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Topographic Effects on Stormwater Drainage Under Different Rainfall Intensities Case Study of Al-Najaf City

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Abstract

Flooding caused by stormwater drainage systems is a key issue in urban development that is influenced by land use, climate change, and topography. Simulation models, such as the Stormwater Management Model, can be used to accurately estimate flood problems (SWMM). This study calculated the effect of topography on the Al-Ameer District. In addition, the impacts of climate change (2, 5, 10, and 25 years) with topography slope of 0.5% to 0.4%, 0.3%, 0.2%, and 0.1%, and concentration-time (downstream and upstream) on the stormwater drainage system were evaluated using SWMM simulation. The results showed, during the return period of 2 years and a slope changed from 0.5% to 0.1%, the flood decreased 44%. During the return period of 5 years and a slope changed from 0.5% to 0.1%, the flood decreased 29%. During the return period of 10 and 25 years and a slope changed from 0.5% to 0.1%, the flood decreased 21%. A limited sub-catchment slope effect was inferred with a significant decrease in flooding, while a low sub-catchment slope had little effect on flooding in a return period of 10 and 25 years. Finally, the rise of the sub-catchment slope has resulted in a further increase in runoff, leading to flooding. The results also showed that the flood time occurs downstream before upstream, indicating that the downstream region suffers from topographic and design problems. This was demonstrated by flooding the manhole R315 before the manhole R15 because the slope of the sub-catchment in the opposite direction of the flow in the pipes, as well as the depth of the manhole, is shallow. In conclusion, as the locations and magnitude of the floods were determined, the system failed to

drain rainwater in some critical conditions. Also, designers should match the sub-catchment with the slopes of the network tubes to reduce flooding.

Keywords: Topography, SWMM simulation, Stormwater drainage system, Flooding, Al- Najaf, Rainfall intensity, Time of concentration.

1. Introduction

Urban floods have become a common threat to urban areas, causing loss of life and massive property damage, Urban growth generally causes hydraulic hazards, due to the sealing of natural surfaces and directing of the natural underground drainage network to the pipes, thus increasing surface runoff [1]. Infrastructure is adversely impacted by the flooding of storm systems in urban areas. Climate change increases the amount of runoff by increasing the intensity of rainfall, hence, it's the most significant parameter that influences the rate of flooding. Urban growth also increased urbanization and produced an increase in impermeable areas, which in turn reduced the rate of infiltration that causes the amount of runoff, peak flow, and concentration-time to increase[2]. Modelling for assessing urban floods relies on terrain and urban engineering. Urban surface features ranging from macro features (e.g. construction) to subtle features (e.g. sidewalks, etc.) have been included in flood modelling approaches for various purposes of urban hydrology and flood assessment[3]. However, the implications of using high-resolution data for urban drainage modelling further increase the acquisition of accurate results[4]. The effective drainage of the rain network has a powerful link with drain duration and concentration-time Sub-catchment that affects speed and peak runoff Releases. Besides, urbanization affects hydrology, which is characterized by the rise in peak flooding values. This triggers a rise in runoff volume and reduces the time lag. The stormwater management model (SWMM) has a lot of promise for generating important relationships between a lot of characteristics and the storm network's efficiency. The model is frequently used for planning, research, and design of drainage systems in urban areas [5]. Detailed and simplified topographical implementation affects the modelling of intense runoff, where the areas are characterized by steep slopes and slopes that suffer from an increase in the speed of the surface runoff, which leads to the lack of flow regularly entering the network. The investigation can address such a problem by collecting topographic data and high-resolution images from geographic information systems (GIS) before proceeding with the design of rain networks[6]. As a result, the primary objective of this study is to evaluate the network and determine the flood areas as a result of the topography and intensity of precipitation as a result of climate change on the performance of the rainwater drainage system. Second, this paper will use SWMM modeling to examine the current state of the rainwater drainage system in Al-Amir District, Najaf Governorate, Iraq.

2. Materials and Methods

2.1 Study Area

The governorate of Al-Najaf is located 165 km southwest of Baghdad, Iraq (32° 01' 33.38" N, 44° 20' 46.50" E). The climate is arid to semi-arid, with an average temperature of 24 degrees Celsius, annual rainfall of 99 mm evaporation of 3483 mm, average wind speed of 10 mm per hour, and humidity of 41% [6]. The study region of AL-Ameer District is located near the heart of Al-Najaf Governorate, as illustrated in Figure 1, with longitude and latitude (32 00 28 N and 44 21 51 E). The land is on a slope ranging from 46 to 40 meters above sea level. As indicated in Figure 2, the total area is approximately 1.64 km2, with 34% pervious surface and 66% impervious surface.

