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Effects of Rainfall Intensity-Duration-Frequency Curves Reformation on Urban Flood Characteristics in Semiarid Environment

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Background: A design storm is a theoretical storm event based on rainfall intensities associated with frequency of occurrence and having a set duration. Estimating design storm via rainfall intensity–duration–frequency (IDF) curves is important for hydrological planning of urban areas.

Material and Methods: The impact of changes in rainfall intensity–duration–frequency (IDF) curves on flood properties in an urban area of Zanjan city was investigated, using Storm Water Management Model (SWMM). For the IDF curve generation, Sherman and Ghahreman-Abkhezr methods were compared.

Results: According to results, the estimated rainfall depth and, consequently the peak runoff rate for different return periods had decreased in the recent years, except for 2-year return period. Decrease in peak runoff rate was 30, 39, 41 and 42 percent for 5-10-20 and 50-year return periods, respectively. Based on the results, for peak runoff evaluated in 50-year return period using Sherman and Ghahreman-Abkhezr hyetograph, percent of flood that occurred before the peak runoff were 27 and 22 percent, respectively.

Discussion and Conclusion: Design rainfall hyetograph showed that Sherman method gave larger rainfall intensity compared to Ghahreman-Abkhezr method. Estimated peak and total runoff volume follow trend of rainfall intensity. As Ghahreman-Abkhezr method use longer and newer rainfall data for creating IDF curves, we can conclude that climate change cause change in rainfall characteristics. The runoff modeling show that main urban drainage system had enough transfer capacity against the flood condition, but survey information indicated several inundations in some flat areas, curbs and gutters. Inappropriate design and obstruction of the runoff paths via urban garbage and sediments are some parameters that could lead to such local inundation.

Keywords: Design storm, Flood, Rainfall IDF curve, Storm water, SWMM

1. Background

Study of the spatial and temporal trends of precipitation is applicable for future sustainable management of water resources (1). The estimation of runoff is also important in scientific researches in hydrological processes (2). Due to variation and complexity of land use, population and social economic activities, storm water runoff management is a complex task in urban areas (3,4). This issue will become more complex due to urban development. By 2030, the urban population will reach to 5 billion or 60 percent of the world's population (5). In many countries, less than 5 percent of the land area was occupied via urban area, consequently, concentration of human activities leads to local competition for all types of natural resources, especially for water (6). Due to local change in hydrological cycle and hydro-meteorological conditions in urban areas, urbanization should increase flood risk (7, 8, 9). Modeling is an important facility for development, design and planning of the urban drainage infrastructure (10, 11). Application of rainfall intensity-duration-frequency (IDF) curves, as important parameters in hydrological modeling, is critical for flood estimation.

Several studies have indicated changes in the rainfall conditions as the result of climate change (12, 13) that should lead to change in rainfall IDF curves (13). Besides, impacts of urbanization and climate change on flood properties show that increase in rainfall intensity and impervious surfaces should lead to greater peak flows (14, 15). The impact of the current and future climate change on the rainfall IDF curves and urban design storms in Quebec was estimated using SWMM model (16). In the North-West of Angola, a flood index was used for generate the theoretical regional distribution equation of IDF curve (17). Rainfall IDF relationship was also developed for two regions in Saudi Arabia (18).

2. Objective

In this study, rainfall IDF curves were prepared based on two methods: Sherman method using rainfall data of 1972-1993; Ghahreman and Abkhezr method using long term rainfall data (1972-2004). Then the effects of rainfall intensity-duration-frequency curves reformation on urban flood characteristics was investigated using SWMM model. Finally, the effect of rainfall IDF curves updating on peak and volume of flood was examined.

3. Materials and Methods

3.1. The study area

Covering an area about 39km^2, the study area is located in the center of Zanjan province, north-west of Iran (36°38′26″ to 36°42′20″N, and 48°26′29″ to 48°35′02″ E), at an altitude ranging from 1590 m a.m.s.l in the southern plain to 1773m a.m.s.l in the northern mountain (Figure 1); the mean annual rainfall of the Zanjan city is 290 mm, the main part of which occurs in the autumn and spring. This city experienced a rapid development and population expansion since 1956. Artificial draining canals of the study area have an important role in flood routing during storm events. Flow direction of these canals is from north to south of the city and end to the Zanjanrood River. Gavazang earthen dam, built to the north of the city, controls the upstream surface water and floods.

3.2. Methodology

Flood in urban areas can occur via river or coastal swells or flash floods, but there is also a specific flood type called urban flooding that the cause is a lack of drainage in an urban area. In this study, this kind of flood was investigated using IDF curves and SWMM model.

