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ESTIMATION OF STORMWATER RUNOFF GENERATED IN BASRAH PROVINCE ROADS FOR DIFFERENT RAINFALL RECURRENCE INTERVALS

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ABSTRACT

The main objective of this research is to estimate the surface runoff which is generated by rainfall for a residential area in Basrah Province, south of Iraq for different recurrence intervals of rainfall. The depth of runoff is based on changing of rainfall intensity when it exceeding the rainfall intensity of 17 mm / hr (the approved value in the design of the stormwater network in the area under consideration). Two common probability techniques (Weibull and Gamma distribution) were used for developing the relationship between annual maximum rainfall intensity and recurrence intervals. Weibull and Gamma probability distribution passed the Chi-squared test for degree of freedom equaled to three. EPA Storm Water Management Model (SWMM) is used for simulating a rainfall –runoff routing process. Modified Green-Ampt method is used to describe the infiltration of water into the soil. Kinematic wave routing is used for routing flows through drainage system. The recurrence intervals have been used for estimating of surface runoff are ranged from 5 to 50 years with increment is equaled to 5 years. The depth of runoff is ranged from 16.2 mm for recurrence interval (5 years) to 29.6 mm for recurrence interval (50 years); these values are related to storm with duration is equaled to one hour, while it is ranged from 49.5 mm to 101.6mm for storm duration of three hours.

Key words: Stormwater, Runoff, Recurrence interval, Weibull, Gamma, Basrah Province

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1. INTRODUCTION

When the rain falls to the ground, it begins to move according to the laws of gravity. A portion of the rain infiltrates to the underground for replenishing groundwater. Most of the rainfall flow down as runoff. Surface runoff is likely to cause a series of impacts on real estate and road operations, such as flooding of neighboring properties, erosion of road surfaces and failure of paving layers, or blockage of vehicles and traffic due to surface runoff. The main risk factor for road runoff is traffic density because this is the main driver of vehicle-derived pollutants. While traffic volumes are a major feature, the degree of traffic congestion and road characteristics have a strong impact on vehicle emission rates, and therefore polluted loads in runoff. Roads that have the same traffic flows but properties of different roads have been found to significantly generate different polluted loads in runoff.

Overland flow is the main reason for causing the surface erosion in the roads. The specific weight of water is produced the power of overland flow. The depth of flow and the slope of energy are important parameters for controlling the erosion amount and deposition (Hairsine and Rose 1992a, 1992b). Water erosion is the important environmental problem in many parts of the plant (Smith et al, 2003). Erosion produce very dangerous conditions on roads, it can cause depression on pedestrian and vehicles routes, increasing the risk of injury and death (Pineo and Barton, 2009). The continuous problem of the groove on the roads, the sculpture of the bridges and the swelling of the subgrade and sub-base layers due to uncontrolled runoff intrusion to the pavement foundation, where all these causes exacerbate the problem of road.

Runoff has great effects on asphalt pavement performance. There is a global interest for detecting the extent of damage caused by moisture to asphalt streets. Moisture damage can be defined as loss of strength and durability in asphalt mixtures resulting from the water. The existence of water in the road pavement is mainly due to the leakage of water across the pavement and shoulders surfaces. Where the presence of water on the surface of the roads for long time coincided with cracks in the surface of the pavements and shoulders are the main reason for the infiltration of water inside the asphalt layer (Dawson and Hill, 1998).

Drainage system is designed to reduce and / or eliminate energy produced from water flow. Therefore, water must not be allowed to generate sufficient velocity and volume for causing excessive erosion along the trenches, under the sewers, or along exposed surfaces. The presence of excess water or moisture in the road will negatively affect the engineering characteristics of the materials that have been constructed. The design of drainage structures depends on hydrology and hydraulics. The hydrology science deals with the occurrence and form of water in the natural environment (rainfall, runoff, soil moisture, etc.) while the latter deals with the engineering characteristics of fluids. The diameter size of any drainage system pipe shall be determined according to the occurrence probability of peak discharge during the design life of the construction. This, of course, is based on the duration and intensity of rainfall events that occur. In this study, the surface runoff which is generated by rainfall over the road surface for a residential area in Basrah Province, south of Iraq was calculated for different rainfall recurrence intervals. The depth of runoff is based on changing of rainfall intensity when it exceeding the rainfall intensity that used in the design of stormwater networks in Basrah Province which is equaled to (17 mm / hr).

