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# An evaluation of flood mitigation using a storm water management model [SWMM] in a residential area in Kerbala, Iraq

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**Abstract.** The control of the urban flooding is one of the major challenges currently facing decision makers and municipalities. Flooding rates increase positively with increases in urbanisation, climate change, and a lack of consideration when using drainage networks. In the Middle East, and in Iraq especially, research in the field of flood control has been rare prior to this study. This study thus aims to provide technical support for decision makers by offering a proposed solution to mitigate flooding in a case study in Kerbala, Iraq. A storm-water management model [SWMM] has been utilised to check the extent to which the proposed solution will mitigate the flooding in the study area. SWMM was used to simulate the network in the study area utilising hourly precipitation intensity data from 2008 to 2016, and with the inclusion of estimated illegitimate sewage quantities. The results indicated that the solution was effective, and the percentage of sewer holes flooding under maximum rainfall intensity of 33.5 mm/hr saw a decrease from 48% to 33%; flooding occurred in the study area only with discharges greater than 0.04 $m^3$/sec, and the flooding duration also decreased from 72 hours to 26 hours.

**Key words:** Karbala, flooding, mitigation, runoff, SWMM

## 1. Introduction

Flooding events in urban areas are affected by many factors, including urbanisation, climate change, and the inconsiderate use of drainage networks. Increases in urbanisation in particular lead to natural ground being covered with impervious surfaces. Such urbanisation thus causes a decrease in the infiltration rate, increasing the peak discharge and volume of runoff. Climate change due to warming also tends to cause to increased rainfall intensity, which is thus higher than the design intensity of existing systems, which causes flooding. Overuse of the drainage networks such as additional quantities of sewage entering the system or users clogging the inlets of the system with rubbish further increase the rate of flooding.

In areas where mean rainfall has seen reductions, which includes most subtropical and mid-latitude regions, rainfall intensity is actually likely to rise, though longer intervals between rainfall events would be expected [1]. The development of urbanisation and increases in extreme rainfall events due to climate change thus have the most significant impact on the assessment of the hydraulic capacities of urban drainage networks [2]. Global warming influences the water cycle, producing significant increases in sea level and increasing the overall temperature of the earth. This increase also produces a rise in precipitation intensity and frequency [3]. In addition to climate change, increased urbanisation also demonstrates a strong connection with rises in flooding rates where the surface runoff patterns differ due to changes in land use. The rise of urbanisation generally decreases the time to peak water volume and increases the volume and peak discharge; the use of control equipment and drainage networks also has a progressive effect on runoff patterns [4].

The research in [5] used SWMM to assess the reduction in percentage of flooding discharge due to the existence of storage tanks with a capacity of 70 $m^3/s$ during continuous precipitation events over a 5-year period. The simulation results showed that the flooding discharge was reduced by between 14 to 20% compared to cases with no tanks. In [6], growing urbanisation and encroachments on the storm drainage system by inhabitants were identified as the main reasons for the increased the flooding problems in Patna and Chennai, India. The drainage network was modelled using SWMM to enable the researchers to better understand the behaviours of the storm drainage network under flooding conditions. SWMM showed that the network is likely to flood in a 2-year return period; this was attributed to the poor maintenance of the system, including the fact that the local people were not concern with the health of the system, throwing rubbish and polythene bags into the drainage stream. The research in [7] used SWMM to analyse the effect of proposed solutions on the drainage efficiency of network drainage systems in China. This work discovered that, by increasing the pipe diameter, flooding in the study area could be decreased by 81.62%; similarly, by altering the size of the sewer holes, the flooding in the study area was reduced by 44.78 %.

SWMM was also used in [8] to analyse a storm drainage network in Kerbala, Iraq. The storm system suffered from flooding during the rainy season, and the results indicated that the rainfall intensity occasionally reached levels of three times the design intensity of the system. Due to climate change, the storm system flooded for 43.5 hours, and 47% of flooding sewage holes had very high levels of flooding discharge. In addition to the known effects of climate change, the existence of an illegitimate sewage quantity increased the problem of the flooding in this storm system. The study indicated that a solution must be provided to reduce this flooding problem.

Previous studies have thus shown that SWMM is able to simulate urban flooding effectively. In this study, SWMM has been used to assess a proposed mitigation for the flooding effects in the study area, which has been exposed in recent years to very high rain intensities due to the climate change. The results will provide technical support to the relevant municipalities in terms of the effectiveness of the proposed solution.

