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# EFFECTUATION OF ILLEGAL DISCHARGE OF DOMESTIC WASTEWATER UPON STORMWATER NETWORK PERFORMANCE

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## Abstract

Urbanization and climate change are the main factors that cause urban flooding accompanied in some areas by wastewater pollutants, as a result of the illegal connection of domestic wastewater with the stormwater network. In this study, a Stormwater Management Model (SWMM) was used to evaluate a stormwater network performance as a combined system in an urban area in the Al-Kut city, Iraq. Rainfall data were obtained from the IDF curves for storm of 2-hr with time interval 15-minutes and 2, 5, 10, 25, 50 year return periods. The SWMM model was set up, and the Curve Number model and the Dynamic wave method was used for infiltrations processes and the flow routing, respectively. The parameter sensitivity results shown that N-Manning, N-Imperv, D-Imperv, and D-Perv are more sensitive to the model. The simulation results shown flooded nodes with ratio 59.8%, 72.4%, 72.9%, 68.7%, and 67.3% during rainfall return periods 2, 5, 10, 25, and 50 years, respectively. These nodes flood led to surface floods accompanied by illegal domestic wastewater pollutants as a result of the insufficiency of some network parts on carrying the various rainfall intensity. This study suggested to redesign some network parts and installing a separate sewage network.

Keywords: Flooding, Sewage, Simulation, Stormwater network, SWMM.

## 1. Introduction

Urbanization is considered a global phenomenon, and sometimes a local issue where urban areas to expand and population density to increase [1]. At present, more than 50% of the world's population lives in urban areas. The principal cause of population change in urban areas is due to births, deaths, and rural-to-city migration [2]. Urbanization and population growth are two major factors in converting natural lands into urban areas and increasing the proportion of impervious surfaces such as roofs, roads, and other urban surfaces [1]. This leads to increased runoff and decreased infiltration when climate change, thus it produces urban floods.

Around the world, urban floods pose a challenge to urban planners and are considered a global phenomenon [2]. It is can be described as a case of the surface water escape or wastewater, or both together from drainage systems and water that cannot enter drainage systems, thus remains on the surface of the earth. Climate change and urbanization are the main factors of severe urban flooding [3]. Therefore, it has been confirmed through many studies that there is a strong relationship between urbanization and climate change [2]. Also, floods can be caused by insufficient capacity of drainage networks or a bad drainage system when occurring heavy rainfall [4]. If the flow exceeds the capacity of the drainage network, it may lead to flooding streets and thus waterways happen [5].

Urbanization and rapid population growth are increasing pressure on the drainage systems [6]. A separate sewer drainage system is one of the most important infrastructures that consist of a sewage system and stormwater system. The sewage system transports domestic and industrial wastewater to treatment plants. While the stormwater system conveys the stormwater to the receiving water bodies without treatment. The importance of separate drainage systems lies in maintaining public safety and provide a healthy environment. In some cities, there are illegal connections by residents to connect domestic wastewater (sewage) with separate stormwater systems. In the event of deterioration and failure of these systems, the result is urban floods accompanied by polluted waters that threaten wildlife and aquatic life [7].

Stormwater management is deemed a challenge in the cities of the world [8]. Several hydrologic models were widely used in the rainfall-runoff issues and management of flood urban [9]. Researchers have indicated that one of the important hydrological models is the Stormwater Management Model (SWMM), which is widely used by practitioners and researchers in drainage systems and water resources [10, 11].

Many researchers have used an SWMM model in the study of stormwater systems. As a related study, Hassan et al. [12] used the SWMM model to assess the performance of a stormwater drainage system and estimate floods when rainfall intensity of 33.54 mm/hr in the Al-Eskari quarter of Karbala, Iraq. A storm network simulation was performed for two cases when only rainwater is drained, and another is when rainwater and its illegal sewage are drained together. Their results indicated to floods in the manholes by 47% and will increase at this intensity of rainfall from 39% to 52% when adding sewage to the storm network.