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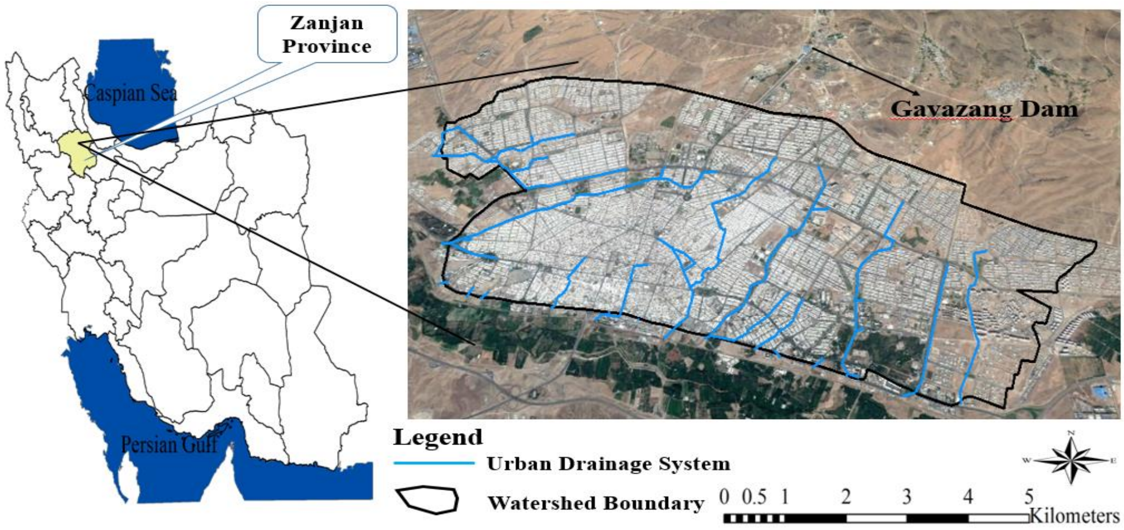

Figure 1 Locations of the Zanjan City watershed

3.2.1. Model description

Storm Water Management Model (SWMM), developed under the support of the US Environmental Protection Agency (19), is a dynamic rainfall-runoff simulation model that computes runoff quantity from primarily urban areas. SWMM is widely used throughout the world for planning, analysis, and designing related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban and non-urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receives precipitation and generates runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps and regulators. SWMM tracks the quantity of runoff generated within each sub catchment and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (20).

3.2.2. Model implementation

The primary objective of this study was to evaluate the hydrologic and hydraulic response of an urban watershed to the rainfall IDF curves updating based on the increasing of the statistical period of the rainfall data. IDF curves of the study area were prepared based on Sherman method using rainfall data (1972-1993). At the first step, rainfall hyetographs of the area were prepared via Sherman method (for return periods of 2, 5, 10, 20 and 50 year). These hyetographs were used as the input of SWMM model for estimating peak and volume of runoff.

In 2004, Ghahreman and Abkhezr (13) proposed a new general relationship for rainfall IDF curves by updating it using long term data (1972-2004), since the previous relationship is not useful for estimating 10-year rainfall.

At the second step of this study, rainfall hyetographs of the area were prepared via IDF curve generated by Ghahreman and Abkhezr method. This hyetograph was also used as the input of SWMM model for estimating peak and volume of runoff.

The implementation of SWMM model necessitates several steps, including (1) identification of sub-watersheds, (2) representation of the channel network, and (3) identification of the model parameters.

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3.2.3. Determination of sub-watershed

Sub-watersheds of the study area were determined based on the urban drainage system. Watershed and sub-watersheds boundaries were determined using land use maps, topographic map (1:2000), building blocks, direction of flow in canals and land survey, based on which,16 sub-watersheds were determined for the study (Figure 2 and Table 1).

3.2.4. Urban drainage system representation

The canal-networks as a link-node system were put into the model. Additional nodes (junctions) were inserted where a quick change in links (conduits) characteristic was detected, including such geometrical changes as depth, width, bed slope, roughness coefficient and shape or when tributary canals is connected to the main canal. The network geometry (canal profile and cross-sections) was derived from the topographical map and land survey.

3.2.5. Model parameters

Surface area, Manning roughness coefficient of canals, impervious and pervious areas, average width of overland path, average surface slope, percent of impervious area, depth of depression storage on impervious and pervious area, percent of impervious area with no depression storage and infiltration parameters were prepared.

Average surface slope was achieved from the digital elevation model (DEM) using ArcGIS 9.3 software. Width of the overland flow path calculated (Equation 1).

$$L = \frac{C\sqrt{A}}{1.128}\left[1 - \sqrt{1 - \left(\frac{1.128}{C}\right)^2}\right] \qquad (1)$$

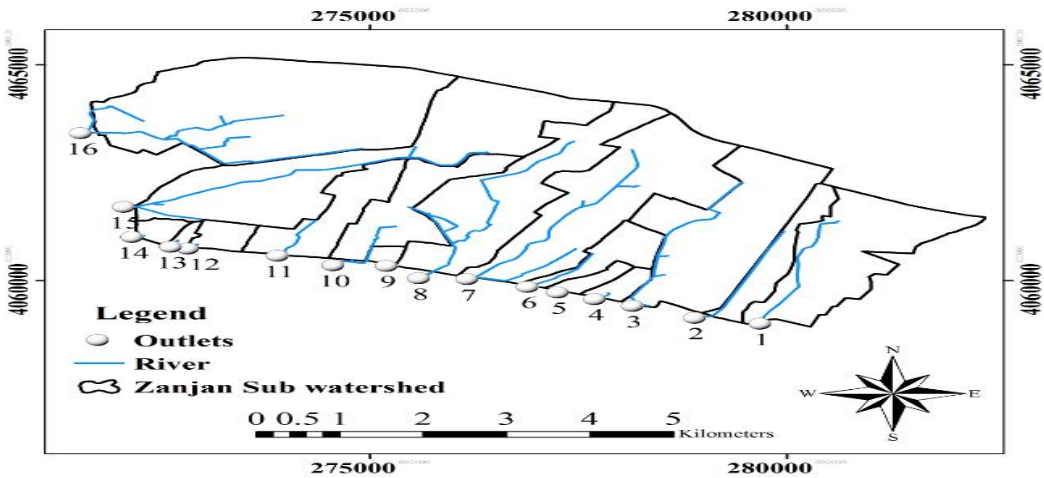

Figure 2 Urban drainage network, sub-watersheds and outlets location of Zanjan City watershed

