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Simulation of Storm Sewer Network Using a Storm Water Management Model (SWMM), Ramadi City as a Case Study

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ABSTRACT

Ramadi city is suffering from severe flood problems during rainfall season as in many cities in developed countries. Storm Water Management Model (SWMM) was used to simulate storm sewer network in the study area and depending on design rainfall intensity of 9.6 mm/hour. The rainfall intensity was proposed to increased by two to three times of the design intensity because of the absence of metrological stations in the study area to record rainfall intensity data of the rain storm. The intensity increasing by three times led to maximizing the flood risk by 43%. The proposed management to overcoming this problem is linking the collateral lines in Al-Andalus and Alhoz suburbs by additional pipes, this method reduces the percentage of flooding to 31%. Moreover, Economic Indicators (EI) were suggested to evaluate the cost of the network development. The area index (EA_i) which represents the total cost of the added pipes to the total area of the suburb, and the longitudinal index (EL_i), which represents the total cost of the added pipes to the length of the main pipe, the magnitudes of these indexes are 178 US dollar/hectare, and 57 US dollar/m respectively.

1. Introduction

Storm Sewer Management (SSM) is one of the most important infrastructure elements in the modern cities which is designed to control the rainwater flow and other types of surface water flow on the streets and in car parks [1]. In general, the storm sewer network consists of pipes, manholes, pumps, etc.

The best optimal situation for storm sewer network is to be separated from the sewage system, so that the pressure on the network can be reduced as the water can be relieved into lakes and rivers directly. Engineers have used computer design and analyses models which are quicker, cheaper and produce better results. In the last four decades, many computer designs have been developed; most of them were designed by the American Federal Government or the local governments. Many researches in Iraq have designed and analysed storm sewer networks by using the aforementioned models. [2] used Sewer CAD V8, [3, 4, 5, 6] used SWMM program to develop storm sewer network. Around the world, there is hundreds research used this program [7, 8, 9, 10, 11]. What sets SWMM apart from other urban watershed models is its emphasis on engineered water conveyance systems for stormwater runoff and wastewater management, considering both combined and sanitary sewer design and performance, also the effectiveness of the program for the operational management of the storm sewer drainage systems even in the case of scarcity of hydrological and hydraulic data. Therefore, it was approved in this study.

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This study proposed Expansion Cost Ratio (EI) to evaluate the benefit of expansion to minimize flood percentage to minimize value with minimum cost.

2. Study Area

Ramadi city is the capital of Anbar governorate, about 110 kilometers west of Baghdad, (Latitude: 33°25'11'' N, Longitude: 43°18'45'' E), with an area of 180 square kilometers as shown in Figure (1). Ramadi city is characterized by flat lands nearly 50m above mean sea level. The city center which represents the study area is bounded by Al-Warrar canal to the east. To the north, the city is bounded by the Euphrates [12]. According to the 2020 census, the population of Ramadi was 274,539 people (WPR, 2020).

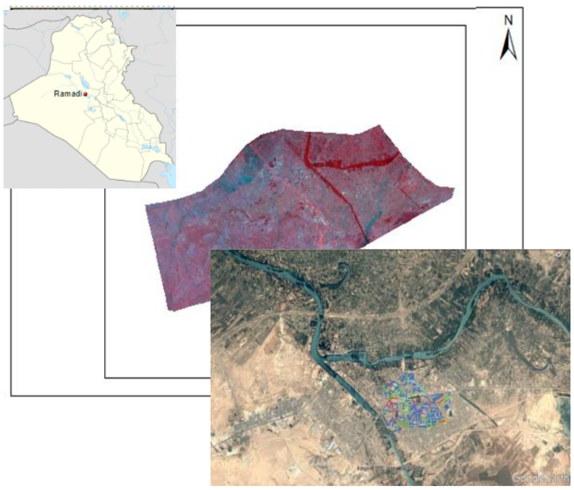

Figure 1. Study area as generated by GIS and Google Earth

3. Materials and methods

3.1 Data Collection

Digital Elevation Model (DEM) for Ramadi city obtained from the United States Geological Survey (USGS) [13] for June 2019, by using Landsat 8 satellite. Pipe lengths, diameters, and network design were obtained from the Sewer Department in Ramadi and then were drawn by using Google Earth as shown in Figure (1 and 3). Design intensity for each hour also obtained from the Sewer Department which was used as an input for SWMM program.

