Modeling the effects of land-use and climate change on the performance of stormwater sewer system using SWMM simulation: case study

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ABSTRACT

Flooding of stormwater drainage systems represents a major problem in developing urban areas that could be influenced by land-use and climate change. Flooding problems can be assessed using simulation models such as the stormwater management model (SWMM). In this study, the generation of intensity duration frequency curves (IDF) that integrates climate change effect was conducted for Al-Najaf Governorate in Iraq for the first time. In addition, the effects of land-use and climate change on the stormwater sewer system of Al-Ameer District was simulated using SWMM. The results indicated that by increasing the sub-catchment area from 50 to 100%, an increment in total surface runoff from 20,380 to 37,350 m³, and total flooding from 10,513 to 26,032 m³ have occurred, respectively. As a response to climate change, changing the return period from 2 to 5 years has increased the total surface runoff from 14,120 to 27,110 m³ (representing 48% of raise), and total flooding increased from 5,914 to 17,591 m³ (accounting 72% of increment). To conclude, flooding locations and magnitude were identified, whilst the system failed to discharge surface runoff at critical conditions, whereas the effect of climate change on the stormwater drainage system was more adverse than the effect of land-use.

Key words: Al-Najaf, climate change, flooding, rainfall intensity, stormwater drainage system, SWMM simulation

HIGHLIGHTS

- An IDF curve was generated for the first time for Al-Najaf Governorate.
- SWMM successfully simulated the stormwater drainage system in the study area.
- The system will not withstand climate change impacts in the next 10 years.
- Change in land-use has increased impervious surfaces, causing floods in downstream.
- Flooding locations and magnitude, and number of flooded manholes were identified.

1. INTRODUCTION

Urban flooding presents a major threat to population, infrastructure, properties, and the environment. In recent years, urbanization is changing land-use, increasing surface runoff generation, and causing urban flooding. Furthermore, extreme rainfall events due to climate change have increased in severity and frequency worldwide (Nile et al. 2018). In addition, urban flooding occurs when stormwater drainage systems are insufficient to discharge surface runoff. This runoff moves over surfaces, stores in low-lying areas within the catchment until it infiltrates, drains or evaporates (Hossain Anni et al. 2020). However, infiltration rates in the urban areas depends on the land-use, whether it is impervious or previous cover. In the process of urbanization, large non-urban or agricultural lands are transformed into impervious land, leading to change in land-use that totally alters natural hydrological processes (Hu et al. 2020).

Moreover, climate change alters rainfall patterns that can increase runoff, resulting in an increase in sewer-related problems such as regular flooding and contamination of receiving waters (Abdellatif et al. 2015). Higher short-term precipitation intensities are anticipated as a result of climate change, which could have negative effects such as increased flooding and sewer overflow risks (Olsson & Foster 2014). Climate change is one of the main challenges facing Iraq. It is likely to have a catastrophic impact on the environment and the economy, especially in urban areas. Iraq is located in an arid to semi-arid region,
where the prevailing continental climate is usually cold in winter and hot in summer, as well as fluctuating rainfall in winter periods (Hassan & Nile 2020). Iraq suffers from a number of serious problems, especially in Al-Najaf Governorate. This was evidenced by the rapid expansion of the urbanization process in the city, the increase of impervious areas, and frequent and increasingly intense rainstorms. The unpredictable and unprecedented rainfall intensities in the city and lack of networks maintenance are among the main reasons for floods increase (Zwain et al. 2021).

Furthermore, sewer systems are often not proportionally designed to accommodate large surface runoff volumes resulting from urbanization and climate change, thus, there is a great need for rainwater management. Therefore, simulation models may rapidly present indicative results to predict flooding information that helps to protect the population, infrastructure, and property (Babaei et al. 2018). In order to predict water flooding and water depth in stormwater sewers and manholes, the stormwater management model (SWMM) has great potential to produce relevant relations between many parameters and the efficiency of the stormwater network. The model is widely used for drainage systems in urban areas for planning, research, and design (Rabori & Ghazavi 2018). In several studies, the SWMM program has been used to simulate the flow on catchment surfaces as well as in sewer systems (Jiang et al. 2015). Obaid et al. (2014) used SWMM software to model the impacts of climate change and increased population during peak tourism season on the sewer system in Karbala city of Iraq. In Al-Anwar suburb of Al-Kut city, Iraq, Hadia et al. (2015) used the SWMM program to assess the performance of the sewer system, whereas they reported that flow velocity was sufficient, but pipe diameters were larger than those needed to discharge the sewage flow. To determine the best return time for designing an urban drainage system in Palermo, Italy, Fortunato et al. (2014) used SWMM to evaluate the socioeconomic landscape impacts of floods and future solution scenarios to avoid economic losses during future flooding.