Table 1Canals number, length and corresponding sub-watershed area

Canal Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Main Canal length (km)	2.9	2.4	3.6	0.2	0.2	1.1	4.3	4	0.03	1.5	1	0.2	0.2	0.1	5.1	2.8
Sub-watershed area (km^2)	3.7	1.1	4.6	0.3	0.3	0.9	4.9	4.5	0.2	1.5	1.6	0.4	0.1	0.3	6.1	7.9

Where L is the width parameter (m), A is the area of sub-watershed (km^2) and C is the compactness coefficient. Compactness coefficient was calculated via equation 2 for sub-watershed with compactness coefficient greater than 1.128 (21). Otherwise, based on the user manual of SWMM, an initial estimate of the width was considered (sub-watershed area divided by the average maximum overland flow length).

$$C=0.282\frac{P}{\sqrt{A}} \qquad (2)$$

Where P is the perimeter of the sub-watershed (km).Manning roughness coefficient was obtained from McCuen *et al.* (22) and ASCE (23) manuals. Curve number method was selected for infiltration modeling. Land use map of the study area was prepared via processing the Thematic Mapper (TM) images in the IDRISI Selva and ArcGIS 9.3 software. Land use map consisted of five classes, including residential area, green space, main roads, dense rangeland and degraded rangeland or urban flatted land. Soil texture data was obtained from the Atlas of Deserts Soil Surveys of Iran and controlled with soil studies of Agriculture and Natural Resources Research and Education Center of Zanjan. Soil hydrological group map was determined based on NRCS Hydrologic Soil Group Definitions in user manual of SWMM (24). Percent of the impervious area was also calculated based on the land use map of 2012 (Figure 3). Based on the land use map, urban areas, main roads, green space, dense and destroyed rangeland occupied 82.9, 5.5, 3, 0.4 and 8.2 percent of the city area, respectively.

3.2.6. Rainfall hyetograph generation

Rainfall is a climate parameter of SWMM model that entered to the model in the form of hyetograph. Maximum flood occurs when rainfall duration is equal to the time of concentration. In this study, for all sub-watersheds, time of concentration calculated via TR-55 model suggested by Natural Resources Conservation Service (25). Rainfall hyetographs were prepared using alternating block method as a simple way for developing a design storm from an IDF curve. The design storm produced by this method specifies the rainfall depth occurring in "n" successive time intervals of duration (Δt) over a total duration ($T_d = n * \Delta t$). Based on the design return period, the rainfall intensity extracted from the IDF curve/relation (26). This hyetograph represent a rainfall with distinct return period and a rainfall duration equal or less thanT_d.Also when rainfall duration is less thanT_d, the central part of the main hyetograph with rainfall duration of$T_d$will be used (27).

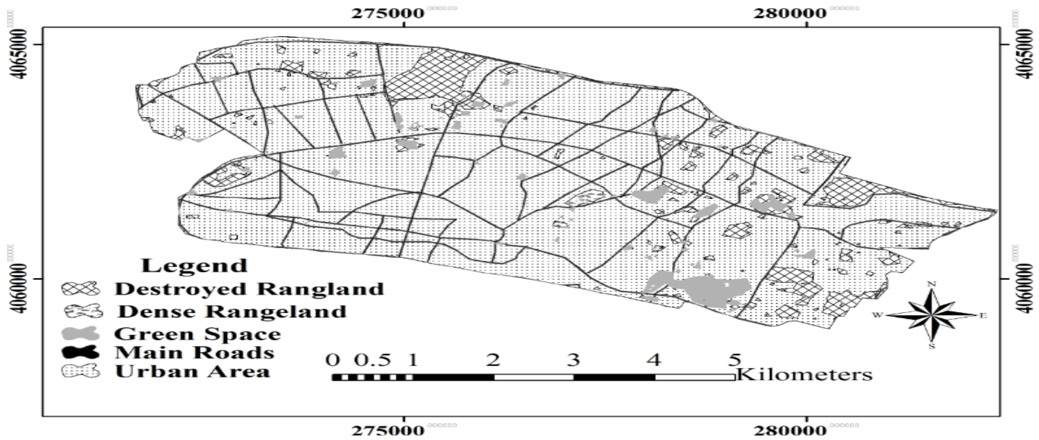

Figure 3 Land use map of Zanjan City watershed

3.2.7. Rainfall hyetograph of Zanjan City based on Sherman equation

The rainfall IDF curves were derived for all rain gauge stations using Sherman Equation (3).

$$i = \frac{a}{(d+b)^{e}} \quad (3)$$

Where i is the rainfall intensity (mm/hour), d is duration (minutes), a, b and e are constant parameters related to the metrological conditions. These empirical equations show rainfall intensity decreases with rainfall duration for a given return period. At the Zanjan station (36° 41′ N, and 48° 29′E, and altitude 1620m) the parameters of Sherman empirical equation were determined in 1995 (Meteorological Organization of I.R IRAN), (Table 2).