## 2. The study area

The study region is the Al-Esqari quarter, situated in the north of Kerbala city, Iraq, at latitude 32˚ north, and longitude 43˚ east, as displayed in figure 1. It is an urban residential community with intermediate density. The Al-Esqari quarter is very flat, with altitudes ranging from 34 to 41 m, with a mean elevation of 37.5 m. The study area is 1,100,000 $m^2$, with a high imperviousness of 66%. The study area involves several impervious areas, such as residential, commercial, and educational zones, along with roads and public spaces, and some more pervious areas such as unpaved roads and green zones. The soil in the area is generally a sandy clay. Kerbala has to desert climate with short cold winters and extensive dry summers, with an average temperature of 8˚C in winter and 48˚C in summer, and a total annual precipitation of 92 mm/year [9,10]. Most of the annual precipitation is concentrated in winter, which runs from November to April. The study area officially has only a storm drainage network; however, an illegitimate sewage quantity is also deposited into the storm drainage system.

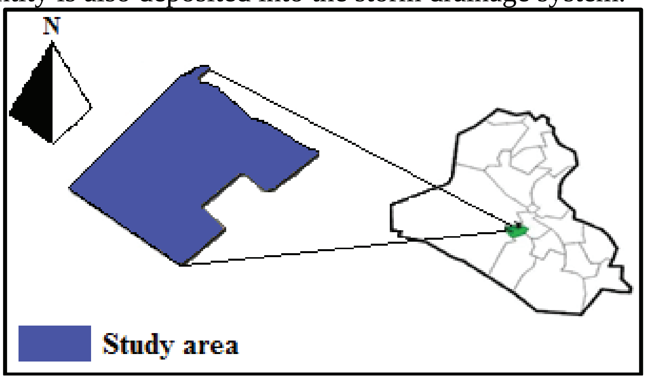


**Fig. 1:** The location of the Al-Esqari quarter relative to Karbala on the Iraqi map.

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## 3. METHODOLOGY

### *3.1 The Simulation Model*

The study area was modelled using the Environmental Protection Agency [EPA] Storm water Management Model [SWMM] version 5.1. SWMM is one of the top urban rainfall-runoff models that can be utilised to simulate hydrological processes in an urban area. The hourly precipitation intensity data from 2008 to 2016 was used to simulate the study area as supplied by the agricultural meteorology Iraqi network [9]. The SWMM model requires several parameters to simulate flooding in urban areas, such as topography data, soil data, network data, and climate data. The main five steps of this research can be seen as:

1. Data collection
2. Delineating the storm drainage network and the sub-catchments of the study area.
3. Calibrating the parameters of the model for more accurate results.
4. Running the simulation.
5. Analysing the outcomes of the simulation.

More details of the simulation model can be found in [8].

Flow routing approaches include steady, dynamic, and kinematic wave options. Infiltration rates were assessed using either the Green-Ampt, Horton, or Curve Number methods. For this study, the dynamic wave model was utilised for flow routing and Green-Ampt method used for infiltration.

### *3.2 The SWMM calculations and equations*

SWMM uses multiple equations to simulate different hydrological processes. The runoff in SWMM is calculated using the following equation:

$$Q_{storage}=Q_{input}-Q_{output} \qquad (1)$$

where $Q_{storage}$ is the maximum surface storage provided by ponding, surface wetting, and interception ($m^3$/sec) , $Q_{input}$ is the inflow including precipitation and any nominated upstream sub-catchment flows ($m^3$/sec), and $Q_{output}$ is the outflow, including evaporation, infiltration, and surface runoff ($m^3$/sec).

Each sub-catchment surface is handled as a nonlinear equation in which the storage of the reservoir is considered to be a function of inflow and outflow [11].

Surface runoff occurs only when the depth of water in the reservoir exceeds the maximum depression storage [12]. The concept accounting for the surface runoff for each sub-catchment depends on the continuity of mass per equation 2:

$$\frac{dV}{dt} = \frac{d\,[A*d]}{dt} = A * I_e - Q \qquad (2)$$

where: $\frac{dV}{dt} = \frac{d\,[A*d]}{dt}$ refers to the change of volume stored over the sub-catchment over time; **V=A*d** refers to the volume of water in the sub-catchment ($m^3$); **A** is the sub catchment area ($m^2$); **d** is the water depth in the sub catchment (depth of storage in the reservoir in m); $I_e$ is the excess rainfall, which is the difference between the rainfall intensity, evaporation, and the infiltration rate (m/sec); $A * I_e$ is the precipitation excess from the sub catchment; and **Q** is the runoff flow rate from the sub-catchment ($m^3$/sec). This depends on the Manning equation:

$$\mathbf{Q} = \frac{A_{cs} * R^{\frac{2}{3}} * S^{\frac{1}{2}}}{\mathbf{n}} \tag{3}$$

where $\mathbf{A_{cs}}$ is the cross sectional area of flow over the sub-catchment (m²), which is equal to $\mathbf{W*(d\text{-}d_p)}$; **R** is the hydraulic radius of flow over the sub-catchment (m); **S** is the slope of the sub-catchment; **W** is the width of the sub catchment (m); and **n** is the Manning roughness coefficient for overland flow.