Al-Rabee Quarter is an urban area that contains only a stormwater network and lacks a sewage network. In this district, the domestic wastewater is illegally discarded into the stormwater network drains. During the rainy seasons, stormwater flows in the area streets that causing floods in different locations, which allows causes disable Traffic movement and inconvenience of the population in addition to the gathering of insects and pollutants and bad smells. The study main goal is to evaluate the performance of the current stormwater system in Al-Rabee Quarter as a combined system during rainfall return periods 2, 5, 10, 25, and 50 years and determine flooded nodes using the SWMM model.

## 2. Study Area and Data Collection

The study area is sited in Al-Rabee Quarter in Al-Kut city, which has located in Wasit province, 180 kilometres south of Baghdad, Iraq [13]. The study area also included the Al-Sharqiyah district. Figure 1 shows the location of the study area.

**Fig. 1. Study area according to Iraq map.**

The total study area is about 0.43 km$^2$, and over 88% is impervious surfaces in the form of streets and buildings. Topographically, it is flat, and altitude ranges 18 to 19 m above sea level. The population of Al-Rabee Quarter is approximately 4667, according to the 2009 census (Source: Department of Statistic of Wasit). The study area has hot and dry summers and cold and wet winters. Rain falls in the winter and spring season and varies from year to year. The total rainfall is 168 mm in 2018 (Source: Agricultural Meteorological Network, Iraq). The study area contains two stormwater networks, are Al-Rabee and Al-Sharqiah networks, which are connected to the last Manhole before entering the collection basin. The total length of network pipelines and Manhole numbers are 7.15 km and 214, respectively. The pipes diameters range are 315 to 600 mm and made of plastic material.

The satellite image of the study area and the stormwater network schematic were obtained from Wasit Sewerage Directorate. The stormwater network schematic includes the network characteristics data (manholes and pipes). The satellite image illustrates spatial information for land uses, also paths and location of the storm network. Rainfall data were obtained in the form of the Intensity-Duration-Frequency (IDF) curves for the city of Kut with various return periods.

## 3. Methodology

### 3.1. SWMM model description

Storm Water Management Model (SWMM) is a mathematical, a dynamic rainfall-runoff simulation model. It used for a single event or long-term (continuous) simulation of runoff quantity in urban areas [14]. The SWMM was first developed by the Environmental Protection Agency in 1971 and has undergone several upgrades since [15]. The last version was SWMM 5.1, which was used in this study. SWMM offers three models of infiltration are Horton, Green - Ampt, Curve Number models. In addition to three methods for solving network hydraulic equations and flow routing: the steady flow, the kinematic wave, and the dynamic wave [14]. In this study, the Curve Number model and dynamic wave method have been used. The runoff model of the nonlinear reservoir in the SWMM depends on the continuity equation Eq. (1), and Manning's equation Eq. (2) in the calculation of surface runoff [16].

$$\frac{dV}{dt} = (A \times i_e) - Q \tag{1}$$

$$Q = W \frac{1}{N} (D - D_P)^{5/3} S_{av}^{1/2} \tag{2}$$

where $V$ is water volume on the sub catchment (m$^3$), $Q$ is surface runoff flow (m$^3$/s), $t$ is time ($s$), $i_e$ is excess rainfall (m/s), $A$ is sub catchment area (m$^2$), $W$ is sub catchment width (m), $N$ is Manning roughness coefficient (s/m$^{1/3}$), D is water depth over the sub catchment (m), $DP$ is depth of maximum depression storage (m), and $S_{av}$ is average slope of sub catchment.