However, efficient simulation requires good hydrological analysis that is a prerequisite for any project. It is used to assess the catchment area and determine the design discharge or the amount of runoff that the stream must be designed to transport. However, there is a huge problem in the availability, accuracy and duration of the hydrological data in Al-Najaf Governorate. For example, there is no IDF curve data for any city in the state. This leads to obvious difficulties in preparing a viable and effective design of sewer networks. As a result, the seweage system suffers from recurring failures. One of the most severe cases can be observed at Al-Ameer District, where flooding is happening repeatedly. Since the stormwater drainage system is already built, it could be possible to reassess its efficiency in order to modify it or develop it with relevant solutions. These improvements should be based on useful and up to date analysis.

Therefore, this study first aims to provide hydrological information that is not available for Al-Najaf Governorate by predicting the precipitation intensity using the intensity-duration-frequency (IDF) curve for the first time. Second, this study aims to assess the current condition of the stormwater drainage system in Al-Ameer District located in Al-Najaf Governorate of Iraq using SWMM simulation. Third, the effects of land-use characteristics and rainfall intensity change as a response to climate change on the performance of stormwater drainage system were also evaluated. After achieving the above objectives, this study is expected to provide a technical solution for experts, engineering and decision makers in order to identify flood problems and evaluate proposed solutions.

2. MATERIALS AND METHODS

2.1. Study area

Al-Najaf Governorate is located 165 km southwest of Baghdad, Iraq (32° 01’ 33.38” N and 44° 20’ 46.50” E). The climate is arid to semi-arid with an average temperature of 24 °C, average annual rainfall of 99 mm/year, evaporation of 3,483 mm/year, average wind speed of 10 km/hr, and humidity of 41% (Zwain et al. 2021). As shown in Figure 1, the study area of Al-Ameer District is located close to the center of Al-Najaf Governorate, with longitude and latitude of 32° 00’ 28” N and 44° 21’ 51” E. The land is on a slope that ranges from 41.78 to 36.008 m above sea level, the total area is about 1.64 km2 with 34% pervious surface and 66% impervious surface.

2.2. Rainfall intensity analysis

The relationship between precipitation intensity and frequency (IDF) is one of the most widely used tools in many anti-flood engineering projects. The IDF curves express the relationship between precipitation intensity, duration, and return period. In order to construct the IDF curves in Al-Najaf, an historical series of maximum rainfall intensity is required with a higher time accuracy (within 1 minute time interval) (Nhat et al. 2006). The steps for an IDF drawing using Easy Fit 5.6 and Microsoft EXCEL 2016 can be illustrated as follows:
1. Finding the maximum daily rainfall per year, as shown in Table 1.
2. The maximum precipitation of 5, 10, 20, 30, 60, and 120 minutes are evaluated using the IMD reduction formula (Rathnam et al. 2001) as shown below in Equation (1), and calculated data are listed in Table 2.

\[ p_t = P_{24} \left( \frac{t}{24} \right)^{\frac{1}{3}} \]  

(1)

where:

- \( p_t \) is required precipitation depth for the specific duration in mm, \( P_{24} \) is daily precipitation in mm, and \( t \) is the time duration in hours for which precipitation depth is required.

Table 1 | Maximum daily rainfall recorded in Najaf governorate during 1989–2018

| Year | Maximum Daily Rainfall (mm) | Year | Maximum Daily Rainfall (mm) | Year | Maximum Daily Rainfall (mm) |
|------|-----------------------------|------|-----------------------------|------|-----------------------------|
| 1989 | 5                           | 1999 | 8.2                         | 2009 | 12.6                        |
| 1990 | 12                          | 2000 | 10.7                        | 2010 | 10.9                        |
| 1991 | 8.8                         | 2001 | 17.3                        | 2011 | 13.8                        |
| 1992 | 16.2                        | 2002 | 15.2                        | 2012 | 18.2                        |
| 1993 | 34.4                        | 2003 | 19                          | 2013 | 64.5                        |
| 1994 | 42                          | 2004 | 8.7                         | 2014 | 22.2                        |
| 1995 | 11.5                        | 2005 | 27.7                        | 2015 | 32.9                        |
| 1996 | 17.9                        | 2006 | 22.6                        | 2016 | 26.6                        |
| 1997 | 21.1                        | 2007 | 12.8                        | 2017 | 8.6                         |
| 1998 | 12.4                        | 2008 | 26.8                        | 2018 | 19.3                        |
3. Using the software Easy Fit 5.6, data in Table 2, Gumbel Distribution, and selecting the probability of 2, 5, 10 and 25 years, the probability of rain per minute can be obtained, as shown in Table 3.