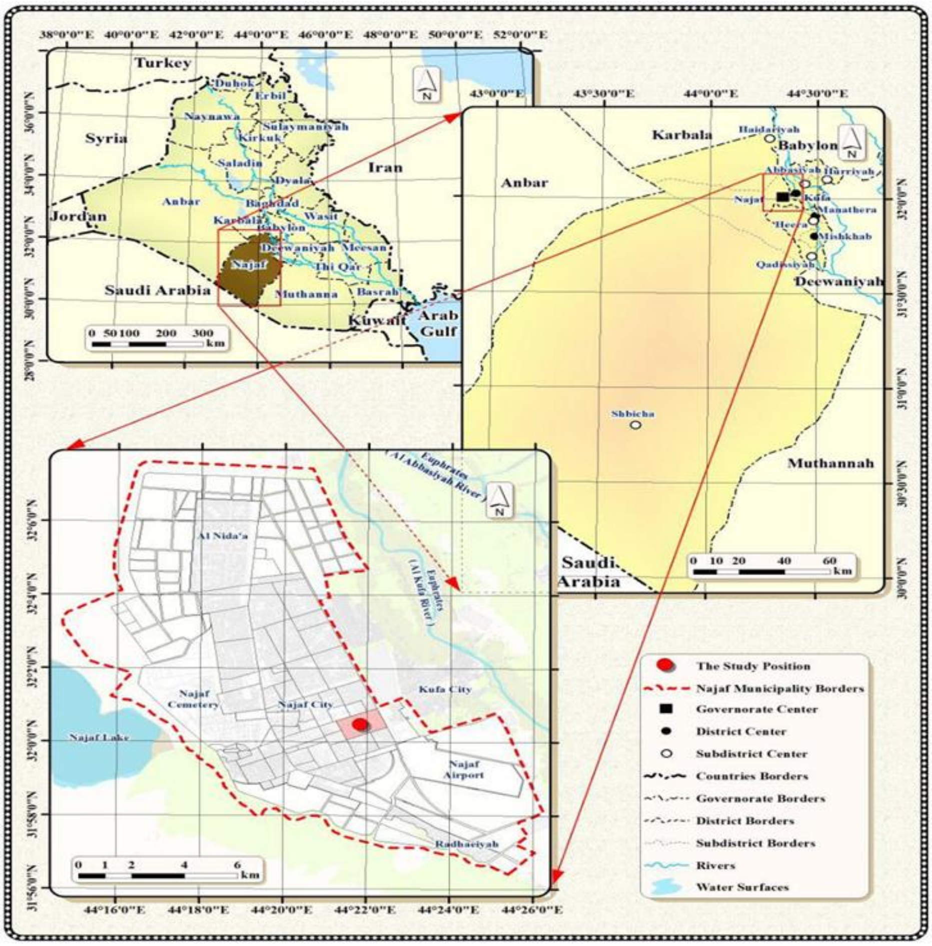

Figure1 Location of AL-Ameer in Al-Najaf, Iraq (Google map).