The hydraulic radius is defined as the ratio of cross section area to the wetted perimeter:

$$\mathbf{R} = \frac{\mathbf{A}}{\mathbf{p}} = \{\mathbf{W} \cdot [\mathbf{d} - \mathbf{d_p}]\}/\mathbf{W} = \mathbf{d} - \mathbf{dp} \tag{4}$$

Thus, the Manning equation for calculating surface runoff becomes

$$\mathbf{Q} = \frac{\mathbf{W} * (\mathbf{d} - \mathbf{d_p})^{\frac{5}{3}} * \mathbf{S^{0.5}}}{\mathbf{n}} \tag{5}$$

Substituting Equation 5 into Equation 2 gives

$$\frac{\mathbf{dd}}{\mathbf{dt}} = \frac{\mathbf{d}_{i+1} - \mathbf{d}_i}{\mathbf{t_{i+1}} - \mathbf{t_i}} = \mathbf{I_e} - \frac{W * (d - d_p)^{5/3} * S^{0.5}}{A * n} \quad \ldots (6)$$

where **i, i+1** are subscripts representing boundary conditions at the end of time step **i** (or the start of time step i+1) and the end of time step **i+1** (e.g., $d_{i+1}$ is the depth at the end of time step i+1); $\mathbf{t_{i+1} - t_i = \Delta t}$ is the time step size (sec); **Q** is the average runoff flow rate through time step n+1 ($m^3$/sec); $\mathbf{I_e}$ is the average rainfall intensity through time step n+1 (m/sec); and **d** is the average depth of flow during time step n+1, represented as $\mathbf{d} = \mathbf{(d_i + d_{i+1})/2}$ (m).

The infiltration in SWMM can be modelled using three different formulas: Horton, Green-Ampt, and SCS curve number method. In this research, the Green-Ampt model was used. The general equations for the Green-Ampt method are given below [13]:

$$\mathbf{f = K * \{ [\frac{\Psi * N}{F}] + 1\}} \tag{7}$$

$$\mathbf{F = K * t + \Psi * N * In \{1 + [\frac{F}{\Psi * n}]\}} \tag{8}$$

where **f** is the infiltration capacity (mm/h); ***K*** is the saturated hydraulic conductivity (mm/h); **Ψ** is the suction head (mm); **N** is the available porosity, calculated by subtracting the wilting point from the field capacity; and F is the Mass infiltration (mm).

In SWMM, the process of determining the time and magnitude of flow at any point in the drainage system based on known or assumed hydrographs at one or more point in upstream is known as flow routing. There are three levels of sophistication used in SWMM for flow routing to solve the conservation of mass and momentum equations for conduits of open channels; the resultant equation is a comprehensive one-dimensional Saint-Venant [11]. The three levels of flow routing in SWMM are steady flow routing, kinematic flow routing, and t dynamic flow routing. In this study, dynamic flow routing was used. For the Saint-Venant, the flow can be represented by two partial differential equations [12], the first for momentum:

$$\frac{1}{A}\frac{\partial q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left[\frac{q^2}{A}\right]+g\frac{\partial y}{\partial x}-g\,[S_0-S_f]=0 \qquad (9)$$

and the second for continuity:

$$\frac{\partial A}{\partial t}+\frac{\partial q}{\partial x}=0 \qquad (10)$$

where **q** is the flow rate in the system ($m^3$/sec); **g** is the acceleration due to gravity (m/$s^2$); **y** is the depth of flow (m); $S_0$ is the bed slope (m/m); $S_f$ is the friction slope (m/m); **A** is the cross-sectional area ($m^2$); **x** is the distance along the channel (m); and **t** is time (sec).

### *3.3 Sewage quantity*

The illegitimate sewage quantity discharged into the storm drainage network must be considered. Based on reports from the Iraqi Planning Ministry [14], the water consumption is about 422 litres/day per capita in Karbala city. An estimate of the average sewage for each sewer hole is thus as follows:

$$Q_{avg} = G * 0.8 * P \qquad (11)$$

where $Q_{avg}$ is the average quantity of sewage flow in litres/day, P is the number of residents (thousands) and G is the water consumption per person in litres/day.

The rate of the sewage from water consumption per person varies from 70 to 130% [15]. An average of 80% has been used as the relevant percentage in Iraq. SWMM requires a time pattern for variations in sewage flow, and [16] was used to provide a time pattern for sewage flow variations, as presented in Table 1. This pattern is suitable for residential regions.