The dynamic wave method uses Saint-Venant basic one-dimensional equations to describe the unstable network flow and also for surface flow analysis. This equation consists of two parts, which are the continuity equation Eq. (3), and the full momentum equation Eq. (4) [16].

$$\frac{\partial q}{\partial x} + \frac{\partial a}{\partial t} = 0 \tag{3}$$

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} + g \frac{\partial h}{\partial x} + g(S_o - S_f) = 0 \tag{4}$$

where $v$ is velocity (m/s), $q$ is discharge (m$^3$/s), $a$ is cross-sectional area of flow (m$^2$), $x$ is longitudinal distance (m), $h$ is water head (m), $g$ is gravitational acceleration (m/s$^2$), and $S_f$ and $S_o$ is the friction and bed slopes, respectively.

Curve number model was developed by the US Department of Agriculture in 1954 by Soil Conservation Services (SCS). It is an empirical model widely used in calculating direct surface runoff [1]. The basic equation is follows [17]:

$$R = \frac{(P - I_a)^2}{P - I_a + S} \quad , \quad \text{for} \quad P > I_a, \quad \text{else} \quad R = 0 \tag{5}$$

where $R$ is runoff depth (mm), $P$ is precipitation depth (mm), $I_a$ is initial abstraction (mm), and $S$ is the maximum potential water retention of a catchment (mm). SCS assumes that [17]:

$$I_a = \lambda S = 0.2S \tag{6}$$

The value of S is calculated by the following expression [17]:

$$S = \frac{25400}{CN} - 254 \quad 0 \le CN \le 100 \tag{7}$$

where $CN$ is Curve Number parameter (dimensionless).

## 3.2. Model set up

Both stormwater system properties and sub catchments were drawn in the SWMM software. The study area was divided into suitable sub-catchments with random sizes ranging from 0.023 to 0.779 ha by ArcGIS tools, and depending on land uses and the direction of the drainage system paths. The physical parameter values were entered into the storm network in the SWMM model which include node depth, node invert level, conduit length, conduit diameter, the offset, and conduit cross-section, pump information and storage unit. Details of how to set up the Model are available in the SWMM user's manual [14]. Stormwater network and sub catchments in SWMM, are represented in Fig. 2. The model consists of 277 sub catchments, 214 junctions, 214 conduits, 3 pumps, storage unit, outlet, and a rain gauge.

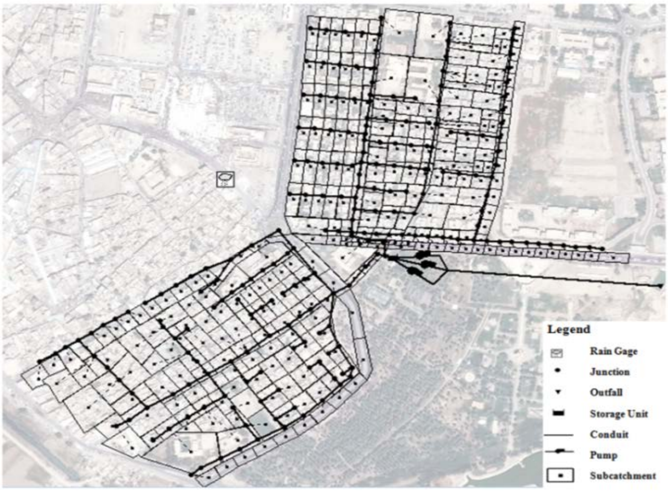


**Fig. 2. The SWMM model of the study area.**

After defining the physics parameters of the storm network into SWMM, the parameters inferred are defined. The sub catchment width has calculated by (dividing the ratio of the catchment area to the length of the overflow) [14]. The slope of each sub catchment was calculated by (dividing the ground elevation difference between a node and another node on the distance length between these two nodes). The percentage of impervious areas was estimated through the eye estimation for the study area satellite image in addition to Google Earth. Manning roughness of conduit, manning roughness for the impervious and pervious surface, depression storage for the impervious and pervious surface were set from the values suggested in the SWMM user manual [14]. Also, the value of percent of the impervious area with no depression storage was estimated as a fixed value for all sub catchments. The values of the curve number parameter were set through the hydrological soil group table found in the SWMM user manual [14].