4. From data in Table 3, an IDF curve for Al-Najaf Governorate is generated.

### Table 2 | Maximum daily precipitation depth (mm) for the duration T-minutes

| Year | 5 (min) | 10 (min) | 20 (min) | 30 (min) | 60 (min) | 120 (min) |
|------|---------|----------|----------|----------|----------|-----------|
| 1989 | 0.76    | 0.954    | 1.202    | 1.376    | 1.733    | 2.184     |
| 1990 | 1.82    | 2.289    | 2.885    | 3.302    | 4.160    | 5.242     |
| 1991 | 1.33    | 1.679    | 2.115    | 2.421    | 3.051    | 3.844     |
| 1992 | 2.45    | 3.091    | 3.894    | 4.458    | 5.616    | 7.076     |
| 1993 | 5.21    | 6.563    | 8.269    | 9.466    | 11.926   | 15.026    |
| 1994 | 6.36    | 8.015    | 10.096   | 11.557   | 14.561   | 18.345    |
| 1995 | 1.74    | 2.194    | 2.764    | 3.164    | 3.987    | 5.023     |
| 1996 | 2.71    | 3.415    | 4.303    | 4.925    | 6.206    | 7.819     |
| 1997 | 3.2     | 4.026    | 5.072    | 5.806    | 7.315    | 9.216     |
| 1998 | 1.88    | 2.366    | 2.981    | 3.412    | 4.299    | 5.416     |
| 1999 | 1.24    | 1.564    | 1.971    | 2.256    | 2.843    | 3.582     |
| 2000 | 1.62    | 2.041    | 2.572    | 2.944    | 3.710    | 4.674     |
| 2001 | 2.62    | 3.301    | 4.159    | 4.760    | 5.998    | 7.557     |
| 2002 | 2.30    | 2.900    | 3.654    | 4.182    | 5.270    | 6.639     |
| 2003 | 2.88    | 3.625    | 4.567    | 5.228    | 6.587    | 8.299     |
| 2004 | 1.32    | 1.660    | 2.091    | 2.394    | 3.016    | 3.800     |
| 2005 | 4.2     | 5.285    | 6.658    | 7.622    | 9.603    | 12.1      |
| 2006 | 3.42    | 4.312    | 5.433    | 6.219    | 7.835    | 9.872     |
| 2007 | 1.938   | 2.442    | 3.077    | 3.522    | 4.438    | 5.591     |
| 2008 | 4.058   | 5.113    | 6.442    | 7.374    | 9.291    | 11.706    |
| 2009 | 1.908   | 2.404    | 3.029    | 3.467    | 4.368    | 5.504     |
| 2010 | 1.651   | 2.080    | 2.620    | 2.999    | 3.779    | 4.761     |
| 2011 | 2.090   | 2.633    | 3.317    | 3.797    | 4.784    | 6.028     |
| 2012 | 2.756   | 3.472    | 4.375    | 5.008    | 6.310    | 7.950     |
| 2013 | 9.767   | 12.306   | 15.504   | 17.748   | 22.361   | 28.173    |
| 2014 | 3.362   | 4.236    | 5.336    | 6.109    | 7.696    | 9.697     |
| 2015 | 4.982   | 6.277    | 7.908    | 9.053    | 11.406   | 14.371    |
| 2016 | 4.028   | 5.075    | 6.349    | 7.319    | 9.222    | 11.619    |
| 2017 | 1.302   | 1.641    | 2.067    | 2.366    | 2.981    | 3.756     |
| 2018 | 2.923   | 3.682    | 4.639    | 5.311    | 6.691    | 8.430     |

3. Using the software Easy Fit 5.6, data in Table 2, Gumbel Distribution, and selecting the probability of 2, 5, 10 and 25 years, the probability of rain per minute can be obtained, as shown in Table 3.