**TABLE 1.** TIME PATTERNS OF SEWAGE VARIATION [16] .

| HOURLY PATTERN | | | |
|---|---|---|---|
| AM 12:00:00 | 0.9 | PM 12:00:00 | 1.17 |
| AM 01:00:00 | 0.82 | PM 01:00:00 | 1.17 |
| AM 02:00:00 | 0.7 | PM 02:00:00 | 1.13 |
| AM 03:00:00 | 0.64 | PM 03:00:00 | 1.1 |
| AM 04:00:00 | 0.6 | PM 04:00:00 | 1.07 |
| AM 05:00:00 | 0.63 | PM 05:00:00 | 1.08 |
| AM 06:00:00 | 0.75 | PM 06:00:00 | 1.1 |
| AM 07:00:00 | 0.91 | PM 07:00:00 | 1.12 |
| AM 08:00:00 | 1.06 | PM 08:00:00 | 1.12 |
| AM 09:00:00 | 1.18 | PM 09:00:00 | 1.15 |
| AM 10:00:00 | 1.23 | PM 10:00:00 | 1.11 |
| AM 11:00:00 | 1.22 | PM 11:00:00 | 1.01 |

| DAILY PATTERN | |
|---|---|
| SUNDAY | 1.02 |
| MONDAY | 1 |
| TUESDAY | 0.99 |
| WEDNESDAY | 0.95 |
| THURSDAY | 0.94 |
| FRIDAY | 1.01 |
| SATURDAY | 1.1 |

| MONTHLY PATTERN | |
|---|---|
| JANUARY | 1 |
| FEBRUARY | 1 |
| MARCH | 1 |
| APRIL | 1 |
| MAY | 1 |
| JUNE | 1 |
| JULY | 1 |
| AUGUST | 1 |
| SEPTEMBER | 1 |
| OCTOBER | 1 |
| NOVEMBER | 1 |
| DECEMBER | 1 |

### *3.4 The proposed solution*

According to analysis of the storm drainage network in the study area [8], the storm drainage network is not able handle the rainfall intensity that it is exposed to as a result of climate variation. This is because climate variation has caused increases of up to three times the design intensity of the system. The existence of the illegitimate sewage quantity also increases the risk of flooding in the study area, as well as causing flooding duration to roughly double. These problems make it necessary to find solutions to these flooding problems, which may be happened in any region with similar circumstances, especially in the middle east. To solve the problem of flooding, a number of solutions, both economic and hydraulic, have been presented for implementation. These include

1. Increasing the diameter of the pipes
2. Adding a new line to reduce choking in the system
3. Increasing the percentage of local green areas to help with the discharge a large quantity of rainfall water.

Here, the second solution is the most practical and suitable for the study area.

SWMM was run for the storm drainage network under conditions of climate variation only and adding the illegitimate sewage quantity to the system. After studying the flooding resulting under all conditions based on the rainfall intensity from 2008 to 2016, several solutions were suggested to mitigate the flooding intensity and duration in the study area. The best of these solutions represented a balance between cost of construction and maximum percentage reduction of flood quantity and duration. The proposed solution is thus an additional pipeline transmission with a length of 344 m and a diameter of 900 mm, extending in an unpaved area. The construction cost for 1 m length is estimated at approximately 1,500,000 DI, around $1,154. Figure [2] shows the location of the proposed pipeline.

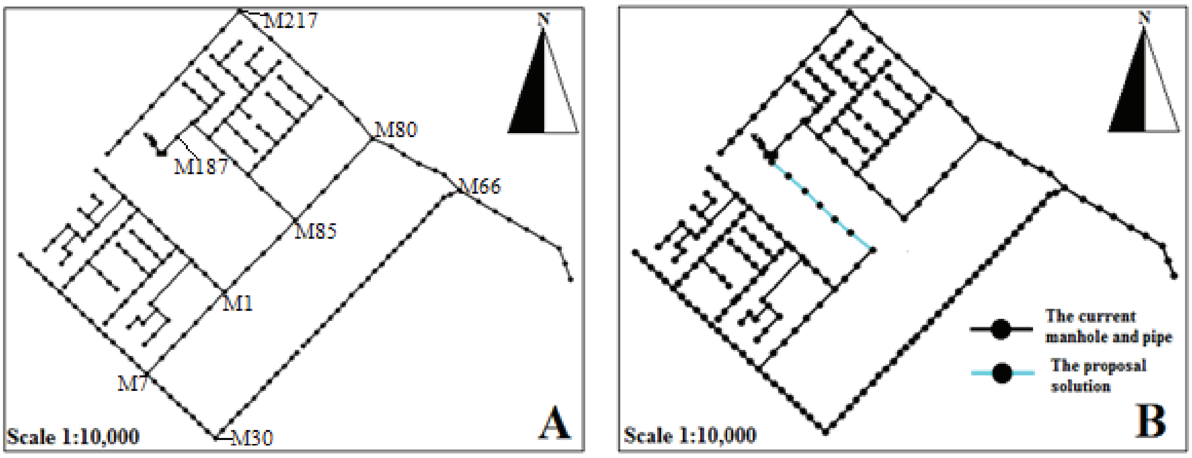


**Fig. 2:** A Current storm network, B Proposed pipeline transmission

## 4. RESULTS AND DISCUSSION

To evaluate the effect of the new proposal, two approaches were taken. The model of the drainage network in the Al- Esqari quarter was calibrated and then the effect of the proposed solution estimated.