The rainfall IDF curves for the Zanjan station constructed with the Sherman equation (Figure 4).

Table 2 Constant parameter with Sherman empirical equation at the Zanjan City watershed in different return period

Return periods T (year)	A	*b*	*e*
2	2654.628	164.735	1.093
5	1977.214	87.108	1.017
10	2111.948	69.215	1.007
20	2473.737	60.915	1.016
50	2884.057	53.450	1.021

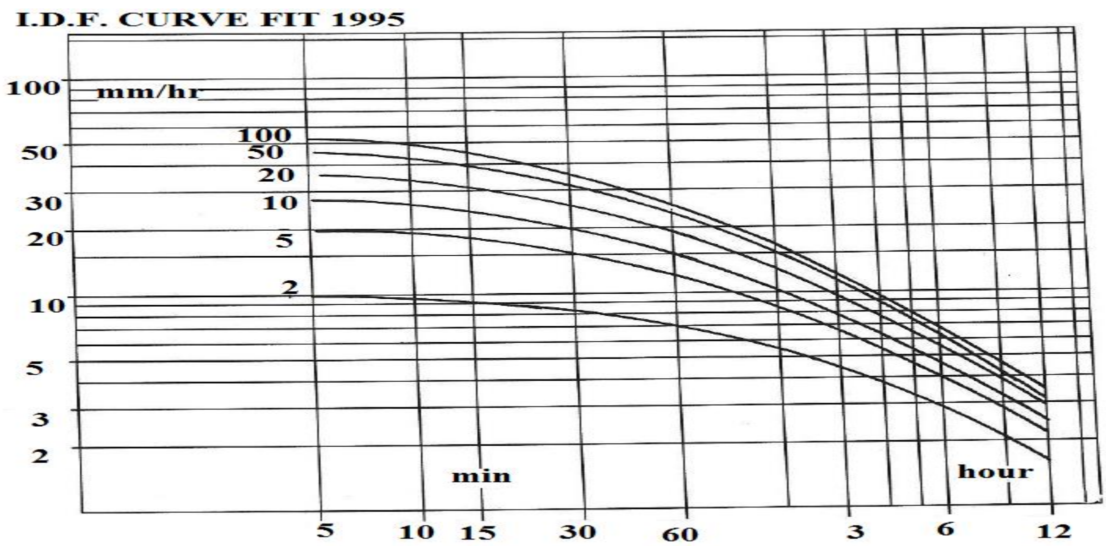

Figure 4 Rainfall intensity–duration–frequency curves of Zanjan station for 1995(Meteorological Organization of I.R IRAN, 1955)

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Zanjan rainfall hyetographs for different return periods in time intervals of 10, 20, 30 and 40 minute were prepared using rainfall IDF curves of the year 1995.

3.2.8. Rainfall hyetograph of Zanjan city based on Ghahreman and Abkhezr equation

Ghahreman and Abkhezr (13) showed that rainfall IDF curves had changed significantly as the result of climate change in the recent years, hence presented a new equation for rainfall IDF curves in Iran (Equation 4).

$$R_t^T = At^B[\alpha_1 + \alpha_2 ln(T - \alpha_3)]R_{60}^{10} \qquad (4)$$

Where R_t^T is the rainfall depth (mm) with time increment of "t" and return period of T. A and B are the coefficients of rainfall duration (for rainfall less or equal to an hours are 0.1299 and 0.4952, respectively). α_1, α_2 and α_3 are coefficients of rainfall duration (for rainfall less or equal to two hours are 0.4608, 0.2349 and 0.62, respectively). R_{60}^{10} is hourly rainfall with 10-year return period. R_{60}^{10} calculated via Equation 5.

$$R_{60}^{10} = e^{0.291}(R_{1440}^{2})^{0.694} \qquad (5)$$

Where R_{1440}^{2} is the average of the maximum daily rainfall calculated based on the maximum of daily rainfall (1969- 2015) in Zanjan station. Rainfall hyetographs of the study area for different return periods and rainfall duration (10, 20, 30 and 40 minute) were prepared using Equation (4) and (5).

3.2.9. Model Calibration

For model calibration, real field measured hydrographs were compared with simulated flow hydrographs (28). The evaluation criterion of root mean square error (RMSE) was used to compare the simulated model output with the observed data (Equation 6).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}[Q_o(i) - Q_s(i)]^2}{n}} \qquad (6)$$

Where Qs (i) and Qo (i) are the simulated and observed discharges, respectively, and, n is number of observations in the time series.

Hyetograph of each hydrological unit was prepared separately (16 hyetograph based on Sherman method and 16 hyetograph based on Ghahreman and Abkhezr) and presented to model. For each outlet, a separated hydrograph was created via SWMM model. Sub watershed 12 was selected for model calibration.