2. STUDY AREA AND DATA SET

Basrah Province lies in southern Iraq, it bordered by Kuwait to the south and Iran to the east. Basrah City is located on the Shatt Al-Arab River. Shatt Al-Arab River about 200 km long, it is formed by the confluence of the Euphrates and the Tigris River in Qurna (north of Basrah City). At the lower end of the river forms the border between Iraq and Iran and continuous to flow until it reaches the mouth of the river as it flows into the Arabian Gulf. Its population was estimated at 2.5 million in 2012 (Bara city profile, 2017). Basrah is the main port of Iraq, although it has no access to deep water, which is traded at the port of Umm Qasr. Basrah's climate in summer is very hot like the rest of its surrounding area, although it has slightly more rainfall than other vicinity area due to its location near the Arabian Gulf. During the summer season, Basrah is one of the hottest cities, with temperatures (through July and August) exceeding 50 °C. In the winter season, Basrah is experiencing moderate weather with average maximum temperatures not higher than 25 °C. In some cold winter nights, the minimum temperatures are lower than 0 ° C. It has high humidity especially when the wind direction is southeastern; sometimes reaching higher than 90%, where it has this property due to it is very close to the Arabian Gulf. Values of Rainfall intensity (mm/hr) for duration of 60 minutes during (1971-2000) are obtained from meteorological recording station in Basrah City. A statistical summary for annual maximum values of rainfall intensity is presented in Table 1. The frequency distribution of rainfall intensity values at the observed period in the study area is shown in Fig. 1. The range of highest frequent value of rainfall intensity is from 10 mm/hr to 15 mm/hr. A new residential area lies in the west of Basrah Province, adjacent to the Shatt Al-Basra Canal (Fig. 2) with total area equal to 0.52 Km2 and total number of houses (1920 house), has been identified as case study for determining the surface runoff in its roads according to different rainfall recurrence intervals.

Table 1 Statistical summary of the annual maximum rainfall intensity during (1971-2000).

Statistic	Value	Percentile	Value
Size of sample	30	Min	0
Range	53.5	5%	0.22
Mean	15.57	10%	3.79
Variance	136.56	25% (Q1)	9.2
Standard Deviation	11.686	50% (Median)	12.05
Coefficient of Variation	0.75055	75% (Q3)	20.8
Standard Error	2.1336	90%	35.05
Skewness	1.4973	95%	43.545
Excess Kurtosis	2.6923	Max	53.5

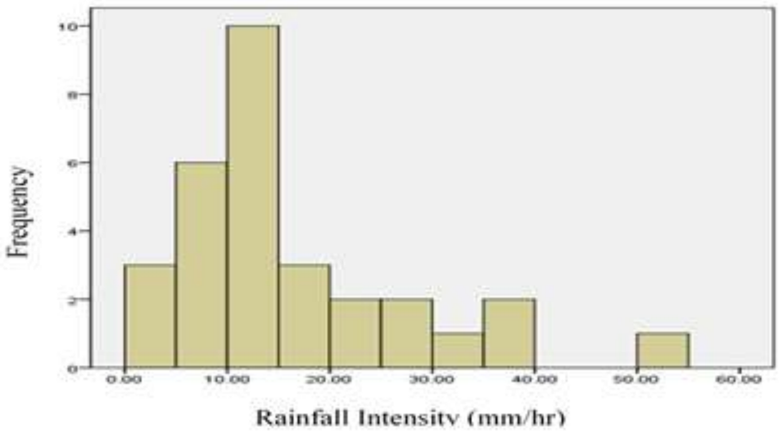

Figure 1 Frequency distribution of the annual maximum rainfall intensity during (1971-2000).