### *4.1 Model calibration*

A manual trial and error method was used to achieve calibration of the model. Rainfall-runoff data for model calibration and validation were recorded over two rainy days. The first day was 18 June 2016, with a precipitation intensity of 2 mm/hour. The second day was 22 June 2016, with a precipitation intensity of 4 mm/hour. To emphasise the reliability of the input data in the model, cross validation was conducted on the data, as in Table 1. For the first precipitation event, the coefficient of determination [$R^2$] was 0.95 and for second precipitation event, it was 0.94, as presented in Figures 3 and 4. Table 2 shows that the selected model and its parameters are acceptable based on this testing.

**TABLE 2.** CROSS-VALIDATION OF THE MODEL.

| Constraints | The rainy day | |
|---|---|---|
| | 18/Jun/2016 | 22/Jun/2016 |
| MSE | 0.06 | 0.04 |
| ME | 0.01 | 0.003 |
| $R^2$ | 0.95 | 0.94 |

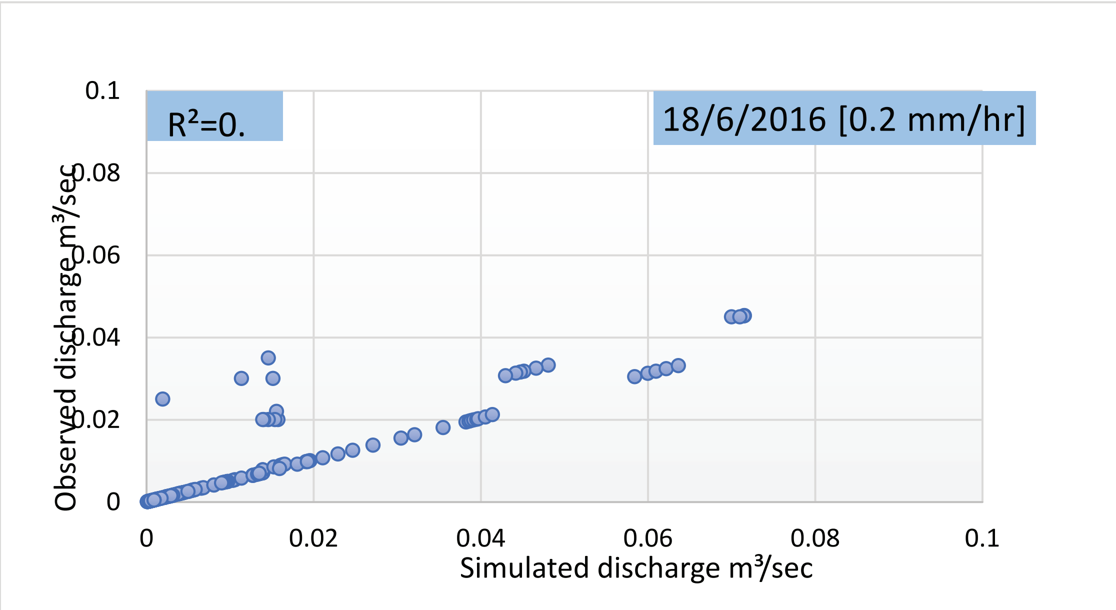


**Fig.3:** The result of simulation model calibration in SWMM for 18/6/2016

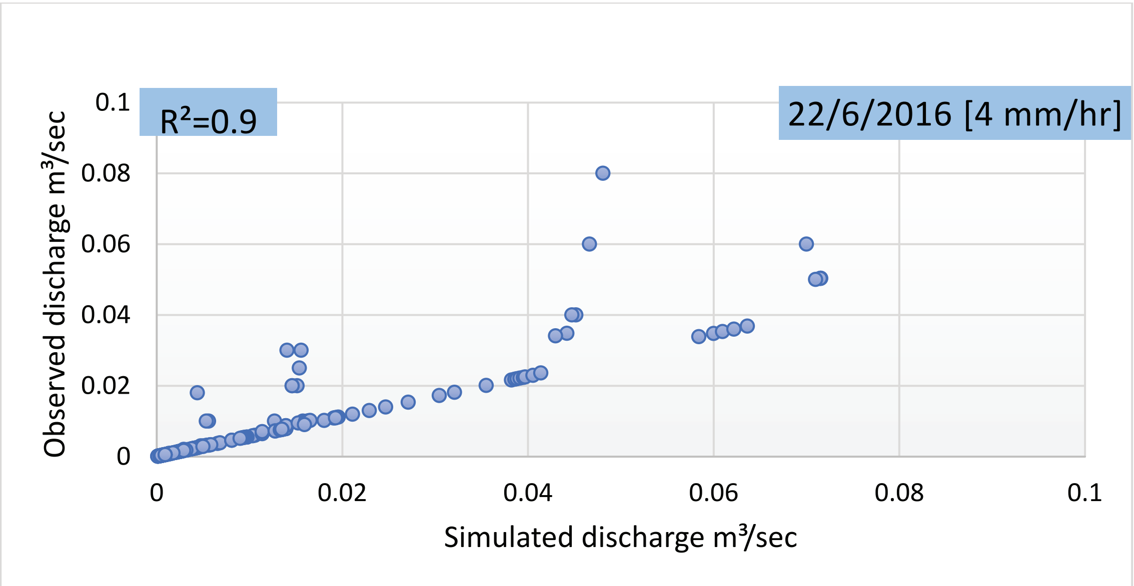


**Fig.4:** Results of the simulation model calibration in SWMM in [22/6/2016]

*4.2 The effect of the proposed solution*