4. Results

Based on both Sherman and Ghahreman-Abkhezr methods, for all 16 sub-watersheds, rainfall hyetograph developed in 10-minute growths for different return periods. As the same results obtained for all study sub-watershed, the result for the sub-watershed 16, as the biggest sub-watershed, was presented in this section. Figure 5 indicates the rainfall hyetograph for 50 year return period created via alternative block method based on both Sherman and Ghahreman-Abkhezr equations.

Based on Sherman and Ghahreman-Abkhezr equations, rainfall hyetograph was developed in 10-minute increments for the 16 sub-watershed for different return periods with 40-minute duration using alternative block method (Table 3). According to results, the rainfall depths increased with increasing of the return period, whereas rainfall amount decreased with increasing of rainfall duration in all return periods. The results obtained from both methods had a good uniformity. Based on rainfall hyetographs in different return periods, rainfall depth calculated via Sherman method was greater than rainfall depth calculated via Ghahreman-Abkhezr method, except for 2-year return period. As recent data was used in Ghahreman-Abkhezr equation, we could conclude that rainfall depth decreased in the recent decade (Table 3). Same results were observed for all sub-watersheds in the study area.

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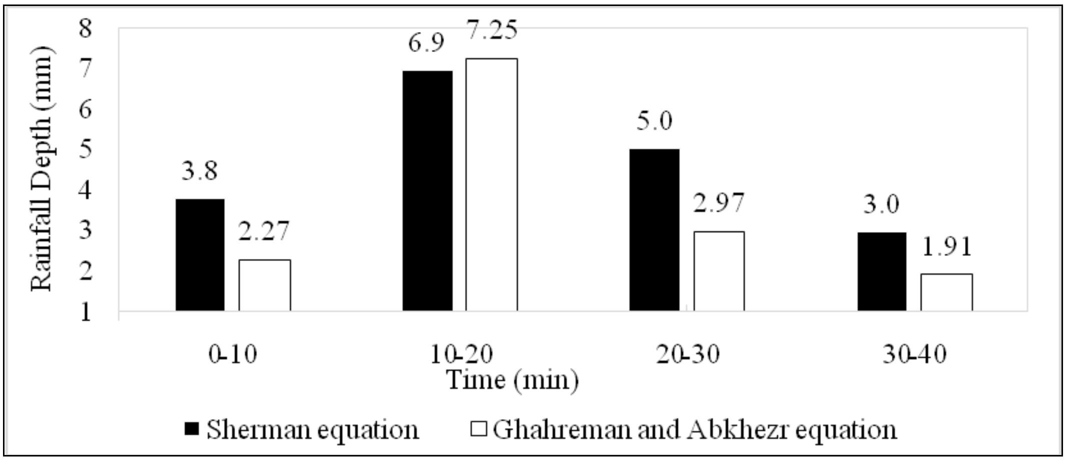

Figure 5 A rainfall hyetograph created via alternative block method based on Sherman and Ghahreman-Abkhezr equations with 50 year return period

Table 3 Rainfall hyetograph developed in 10-minute increments for different return periods using Sherman and Ghahreman-Abkhezr equations

Method	Return Period(year)	Time (min) 0-10	10-20	20-30	30-40	Rainfall Depth (mm)
Sherman	2	1.2	1.6	1.4	1.1	5.3
	5	2.1	3.1	2.5	1.8	9.6
	10	2.7	4.3	3.3	2.2	12.5
	20	3.2	5.4	4.1	2.5	15.2
	50	3.8	6.9	5.0	3.0	18.7
Ghahreman – Abkhezr	2	0.9	2.8	1.2	0.7	5.6
	5	1.3	4.3	1.7	1.1	8.5
	10	1.6	5.2	2.1	1.4	10.3
	20	1.9	6.1	2.5	1.6	12.1
	50	2.3	7.3	3.0	1.9	14.5

Based on the results, peak of the hyetograph created via Ghahreman-Abkhezr method is greater than Sherman method (Figure 5). Rainfall hyetographs for 50-year return period indicated that 57.22 percent of rainfall depth had occurred in the first twenty minutes for both Sherman and Ghahreman-Abkhezr methods, whereas the percent of rainfall depth that happened after hyetograph peak was 42.88 percent in the Sherman method and 33.79 percent in Ghahreman-Abkhezr method (Table 3). This result indicated that estimated hyetograph peak in Ghahreman-Abkhezr method was greater than Sherman method, while the depth of rainfall in Sherman method was greater Ghahreman-Abkhezr.

The results of model calibration based on three measured rainfall runoff events in sub-watershed12 (canal number 12) is shown in Table 4, which indicates an acceptable accuracy served between simulated and measured hydrograph (Figure 6a, b and c). The Drainage area of this canal is 2.98 km^2. The area and shape of this canal was closed to the average of all 16 studied sub watershed in the study area.