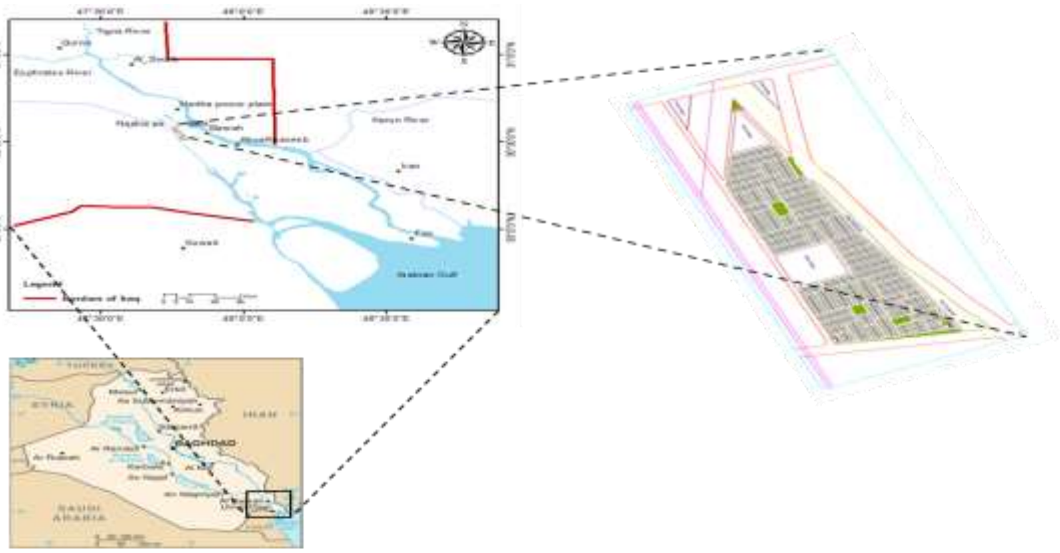

Figure 2 Location of study area in reference to Basrah and Iraq map.

3. METHODOLOGY

The intensity, duration and frequency of rainfall for an area can be used for describing the properties of rainfall for the various storms occurring in this area (Koutsoyiannis et al, 1988, Bougadis and Adamowski, 2006, Mohymont et al, 2004). A mathematical function can be used for determining the style probability distribution of an event that occurring at a particular recurrence interval. EasyFit 5.6 is applied for representing the probability distribution of rainfall intensity in Basrah Province. EasyFit software is used for data analysis and for fitting the probability distributions of data samples, selection of the best model, and application of analysis results for better decisions. Two common probability techniques (Weibull and Gamma distribution) were used for developing the relationship between annual maximum rainfall intensity and recurrence intervals in the studied area. The Weibull distribution is one of the most widely used lifetime distributions in reliability engineering. It is a multi-faceted distribution; it can describe the characteristics of other types of distributions according to the value of the continuous shape parameter (α). The probability density function for two parameters Weibull distribution is presented in the following equations:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right) \quad (1)$$

Where:

α : continuous shape parameter ($\alpha > 0$)

β : continuous scale parameter ($\beta > 0$)

Cumulative distribution function is expressed by following equation

$$F(x) = 1 - \exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right) \quad (2)$$

Two parameters Gamma distribution is used here for representing the relationship between the rainfall intensity and its probability, this expression is presented as follow:

$$f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} \exp\left(-\frac{x}{\beta}\right) \quad (3)$$

Where:

α : continuous shape parameter ($\alpha > 0$)

β : continuous scale parameter ($\beta > 0$)

Where cumulative distribution function is presented by following equation:

$$F(x) = \frac{\Gamma_{\frac{x}{\beta}}(\alpha)}{\Gamma(\alpha)} \quad (4)$$

Where:

Γ is Gamma function.

$$\Gamma(\alpha) = \int_0^\infty e^{-x} x^{\alpha-1} dx \quad (5)$$

The Chi-Squared test is used here for representing whether the sample is taken from a specific probability distribution and determine the appropriateness of this distribution for rainfall intensity data in the studied area. The following empirical formula is used by EasyFit:

$$K = 1 + log_2 N \quad (6)$$

Where:

K : Number of bins

N : Sample size

Data can be grouped into equaled probability intervals or equaled width. The first approach is generally acceptable because it deals with peaked data better than second approach. Each bin must have at least 5 or more data points, so some neighboring bins sometimes need to be joined with each other until these conditions are met.