The proposed solution is intended to mitigate the influence of flooding events in the study area. In this section, the proposal solution was thus assessed using SWMM, and the results used to make a comparison between the performance of the system in the current state and with the addition of the new proposal. The effects of the new solution under the maximum rainfall event observed in the study area, with a rainfall intensity of 33.54 mm/hr, is shown in figures 5 and 6.

Figures 5 and 6 show the difference in the percent of sewer holes flooding after adding the new pipeline proposal. The flooding discharge of the sewer holes is divided into five stages:

- Stage 1 [no flooding] ranging from 0 to 0.001 $m^3$/sec.
- Stage 2 [ very light flooding] ranging from greater than 0.001 to 0.01 $m^3$/sec,
- Stage 3 [medium flooding] ranging from greater than 0.01 to 0.02 $m^3$/sec,
- Stage 4 [ high flooding] ranging from greater than 0.02 to 0.04 $m^3$/sec,
- Stage 5 [ very high flooding] for greater than 0.04 $m^3$/sec.

Figure 5 shows the percentage of sewer holes flooding under the current case, with 48% flooding with discharge greater than 0.04 $m^3$/sec and 28% flooding within discharge from 0.02 to 0.04 $m^3$/sec.

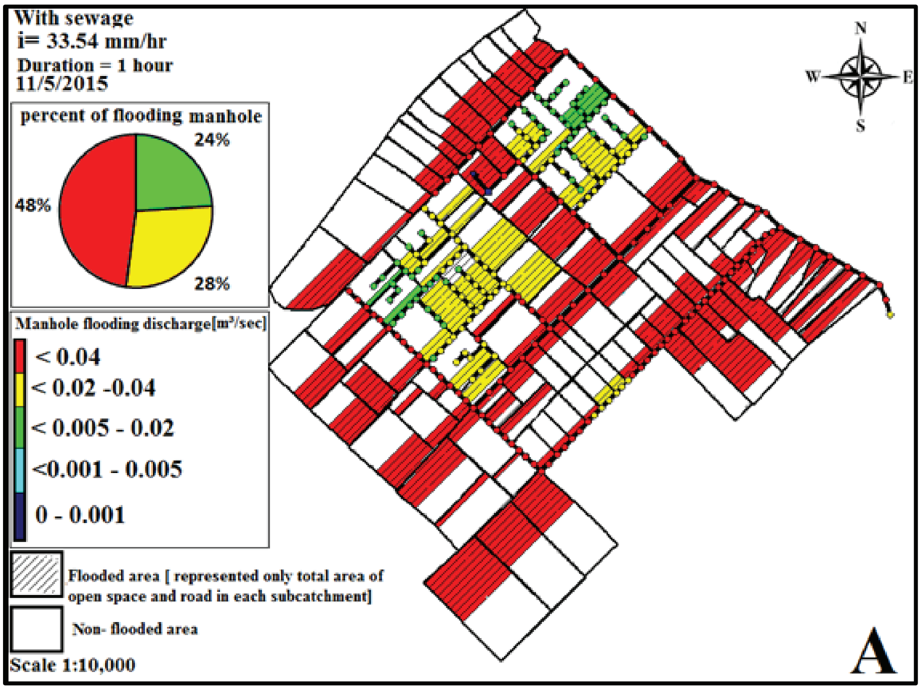


**Fig. 5:** The behaviour of storm drainage under current case with rainfall intensity of 33.54 mm/hr.

Figure 6 shows the effect of the proposed solution under the maximum rainfall intensity of 33.54 mm/hr; the percentage of flooding sewer holes with discharge greater than 0.04 $m^3$/sec decreases from 48% to 33%.