Table 4 Calibration of the model results with peak flow

Rainfall- runoff Events	Observed peak flow ($m^3 s^{-1}$)	Simulated peak flow ($m^3 s^{-1}$)	RMSE
May 02 16	0.088	0.09	0.005
May 03 16	0.018	0.02	0.0033
May 10 16	0.022	0.02	0.001

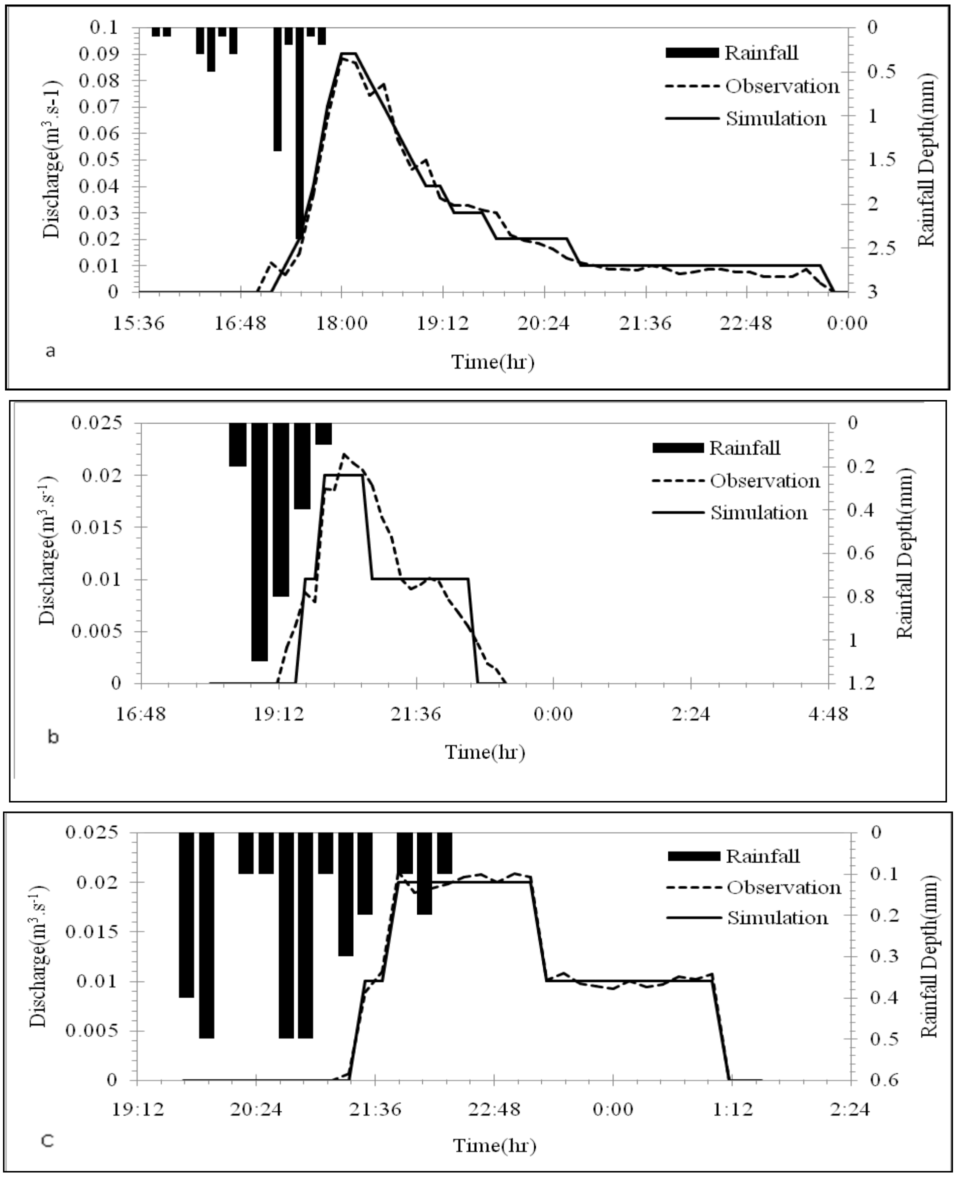

Figure 6 Calibration outfall hydrographs: (a) event at May 02rd 2016, (b) event at May 03rd 2016, (C) event at May 10rd 2016

Based on the input of hyetograph characteristics, change in flood properties were simulated via SWMM model for all sub-watershed. Maximum runoff was calculated via SWMM model in different return period for different watershed outlets. The results of one outlets (outlet number 16) indicated in Figure 7.

