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# The Effect of High Intensities of Rainfall on the Operation of the Combined Sewage System in Populated Areas

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***Abstract:***

The present paper deals with the effect of a densely populated area on operating the combined sewage system under higher rainfall intensities using the Storm Water Management Model (SWMM) modelling program. The aim is to simulate a future increase in rainfall intensities for reducing the combined sewage system overflow in the study area, which was the AL-Rashadiya quarter in the city of Najaf, Iraq. The high rainfall intensities have been modelled using the SWMM software to estimate the maximum flooding volumes in the combined sewage system of the study area. To evaluate the models' performance, a comparison process was used between the values of the pipes flow rates of the combined sewage system models with the design flow rates and the flow rates of only one available event modelling during the study interval. The comparison results showed a good and convergent performance for these models. The results of the flooding volumes using different values of rainfall intensities and different return periods, which were 2,5,10 and 25 years, in the modelling of the combined sewage system are 3817, 6912, 8929, and 13434 $m^3$, respectively. The suggested scenario included increasing diameters of some pipes in the combined sewage system pipelines. The results using this scenario showed a reduction in the total flooding percentage from the integrated sewage system of 53.52%,39.65%,33.3%, and 24.41%. The present study can provide technical support for using software in the planning, controlling, and tests of the sewer systems, which contribute to solving the sewer systems problems.

**Keywords:** Combined sewage, SWMM, Rainfall intensities, Flooding, Gumbel.

## 1. Introduction

The drainage systems have been using since the beginning of the third millennium BC [1]. There are four interrelated but separate consequences of land-use changes on the hydrology of any area: changes in hydrological infrastructure, overall drainage, the characteristics of the peak flow, and the quality of water. Of all the changes in hydrologic facilities that influence the hydrology of the city, urbanization is the greatest [2]. The significant economic losses and human injuries are remain caused by urban flooding during rainy weather, where the recent years showed that world cities are quickly vulnerable to the occurrence and effects of pluvial floods [3], [4], [5].

The aim of the present study is to simulate a future increase in rainfall intensities for reducing the combined sewage system overflow in the study area. Most predicts referred that the urban flooding problem will increase. The first explanation was the rapid population growth of the cities, where the world population became more urbanist. The second explanation trending that the possibility of climate change leads to a lot of rainfall, where several statistically scientific kinds of research showed many high precipitation events happened in the previous hundred years, in North America by Peterson et al. [6] and Denmark by Arnbjerg-Nielsen [7]. Generally, most studies have concentrated on the factors and problems corresponding to water concerns, water management, and sewerage systems. According to Kundzewicz and Kowalczak [8], water problems locate into three essential categories, Too much, Too little or Too dirty. Intergovernmental Panel on Climate Change (IPCC) report [9] stated that hydrological disturbances remain too harmful to the human community, also the environment. Perhaps increase with urbanization extension and the possible climate changes. Wagner and Breil [10] mention that the natural cycles are modifying by the extension of urbanization, where the infrastructure becomes more senile and stagnancy. Obaid et al. [11] stated that the sewer overflow problems are needed more interest because of the population increase, economic advancement, and people movement ability. The study of Ward & Winter [12] pointed out that traditionalistic drainage systems in urban spaces are a build-up to improve human dominance over the biophysical ecosystem causes pollution surface runoff discharged in the urban waterways. Hassan et al. [13] showed that the management and regulation of urban floods, where urban drainage schemes are under pressure due to urbanization growth, population, and climate change, is one of the primary challenges facing municipalities. Also, urban flooding causes damage to the environment and the infrastructure. A study conducted by Rosburg et al. [14] about urbanization impacts on the duration and variation of the flow curve (FDC) showed a rise in the curve's percentages with 34% in urban regions due to the conversion in hydrological path and urbanization that causes increases impervious area. At the same interval, the opposite happened in the rural area due to a drop in groundwater level, where groundwater extracting for agriculture purposes. Salerno et al. [15] studied the impacts of climate change and urbanization on the quality of water receivers in serviced areas via a combined sewage system. Study findings indicated that impenetrable urban surfaces and rainfall rates are important factors that affect the cumulative overflows of the combined sewer systems, subsequently, the quality of water receivers. According to Chang et al. [16], the population growth and migration from rural to urban areas have resulted in the construction of grey cities mainly composed of impervious surfaces. Rangari et al. [17] concluded that the urban flood is self-invited because of the human appetite for more land and unregulated infrastructure construction by changes in natural land use, land cover, and streamflow ways. Also, the study supported the use of separated systems for the limitation of this sewer flooding. According to Tsihrintzis and Hamid [18], The Storm Water Management Model (SWMM) modelling using to achieve national goals in obtaining the best stormwater management and reducing the surface runoff by many mechanisms, such as discharges retention and decrease infiltration methods, which are cause the declining level of water bodies. In a study conducted by Yang et al. [19], the SWMM modelling outcomes (the nodes overflows) took from simulating the runoff. The examination scenarios used different rainfall intensities and return periods. The results showed that nodes flooding, water depths, and region flooding increased proportionally with the return periods.

## 2. Description of the study area

In this study, Al-Rashadiya quarter has been chosen as a study area, which is a small and densely populated area, located on AL-Kufa River to the North-East of AL-Najaf city, (32°02'11.2"N, 44°24'30.5"E), away about 160 km to the south-west from the capital, Baghdad, as shown in Figure 1 by Google earth, 2020.