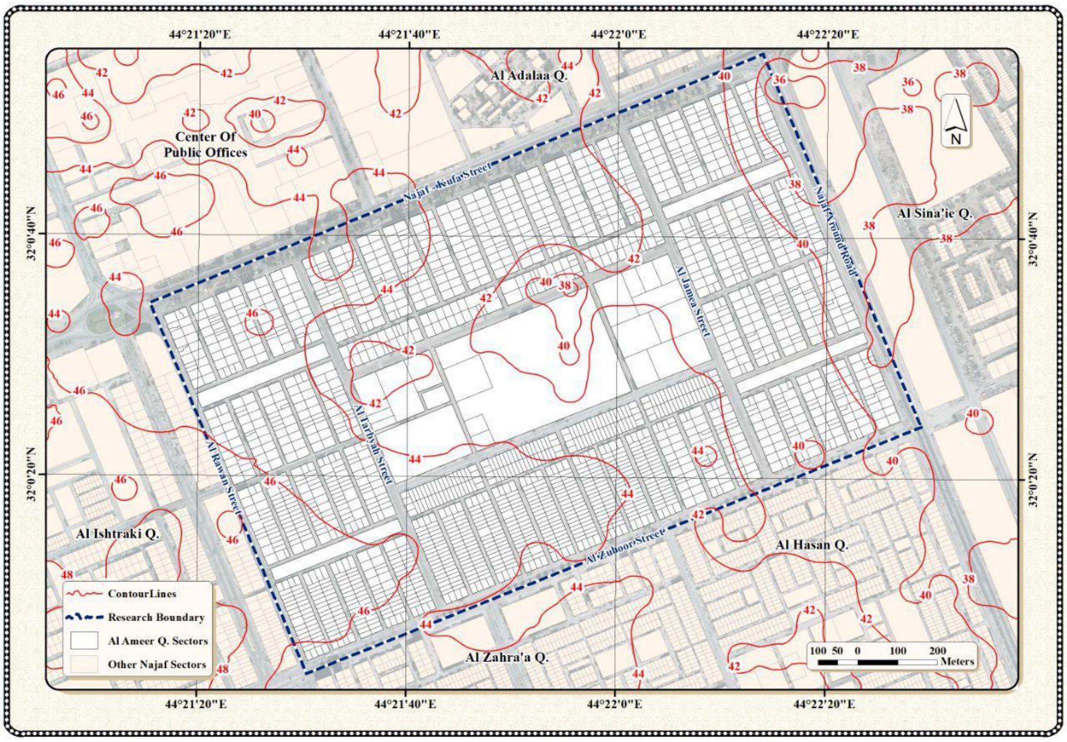

Figure 2 Topography of AL-Ameer District and surrounding areas (USGS website 2020).

2.1.1 Model Setup

USEPA's Stormwater Management Model (SWMM) V.5.1 was used to assess stormwater drainage system performance and determine flood points in the Prince. SWMM is a dynamic runoff simulation model used to simulate the quantity and quality of runoff from urban watersheds, discover flood areas, evaluate various rainwater management systems, and come up with cost-effective solutions for rainwater control. The study area was divided into 43 sub-catchments, with a total of 343 intersections and 343 pipelines, as shown in Figure 3. Each sub-catchment drains rainwater to the nearest intersection.

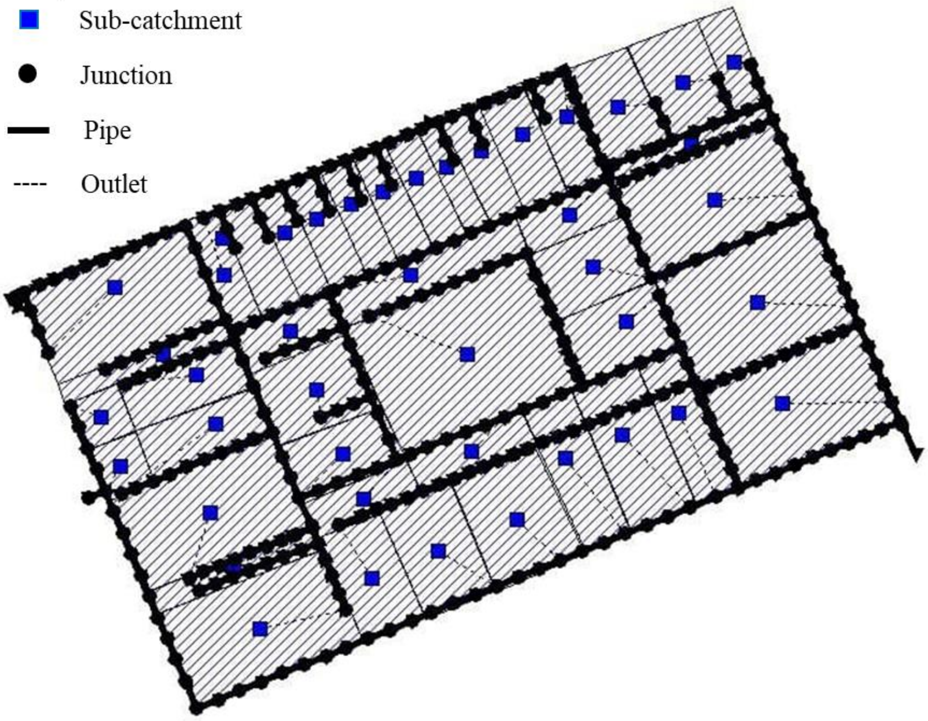

Figure 3 Network details of the study area.