3.2 Simulation Model Storm Water Management Model(SWMM)

Storm Water Management Model (SWMM), is a simulation program for planning analysis and design sanitation network and other drainage systems in urban areas. First developed in 1971 in the USA by the Environmental Protection Agency (EPA), since then it has been widely used around the world [14]. The SWMM program, which is one of the best models for monitoring the flow of rainwater in urban suburbs [15] was used in this study to simulate the flow in the study area. Figure (2) summarizes the fundamentals of the program's works, from input to processing operations and outputs [13].

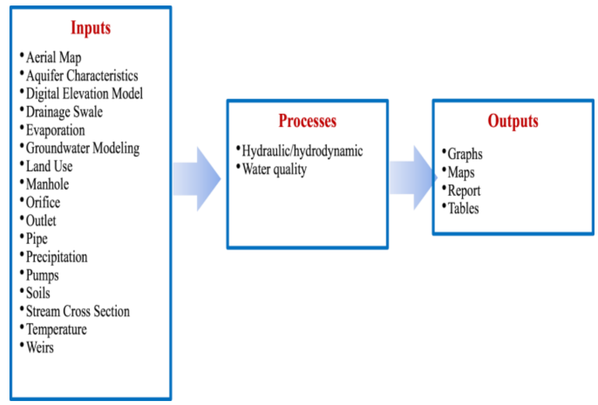

Figure 2. An illustrative diagram of the fundamentals of the program [15]

3.3 Storm Sewer Network Development

From the analysis of the sewage lines using the SWMM model, it was observed that the flood rate increased in the storm sewer network when the intensity of the rainfall increased to three times as shown in Fig. (3, a and b) where we notice the increase of the red dots that represent the flood manholes between the design intensity and after doubling the rainfall intensity to three times.

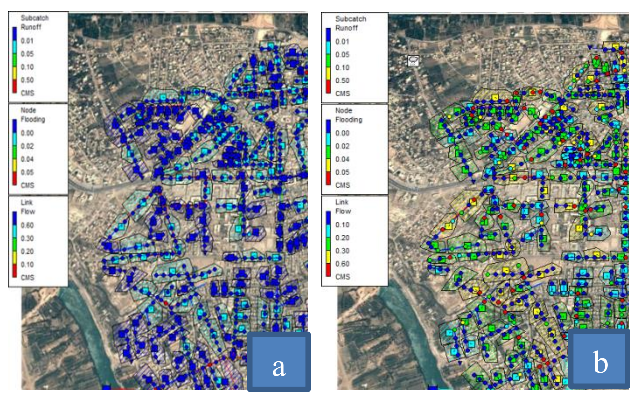

Figure 3. a. Storm sewer network at design intensity
b. Storm sewer network at design intensity

To reduce the flooding in the stormwater network, it was proposed to develop the network to improve the performance. There are more than one method to improve efficiency of the network and to increase its capacity. These methods include:-

1) Increasing the pipe diameter [16].

2) Adding an extra line to reduce the pressure on the network [7, 8, 9].

3) Increasing the green lands which play major role in increasing the infiltration [17, 18, 19, 20].

In this study, the second method was followed by adding, extra line to improve the network performance.

In the western part (Alhoz suburb) added a pipe line to connect the storm sewer network to the network in Al-Dubad suburb which pumps the water into Al-Warrar Canal after collecting it from Alhoz, Al-Andalus and Al-Dubad suburbs. Adding another pipe line is recommended to connect the collaterals to each other in Al-Andalus suburb. In the north of Ramadi city center (Althayala and Aljameai) suburbs there was a design problem as the entry manholes were lower than the exit ones in more than one pipe line of the which caused drainage defects in both suburbs. Figure (4) shows suburbs in Ramadi city center, and Figure (5 a and b) shows the Proposed connection Sewer Lines (PSL) to improve storm sewer network performance. Table (1) shows the charicterstic of proposed sewer lines.