The Chi-Squared statistic is expressed as follow:

$$X^2 = \sum_i^k \frac{(O_i - E_i)^2}{E_i} \quad (7)$$

Where

O_i: is the observed frequency for bin i, and E_i is the estimated frequency for bin i determined by

$$E_i = F(x_2) - F(x_1) \quad (8)$$

Where

F : the cumulative distribution function of the probability distribution being tested, and x_1, x_2 are the limits for bin i.

The hypothesis of the distributional form is rejected at the selected significance level (α) if the test statistic is greater than the specified critical value which can be defined as:

$$X^2_{1-\alpha,k-1}$$

Meaning the Chi-Squared inverse cumulative distribution function with $k-1$ degrees of freedom and a significance level of (α). A value of (α) is equaled to 0.05 is typically used for most applications.

The nature of soil in Basrah City is soft and comprises of large amount of fine clay. For these purposes the project needs special consideration during the design of the stormwater system. The stormwater network for the residential area is designed according to the following points:

- A layout plan of the whole area should be drawn to a scale of 1/2500 or smaller according to the size of the proposed scheme.
- The surface area elevation of this residential area is considered at average elevation of 4 m above the mean sea level.
- In the present study, the value of rainfall intensity is selected to be 17 mm/hr (the approved value in the design of the stormwater network in the province of Basrah).

- The value of runoff coefficient is selected to be 0.85 (Asphaltic pavement in good condition).
- The rational method is usually used to compute the runoff rate. This method uses the following relation:

$$Q = CiA \quad (9)$$

Where Q is total runoff in (m^3/sec); i is intensity of rainfall (=17 mm/hr); A is the area contributing to runoff; C is factor of imperviousness.

- Assume that the flow reached to the sewer pipe is the half-full sewer.
- For a pipe with full flow, the flow rate is equal to twice that in a half-full sewer. The full flow rates of the sewers are used because of the pipe size on the basis that it is filled with liquid.
- The equation of pipe slope (S = (Ei – Eo)/ L), where Ei and Eo: the elevation of the inlet and the outlet above the site datum respectively; L: pipe length from inlet to outlet.
- The Manning formula is used for determining the diameter of sewer pipes:

$$v=(1/n)R^{2/3}S^{1/2} \quad (10)$$

Where:

v: flow velocity; n: a factor that is related for roughness of the pipe; R: hydraulic radius; S: slop of pipe.

- The determination of the full-flow capacity of sewer is performed by using Nomogram figure.
- By figure of hydraulic elements of circular pipe with ratio of half-flow capacity to full-flow capacity, the depth-of-flow ratio is calculated.
- The velocity ratio is obtained, then, the liquid velocity when flowing half-full is the product of the velocity ratio and velocity of full-flow rate.
- The flow velocity of stormwater sewer is higher than the flow velocity of sanitary sewers due to sand and gravel drift with runoff into the pipes. The velocity equal to (0.80 m/s) is used as a usual minimum allowable velocity for above purpose. The liquid velocity should not exceed (2.44 m/s) to prevent excessive wear.

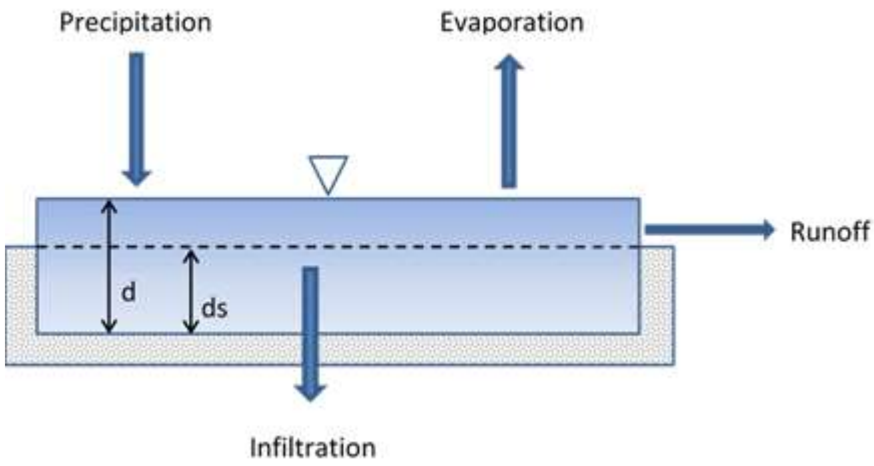

Figure 3 Conceptual view of surface runoff.