4. From data in Table 3, an IDF curve for Al-Najaf Governorate is generated.

### 2.3. SWMM simulation

#### 2.3.1. Model setup

The Storm Water Management Model (SWMM) V.5.1 developed by the US Environmental Protection Agency (USEPA) was operated to assess the performance of stormwater drainage system, quantify flooding, and their locations in Al-Ameer District. SWMM is a dynamic rainfall–runoff simulation model used to simulate runoff quantity and quality from primarily urban watersheds, locate flood areas, test different stormwater management methods, and come up with cost-effective solutions to control stormwater. As illustrated in Figure 2, the whole study area was divided into 43 sub-catchments, a total of 343
junctions and 343 pipes, and each sub-catchment drains stormwater to the nearest junction. According to SWMM three levels of flow routing sophistication, dynamic flow routing has been used because it has the ability to account for pressurized flow, channel storage, flow reversal, backwater, and entrance/exit losses. Hence, dynamic flow routing considers the most theoretically precise consequences (Rossman 2012), and no surface runoff routing is considered. In SWMM, there are three infiltration methods; the Green-Ampt model was used in this study because it assumes sharp wetting interface in the soil column that is separating the soil where the wetting interface above is completely saturated from the soil below, which is at the initial moisture value.

### 2.3.2. Determination of model parameters

The total surface area of the catchment is 1.64 km², with an estimated 66% of impervious surfaces and 34% of pervious surfaces for all sub-catchments. These ratios were selected based on real condition of sub-catchments surfaces in the study area. The slope of all sub-catchments was calculated in the field, and was roughly found to be 0.5%. Based on the properties of studied area and pipes type used in the system, Manning roughness coefficients were 0.013 and 0.009, respectively. The depth of depression storage on impervious and pervious surfaces, and average of sub-catchments width were determined based on the SWMM user’s manual.

Information on pipe diameter and length, pipe inlet and outlet, junction invert elevation, ground elevation, maximum junction depth, minimum pipe cover, and surcharge elevation was supplied by Al-Najaf Sewage Directorate as a geographic information system (GIS) map. The data was converted to shape file using Arc map 10.4.1 software, then processed using

### Table 3 | The rain intensity is converted to mm/hr

| Return Period (Years) | 5 (min) | 10 (min) | 20 (min) | 30 (min) | 60 (min) | 120 (min) |
|-----------------------|---------|----------|----------|----------|----------|-----------|
| 2                     | 29.55   | 18.61    | 11.73    | 8.95     | 5.64     | 3.55      |
| 5                     | 47.46   | 29.90    | 18.84    | 14.37    | 9.06     | 5.70      |
| 10                    | 61.27   | 38.60    | 24.32    | 18.56    | 11.69    | 7.36      |
| 25                    | 80.79   | 50.90    | 32.06    | 24.47    | 15.41    | 9.71      |

### Figure 2 | Distribution of study area sub-catchments, junctions and pipes.
storm and sanitary analysis 2015 (SSA) and exported to input data in SWMM to determine the spatial distribution of precipitation. As for rain intensity, SWMM allows the entry of hydrological data in different methods. In this study, time series is one of the most effective methods that depends on the IDF curve, and was applied with return periods of 2, 5, 10, and 25 years. This method offers more accurate simulation of the model because it is based on predicted future rainfall data at different time intervals.

2.3.3. Additional input data
There is additional flow discharged into the stormwater drainage system from neighboring areas. First, this includes surface runoff flowing from the main street of Al-Kufa/Al-Najaf and discharging into three inlet junctions at the north of study area stormwater drainage system, as shown in Figure 3. The street system is collecting the surface runoff generated from rainfall and is considered as a small urban rain system, where rational method is used to calculate the peak discharge values at each junction inlet and were found to be 0.0461 m³/sec. It is an important factor because the main street of Al-Kufa-Al-Najaf in not served by any stormwater drainage system, and branch roads are acting as open channels discharging stormwater to the study area stormwater drainage system. Second, the stormwater drainage system of the study area is connected to neighboring Districts of Al-Eskan and Al-Istiraki, and discharge is estimated to be 0.226 and 0.4 m³/sec, respectively. All of these additional flows were input data as initial flow in the SWMM simulation.

2.4. Scenarios design
According to the actual land-use of the study area in 2008, 50% of it is designed as a sub-catchment that contributes to the surface runoff. However, this designed percentage is changing over time as the land-use of the area is changing. The area is facing urban expansion; this includes the conversion of public parks into residential areas and commercial centers due to land limitation, and homes yards are transferred into houses due to the high land price and families extension. Therefore, an increase in surface runoff beyond designed quantities is expected to occur over time, but its rate is not exactly specified as the urban expansion is taking place in irregular forms. Hence, to study the effect of land-use and determine expected flooding, the designed sub-catchment area was varied as 50, 75, and 100%. In recent years, Al-Najaf Governorate is witnessing an increase in rainfall intensities within short rainfall duration due to climate change effect. Therefore, the effect of rainfall intensities, as a response to climate change, was simulated using SWMM at different return periods of 2, 5, 10, and 25 years.