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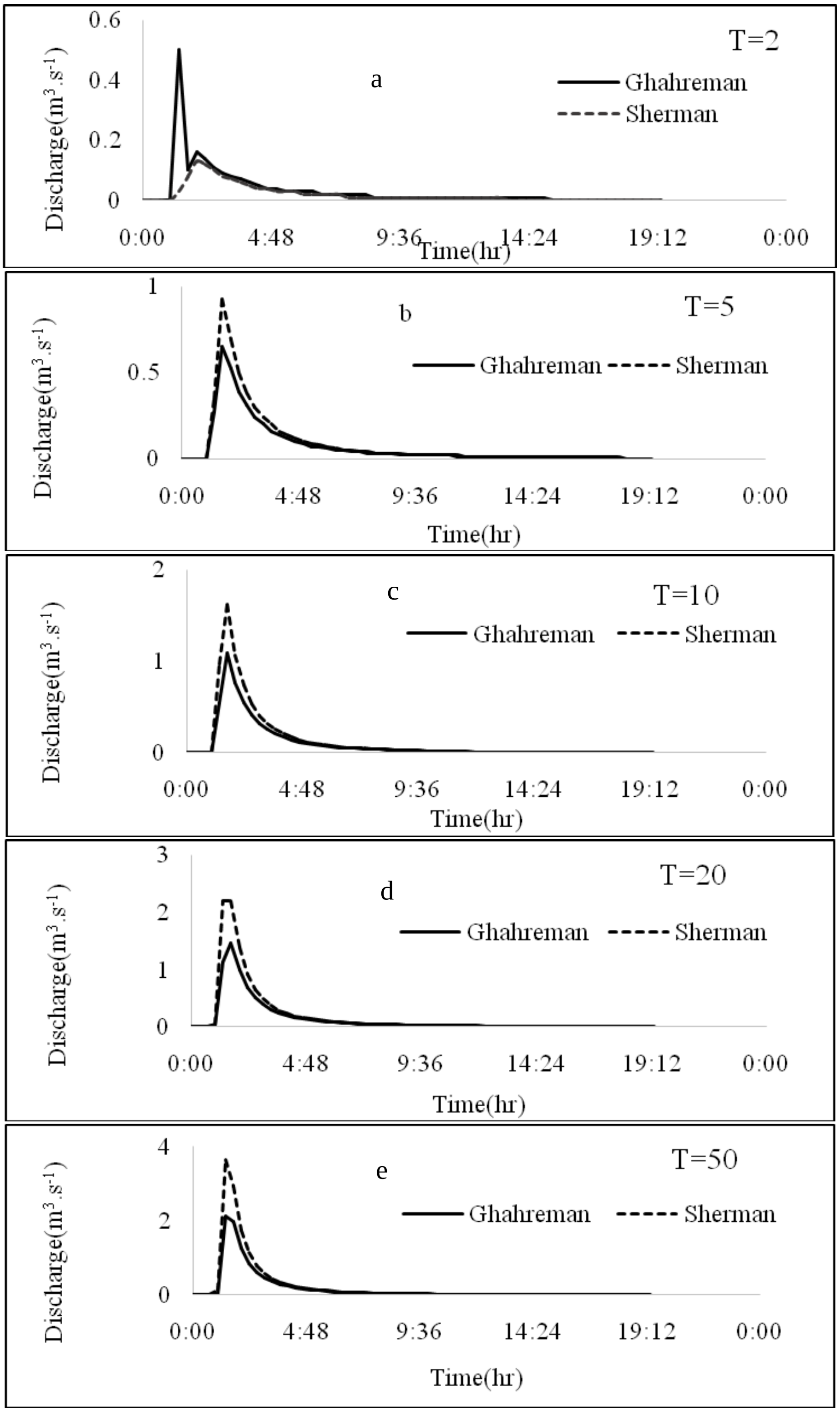

Figure 7 The estimated maximum runoff based on two made hyetograph in different return period. (a) T=2, b) T=5, (c) T=10, (d) T=20 and (e) T=50

Maximum flow (peak runoff) and maximum runoff volume for urban watershed were calculated using sum of the sub-watersheds outlet. Table 5 indicate the estimated maximum runoff of urban drainage system based on two made hyetograph in different return periods for total of the urban watershed drainage system (sum of the 16 sub-watershed).

According to results, for 2-year return period, estimated peak runoff had increased by 20 percent using Ghahreman-Abkhezr hyetographs compared to Sherman method, while for 5,10,20 and 50-year return periods, the peak runoff had decreased by 30, 39, 41 and 42 percent, respectively, in the Ghahreman-Abkhezr method compare to Sherman method. Ghahreman-Abkhezr indicated that the ratio of rainfall depth- return period (DFR) not only related to return period but also it had asystematic change related to rainfall duration. These changes are ascending for return period less than 10 years and descending for return period more than 10 years.

The results showed that volume of runoff decreased using design rainfall hyetograph of Ghahreman-Abkhezr method compared to Sherman method, except for 2-year return period. Decreasing of the total runoff volume for 5, 10, 20 and 50 year return periods was 21, 26, 28 and 29 percent, respectively, while for 2-year return period, evaluated runoff volume increased by 23 percent. Based on the results, for peak runoff evaluated in 50-year return period using Sherman and Ghahreman-Abkhezr hyetograph, percent of flood that occurred before the peak runoff were 27 and 22 percent, respectively (Figure 7).

According to the results of Sherman method, time to peak was 30 minute and base time of runoff hydrograph was17hours and 40 minute. Same time to peak was observed for Ghahreman - Abkhezr method, while base time of hydrograph decreased by 20 minute. Time to peak is an important factor for establishment of flood warning systems. In general, we can conclude that peak and volume of runoff need updating for urban runoff modeling.