## 3.3. Rainfall hyetograph generation

Rainfall intensity is considered a principal factor in analysis and design of the stormwater networks. It is also considered the most important of the climatic parameter that must be added in the SWMM model. It was calculated through an empirical equation of the IDF curves of Al-Kut city Eq. (8). This empirical equation represents the mathematical relationship between the intensity and duration of rainfall for a storm at a given frequency and location [18].

$$I = \frac{113.618 (T)^{0.273}}{(d)^{0.639}} \tag{8}$$

where *I* is rainfall intensity (mm/hr), *T* is rainfall return period (years), and *d* is rainfall duration (min). Figure 3 displays the IDF curves with 2, 5, 10, 25, and 50 year return periods for the Al-Kut City after calculating the intensity of rainfall using an experimental equation. To design a rainfall hyetograph, the Alternating Block method was used in the temporal distribution of rainfall for a 2-hr storm on a 15-minute basis with 2, 5, 10, 25, and 50 years return periods, as shown in Fig. 4. The alternating block method is defined as the simple method of designing a hyetograph of rainfall through a temporal distribution of rainfall that derived from the IDF curves [19].

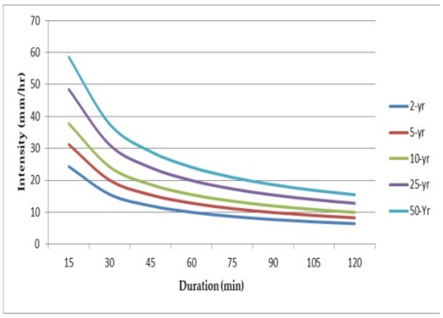


**Fig. 3. Rainfall IDF curves of Al-Kut.**

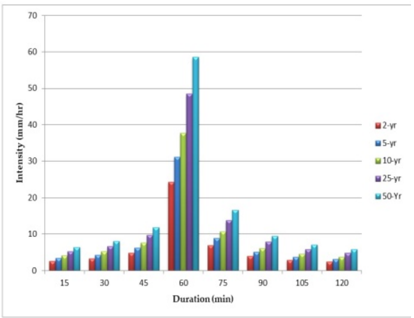


**Fig. 4. Rainfall hyetograph.**

## 3.4. Sewage quantities calculation

The quantities of illegal sewage (domestic wastewater) for the Al-Rabee quarter should be added to the storm network nodes in an SWMM model at the inflow properties editor. The sewage quantities were calculated using six equations below. The population in the future was calculated from Eq. (9) [20]:

$$P_n = P_o (1+i)^n \tag{9}$$

where $P_n$ is future population, $P_o$ is current population, *n* is number of years, and *i* is annual growth rate. The rate of increase in population growth (*i*) is 3%. According to Wasit Sewerage Directorate and Directorate of Physical

Planning/Wasit, the quantity of water consumption per capita locally is about 400 litres per day. The average consumption of sewage calculates from Eq. (10) [21]:

$$Q_{av.} = 0.8 \times q_c \times P_o \tag{10}$$

where $Q_{av}$ is average consumption of sewage ($m^3/s$), and $q_c$ is quantity of water consumption ($m^3/s$). Maximum peak factor ($P.F$) was calculated from Eq. (11) [22], and $P_n$ here, is population in thousand:

$$P.F = \frac{5}{\sqrt{P_n}} \quad \text{where, } P_n < 80{,}000 \tag{11}$$

Maximum flow of sewage, maximum infiltration flow, and design sewage quantity was calculated from the equations below, respectively [20]:

$$Q_{\max.} = Q_{av.} \times P.F \tag{12}$$

$$Q_{\inf.} = 0.1 \times Q_{av.} \tag{13}$$

$$Q_{des.} = Q_{\inf.} + Q_{\max.} \tag{14}$$

where $Q_{max}$. is the maximum flow of sewage ($m^3/s$), $Q_{inf}$. is the infiltration flow ($m^3/s$), and $Q_{des}$. is the design sewage quantity ($m^3/s$).