2.1.2 Determination of Model Parameters

The total surface area of the catchment is 1.64 km2, with a 66 % impervious surface area and a 34 % pervious surface area for all sub-catchments combined. The slope of all sub-catchments was calculated in the field and was found to be roughly 0.5 %. Based on the characteristics of the studied location and the types of pips used in the system, Manning roughness coefficients were ranging from 0.013 to 0.009. The SWMM user's manual was used to compute the average width of sub-catchments and the depth of depression storage on impervious and pervious surfaces.

2.2 Scenarios Design

The illustration of the sub-catchment was compiled in Figure 3. The slope of the sub-catchment was realistically calculated for this study. Appropriate data consists of advanced information with increasing levels of complexity, ranging from terrain modelling to hydraulic data. Here different inclinations of 0.5, 0.4, 0.3, 0.2, and 0.1% are used, with the slope fixed in the tubes, during the return period of 25, 10, 5, and 2 years for a specified 2 hour period. To counter static feedback with dynamic results, three flood-experiencing manholes were also selected to determine the time of the flood. The first is located upstream (R15) while the second is in the center of the study area (R250), and the third is downstream (R315). At a return period of 10 years, the network was analyzed using SWMM simulation.

3. Results and Discussion

3.1 Effect of Topography on Stormwater Drainage System

To study the effect of the topography presented by sub-catchment slope on the stormwater drainage system in the AL-Ameer region, different proportions of sub-catchment slopes contributing to the runoff were taken into consideration. At two hours of rainfall duration, different rainfall intensities at a return period of 2, 5, 10, and 25 years were selected and the slope of sub-catchments was changed from 0.5% to 0.4%, 0.3%, 0.2%, and 0.1%. The results of topography effects at different rerun periods on flooding are shown in Figure 4. In general, the inclination has increased flooding in the study area. Reducing the slope of the sub-catchments, with no change in the slope of the designed pipes, has reduced flooding. At the return period of 2 years, the total flood volumes were 5914 m3 and 3309 m3 for slopes of 0.5% and 0.1%, respectively. This indicates that the volume of flooding decreased by 44 % then the slope decreased. At the return period of 5 years, the total flood volumes were 17591 m3 and 12513 m3 for slopes of 0.5% and 0.1%, respectively. This indicates that the volume of flooding decreased by 29% then the slope decreased. At the return period of 10 years, the total flood volumes were 26032 m3 and 20477 m3 for slopes of 0.5% and 0.1%, respectively. This indicates that the volume of flooding decreased by 21 % then the slope decreased. At the return period of 25 years, the total flood volumes were 41230 m3 and 32512 m3 for slopes of 0.5% and 0.1%, respectively. This indicates that the volume of flooding decreased by 21% when the slope decreased. In general, the sub-catchment slope positively affects the flooding at all rainfall intensities but had less at low rainfall intensities. In 2 years return period, the effect of sub-catchment slope was limited to high flood reduction, whereas low sub-catchment slope had a little effect on flooding at a return period of 10 and 25 years. Finally, it is noted that a high sub-catchment slope leads to a further increase in surface runoff, resulting in flooding. Therefore, the designers must match the sub-catchment with network pipe slops to reduce floods. Similarly,[6] recommended that detailed information on topography is needed to come out with the best design. Also, the topography is an essential parameter that must be used and depending on. It is also well known that topography must be already taken into consideration in the design of the network of the drainage system.