Figure 4. Storm Sewer Network in Ramadi city center as generated by Google Earth

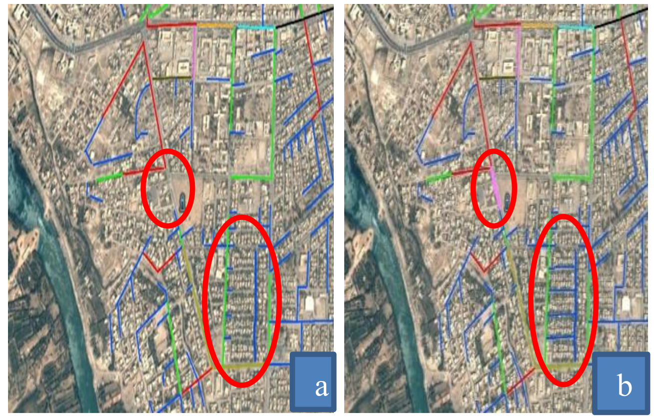

Figure 5. Al-Moulmein, Al-Adel and Al-Jomhori, Ramadi City
a: in current state

b: after adding Proposed Sewer Line (PSL)

Table 1. Characteristics of Proposed connection Sewer Line (PSL), Ramadi city

Extra pipe No.	Dimeter (mm)	Price$/meter legth	Total price
1	Ø315	100	55000
2	Ø700	167	10688

4. Results and Discusion

The flow in the storm sewer networks was simulated using SWMM program, based on the design rainfall intensity data, after the intensity was increased to three times its design value according to climatic changes.

4.1 Effect of Proposed solution

The results of the simulation of the network were compared before and after adding extra lines. Results showed positive effect of the proposed solution on the network. Where, the number of manholes which flood in the current state 96 manholes out of 225 manholes in the whole new storm sewer network of Ramadi city centre, while after adding extra pipe line only 70 manholes are flooded, as shown in Figure (6).

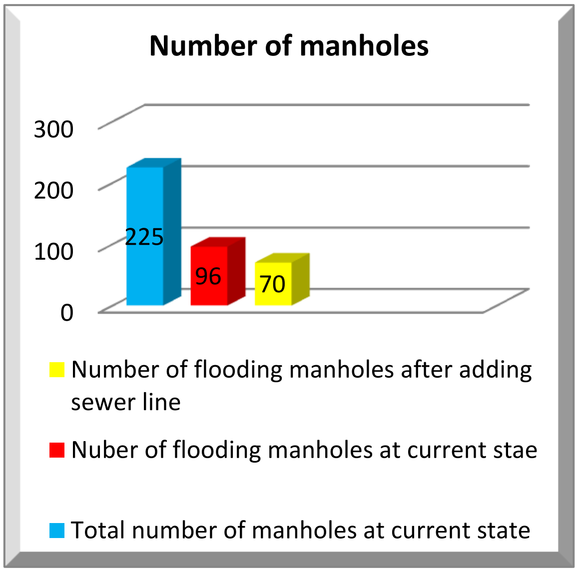

Figure 6. Number of flooding manholes in two cases after and before expansion

Flood discharge for manholes is divided into five stages as shown in Table (2) [4].

Table 2. State of flooding for manholes

Stage	State of flooding	Range of discharge m^3/sec
1	No flooding	0 – 0.001
2	Very light flooding	0.001 – 0.01
3	Medium flooding	0.01 – 0.02
4	High flooding	0.02 – 0.04
5	Very high flooding	>0.04

This modification reduces the flood rate of storm sewer from 43% to 31% as shown in figure (7), (8).

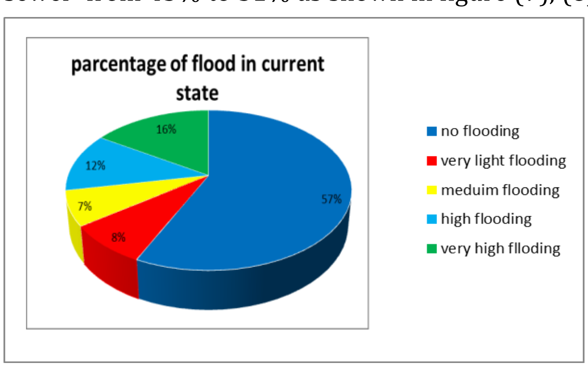

Figure 7. The Percentage of flooding manholes in current state

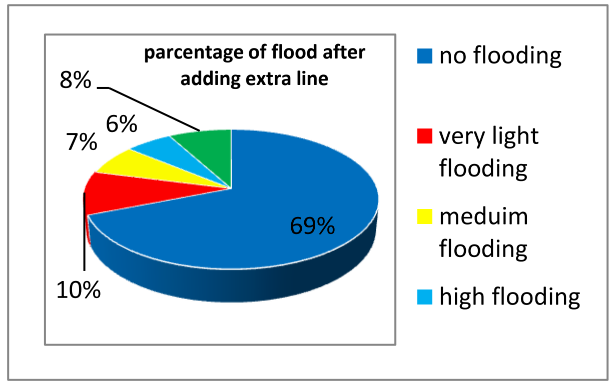

Figure 8. Percent of flooding manholes after adding Proposed Sewer Line (PSL)