## 4. Results and Discussion

### 4.1. Parameter sensitivity

The sensitivity of six parameters are N-Imperv, N-Perv, D-Imperv, D-Perv, % Zero-Imperv, and N-Manning were checked using trial and error method. According to Niazi et al. [23], the trial and error method was used widely by researchers. The process was as follows by changing the value of one parameter with stay the remaining values of the other parameters constant and so on until the better parameters were reached. The values of these parameters were tested within the ranges suggested in the SWMM user manual. The results have shown that N-Manning, N-Imperv, D-Imperv, and D-Perv are more sensitive and affected the total flow, peak runoff flow, surface flooding, time of peak flow, and stability of the pipe flow Index. As for the other of the parameter are the least sensitive. These parameters values after optimized were shown in Table 1.

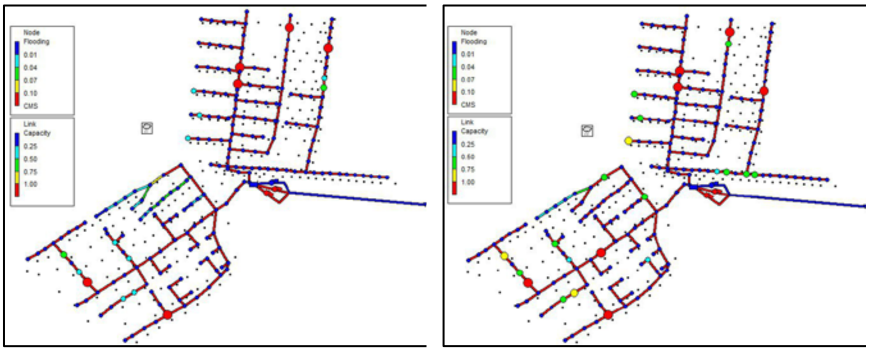
**Table 1. The final parameters of the SWMM model.**

| Parameter | Range value | Final value |
|---|---|---|
| **N-Imperv** | 0.011 - 0.013 | 0.011 & 0.012* |
| **N-Perv** | 0.1 - 0.15 | 0.13 |
| **N-Manning** | 0.011 - 0.015 | 0.011 |
| **D-Imperv** | 1.27 - 2.54 | 1.905 |
| **D-Perv** | 2.54 - 5.08 | 5.08 |
| **%Zero-Imperv** | 80 - 100 | 95 |

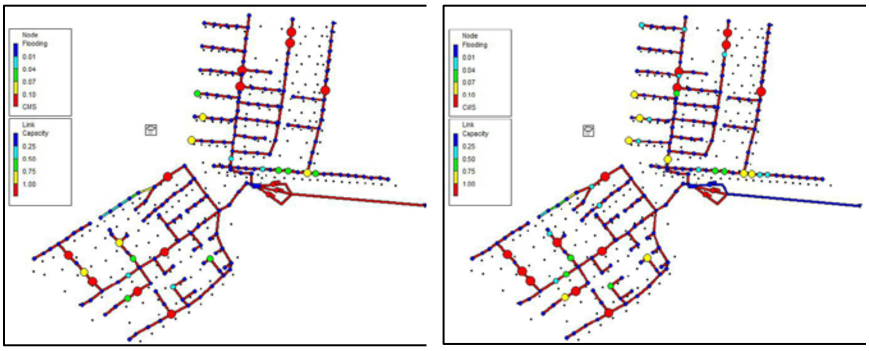
*****Note:*** *0.011 for the asphalt surfaces and 0.012 for the concrete surfaces.*

### 4.2. Network simulation in wet weather (combined system)

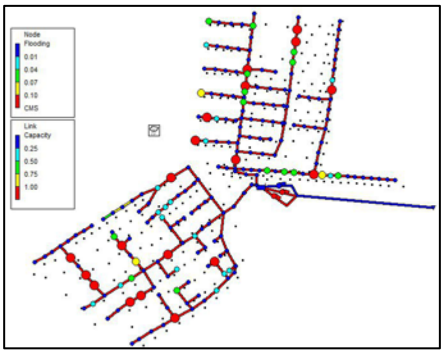
Five simulations of the stormwater system were performed after the introduction of sewage quantities into the system nodes, and for a storm 2-hr with a 15-minute interval and 2, 5, 10, 25, 50-year return periods. The results of the five simulations of the storm system were shown in Fig. 5 at the peak time 01:15:00.