2.5. Model calibration and validation
Validation is a process of comparing the model and its behavior to the real system and its behavior. In this study, model validation was conducted by comparing predicted maximum discharge in pipes acquired from the SWMM program with actual pipes discharge acquired from Al-Najaf Sewage Directorate. As recommended by Zwain et al. 2020, mean of normal squared error (NMSE) and correlation coefficient (R) were statistical parameters selected for model validation. NMSE (Equation (2)) measures mean relative scatter and reflects both systematic and systematic (random) errors, and R (Equation (3)) reflects the

Figure 3 | The surface runoff from Al-Kufa/Al-Najaf Street to the study area.
linear relationship between two variables and is thus insensitive to either an additive or a multiplicative factor.

\[ \text{NMSE} = \frac{(C_o - C_p)^2}{C_o^2} \]  \hspace{1cm} (2)

\[ R = \frac{(C_o - \overline{C})(C_p - \overline{C}_p)}{\sigma C_o \sigma C_p} \]  \hspace{1cm} (3)

where:
- \( C_p \) is predicted data,
- \( C_o \) is observed data,
- \( \overline{C} \) is average data over the dataset, and
- \( \sigma C \) is standard deviation over the dataset.

3. RESULTS AND DISCUSSION

3.1. IDF curve for Al-Najaf governorate

Al-Najaf Governorate has a severe lack of hydrological data and various information is unavailable to conduct further research related to environmental engineering and hydrological analysis. In this study, a detailed procedure and data of IDF curve generation are shown in Tables 1–3. An IDF curve has been successfully generated for Al-Najaf Governorate for the first time as shown in Figure 4. From Table 1, it was noticed that there is an increase in the maximum daily rainfall (mm) in the last 10 years. For example, in 2013 and 2015, the maximum daily rainfall reached 64.5 and 33 mm, respectively. This could be due to the effect of climate change in Al-Najaf Governorate. Unfortunately, although extreme rainfall events have increased in several regions worldwide, there are still uncertainty and limited data available. This will affect the infrastructure capability related to human health and safety, particularly sewer and stormwater drainage systems. For this reason, understanding future extreme events are essential for sanitary systems design. Potential non-uniform and climate-induced changes such as heavy rainfall events question the accuracy and adequacy of current infrastructure design concepts, which rely on an assumption of climate data (Cheng & AghaKouchak 2014).

At any return period, the results in Figure 4 indicated that the rainfall intensity at short duration of 5 min was generally three times higher than at 30 min duration. It is similarly noticed at time duration of 50 and 120 min, that the rainfall intensity decreased about three times also. On the other hand, the stormwater drainage system in Al-Ameer District had been designed in 2008 for a maximum rainfall intensity of 20 mm/h, but the study area has been exposed to the climate change impacts, thereby there has been a noticeable increase in rainfall intensities, especially after 2009. According to Figure 5, rainfall intensity of 20 mm/h was exceeded at several occupations that include 2 years return period and below 10 min duration, 5 years return period and below than 20 min duration, 10 years return period and below than 30 min duration, 5 years return period and below than 35 min duration. Hence, it is expected that more areas will be flooded in the coming years, unless some effective solutions are introduced (Hassan et al. 2017).

Figure 4 | Intensity Duration Frequency (IDF) Curve for Al-Najaf Governorate.
3.2. Model validation

The simulation of Al-Ameer district stormwater drainage system was validated using actual discharge data provided by Najaf Sewerage Directorate and predicted data by SWMM. Statistical results of NMSE and R values are shown in Table 4, and predicted data over actual data are shown in Figure 5. The validation results showed that NMSE was 0.002, which is very close to ideal fit of zero. The R value was 0.95, which shows a positive correlation and very close to ideal value of 1. Linear correlation in Figure 4 showed a very well fitted data of predicted data over actual data. Therefore, the results above indicated that the SWMM simulation predicted data very close to actual data, hence, no model calibration is needed at this stage.

3.3. Effect of land-use on stormwater drainage system

In order to study the effect of land-use on the stormwater drainage system in Al-Ameer District, different sub-catchment areas that contribute to the surface runoff were taken into consideration. This is because the actual land-use in Al-Ameer District is not well known due to progressing random development. At a constant rainfall intensity, return period of 10 years and throughout 2 hours of rainfall duration, different sub-catchments areas of 50, 75, and 100% were simulated using SWMM, and the results are shown in Table 5. Increasing the sub-catchment area from 50 to 75% led to an increment of impervious

![Figure 5](http://iwaponline.com/jwcc/article-pdf/doi/10.2166/wcc.2021.180/933837/jwc2021180.pdf)