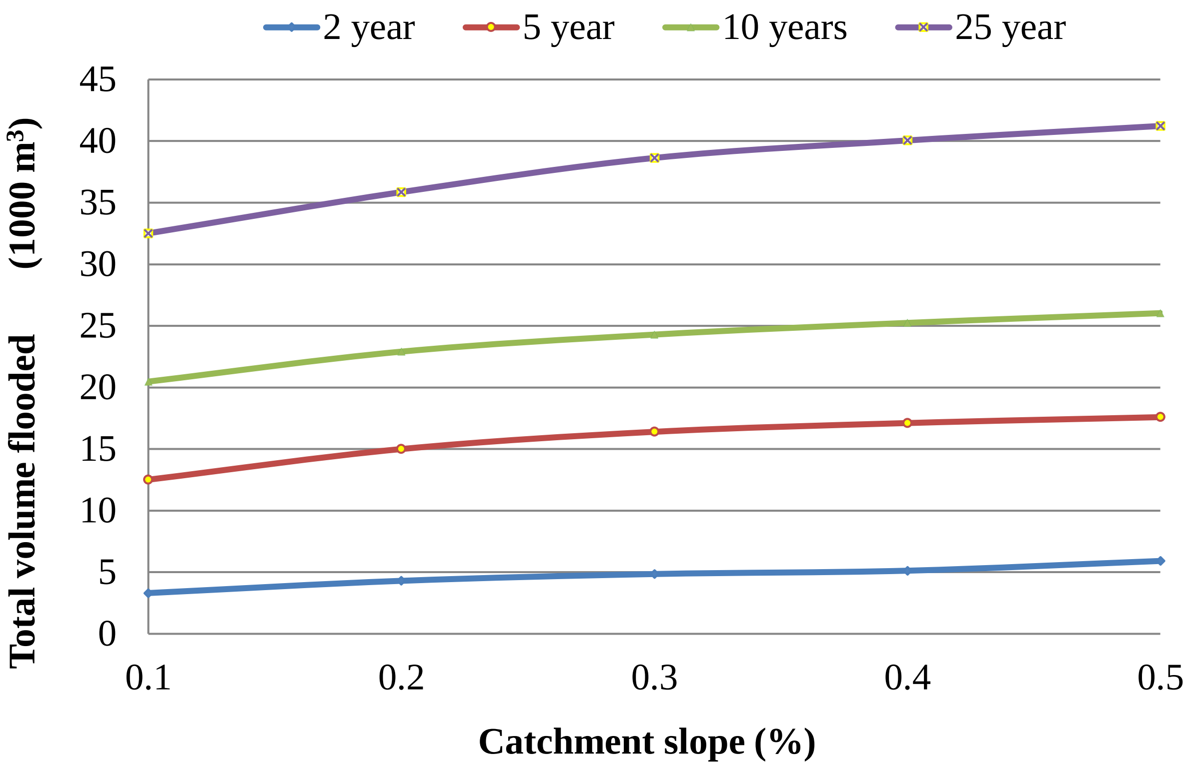

Figure 4 Effect topography on AL-Ameer district stormwater drainage system at different slopes of 0.5, 0.4, 0.3, 0.2, and 0.1%, and 2, 5, 10 and 25 years of the return period.

3.2 Effect of Concentration Time on Stormwater Drainage System

Time of concentration is commonly used in hydraulic flood flow design, precisely estimated peak discharge, and flood hydrograph. Three flood-experiencing manholes were selected to determine the time of the flood. The first is located upstream (R15) while the second is in the center of the study area (R250). The third is downstream (R315). At the return period of 10 years, Figure 5 shows that the maximum flood occurs downstream in manhole R315 after 20 minutes, upstream in manhole R15 after 25 minutes, and study area center in manhole R250 after 20 minutes and reaches a maximum after one hour. These results showed that the flood time occurs downstream before the upstream, indicating that the downstream area suffers from topographical and design problems.