**(a) 2-year return period.** **(b) 5-year return period.**



**(c) 10-year return period.** **(d) 25-year return period.**



**(e) 50-year return period.**

**Fig. 5. Schematics showing storm system nodes that flooded at a 2, 5, 10, 25, and 50 year return periods of rainfall.**

Figure 5 shows the system nodes of the storm that were flooded at various locations after adding sewage to the system nodes. Flooded nodes are indicated in four colours, depending on the size of the flood and the time it took to flood. A flood in nodes was observed, and the proportions of the flooded nodes in each simulation process were 59.8%, 72.4%, 72.9%, 68.7%, and 67.3% during 2, 5, 10, 25, and 50 years return periods of rainfall, respectively. Also, the pipes in red indicated the pipes filled with water, and its percentages were 90.6%, 97.7%, 97.7%, 98.1%, and 98.6% during the 2, 5, 10, 25, and 50 years return periods of rainfall, respectively. From that, it was observed that the more severe the rains, the drainage pipes are filled with water. The percentages of flooded nodes (a Manholes) at various locations in the storm system after adding the sewage quantities with the time it took in flooding, were shown in Table 2.

**Table 2. Ratios of flooded nodes and flooding time when various return periods of rainfall.**

| **Hours Flooded** | **Percent of Manholes Flooding (%) with Sewage** | | | | |
|---|---|---|---|---|---|
| | **Return periods of rainfall** | | | | |
| | **2-year** | **5-year** | **10-year** | **25-year** | **50-year** |
| **< 0.01** | 79 | 76.2 | 71.2 | 55.8 | 43 |
| **0.01 - 0.05** | 6.2 | 8.4 | 7.7 | 9.5 | 14.6 |
| **0.06 - 0.10** | 1.6 | 1.3 | 3.2 | 5.4 | 2.1 |
| **0.11 - 0.15** | 2.3 | 1.9 | 2.6 | 7.5 | 4.9 |
| **0.16 - 0.20** | 4.7 | 1.3 | 1.9 | 3.4 | 11.1 |
| **0.21 - 0.25** | 0.8 | / | 1.3 | 2 | 4.1 |
| **0.26 - 0.30** | 2.3 | 3.2 | 1.3 | 1.4 | 4.1 |
| **0.31 - 0.35** | 2.3 | 3.2 | 0.6 | 0.7 | 0.7 |
| **0.36 - 0.40** | 0.8 | / | 1.9 | 1.4 | / |
| **0.41 - 0.45** | / | 1.9 | 3.8 | 1.4 | 1.4 |
| **0.46 - 0.50** | / | 2.6 | / | 2 | 1.4 |
| **0.51 - 0.55** | / | / | 1.9 | 2.7 | 1.4 |
| **0.56 - 0.60** | / | / | 1.3 | / | 1.4 |
| **0.61 - 0.65** | / | / | 1.3 | 1.4 | 2.1 |
| **0.65 - 0.70** | / | / | / | / | 1.4 |
| **0.71 - 0.75** | / | / | / | 2 | / |
| **0.76 - 0.80** | / | / | / | 2 | 1.4 |
| **0.81 - 0.85** | / | / | / | 0.7 | / |
| **0.86 - 0.90** | / | / | / | / | 1.4 |
| **0.91 - 0.95** | / | / | / | 0.7 | 1.4 |
| **0.96 - 1.00** | / | / | / | / | 1.4 |
| **1.01 - 1.05** | / | / | / | / | 0.7 |

***Note:*** */ is refer that there were no nodes that took this time in flood.*

In Table 2, some flooded nodes recorded the highest time in the flood, as it was less than 0:40 at a period of 2-yr and less than a 1:45 (1.05) at 50 years. The percentages of the nodes that took more than a minute in flood were 21%, 23.8%, 28.8%, 44.2% 57% during 2, 5, 10, 25, 50-year return periods of rainfall, respectively.