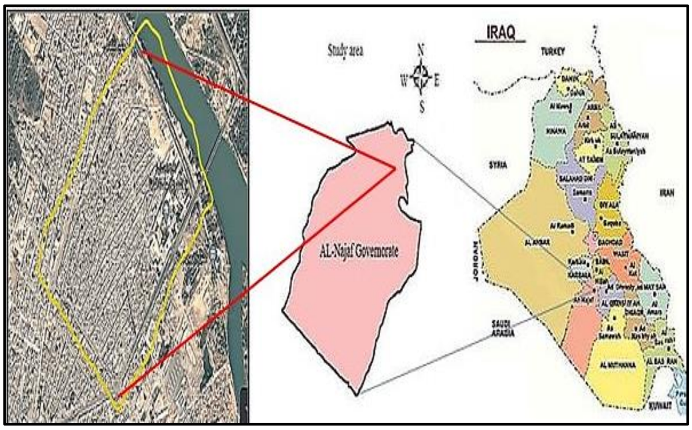


**Figure 1 Study area by Google Earth**.

AL-Rashadiya quarter is served by a combined sewage system that covers all the streets. Figure 2 show the study area and the map of the integrated sewage system using ArcGIS.

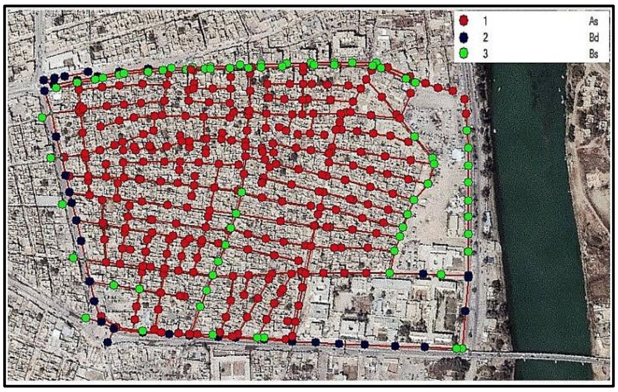


**Figure 2 The Combined Sewage System of the study area by ArcGIS.**

## 3. The field data

The field data of the combined sewage system and the sub-catchments of the study area have been collected from the Sewage Directorate of AL-Najaf (NSD) and the Municipality Directorate of AL-Najaf (DMN). These data included the properties of the sub-catchments, pipes and nodes (manholes) and were transformed by ArcGIS as shapefiles, where exported to AutoCAD Civil 3D to collect data in one file, then exported as (inp.) format to the SWMM program. Also, the rainfall intensities values took from [20].

## 4. The surface runoff

The represent of Runoff using the SWMM is relatively easy, as shown in Figure 3. In SWMM modelling, each sub-catchment surface is treated as a non-linear store by an indivisible inflow (rainfall), the surface runoff, filtering and evaporate considers as outflows. The surface runoff occurs when the water depth in the reservoir exceeds the extra storage of depression, where the reservoir capacity (or depression storage dp) is represented by ponds, wetting of the surface, ... etc. [21], [22].

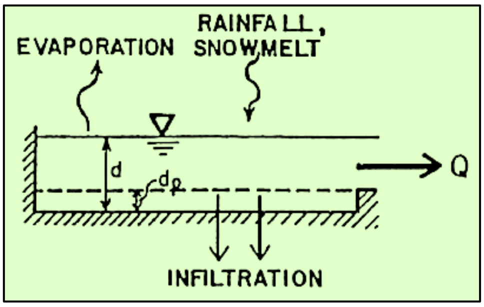


**Figure 3 Non-linear reservoir representation of sub-catchment in SWMM [24].**


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## 5. Hydraulic data modelling

Hydraulic data have been provided from NSD and DMN for the combined sewage system of the study area regarding data on both the sub-catchments, nodes (manholes) and pipes, where the hydraulic data included the area, width, type, depth, diameters, length, invert elevation ...etc., the summary of the hydraulic data for the system manholes and pipes is shown in Tables 1 and 2.

**Table 1 Summary of systems manholes data of the study area (NSD).**

| Manholes (Nodes) Information | Provided data |
|---|---|
| No. of Manholes | 410 |
| Manholes types | As, Bd, Bs |
| Manholes Materials | Reinforced concrete |
| Maximum depth range (m) | 0.92 - 4.67 |
| Invert elevation range (m) | 18.85 - 24.23 |
| Normal ground level (NGL) (m) | 24 - 29 |
| Ponded area | 0 |

**Table 2 Summary of systems pipes data of the study area (NSD).**

| Pipe Properties | Provided data |
|---|---|
| No. of pipes in the system | 408 |
| Shape | Circular |
| Lengths range (m) | 1 – 65 |
| Diameters range (m) | 0.25 – 0.6 |
| Manning's Roughness | 0.009 |
| Pipe material type | PVC |

Manning's equation for partially full pipe flow has been used to calculate the external inflows enter from adjacent districts to the sewer systems in the study area, where will join as a direct inflow in SWMM modelling.