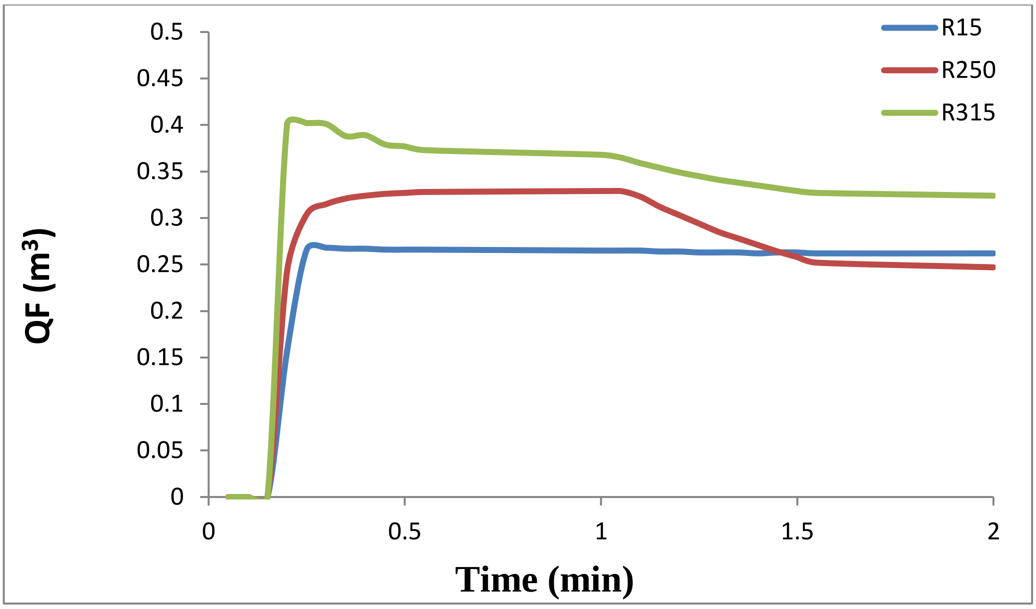

Figure 5 Effect of time concentration on AL-Ameer District stormwater drainage system.

To explain why manhole R315 flooded before manhole R15, Figure 6 shows the slope of the sub-catchments is in opposite direction to the direction of flow in pipes, as well as, the depth of the manhole is short. To reduce concentration-time, open channels barriers can be implemented along the width of the street with dimensions and numbers estimated according to the flood volume and flow velocity. Similarly, [7] utilized permeable pavement to reduce part of the peak runoff and delay flood peak time. Permeable pavement will allow the infiltration of stormwater, reducing the surface runoff.

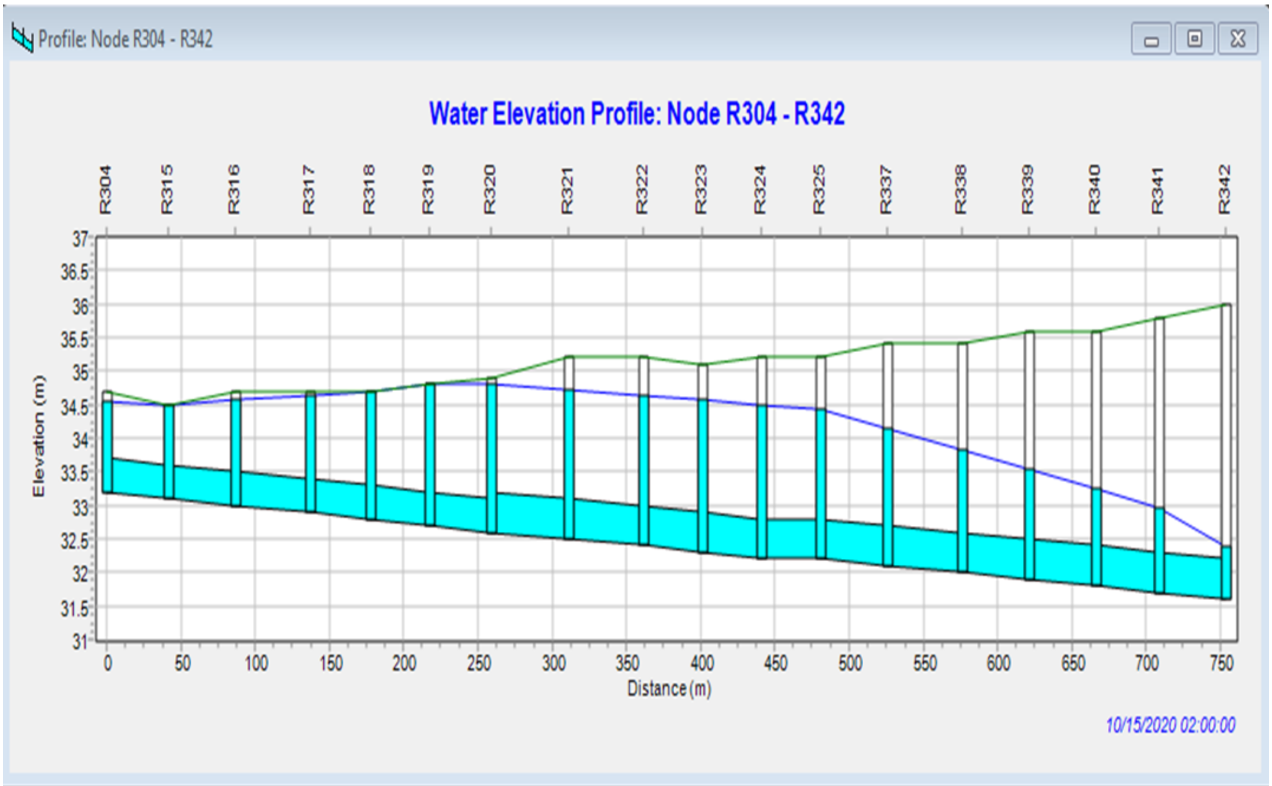

Figure 6 Downstream sewers in AL-Ameer District and depth of water in Manholes.