Head distribution; total energy per unit weight above a datum in some manholes in Alhoz (PcSL) in the two pipe line No.3 and No.4, as shown in Figures (8 a and b). For example, in manhole R97 maximum head decreased from (49.3 to 48.9) that located on pipe line No.3. And in manhole R486 that located on pipe line No.4 head decreased from (50.8 to 50.2) m. This keeps the network stable and reduce the like-lhood of flood.

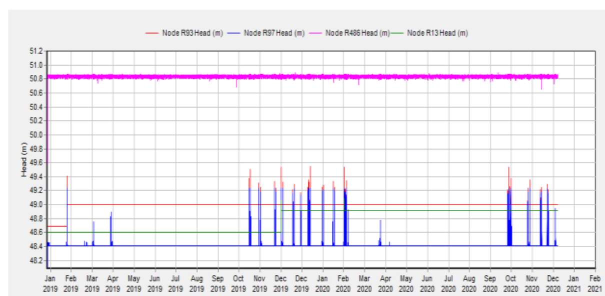

Figure 9 (a) The head distribution in manholes R93, R97, R486, R13 in current state as generated by SWMM

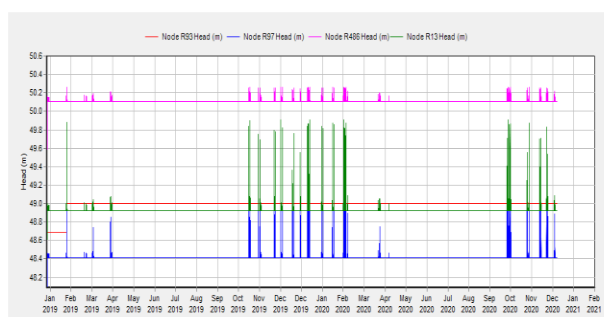

Figure 9 (b) The head distribution in manholes R97, R93, R486, R13 after adding (PSL) as generated by SWMM

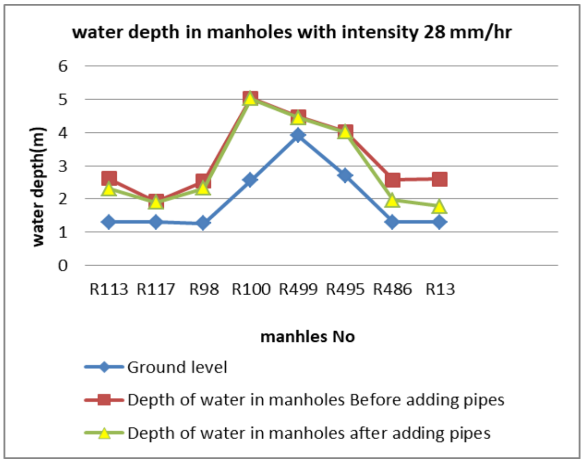

Figure 10. Water depth in some manholes in three cases (ground level , current case and proposed case)

Figure (9), shows a decrease in the peak water depth at the selected manholes according to the added line in peak rainfall intensity 28 mm/hr. In manhole R13, maximum water depth decreased from 2.6m to 1.78m. Table (3) shows that the depth and discharge for other cases rainfall intensity, for 9.6 mm/hr in manhole R866 depth of water decreased from 1.01 m in current state to 0.37 m after adding extra line. Likewise, discharge decreased in this manhole from 0.05 m^3/sec to 0.04 m^3/sec. At rainfall intensity 18 mm/hr water depth and discharge in manhole R963 decreased from 1.25 m to 0.03 m, 0.07 m^3/sec to 0.05 m^3/sec respectively.