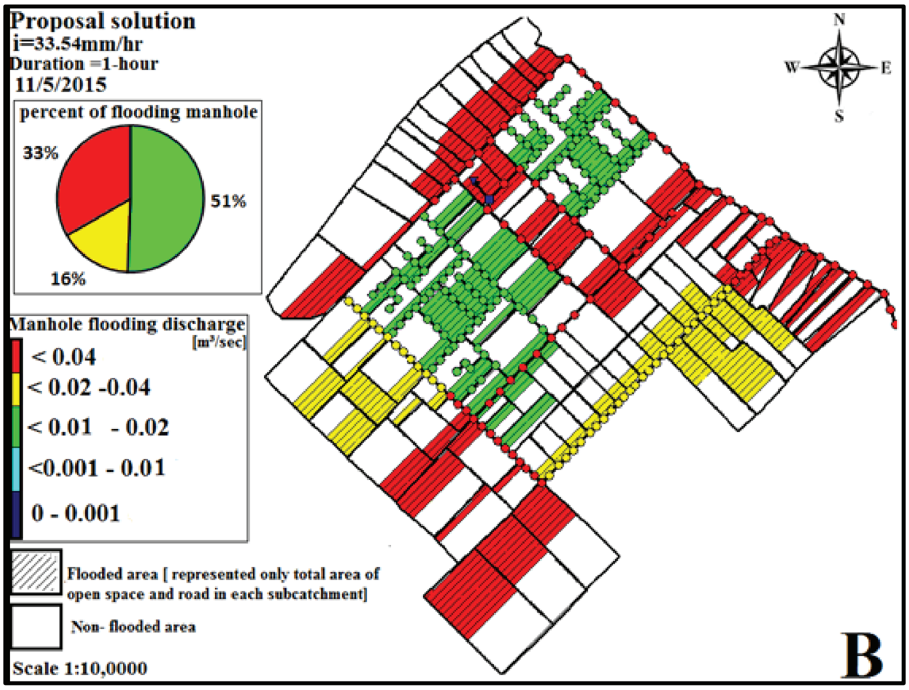


**Fig.6:** The behaviour of storm drainage under the proposed solution with rainfall intensity of 33.54 mm/hr.

The total flooding duration decreases from 72 hours to 26 hours with the new pipe line. Figure 7 shows the maximum water depth under rainfall intensity of 33.54 mm/hr for some selected sewer holes in both cases [current case and new pipeline case].

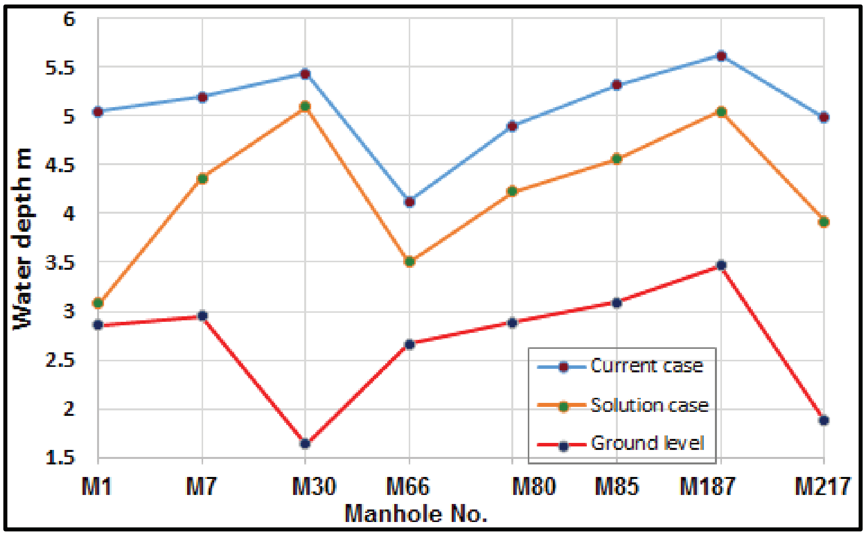


**Fig. 7**: Water depth in selected sewer holes[current case+proposed solution at 33.54 mm/hr rainfall).

Figure 7 shows a rapid decrease in the peak water depth at the selected sewer holes due to the new pipeline transmission solution. In M1, the water depth reduces from 5 m to 3.1 m, while in M7, the water depth decreases from 5.2 m to 4.4 m; the other samples show similar effects. For all other rainfall intensities, the results are as seen in table 3.