### 5.1 Dry Weather Flow (DWF) and Time Pattern

To modelling the combined sewage system by SWMM, the dry weather wastewater flows will be adding to the appropriate conveyance nodes in this sewer system. The dry weather wastewater flows typically represent the locations where the collected sewage discharge to the trunk sewer. Variation in sewage generation or time pattern is happening through the season, month, and day, this depending on water consumption rate. There is a wide variance of water quantity consumption because some months have a high consumption rate, in the hot or warm months. Also, the expected high demand for water supply happens on specific days, like Friday days and holidays. Also, the variation occurs in the same hours of the day, where the peak demand occurs through one day and its hour's occurrence depend on city characteristic and people habits. The ratio between the wastewater generation to water consumption for each capita ranges from 70 to 100 % [23]. In Najaf city, the average ratio is about 80% (NSD). Usually, in the study area, the peak of water consumption occurs between (6 - 10) in the morning, when the people's activities beginning in the day, plus between (6 to 10) in the afternoon. The minimum water consumption always happens between half of the night to 4 mornings (NSD). An hourly pattern of the dry weather flow (DWF) prepared by [24] is approximate proper for the present study area and will use in the combined sewage system modelling by SWMM. The average daily water consumption in Najaf city based on the available data from NSD is about 275 liters per capita per day. In 2009, the number of people in the study area arrived at 9187 people, and the yearly growth factor for Najaf city during the previous decade was equal to 3.5% [25], [26]. So, the forecasting of the study area population number in the year 2020 can be estimated at about 13413 people, which is used in calculate DWF.

## 6. Hydrological data modelling

The hydrological data modelling target represents the best presentation of the precipitation in the study area to estimate the water movement in sub-catchments, the runoff and the run on. The modelling of the hydrological data includes the rainfall intensities and sub-catchments properties.

### 6.1 Rainfall Data in SWMM modelling

Rainfall is considering the source of the most runoff. The rainfall intensity has a wide range according to the geographic location and the seasons of the year. Sometimes, the rainfall intensity is very high and causes damages to the facilities and human lives in the precipitation region, so it is a very concerning case. In the present SWMM modelling, the high rainfall intensities for different return periods, which is 2, 5, 10, and 25 years, and for a duration of 2 hours with a time of concentration (Tc) of 5 minutes were taken from [20], where data of Najaf city annual precipitation has analysis using Gumbel distribution, based on the annual precipitation data that collected by the Meteorology and Seismic Monitoring Authority of Iraq for the duration from 1989 to 2018.

### 6.2 Sub-catchment area properties

The spatial distribution of the sub-catchments and their properties by GIS were provided from NSD in 2020 as an aerial image and shapefile of the study area, where assist in the insert process of the properties of sub-catchments with easy way when the SWMM modelling. The Sub-catchments properties of study area modelling are shown in Table 3.

**Table 3 Summary of the sub-catchment properties of study area.**

| No. | Sub-catchment properties | Range |
|---|---|---|
| 1 | Number of sub-catchments | 1716 units |
| 2 | Width of sub-catchments | 18.86 - 170.03 m |
| 3 | Runoff on (the total area) | 33.69 hectares |
| 4 | Infiltration/Inflow model [27] | Green-Ampt formula were used for the study area soil with the values of:<br>Saturated hydraulic conductivity (k) = 0.02 mm/hr.,<br>Suction head (Ψ) = 9.45 mm, and<br>Cumulative infiltration at the time t (F) = 0.321 inches. |
| 5 | Pervious and impervious area in sub-catchment. | Pervious area of 25%<br>Impervious area of 75% |
| 6 | Slopes of sub-catchments | 0.1 to 3.3 % |
| 7 | Manning's roughness (n) of the sub-catchment runoff [28] | 0.011 streets paved with smooth asphalt, 0.013 for the interior roads that paved with smooth brick concrete, and 0.014 for houses roofs. |
| 8 | Depression storage | 2 mm and 5 mm for impervious and pervious area, respectively. |

## 7. Numerical Results and Discussions

### 7.1 Calibration of models

There was a lack of data required for calibration and validation of the SWMM modelling. In the present study, for the models' validation purpose, a comparison was conducted between the pipes flow rates in the modelling of the combined sewage system using different rainfall intensities, design flow rates, and the lines flow rates from event modelling using the methods of Normalize Mean Square Error (NMSE), Coefficient of determination ($R^2$), and Root Mean Square Error (RMSE) to evaluate the SWMM models performance, where these methods were used in studies conducted by [29], [30], [31], [32], and [33]. The comparison results are shown in Table 4.

**Table 4 The comparison results of the combined sewage system models using the pipes flow rates.**

| Rainfall intensities return periods | Normalize Mean Square Error (NMSE) | R | Coefficient of determination ($R^2$%) | Root Mean Square Error (RMAE) |
|---|---|---|---|---|
| 2 | 0.6970 | 0.9779 | 58.37 | 0.0363 |
| 5 | 0.3038 | 0.8341 | 67.88 | 0.0281 |
| 10 | 0.2317 | 0.8043 | 71.41 | 0.0255 |
| | | | | |
| 25 | 0.1930 | 0.7348 | 69.81 | 0.0241 |

The comparison result between the design flow rates of the pipes and the max flow rate from SWMM models using the rainfall intensities with the different return periods using the NMSE method showed that all R values ranged between (0.7348 – 0.9779) (the acceptable limitation value from 0-1), and the NMSE values were ranged between (0.1930- 0.6970) (the acceptable limitation value is less than 1.5). Also, the results of NMSE showed that rainfall intensity with 25 years return period gave the minimum value of the NMSE, which was 0.1930. The NMSE results appear that the best performance by the SWMM model was by using the rainfall intensity with 25 years return period.