**Figure 5** | Linear relationship between predicted data over actual measured data.

| Parameter | Value | Ideal fit | NOTE |
|-----------|-------|-----------|------|
| NMSE      | 0.002 | Zero      | It is close to zero, the model fits well. |
| R         | 0.95  | 1         | It is close to 1, the model fits well. |

| Return Period (Years) | Sub-catchment (%) | Total Surface runoff (m³) | Maximum flooded manhole volume (m³) | Total flooding (m³) | Number of flooded manholes |
|-----------------------|-------------------|---------------------------|-------------------------------------|--------------------|---------------------------|
| 10                    | 50                | 20380                     | 1703 (R315)<sup>a</sup>             | 10513              | 70                        |
| 10                    | 75                | 29150                     | 2074 (R315)<sup>a</sup>             | 18414              | 84                        |
| 10                    | 100               | 37350                     | 2222 (R315)<sup>a</sup>             | 26053              | 95                        |

*Name of manhole.*
surfaces of 33\%, while enlarging the sub-catchment area from 75 to 100\% increased the impervious surfaces by 25\%. Table 5 details the assessment of Al-Ameer District stormwater drainage system. By increasing the sub-catchment area from 50 to 100\%, an increment in total surface runoff from 20,380 to 37,350 m$^3$, total flooding from 10,513 to 26,032 m$^3$, and the number of flooded manholes from 70 to 95 have occurred, respectively.

Notably for almost 2 hours, manhole R315 (indicated in Figure 6) was mostly flooded with maximum flooding volume of 1,703, 2,074, and 2,222 m$^3$ for 50, 75, and 100\%, respectively. It’s worth reporting that data obtained in Table 5 occurred at any time throughout the 2 hours duration and not after 2 hours. The 2 hours of rainfall duration was selected according to filled survey and sanitary experts in the study area. This period was sufficient to withstand the longest storm event and drain surface runoff. Undrained flows after two hours is considered as a flood and may indicate a problem in the system. It is also important to note that any change in land-use, for example increasing the area of sub-catchment, will lead to extra flooding volumes, in which the stormwater drainage system may not be able to withstand it. Similarly, Kong et al. (2017) reported the effect of land-use changes on stormwater management using SWMM simulation. They found that 33.3\% reduction in pervious surfaces (increased of impervious surfaces) results in 92.9\% increase in surface runoff, 31.7\% increase in peak flow, and 35 min earlier of peak runoff time. In addition, Hu et al. (2020) observed that urbanization increased impervious surfaces in Beijing’s central area, leading to increment in surface runoff and flooding. They correlated impervious surfaces rise with surface runoff increase, leading to flooding risk in the area.

After 2 hours, Figure 6(a)–6(c) illustrates is the locations of flooding in Al-Ameer District, type of flooding, and percentage of flooded manholes, for sub-catchments areas of 50, 75, and 100\%, respectively. Knowing flood locations is very important for specifically identifying flood problems. Hence, this study is expected to provide a technical solution for experts, engineering and decision makers in order to identify problems in the system and evaluate proposed solutions. The type of flooding from manholes is divided into five stages according to the SWMM simulation, as recommended by Hassan et al. (2017):

- Stage 1 (no flooding) ranges from (0 to 0.001 m$^3$/s)
- Stage 2 (very light flooding) ranges from (greater than 0.001 to 0.01 m$^3$/s)
- Stage 3 (medium flooding) ranges from (greater than 0.01 to 0.02 m$^3$/s).
- Stage 4 (high flooding) ranges from (greater than 0.02 to 0.04 m$^3$/s).
- Stage 5 (very high flooding) for (greater than 0.04 m$^3$/s).

Figure 6(a) shows the assessment of stormwater drainage system at 50\% of sub-catchment area, 2 hours of rainfall duration, 10 years of return period, and rainfall intensity of 7.36 mm/hour. Figure 6(a) reveals that the number of flooded manholes was 13 manholes out of 343 total manholes, and the ratio of flooded manholes is 4% only and non-flooded is 96\%. According to the flooding flowrate, the flooded manholes stages were 21\% of medium flooding (Stage 3), 50\% of high flooding (Stage 4), and 29\% of very high flooding (Stage 5). Among all manholes, R315 at system downstream had the most flooded manholes with flooding stage 5 and remains flooded for 1.7 hour of rainfall duration. The total flooded area in the study area in 2 hours was 25,963 m$^2$. It is concluded that the system performance at 50\% sub-catchment area is fairly average during the flood period of 2 hours.