In the present research, the EPA Storm Water Management Model (SWMM) is used for simulating a dynamic rainfall –runoff routing model. The SWMM system tracks the quality and quantity of the flow generated in each subcatchment, flow depth, flow rate, in pipe and channel during a simulated period consisting of several time steps. Fig. 3 shows the conceptual presentation of surface runoff used by SWMM. The subcatcment area is presented as a non-linear reservoir. Rainfall is represented as inflow and any of the specified upstream. There are many outflows, such as, evaporation, infiltration and runoff. The maximum depression storage (surface wetting, interception, and ponding) is represented the capacity of the reservoir. Q (runoff per unit area) occurs when the water depth is higher than maximum storage, ds, the outflow is determined by using Manning's equation. By using water balance equation, the overland flow (d) is continuously updated.

There are many models available to describe the infiltration of water into the soil, among the best of those methods is Green-Ampt equation (Green and Ampt 1911) and its various modifications (Ahuja and Ross 1983; Gowdish and Munoz-Carpena 2009; Voller 2011). The basic concept of the Green-Ampt model is related to the assumption that the surface of ground is ponded by water where it is fully saturated, and the soil infiltration capacity is equal to the actual infiltration rate at all times. Modified Green-Ampt method is used in the present study. According to this method, the moisture of upper soil layer is not depleting during the low rainfall periods as was done in Green-Ampt approach. This modification can yield a more realistic behavior of infiltration for long initial periods of storm when intensity of rainfall is less than the saturated hydraulic conductivity of soil.

Kinematic wave routing is used in this research for routing flows through drainage system. Although this type of approach cannot account for backwater effects, loss of entry / exit, flow reversal, or compressed flow, it is also constrained by dendritic network layouts. It can maintain numerical stability for fairly large time steps (1 to 5 minutes). If the above effects are not expected to be significant, this alternative can be a precise and effective approach, especially for long-term simulations.

4. RESULTS AND DISCUSSION

The rainfall intensity has greatly effect on the characteristics of the hydrological system, and these effects may be very different in small and large spatial scales. There is clear difference in the values of rainfall intensity from time to another depending on the length of the observation period. Rainfall intensity (mm/hr) values for duration of 60 minutes during the period (1971-2000) are obtained from meteorological recording station in Basrah City. The average value is equaled to (15.57), while the standard deviation value is relatively high. The high standard deviation indicates that data points are distributed over a wider range from average value. Because of the large variability in rainfall intensity values in the study area, the design of hydraulic structures and drainage systems should be based not only on monitoring rainfall values for long periods but also on rainfall values for a given probability or return periods. The rainfall intensity probability (P) (for recurrence interval T) is calculated by the following equation.

$$P = \frac{1}{T} \times 100\% \qquad (11)$$

Two common probability techniques (Weibull and Gamma distribution) were used for developing the relationship between annual maximum rainfall intensity and recurrence intervals. The continuous shape parameter and continuous scale parameter of Weibull and Gamma probability distribution are presented in Table (2). The probability density functions of Weibull and Gamma probability distribution are shown in Fig. 4 and Fig. 5 respectively. The highest probability values for both distributions of rainfall intensity are less than 10 mm/hr.

Table 2 Shape and scale parameters of Weibull and Gamma probability distribution.