4. Conclusion and suggested scenarios

SWMM is a powerful tool for flood identification. The sub-catchment slope had a positive effect on flooding at all precipitation intensities. In the two-year return period, the impact of the sub-catchment slope was limited with a significant decrease in flooding, while the low sub-catchment slope had little effect on flooding in the 10- to 25-year return period. Finally, it is observed that the higher slope of the sub-catchment the increased runoff, which leads to flooding. Therefore, designers must match the sub-catchment with the slopes of the network pipes to reduce flooding. When checking the flooding time, it was noted that the manhole R315 was flooded before the manhole R15 because the slope of the sub-catchment is in the opposite direction to the direction of flow in the pipes, as well as the depth of the manhole Short. To provide more discharge after the submerged nozzle (R315), the transmission line can be redesigned by changing the pipe diameter. This change can be considered as a solution scenario to completely solve the flood problem in the rainwater drainage system in the sub-catchment area.

Appendix

Table 1 The rainfall intensity is converted to mm/hr.

Return Period (Years)	Rainfall Intensity (mm\hr)					
	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

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التأثيرات الطبوغرافية على تصريف مياه الأمطار تحت شدة هطول الأمطار المختلفة: دراسة حالة لمدينة النجف

الخلاصة *تعتبر الفيضانات التي تسببها أنظمة تصريف مياه الأمطار قضية رئيسية في التنمية الحضرية التي تتأثر باستخدام الأراضي وتغير المناخ والتضاريس. يمكن استخدام نماذج المحاكاة ، مثل نموذج إدارة مياه الأمطار(SWMM) ، لتقدير مشاكل الفيضانات بدقة. حسبت هذه الدراسة تأثير التضاريس على منطقة الأمير. بالإضافة إلى ذلك ، فإن تأثيرات تغير المناخ (2 ، 5 ، 10 ، 25 سنة) مع منحدر تضاريس من 0.5٪ إلى 0.4٪ ، 0.3٪ ، 0.2٪ ، و 0.1٪ ، ووقت التركيز في upstream وفي downstream على تم تقييم نظام تصريف مياه الأمطار باستخدام محاكاة SWMM. وأظهرت النتائج أنه خلال فترة العودة البالغة عامين وتغير المنحدر من 0.5٪ إلى 0.1٪ ، انخفض الفيضان بنسبة 44٪. خلال فترة العودة لمدة 5 سنوات وتغير المنحدر من 0.5٪ إلى 0.1٪ ، انخفض الفيضان بنسبة 29٪. خلال فترة العودة 10 و 25 سنة وتغير المنحدر من 0.5٪ إلى 0.1٪ ، انخفض الفيضان بنسبة 21٪. تم الاستدلال على تأثير منحدرات مستجمعات المياه الفرعية المحدود مع انخفاض كبير في الفيضانات ، بينما كان للانحدار المنخفض للمستجمعات الفرعية تأثير ضئيل على الفيضانات في فترة عودة تبلغ 10 و 25 عامًا. أخيرًا ، أدى ارتفاع منحدر مستجمعات المياه الفرعية إلى زيادة سرعة الجريان السطحي ، مما أدى إلى حدوث فيضانات. أظهرت النتائج أيضًا أن وقت الفيضان يحدث في downstream قبل upstream ، مما يشير إلى أن منطقة downstream تعاني من مشاكل طبوغرافية وتصميمية. وقد تجلى ذلك من خلال فيضان المانهول R315 قبل المانهول R15 لأن منحدر المستجمع الفرعي في الاتجاه المعاكس للتدفق في الأنابيب ، وكذلك عمق المانهول قليل. في الختام ، نظرًا لتحديد مواقع وحجم الفيضانات ، فشل النظام في تصريف مياه الأمطار في بعض الظروف الحرجة. أيضًا ، يجب على المصممين مطابقة المستجمعات الفرعية مع منحدرات أنابيب الشبكة لتقليل الفيضانات.*