Table 3. Summary of node depth in some manholes

Peak rain-fall inten-sity mm/hr	Dura-tion hr	Man-holes Num-ber	Max. depth of Water flood-ing m With out solu-tion	Max. depth of Water flood-ing m With solu-tion	Total in-flow Q m^3/sec with-out solu-tion	Total in-flow Q m^3/sec with solu-tion
		R113	1.6	1.3	0.03	0.02
		R117	1.03	0.9	0.02	0.01
9.6	1	R98	2	1.1	0.02	0.01
		R100	4.5	3.6	0.04	0.03
		R499	3	1.5	0.07	0.06
		R495	3.6	3	0.38	0.34
		R486	2.1	1.4	0.2	0
		R13	2	0.98	0.01	0
		R113	2.2	2.12	0.1	0.08
		R117	1.5	1.2	0.06	0.03
		R98	2.4	2.04	0.06	0.05
18	1	R100	4.7	4.07	0.08	0.04
		R499	3.4	3.2	0.1	0.09
		R495	3.1	2.8	0.3	0.1
		R486	2.3	2.1	0.1	0
		R13	2.1	1.8	0.4	0
		R113	2.61	2.31	0.5	0.205
		R117	1.93	1.9	0.07	0.02
		R98	2.54	2.32	0.03	0.02
28	1	R100	5.03	5.02	0.02	0.01
		R499	4.48	4.46	0.21	0.1
		R495	4.03	4.02	1.1	0.8
		R486	2.57	1.97	0.4	0.1
		R13	2.6	1.78	0.3	0.2

4.2 Model Calibration

Design discharge that were obtained from the Sewer Department in Ramadi, compared with discharge that obtained from the SWMM program to calibrate the program and verify its results. The value of the coefficient of determination (R^2) that was determined from the comparison was 0.72, as shown in Figure (11). This test demonstrates that the specified model and the applied criteria were acceptable. Sixty- four discharge readings were taken from the program and compared with the design discharge. Most of the readings were closely related.

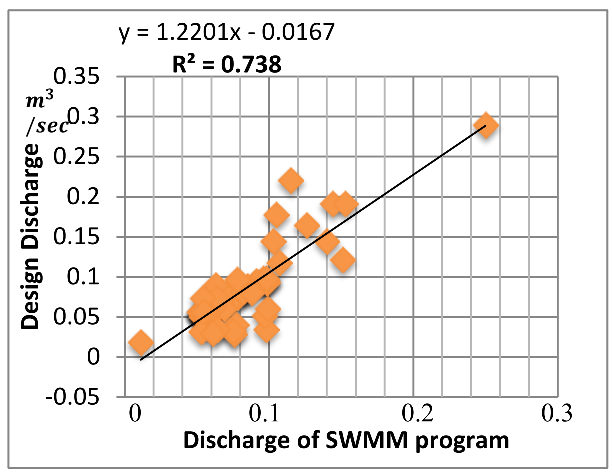

Figure 11. The result of discharge calibration between design discharge and SWWM discharge

4.3 Evaluation of Expansion Cost Ratio

To evaluate the method of improving networks by adding extra line the expansion of the network and its benefit, this study proposed an Economical Indexes (EI) named as Longitudinal index (L_i) and Areal index (A_i).

L_i: is the ratio of network expansion cost in ($) to the length of mean pipe in (m) suburb, while

A_i: is the ratio of the cost to suburb area in (ha) as expressed in equation (1) and (2).
A new term (ECR) is proposed in this study which defined as a ratio of the expanding cost to the main pipe of the expanded suburb.

$$EI_L = \frac{p_c}{EL_i} \quad (1)$$

p_c: added pipe cost ($).
L_i: suburb mean line length (m).

$$EI_A = \frac{p_c}{EA_i} \quad (2)$$

L_i: suburb mean area (ha).

$$EI_L = \frac{65688}{888} = 74 \text{ \$/m} .$$

$$EI_A = \frac{65688}{95} = 690 \text{ \$/ha}.$$

The construction costs of water projects are usually quite high, but the profits gained over time compensate for the construction cost [21]. ECR_L of extra line is calculated in Table 4, by taking into consideration types of pipes that were used.

Table 4. unit cost for pipe construction

Extra pipe No.	Total length (m)	Dimeter (mm)	$\boldsymbol{ECR_L}$
1	555	315	62
2	64	700	12

Other study can applied to optimize the network expansion and find the best limit of these indexes.

5. Conclusions

1) The results obtained from the SWMM program showed the effectiveness of the program for the operational management of the storm sewer drainage systems and to suggest appropriate measures to mitigate the flooding, even in the case of scarcity of hydrological and hydraulic data, as described in this study.

2) The network worked efficiently under the designed rainfall intensity of 9.6 mm/hr. However, there were some points in the storm sewer network that flood due to design defects in many manholes in Althayala, Alhoz and Aljameai suburbs where the entry point is significantly lower than exit point. This design defect led to the flooding of the manholes.