Probability method	α	β
Weibull	1.483417	17.825
Gamma	1.9665	8.1906

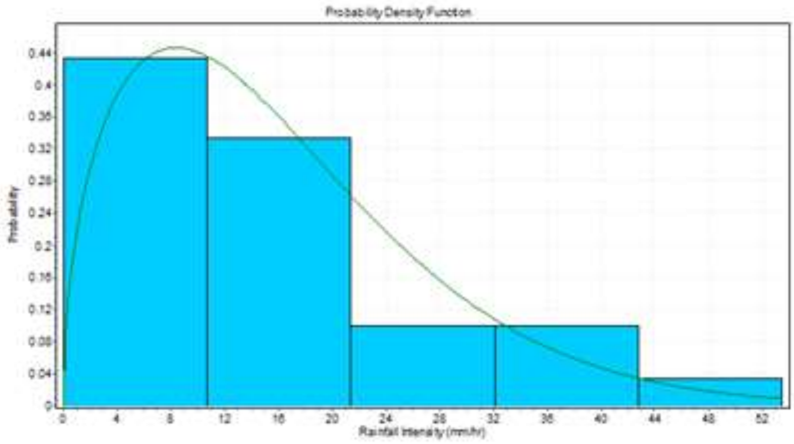

Figure 4 Probability density functions of Weibull distribution.

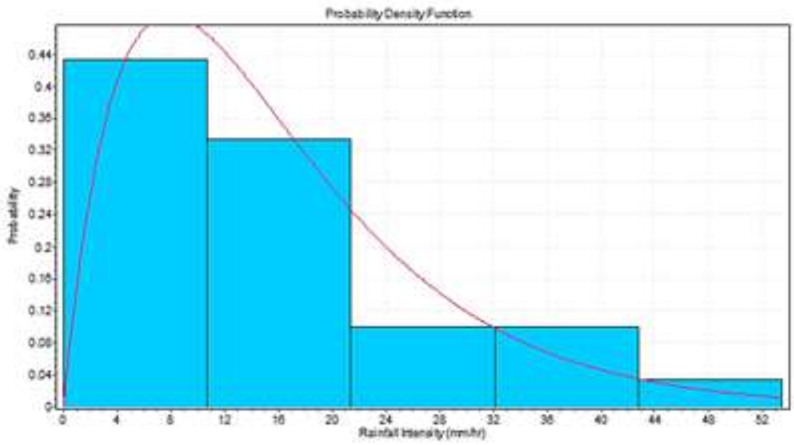

Figure 5 Probability density functions of Gamma distribution.

The rainfall intensity (mm/hr) for different recurrence intervals based on the probability distributions is shown in Table (3). The Chi-squared method was used to check the appropriateness of probability distribution. When the Chi-squared value is lower than the tabulated value, in this case, the theoretical probability distribution is accepted with $k-1$ degrees of freedom and a significance level of (α), (1-α) is a confidence level, typically 95% is usually chosen as the confidence limit. At the selected significance level (α), the distributional form hypothesis is rejected when the statistic test is greater than the specified critical value. The results of Chi-squared test are shown in Table 4.

Table 3 Rainfall intensity (mm/hr) for different recurrence intervals.

T	P	Weibull distribution	Gamma distribution
5	0.2	24.2	23.4
10	0.1	32.3	31.4
15	0.067	37.4	35.8
20	0.05	38.9	38.7
25	0.04	40.9	41.0
30	0.033	42.6	42.9
35	0.029	43.8	44.5
40	0.025	45.0	45.7
45	0.022	46.0	46.9
50	0.02	46.9	47.9

Table 4 Results of Chi-squared index for degree of freedom equaled to 3.

α	0.2	0.1	0.05	0.02	0.01
Critical value	4.6416	6.2514	7.8374	9.8375	11.345
Reject? (Weibull)	No	No	No	No	No
Reject? (Gamma)	No	No	No	No	No

Pipe diameters are designed by using rainfall intensity equaled to 17 mm/hr (the approved value in the design of the stormwater network in Basrah Province). It was selected HDPE pipes with Manning's coefficient is equaled to 0.011. The minimum laying depth of 1.10 m for diameter of pipe equaled to 203mm. The layer depth for different size of pipes ranged from 1.10m to 2.85m, while the minimum grade ranged from 0.41% to 0.10% for minimum velocity equal to (0.80 m/s). The useful life of HDPE pipes is estimated about 40-50 years (cited in Fortunato et al. 2014). 50 years is used here in this study. The recurrence intervals (T) have been used for estimating of stormwater runoff generated in Basrah Province roads are ranged from 5 to 50 years with increment is equaled to 5 years. The choice of the maximum value for the recurrence interval equal to 50 years is appropriate to the useful life of the rainfall drainage network, where choosing a larger value would be useless.