The coefficient of determination ($R^2$) values ranged between (58.37% - 71.41%) for the different return periods, where the results of ($R^2$) showed that at the SWMM modelling using the rainfall intensity for the return period of 10 years, the model gave the high value of $R^2$ and best performance, this when the maximum flow rates values have close to the values of the design flow rates.

All the values of RMSE were close to zero for all SWMM models for the different return periods, ranged between (0.0241- 0.0363) (the acceptable limitation value is less than 1), where the results of RMSE showed that at using rainfall intensity with 25 years return period, the SWMM model gave a better performance.

Only one event data of precipitation was getting during the study interval on 28/11/2020. The rainfall depth of the event was 55 mm, and the rainfall duration of 120 minutes, where the event data was used as an accumulative value in the Time Series of the SWMM modelling. The comparison was conducted using the RMSE and the Coefficient of determination ($R^2$) methods between the max flow rates in the pipes of the event model with the different rainfall intensities models. The comparison results using RMSE and $R^2$ are shown in Table 5 and Figure 4.

**Table 5 The comparison results of the combined sewage system models using the rainfall event.**

| Rainfall intensity return period | RMSE |
|---|---|
| 2 | 0.0505 |
| 5 | 0.0392 |
| 10 | 0.0575 |
| 25 | 0.0615 |

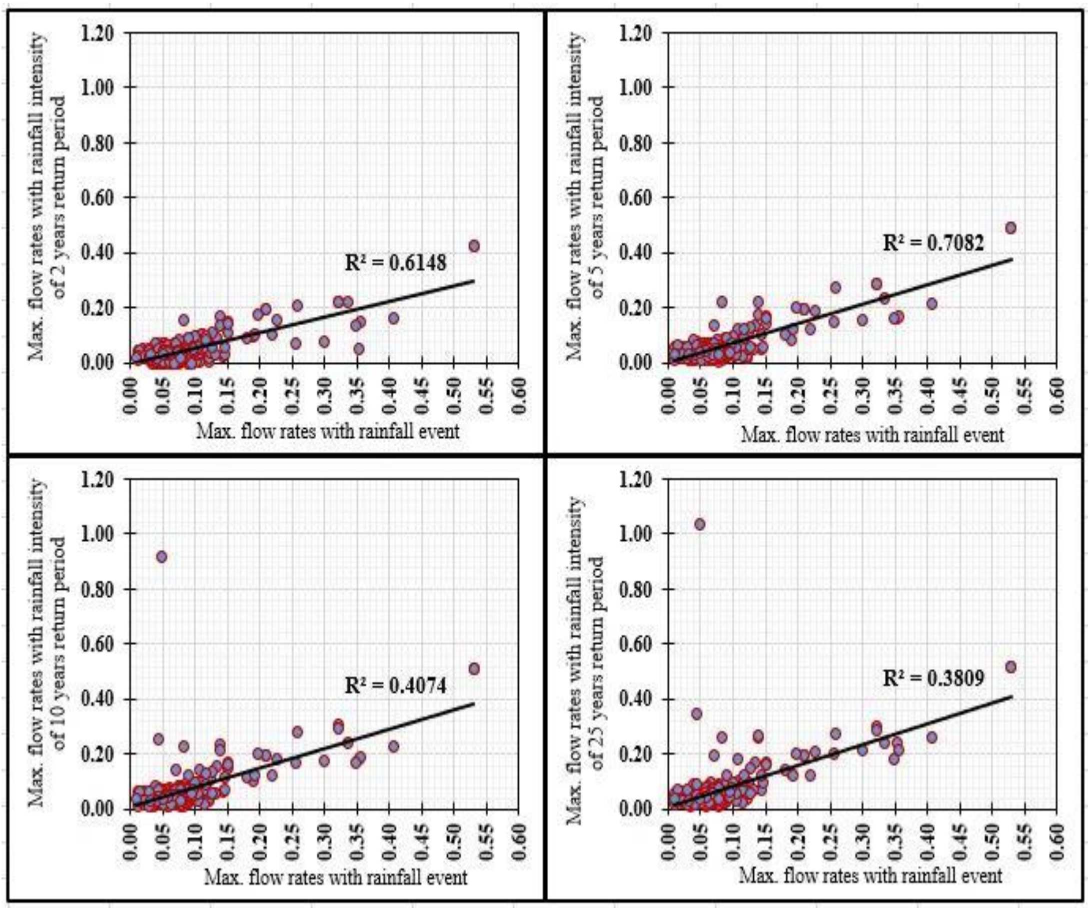


**Figure 4 Coefficient of determination ($R^2$) between pipe flow rates obtained from the rainfall event modelling and rainfall intensity modelling for different return periods.**

The obtained results by using the Root Mean Square Error (RMSE) method showed low values of RMSE (the acceptable limitation value is less than 1) for the relationship between pipes flow rate of the rainfall event and flow rate using the different rainfall intensities for the additional return periods, where this indicates to a good performance of the SWMM models. The RMSE value using the rainfall intensity with a return period of 5-years, which is 0.0392, was close to the zero value more than other RMSE values.