Figure 6(b) displays the behaviour of stormwater drainage system at 75\% of sub-catchment area, 2 hours of rainfall duration, 10 years of return period, and rainfall intensity of 7.36 mm/hour. It is observed that 25 manholes were flooded, constituting 8\% of 343 total manholes, in which 16\% were slightly flooded with Stage 2, 16\% were fairly flooded with Stage 3, 24\% were highly flooded with Stage 4, and 44\% were the very highly flooded with Stage 5. It’s interesting to report that the flooding mostly observed in the downstream of the study area (north-east direction) and total flooded area after 2 hours increased to 33,750 m$^2$. In this regard, it can be concluded that the system could hardly withstand the surface runoff generated from 75\% of sub-catchment, and flood is therefore considered relatively high.

By considering 100\% of sub-catchment area, Figure 6(c) reveals a deterioration in the system performance, in which 36 manholes were flooded, representing 11\% out of a total 343. Flooding stages were distributed as 14\% very light flooding (Stage 2), 11\% medium flooding (Stage 3), 32\% high flooding (Stage 4), and mostly 43\% very high flooding (Stage 5). The flooding condition in this case was the worst due to increased impervious surfaces and reduced green areas. The downstream area (north-east direction) was completely flooded, and total flooding area rose to 54,900 m$^2$. Flooding water level is very high and might even enter properties, causing damage to property and infrastructure. Accordingly, it’s concluded that the system can’t withstand a sub-catchment area of 100\% and flooding was very high at 2 hours of rainfall. After all, it was observed that the flooding map has expanded as a result of urbanization and change in land-use from pervious to impervious surfaces.
Figure 6 | Effect of land-use on Al-Ameer District stormwater drainage system at 10 years return period and (a) 50% sub-catchment, (b) 75% sub-catchment and (c) 100% sub-catchment.
Likewise, Shanableh et al. (2018) revealed a positive correlation between urbanization and floods, in which flooding increased substantially in areas where land-use has changed to residential area. They also reported that flooding increased by 60% in 10 years due to rapid urbanization.

### 3.4. Effect of climate change on stormwater drainage system

Climate change have a direct influence on increased rainfall intensity that will affect surface runoff generation. Different return periods of 2, 5, 10, and 25 years that represent a series of rainfall intensities were selected as a response to climate change effect. Throughout 2 hours of rainfall duration, the assessment results are tabulated in Table 6, and rainfall intensities can be obtained from the IDF curve in Figure 4. It is observed that increasing the return period has dramatically increased the surface runoff generated in the study area. For example, when the return period shifted from 2 to 5 years, the total surface runoff rose from 14,120 and 27,110 m$^3$ (representing 48% of raise), and total flooding increased from 5,914 to 17,591 m$^3$, accounting for 72% of increment. When higher return period is selected, higher flooding volume and number of flooded manholes were observed. For instance at 25 years of return period, the surface runoff and total flooding were 52,006 and 41,250, respectively. This means that 21% only of the surface runoff is discharged by the system and 79% of it is flooded, indicating the failure of the system.

Hence, from the results in Table 6, it is expected that the system may withstand climate change effect only for the next 10 years. In general, the greater the return period, the greater the flooding volume. Similarly, an increase in peak runoff was observed when the total rainfall was increased due to increasing return period (Babaei et al. 2018). In support of that, Hossain Anni et al. (2020) reported that the number of flooded manholes and volume of flooding increased by 47 and 48% when the return period increased from 10 to 25 years. In like manner, Hassan et al. (2017) noticed a positive correlation between climate change and increased rainfall intensity, where they reported an increase in flooding of 47% as an effect of climate change in the last 8 years.

For more realistic evaluation of stormwater drainage system, the system was assessed after 2 hours of rainfall duration. In this duration, it is expected that the stormwater drainage system Al-Ameer District will discharge most of the excess stormwater, but remaining flooding may be considered a risk warning. Figure 7 showed flooded manholes, flooding magnitude, and flooding locations. Flooding may occur whenever that water discharge at manholes or sewers exceeds the maximum designed values. At 2 years of return period, Figure 7(a) displayed that 15 manholes out of a 343 were flooded, consisting of 4% of total manholes. Flooded manholes distribution was 7% of very light flooding, 20% of medium flooding, 40% of high flooding, and 33% very high flooding. Again, R315 manhole was mostly flooded for about 1.51 hr. It is noticed that flooding in small quantities was mainly in the downstream, and therefore surface runoff can be well controlled at this return period. Figure 7(b) assesses the stormwater drainage system at the end of 2 hours rainfall duration and 5 years of return period. The flooded manholes were 26 out of 343 manholes, which is equivalent to 8% of the total manholes. Flooded manholes are classified as 14% very light flooding, 11% medium flooding, 26% high flooding, and 46% very high flooding. Very high flooding locations were scattered mainly in downstream (east direction) and few locations in the center and upstream (west direction). In addition, flooding occurred mostly in main sewer lines, and manhole R315 had the longest duration flood of a very high flood. Increased flooding magnitude is due to increased rainfall intensity, however, the system still can withstand a return period of 5 years with climate change effect.