## 4.3. Model validation

Stakeholder information was used to identify flood sites during the field visits as a means to validate the model [24]. The model results were close to stakeholder information. Figure 6 displays the satellite image of the study area that shows the compatibility of most nodes flood locations in the model with reality according to stakeholder information.

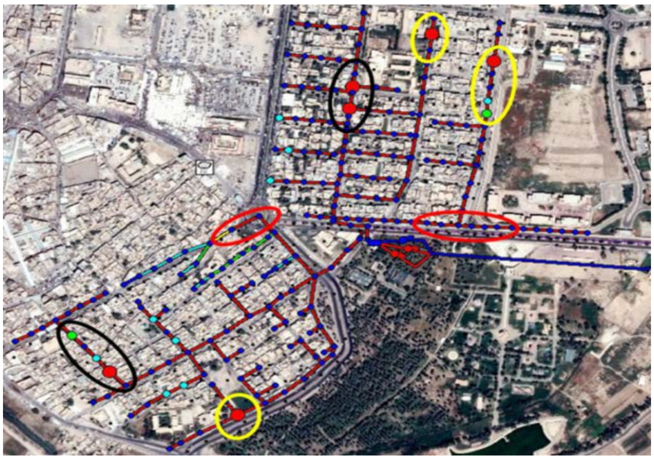


**Fig. 6. Displays nodes flood locations for a 2-yr return period of rainfall according to model and stakeholder information.**

In Fig. 6, the sites where the nodes flooded (Manholes) were indicated by circles. The black circle indicated areas of flooded nodes, according to stakeholders. The red circle indicates areas of flooded nodes when increasing rainfall intensity. As for the yellow color indicated to areas not flooded according to the stakeholder's information, but it flooded in the SWMM model due to the lack of proper planning and design of the network scheme in these areas.

## 5. Conclusions

This study focused on evaluate the current stormwater system performance with its original dimensions without clogging using the SWMM5.1 model. The following are the conclusions extracted from this study with suggestions.

- The simulation results indicated that some parts of the storm network are unable to carry the rainfall intensity in 2, 5 , 10, 25, 50 yr. return periods. This is due to the smaller depths of some Manholes than others. Also, the installation of pipes of large diameters with pipes of small diameters caused bottlenecks in the network. Besides, some catchments in study area lack stormwater drains, which led to the drainage of large catchments in one Manhole.
- This study suggests to improve the structure of the stormwater system in some flooding locations and implementing a separate sewage network that would be directed directly to treatment plants.
- This study demonstrated the ability of the SWMM model to drainage networks modeling and manage urban floods. Also, When it is combined with ArcGIS software, it certainly creates a suitable and useful tool for decision-makers decision-makers, and consulting engineers and a means of field examination for offices.

## Acknowledgment

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## Nomenclatures

| | |
|---|---|
| D-Imperv | Depth of depression storage in impervious areas, mm |
| D-Perv | Depth of depression storage in pervious areas, mm |
| N-Imperv | Manning's coefficient in Impervious areas, s/m$^{1/3}$ |
| N-Manning | Manning coefficient of the pipeline, s/m$^{1/3}$ |
| N-Perv | Manning's coefficient in Pervious areas, s/m$^{1/3}$ |
| Zero-Imperv | Percent of the impervious area with no depression storage, % |

***Greek Symbols***

| | |
|---|---|
| $\lambda$ | Constant correlation parameter |

**Abbreviations**

| | |
|---|---|
| GIS | Geographic Information System |
| IDF | Intensity-Duration-Frequency |
| SWMM | Stormwater Management Model |
| US | United Nations |

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