The variances in $R^2$ values indicate the convergence and divergence between the values of the rainfall intensity used in the event model with the values of the different rainfall intensities used in SWMM models, where the increase of $R^2$ value indicates the convergence of the rainfall intensity values used in the SWMM models with the rainfall intensity values used in the event model, and the decrease of $R^2$ value indicates to the rainfall intensity values which used in the SWMM models are getting away from the rainfall intensity values used in the event model. The value of $R^2$, that equal to 70.82, utilising the rainfall intensity for the return period of 5-years, gave the best coefficient of determination ($R^2$), which means that the rainfall event is close to the rainfall intensity for the return period of 5 years. The obtained results gave more credibility to the SWMM models in this study.

### 7.2 SWMM models flooding volumes

In the SWMM modelling process for the combined sewage system, there are two sources of wastewater. First, the run-off on the sub-catchments due to the precipitation, and second, the wastewater produced from domestic uses. In the case of arriving of these liquids volume to levels excide the design capacity for the sewer system, this causes floods in the nodes of the sewage system, this what happened within varying percentages in the combined sewage system of the study area when using the different rainfall intensities for different return periods. The node flooding, in most cases, is caused by the misuse and the unregular distribution of sewage quantity in the combined sewage system in the study area, where the flooding in some nodes occurs by exceeding in criteria of the sewer system design. For example, by observing the nodes during the rainfall event, the flooding occurs caused by the direct connections of the home sewers to the nodes, not on houses connections (sewer pipes). The remaining volume of the runoff distributes between infiltration in the soil, depression storage, and the sewage liquids volume discharged by the combined sewage system. Table 6 and Figure 5 lists the volume of the total runoff and other above details.

**Table 6 The results obtained from the SWMM modelling of the combined sewage system using the different rainfall intensities for different return periods.**

| Rainfall intensities return period (years) | Total Runoff ($m^3$) | Total Nodes Flooding ($m^3$) | Percentage of flooding nodes / total nodes in combined sewage system | Remaining volume ($m^3$) |
|---|---|---|---|---|
| 2 | 5090 | 3817 | $(36/410) \approx 9\%$ | 1273 |
| 5 | 10670 | 6912 | $(83/410) \approx 20\%$ | 3758 |
| 10 | 14410 | 8929 | $(106/410) \approx 26\%$ | 5481 |
| 25 | 23450 | 13434 | $(138/410) \approx 34\%$ | 10016 |

The results in Table 7 appears that the total of the over sub-catchments runoff, nodes flooding volume, numbers of flooded nodes and the remaining from the total runoff volume increased with the increase of the rainfall intensity having the high return period. The rainfall intensity for the return period of 25 years recorded high values for total runoff volume, which is 23450 $m^3$, total nodes flooding volume was 13434 $m^3$, the number of flooding nodes was 138 nodes, which represent 34% from the total system nodes, and the remaining volume from the total runoff volume, which is 10016 $m^3$, and this considered a logical result because of the increase in the runoff rates.

Figure 7 shows percentages for the total flooding volume from nodes comparing with the remaining runoff from the total runoff volume due to precipitation, where the ratio of total nodes flooding volume comparing with the total runoff decreases with the higher rainfall intensity having the higher return period, where these results agree with studies results of [34], and [35].

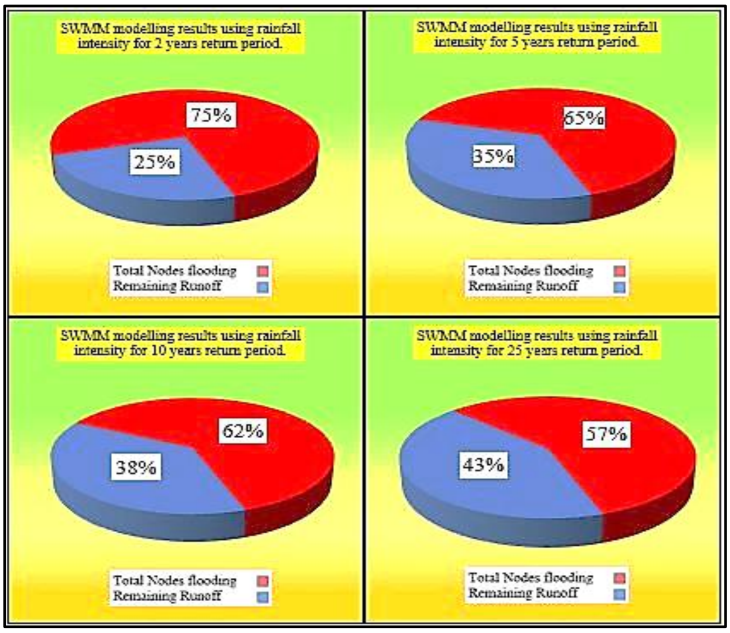


**Figure 5 Percentages of the total nodes flooding volume comparing with the remaining runoff volume in SWMM modelling.**

Figures 6, 7, 8, and 9 presents hydrographs of the maximum flooding rate occurring from SWMM modelling for the combined sewage system using the four rainfall intensities.