3) When the rainfall intensity increased to three times 28 mm/hr which is a possible scenario due to the climate changes, a major defect happened where the flood rate of manholes reached 43% of storm sewer network in the study area. So, it is very important to upgrading the network to accommodate the falling rainwater.

4) Economical Indexes (EI) which was proposed in this research showed that the cost of expanding the network that was equal to 74 US dollar/m, was negligible compared to the benefit were flood rate was reduced from 43% to 31%.

References

[1] Kumar R. (2017). Use of Network Analysis for Designing Better Water Drainage System of Cities in India. IJSRD – International Journal for Scientific Research & Development, Vol. 4, No. 12, PP 846-848.

[2] Najeeb Z. A. (2017). Evaluation of Combined Sewer Network Design Using GIS and Multi Criteria Decision Making (MCDM). Al- Nahrain Journal for Engineering Sciences (NJES), Vol.20 No.5, PP.1143-1153.

[3] Obaid H. A. (2015). Modelling Sewer Overflow of Karbala City with Large Floating population. PHD Thesis, university Knol Ogi Malaysia, PP 306.

[4] Nile B K, Hassan W H and Esmaeel B A. (2018). An evaluation of flood mitigation using a storm water management model (SWMM) in a residential area in Karbala Iraq. IOP conference.

[5] Hadi M O, El-Mewafi M, Metwally S, Awad A and Suliman S. (2015). Evaluation of Wastewater Network of Al-Anwaar in Al-Kut city. Iraq by using SWMM and GIS techniques. International Journal of Scientific and Engineering Research, (6) 8, 1440-1456.

[6] Azawi H K S and Sachit D E. (2018). Investigation of Permeable Pavement Implementation in Baghdad using PCSWMM model. Canadian center of Science and Education, (8)3 , 117-125.

[7] Fang X., Chhetri O. B. G. and Thompson D. B. (2014). Synthesis of Storm Drainage Design. www.researchgate.net/publication/22883487.

[8] Jiang L., Chen Y. and Wang H. (2015). Urban flood simulation based on the SWMM model. Remote Sensing and GIS for Hydrology and Water Resources, 368 PP(186-191).

[9] Waikar M. L. and Namita U. U. (2015). Urban Flood Modeling by using EPA SWMM 5. Clean Earth- Green Earth, No 1, PP 73-82.

[10] Kaadan M Y. (2015). Storm Sewer Management Modeling (with applications into Aleppo). MSC Thesis, university of Aleppo Syria, PP 189.

[11] Bohman A., Glaas E., and Karlson M. (2020). Integration Sustainable Stormwater Management in Urban Planning: Ways Forward towards Institutional Change Collaborative Action. Water, Vol. 12, No. 203, PP 17.

[12] Public works/ water sector, Venture A. 2007. Feasibility & Environmental Impact Assessment studies for the wastewater network and treatment systems. Iraq Public Work Sector.

[13] Environmental Protection Agency's, Earth Explorer United State Geological Survey (USGS).

[14] Rangari V. A., Prashanth S. S., Umamahesh N. V. and Patel A. K. (2018). Simulation of Urban Drainage System Using Storm Water Management Model (SWMM). Asian Journal of Engineering and Applied Technology, Vol. 7, No. S1, pp.7-10.

[15] Rossman L A. (2015). Storm water management model user's manual, version 5.1 (National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency Cincinnati).

[16] Li Y. W., Ji M., Wang X. D., Zhao L. J. and Pan L. M. (2010). Optimization of Rainwater Drainage System Based on SWMM Model. China Water & Wastewater. 26 PP3-40.

[17] Simpson M. G. (2010). Low Impact Development Modeling to Manage Urban Storm Water Runoff and Restore Predevelopment Site Hydrology. MSC theses, Colorado state university, PP 147.

[18] Imran H. M., Akib S., and Karim M. R. (2013). Permeable Pavement and stormwater management system: a review. Environmental Technology, PP 9.

[19] Akhter M S and 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, Journal of Water Research, 8,511 PP17.

[20] Bai Y., Zhao N., Zhang R. and Zeng X. (2019). Storm Water Management of Low Impact Development IN Urban Areas Based on SWMM. Water, v11, no.33, PP16.

[21] Butler D., and Davies J. W. (2004). Urban Drainage. 3rd Edition. Spon Press an imprint of Taylor & Francis, PP 657.

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