Bailee (2017) which indicated that 87.2 % of runoff volume was reduced by the swale. Conversely, Qinghua *et al.* (2017) also corroborated that vegetative swale as an effective low impact

development procedure in mitigating runoff. A very low runoff percentage reduction was observed in the application of Rain garden with the value ranging from 0.0003% to 0.31%. Though, this agreed with Derek (2011) who reported that rain gardens can help the existing developments by mitigating storm water volume and peak flow and provide a dynamic internal saturation zone with the potential for water quality benefits, the percentage reduction is low compared with a similar study in Nepal by Neupane *et.al.*, (2020) where the rain garden reduced the runoff generated by about 42%. The green roof has the lowest storm water reduction of 0.0003 % in reducing storm water and Aruna *et al.*, (2012) confirmed the efficacy of green roof as an alternative procedure for runoff reduction in watershed.

Table 1: - Summary of Rainfall Runoff Reduction by Low Impact Development

Sub-catchment	Low Impact Development	Area Covered (%)	Number of Units per LID (sc)	Initial storage (in)	Final storage (in)	LID performance differences	LID performance (%)
Sc1	Green Roof	10	10	669199.56	669197.65	1.91	0.0003
	Vegetable swale	10	10	669199.56	565156.19	104,043.37	15.55
	Permeable pavement	10	10	669199.56	334112.46	335,087.10	50.07
	Rain garden	10	10	669199.56	667112.86	2,086.70	0.31
Sc2	Green Roof	10	10	668743.35	668741.44	1.91	0.0003
	Vegetable swale	10	10	668743.35	564710.93	104,032.42	15.56
	Permeable pavement	10	10	668743.35	333884.36	334,859.00	50.07
	Rain garden	10	10	668743.35	667605.45	1,137.9	0.17
Sc3	Green Roof	10	10	666689.18	666687.26	1.92	0.0003
	Vegetable swale	10	10	666689.18	571731.36	94,957.82	14.24
	Permeable pavement	10	10	666689.18	332848.50	333,840.62	50.07
	Rain garden	10	10	666689.18	665522.62	1,166.56	0.17
Sc4	Green Roof	10	10	668585.18	668583.26	1.92	0.0003
	Vegetable swale	10	10	668585.18	565564.86	103,020.32	15.41
	Permeable pavement	10	10	668585.18	333804.74	334,780.44	50.07
	Rain garden	10	10	668585.18	667445.57	1,139.61	0.17
Sc5	Green Roof	10	10	665467.68	665465.76	1.92	0.0003
	Vegetable swale	10	10	665467.68	563056.22	102,411.46	15.40
	Permeable Pavement	10	10	665467.68	332245.18	333,222.50	50.07
	Rain garden	10	10	665467.68	664325.43	1,142.25	0.17
Sc6	Green Roof	10	10	666206.33	666204.41	1.92	0.0003
	Vegetable swale	10	10	666206.33	573246.62	92,959.71	13.95
	Permeable pavement	10	10	666206.33	332604.45	333,601.88	50.07
	Rain garden	10	10	666206.33	665032.15	1,174.18	0.18



	Sub -catchment 1	Sub -catchment 2	Sub -catchment 3	Sub -catchment 4	Sub -catchment 5	Sub -catchment 6
Green roof	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
vegetative swale	15.55	15.56	14.24	15.41	15.4	13.95
permeable Pavement	50.07	50.07	50.07	50.07	50.07	50.07
Rain garden	0.31	0.17	0.17	0.17	0.17	0.18

Figure 3: Percentage runoff reduction by selected LIDs in the watershed

5. CONCLUSION

The findings indicate that all the four LIDs examined through model simulation were means of controlling and managing the effects of storm water on environment and water quality. It was also discovered that Permeable pavement and Green roof have the highest and lowest percentage runoff reduction respectively in the study area. Therefore, the outcome of this study can be a decision support tool that can be adopted by different stakeholders and relevant authorities in the area while selecting appropriate LIDs practice to mitigate urban impact of storm water generation.

ACKNOWLEDGEMENT

I sincerely appreciate Almighty Allah for the opportunity given to carry out this research work. I would also like to express my sincere gratitude to my supervisor in person of Dr. A. G Adeogun for his guidance and constructive criticism. I am grateful to my parents, siblings, colleagues and friends for their support and encouragement through this research work.

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