The stormwater runoff generated in the roads of the studied area for different recurrence intervals have been estimated using EPA SWMM model in kinematic wave routing. The continuity and momentum equations are solved by this routing method. The water surface slope is equal to the inclination of the slope. The average value of rainfall intensity based on Weibull and Gamma probability distribution for different recurrence intervals has been taken for estimating simulated runoff. The depth of stormwater runoff is simulated after one, two, and three hours duration of storm as illustrated in Table (5) and Fig. 6.

Table 5 Depth of stormwater runoff for one, two, and three hours duration.

T	5	10	15	20	25	30	35	40	45	50
Runoff (mm) One hour duration	16.2	18.8	21.5	22.8	24.9	26.2	26.9	27.6	28.9	29.6
Runoff (mm) Two hours duration	31.5	42.8	48.5	51.3	55.6	58.5	59.9	61.3	64.2	65.6
Runoff (mm) Three hours duration	49.5	66.8	75.5	79.8	86.4	90.7	92.9	95.1	99.4	101.6

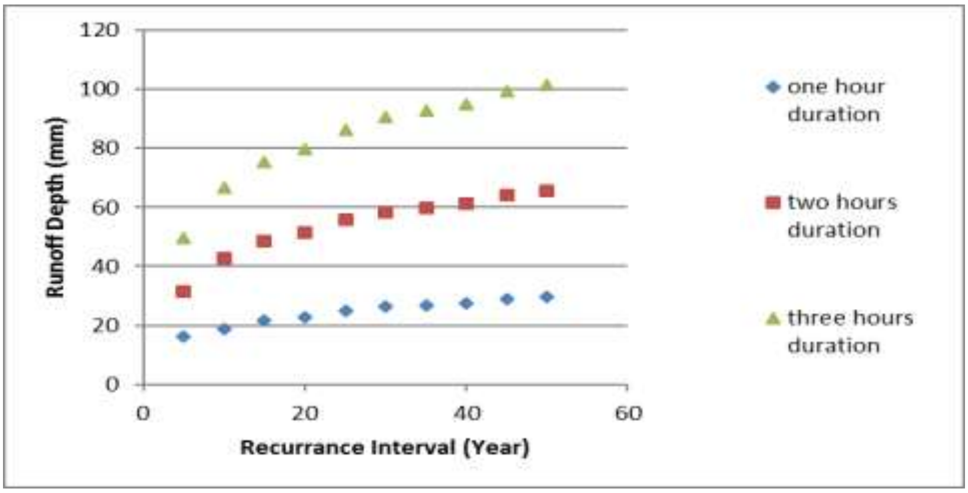

Figure 6 Runoff depth versus recurrence interval for one, two, and three hours duration of storm.

4. CONCLUSIONS

The surface runoff which is generated by rainfall over the road surface for a residential area in Basrah Province was determined for different rainfall recurrence intervals. The depth of runoff is based on changing of rainfall intensity when it exceeding the rainfall intensity that used in the design of stormwater networks in Basrah Province which is equaled to (17 mm / hr). The range of highest frequent value of rainfall intensity is from 10 mm/hr to 15 mm/hr. The average value of the observed rainfall intensities is equaled to (15.57), while the standard deviation value is relatively high (11.686). Weibull and Gamma probability distribution were used for developing the relationship between annual maximum rainfall intensity and recurrence intervals in the area under consideration. Weibull and Gamma probability distribution passed the Chi-squared test for degree of freedom equaled to three. The recurrence intervals (T) have been used for estimating of stormwater runoff are ranged from 5 to 50 years with increment is equaled to 5 years. The depth of stormwater runoff is simulated after one, two, and three hours duration. The depth of runoff is ranged from 16.2 mm for recurrence interval (5 years) to 29.6 mm for recurrence interval (50 years), these values are related to storm with duration is equaled to one hour, while it is ranged from 49.5 mm to 101.6mm for storm duration of three hours.

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