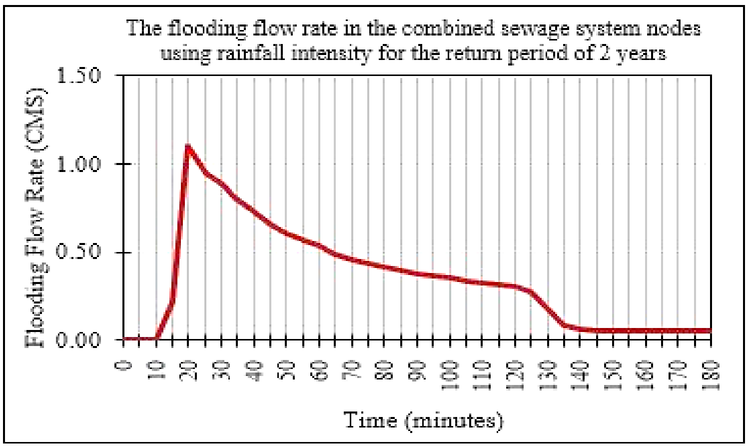


**Figure 6 The maximum flooding rate hydrographs from the SWMM modelling of the combined sewage system using the rainfall intensity for the return periods of 2 years.**

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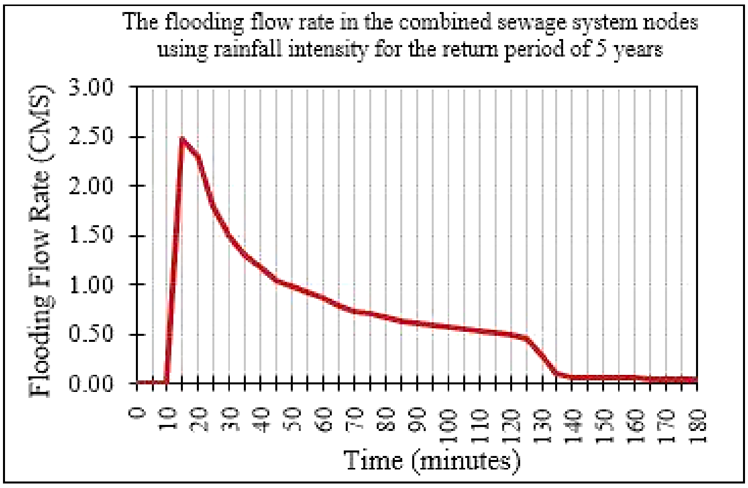


**Figure 7 The maximum flooding rate hydrographs from the SWMM modelling of the combined sewage system using the rainfall intensity for the return periods of 5 years.**

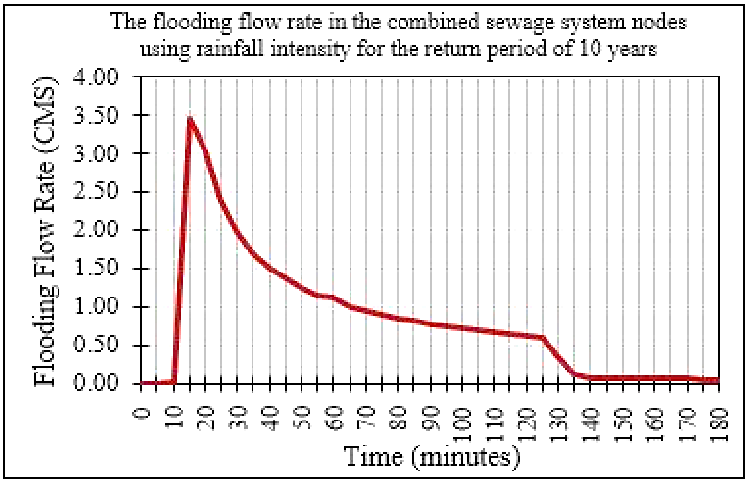


**Figure 8 The maximum flooding rate hydrographs from the SWMM modelling of the combined sewage system using the rainfall intensity for the return periods of 10 years.**

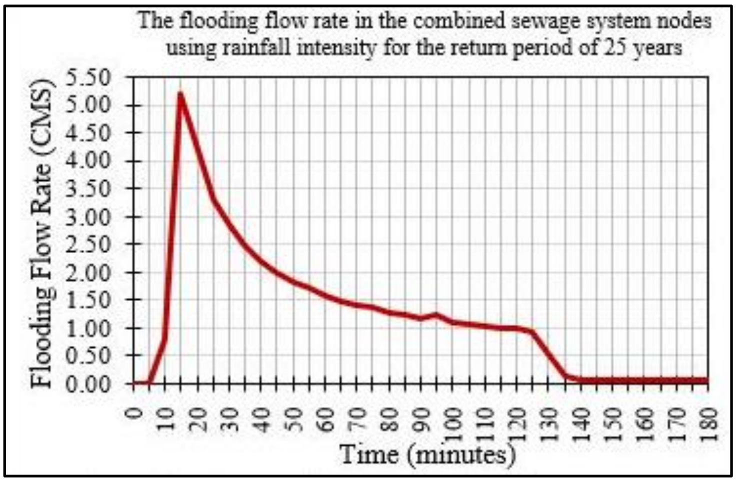


**Figure 9 The maximum flooding rate hydrographs from the SWMM modelling of the combined sewage system using the rainfall intensity for the return periods of 25 years.**