**TABLE 3.** SUMMARY OF THE RESULTS OF THE PROPOSED SOLUTION ON THE SYSTEM

The effect of the proposal solution

| Peak rainfall intensity mm/h | Duration of the storm | Percent of flooding manholes: Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Manhole no. | Max. water volume flooding m³ without solution | Max. water volume flooding m³ with solution | Max. depth of water flooding at the outlet without solution | Max. depth of water flooding with solution | Total flooding duration without solution at the outlet | Total flooding duration with solution at the outlet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.6 | 1-hour | 94% | 6% | 0 | 0 | 0 | M1 | 16.616 | 0 | 3.88 | 1.594 | 7-h | 3-h |
| | | | | | | | M7 | 9.166 | 0 | 3.52 | 2.152 | | |
| | | | | | | | M30 | 8.662 | 0 | 2.23 | 1.3 | | |
| | | | | | | | M66 | 5.576 | 0 | 3 | 2.4 | | |
| | | | | | | | M80 | 16.3 | 0 | 3.79 | 2.5 | | |
| | | | | | | | M85 | 18 | 0 | 3.8 | 2.85 | | |
| | | | | | | | M187 | 20 | 0 | 4 | 2.9 | | |
| | | | | | | | M217 | 17 | 11.03 | 3.32 | 2.591 | | |
| 12.8 | 1-hour | 77% | 9% | 14% | 0 | 0 | M1 | 71.84 | 0 | 3.74 | 1.994 | 12.5-h | 5-h |
| | | | | | | | M7 | 39.49 | 0 | 3.44 | 2.648 | | |
| | | | | | | | M30 | 60.5 | 37.3 | 2.47 | 2.148 | | |
| | | | | | | | M66 | 14.3 | 0 | 2.83 | 2.378 | | |
| | | | | | | | M80 | 66.84 | 23.37 | 3.63 | 3.138 | | |
| | | | | | | | M85 | 93.07 | 43.29 | 4.15 | 3.618 | | |
| | | | | | | | M187 | 105 | 67.53 | 5.3 | 4.295 | | |
| | | | | | | | M217 | 90.08 | 49.61 | 3.04 | 2.513 | | |
| 17.8 | 1-hour | 0% | 53% | 41% | 6% | 0% | M1 | 126.14 | 60 | 4.4 | 2.371 | 50-h | 10-h |
| | | | | | | | M7 | 99.48 | 12.38 | 4.2 | 3.105 | | |
| | | | | | | | M30 | 116.42 | 84.57 | 3.23 | 2.792 | | |
| | | | | | | | M66 | 71.73 | 9.71 | 3.53 | 2.777 | | |
| | | | | | | | M80 | 128.97 | 58.92 | 4.32 | 3.531 | | |
| | | | | | | | M85 | 110 | 72.04 | 4.78 | 3.968 | | |
| | | | | | | | M187 | 135.55 | 90.75 | 5.13 | 4.578 | | |
| | | | | | | | M217 | 120 | 85.81 | 4.22 | 2.975 | | |
| 33.5 | 1-hour | 0% | 0% | 51% | 16% | 33% | M1 | 179.24 | 80 | 5.05 | 3.08 | 70-h | 20-h |
| | | | | | | | M7 | 179.61 | 113.29 | 5.2 | 4.364 | | |
| | | | | | | | M30 | 278.41 | 253.46 | 5.44 | 5.093 | | |
| | | | | | | | M66 | 121.04 | 70.03 | 4.12 | 3.501 | | |
| | | | | | | | M80 | 181.25 | 122.02 | 4.9 | 4.228 | | |
| | | | | | | | M85 | 196.56 | 120.87 | 5.32 | 4.563 | | |
| | | | | | | | M187 | 175.12 | 129.2 | 5.62 | 5.048 | | |
| | | | | | | | M217 | 240.86 | 159.96 | 4.98 | 3.922 | | |

## 5. CONCLUSION

This study aimed to was assess the behaviour of the storm drainage network in the study area after adding an alternative solution to mitigate flooding events. This study concentrated on flooding control problems in the Middle East, particularly Iraq, where previous research in the field has been rare. SWMM was utilised to assess the storm drainage system in the Al-Esqari quarter, Karbala, Iraq, using this as a case study to fulfill the aims of the study. The model of the storm drainage network was designed for a 2-year return period with precipitation intensity of 9.6 mm/hr and 1-hr duration. The best solution to decrease the quantity and duration of flooding was found to be adding a pipeline with diameter of 900 mm and length of 344 m in the nourth east of the Al-Esqari quarter.The results of the study indicated that this solution mitigated the flooding under the maximum rainfall intensity such that the flooding duration decreased from 72 hours to 26 hours. This result provides technical support for decision makers seeking effective solutions to mitigate such flooding events.

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