Figure 7(c) shows the condition of the stormwater drainage system at a return period of 10 years. The number of flooded manholes reached 36 out of 343, representing 11% of total manholes. It is distributed as 13% very light flooding, 11% medium flooding, 32% high flooding, and 44% high flooding. However, it is noticed that the number of flooded manholes

| Sub-catchment (%) | Return Period (Years) | Total Surface runoff (m$^3$) | Maximum flooded manhole volume (m$^3$) | Total flooding (m$^3$) | Number of flooded manholes |
|-------------------|-----------------------|-----------------------------|--------------------------------------|-----------------------|---------------------------|
| 100               | 2                     | 14120                       | 1306 (R315)*                        | 5914                  | 26                        |
| 100               | 5                     | 27110                       | 1835 (R315)*                        | 17591                 | 72                        |
| 100               | 10                    | 37350                       | 2222 (R315)*                        | 26032                 | 95                        |
| 100               | 25                    | 52006                       | 2295 (R319)*                        | 41230                 | 106                       |

*Name of manhole.
is less important than the magnitude of manholes flooding. For example, the magnitude flooding in manhole 315 (Stage 5) is five times higher than in other manholes (Stage 1). Therefore, flooding area drawing was used to illustrate flooding magnitude, in which maximum flooding occurs in the downstream (north-east and south-east directions) area and in the main sewer that passes through the center of the area. At 10 years return period, the system fails to discharge excess rainfall, resulting in the accumulation of stormwater at downstream. Flooding quantities greatly increased and flooding depth is expected to rise more than 13 cm (curbstone height) and may enter the houses, causing damage to infrastructure and properties.

At a return period of 25 years, Figure 7(d) showed that 48 manholes out of 343 were flooded, consisting of 14% of the total manholes. Again, an increased number of flooding manholes does not affect the area as much as flooding magnitude. Therefore, flooding magnitude were distributed as 5% very light flooding, 15% medium flooding, 26% high flooding, and 54% high flooding. A major system failure was observed, where 26% of Al-Ameer District was flooded. Many locations were flooded, not only in downstream, but also in the center and upstream. Figure 7(d) also showed that stormwater entered the housing, causing damage to infrastructure and properties. It worth reporting that branch sewers were also flooded in addition to main sewers. High quantities of flooding is due to high rainfall intensity of 80 mm/hr at the beginning of a rainstorm. The system fails to discharge surface runoff because it was beyond the design capacity. This indicates that climate change effect was not considered in future prediction of rainfall intensities needed for storm system design. Hence, climate change effect should be
integrated in the generation of IDF curves (Noor et al. 2018). It is concluded that this prediction of rainfall intensity is one of the most high-risk expected intensities and has severe effects on the system and properties.

Moreover, more areas were flooded when the return period increased further. Likewise, Babaei et al. (2018) observed that when the return period increased from 2 to 5 years and then to 10 years, more areas were flooded each time and the drainage system should be expanded by 20% to prevent flooding. On the other hand, most stormwater drainage systems are designed to serve a certain maximum value of rainfall intensity based on previous hydrological data. Meanwhile in recent years, rainfall total amounts are less than before, but rainfall intensities are 4 times higher due to the effect of climate change (Nile et al. 2019).

4. CONCLUSION

For the first time in Al-Najaf Governorate of Iraq, an IDF curve that integrated climate change effect was produced with return periods of 2, 5, 10, and 25 years. SWMM successfully simulated the impacts of sub-catchments and climate change on the stormwater drainage system in Al-Ameer District. Without calibration, SWMM model was validated over actual discharge in the system, with NMSE value of 0.002 and R value of 0.95. Random urban development in Al-Ameer District has changed the land-use from pervious to impervious areas; when the sub-catchment increased from 50 to 100%, the total flooding area rose from 25,965 to 54,900 m² and ratio of flooded manholes increased from 4 to 11%. It is recommended to preserve green lands to improve infiltration of stormwater and increase pervious surfaces that will lead to reduction in surface runoff, resulting in low flooding volume. On the other hand, the adverse effect of the climate change on the stormwater drainage system was more than effect of land-use. When the return period increased to 25 years, a major system failure was observed, whereas 26% of Al-Ameer District was flooded. Finally, it is expected that the system may withstand climate change effect only for the next 10 years only.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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