As shown in all hydrographs, the flooding flow begins after 10 minutes after the simulation start. The nodes flooding occurs at a late time of the simulation starting (at the minute 20) when using the rainfall intensity for the return period of a 2-years due to the low values of this rainfall intensity, which is considered less than other rainfall intensities for the return periods of 5, 10, and 25-years (at the minute 15). Also, the maximum value of the flooding flow rate using the rainfall intensity for the return period of 2-years is about 1.098 CMS, and this value is considering the lowest between the values obtained from the simulation of the three other rainfall intensities having 5, 10, and 25 years of the return period, which are 2.467, 3.441, and 5.192 CMS, respectively. All rainfall intensities are equalled approximately at the same time in the flooding rate values, in the minute of 150, where equal to 0.05 CMS, after that time, the values continue to decrease until the flooding flow rate stops when the wastewater flow rate arriving at the design capacity for the system.

### 7.3 Effects of population activities on sewer systems in a study area

The previously mentioned sewer flooding volumes are submissive to the increase due to population behaviours (activities and habits), where these behaviours can cause an increase in the flooding rate during dry and rainy weather. The population behaviours affect the sewer systems operation such as the misuse and the un-legal sewers connections, closing the inlets of sewer systems by the rubbish, the wastes from the commercial activities, the spill of the untreated liquid and solid wastes, such as cars oils, butchers waste and food industries such as vinegar and vegetable market waste, ..., etc. Also, the above reasons are cause pollution in the rainwater during the rainy weather, which finally deposits in Kufa River, and this agrees with the results of studies of [11], [36] and [37].

All of the above causes, with the shortage in the periodic maintenance of the sewer systems, weak municipal services in waste collection and the significant increase in population growth in the study area, increase the pressure on the sewer systems in both levels quantity and quality and affect the wastewater treatment plant performance and water environment in the Kufa River. Figure 10 show the flooding locations and the effects of population activities on the sewer systems during dry and rainy weather in the study area.

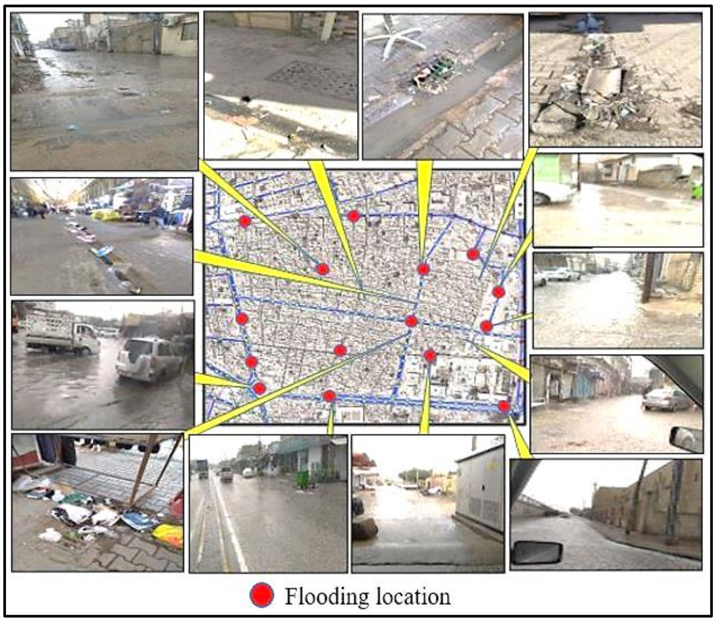


**Figure 10 Flooding locations and the effects of population behaviours**

### 7.4 The suggested scenario

The change of pipes diameter scenario has been used before in the study of [38] as one of the solutions for reducing the overflows in the sewer systems. This scenario involves increasing the diameters of some pipes in pipelines of the combined sewage system, which include pipes that have diameters of 0.25, 0.4, and 0.5 m, where the diameter change was based on the balance between the economic selection and the practical solution. The targeted pipelines collect rainwater either from large space areas or from other sewage pipelines that come from the sub streets, which are similar diameters to the diameters of the targeted pipelines. This causes a slow discharging of the sewage in these pipelines, therefore, presses on the targeted pipelines nodes and causes nodes overflow. Using this scenario achieves two targets:

1. The first target is to reduce the overflows quantities from the nodes of the combined sewage system produce during rainfall events, therefore, reduce the flooding volume in the study area.

2. The second target of this scenario is to decrease pollutants concentrations on the study area that come from the combined sewage system nodes overflow, where these pollutants inflow to the stormwater system by the runoff during the rainy weather.

Figure 11 shows the mechanism of applying the scenario on the pipelines of the combined sewage system. The pipelines with blue colour represent the lines that need to change their pipes diameters from 0.25 m to 0.4 m, and the pipelines with yellow colour represent the lines that need to change their pipes diameters from 0.4 m to 0.5 m. Also, lines with red colour represent the lines that need to change their pipes diameters from 0.5 m to 0.6 m.

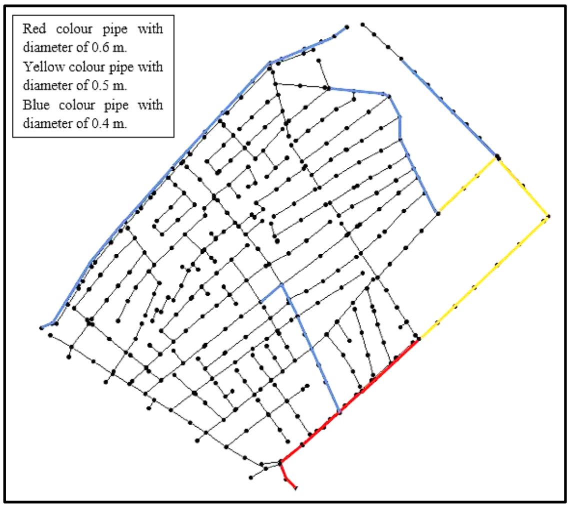


**Figure 11 The combined sewage system pipelines which diameters changed.**

Table 7 show the results obtained from using this scenario in SWMM modelling to reduce the total flooding volumes in the combined sewage system nodes using the different rainfall intensities for the different return periods.

**Table 7 Flooding in the combined sewage system before and after increase the pipes diameters and the reduction percentage in the flooding volumes.**

| Rainfall intensity return period | Total flooding volume before pipes diameter change ($m^3$) | Total flooding volume after pipes diameter change ($m^3$) | Percentage of flooding reduction efficiency (%) |
|---|---|---|---|
| 2 | 3817 | 1774 | 53.52 |
| 5 | 6912 | 4171 | 39.65 |
| 10 | 8929 | 5955 | 33.3 |
| 25 | 13434 | 10154 | 24.41 |

The results in Table 8 presents the efficiency of using the scenario in reducing the combined sewage system flooding, where the results appear that the scenario efficiency in the flooding reduction was high when using the model of the rainfall intensity for the return period of 2-years, which was 53.52%, more than the other models using the different rainfall intensities. Also, these results showed that the scenario efficiency has negatively related to the return period of the rainfall intensity. In other words, the scenario efficiency decreases with the increase of the rainfall intensity return period because of the increase in the runoff produced by the higher rainfall intensity.

## 8. Conclusions

1. The comparison results, between the designed and the predicted flow rates showed that the obtained values of NMSE ranged between (0.1930 - 0.6970), the obtained values of the Coefficients of determination ranged between (58.37% - 71.41%), and the values of RMAE ranged between (0.0241 - 0.0363). Also, the comparison results, between the design flow rates and the rainfall event flow rates on 28-11-2020, using the Normalize Mean Square Error (NMSE) and the Coefficient of determination ($R^2$), showed that the obtained values of NMSE ranged between (0.0392 - 0.0615), and the values of the Coefficient of determination ranged between (38.09% - 70.82%). The present study used the SWMM model, which can lead to finding the best solutions for the sewer system problems.
2. The results obtained from the combined sewage system models by SWMM showed the flooding volumes of the nodes using the rainfall intensities for the return periods of 2, 5, 10, and 25 years were 3817, 6912, 8929, and 13434 $m^3$, respectively.
3. For the present study, the suggestion was applied for reducing the flooding quantities from the combined sewage system nodes by increasing diameters of some pipes in the integrated sewage system, the total flooding volumes reduced with per cent of 53.52%, 39.65%, 33.3%, and 24.41% using the rainfall intensities for the return periods of 2, 5, 10, and 25 years, respectively.

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## تأثير شدة هطول الأمطار على تشغيل نظام الصرف الصحي المشترك في المناطق المأهولة بالسكان.

***الخلاصة:*** *تتناول هذه الورقة تأثير منطقة مكتظة بالسكان على تشغيل نظام الصرف الصحي المشترك في ظل كثافة هطول الأمطار العالية باستخدام برنامج نمذجة، نموذج إدارة مياه العواصف (SWMM). الهدف هو محاكاة الزيادة المستقبلية في شدة هطول الأمطار للحد من فيضان نظام الصرف الصحي المشترك في منطقة الدراسة، والتي كانت في حي الرشادية في مدينة النجف، العراق. تم نمذجة شدة هطول الأمطار باستخدام برنامج SWMM لتقدير أحجام الفيضانات القصوى في نظام الصرف الصحي المشترك في منطقة الدراسة. لتقييم أداء النماذج، تم استخدام عملية المقارنة بين قيم معدلات تدفق الأنابيب لنماذج نظام الصرف الصحي المدمجة مع معدلات تدفق التصميم ومعدلات التدفق لنمذجة حدث واحد فقط متاح خلال فترة الدراسة. أظهرت نتائج المقارنة أداءً جيدًا ومتقاربًا لهذه النماذج. كانت نتائج أحجام الفيضانات باستخدام قيم مختلفة لشدة هطول الأمطار وفترات العودة المختلفة والتي كانت 2 و5 و10 و25 سنة، في نمذجة نظام الصرف الصحي المشترك 3817، 6912، 8929، 13434 متر مكعب على التوالي. تضمن السيناريو المقترح زيادة أقطار بعض الأنابيب في خطوط أنابيب نظام الصرف الصحي المشترك. أظهرت النتائج باستخدام هذا السيناريو انخفاضًا في نسبة الفيضانات الكلية من نظام الصرف الصحي المجمع بنسبة 53.52٪، 39.65٪، 33.3٪، 24.41٪. يمكن أن توفر الدراسة الحالية الدعم الفني لاستخدام البرامج في التخطيط والتحكم والاختبارات لأنظمة الصرف الصحي، مما يساهم في حل مشاكل أنظمة الصرف الصحي.*