Table 5 The estimated maximum runoff of urban drainage system based on two made hyetograph in different return period

Return period	2	5	10	20	50
Sherman method ($m^3 s^{-1}$)	0.44	3.08	6.31	9.95	15.39
Ghahreman- Abkhezr method ($m^3 s^{-1}$)	0.53	2.17	3.85	5.85	8.97
Difference between two methods (%)	20	-30	-39	-41	-42

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5. Discussion

Rainfall intensity in the IDF curve is the average rainfall depth that falls per specific time duration. In this study, rainfall hyetographs were developed for 16 sub-watersheds for different return periods using Sherman, and Ghahreman-Abkhezr equations. According to results, more accuracy was observed between simulated and real condition when Ghahreman-Abkhezr method was used. When we used Ghahreman-Abkhezr method, peak of the rainfall hyetograph increased but depth of rainfall decreased, consequently flood volume should decrease. This means that climate change would affect rainfall pattern of the study area. Desramaut (16) indicated that change in rainfall characteristics led to runoff decreasing. Willems (29) also indicated that changes in flood frequencies of sewer systems and overflow frequencies of storage facilities should be quantified based on the climate scenarios and related changes in rainfall statistics. Due to climate change, peak and volume of runoff decreased in the recently decade. According to results of SWMM model, the main urban drainage system of Zanjan city watershed has enough transfer capacity against the flood condition. But survey information indicated several inundations in some flat area, curbs and gutters of the studied watershed. Poor maintenance of drainage systems, instantaneous heavy rainfall, erosion and sedimentation are some parameters that could lead to such local and temporal inundation. Change in rainfall pattern due to climate change should also lead to heavy rainfall and consequently to temporal flood in the study area. Precipitation varies from year to year and over decades, and changes in amount, intensity, frequency and type of rainfall affect the environment and society. As Ghahreman-Abkhezr method use longer and newer rainfall data for creating IDF curves, we can conclude that this method considers new climate condition and rainfall characteristics. Urbanization should also change hydrological behavior of watershed. So, in hydrological modeling, the role of land-use change should be appropriately considered due to its impact on water resources and ecosystem health in the watershed (30,31).

6. Conclusion

Urbanization and climate change have affected local rainfall pattern and intensity. As rainfall characteristics are often used to design urban drainage system, so watershed modeling, estimation of the flood properties, updating, and reviewing of rainfall characteristics is necessary. This study was conducted for analyzing the effect of rainfall IDF curves updating on the flood properties in Zanjan city watershed using SWMM model. Rainfall hyetographs in different return periods and rainfall duration determined based on two methods (Sherman and Ghahreman- Abkhezr). Ghahreman and Abkhezr (2004) attempted to reform the equations of the rainfall intensity estimation in Iran using longer statistic period. Design rainfall hyetograph showed that Sherman method gave larger rainfall intensity compared to Ghahreman-Abkhezr method. Estimated peak and total runoff volume follow trend of rainfall intensity. As Ghahreman-Abkhezr method use longer and newer rainfall data for creating IDF curves, we can conclude that climate change cause change in rainfall characteristics.

Conflict of Interest

The Authors stat that there is no conflict of interest.

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Authors' Contributions

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the journal of ECOPERSIA.

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اثرات اصلاح منحنی‌های شدت-مدت-فراوانی بارش بر خصوصیات سیلاب شهری در مناطق نیمه خشک

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مقدمه: برآورد میزان دبی طراحی با استفاده از منحنی‌های شدت، مدت، فراوانی برای استفاده در برنامه‌ریزی‌های هیدرولوژیکی حائز اهمیت است. رابطه شرمن جهت تهیه منحنی‌های شدت، مدت و فراوانی در سال ۱۹۹۵ ارائه گردیده است ولی به دلیل تغییرات اقلیمی، قهرمان و آبخضر (۲۰۰۴) نشان دادند که این منحنی‌ها شدت، در ایران به طور معنی‌داری تغییر یافته و روابط جدیدی جهت برآورد پارامترهای این منحنی‌ها ارائه دادند.

مواد و روش‌ها: جهت انجام این مطالعه منحنی‌های شدت، مدت و فراوانی شهر زنجان به وسیله دو روش شرمن و قهرمان و آبخضر تهیه شد و از آنها جهت برآورد میزان رواناب حوضه شهری زنجان با مدل SWMM استفاده گردید. برازش نتایج مدل از طریق اندازه‌گیری سه واقعه بارش و رواناب متناظر با آن مورد بررسی قرار گرفت.

اهداف: هدف اصلی از انجام این مطالعه بررسی تغییرات منحنی‌های شدت، مدت و فراوانی بارش بر خصوصیات سیلاب مناطق شهری با استفاده از مدل SWMM بود.

نتایج: نتایج حاصل از این مطالعه نشان داد که ارتفاع بارش برآورد شده از منحنی‌های حاصل از روش قهرمان و آبخضر برای دوره بازگشت‌های بیش از ۲ سال کاهش یافته و در نتیجه میزان دبی پیک رواناب حاصل از این بارش‌ها هم کم شده است. میزان کاهش دبی پیک رواناب برای دوره بازگشت‌های ۲، ۵، ۱۰ و ۵۰ سال به ترتیب برابر ۳۰، ۳۹، ۴۱ و ۴۲ درصد برآورد گردید.

بحث و نتیجه‌گیری: نتایج حاصل از این مطالعه نشان داد که میزان بارش برآوردی برای دوره بازگشت‌های مختلف و براساس منحنی‌های ارائه شده به وسیله قهرمان و آبخزر با داده‌های جدیدتر نسبت به میزان بارش برآورده شده در هنگام استفاده از منحنی‌های شرمن کاهش یافته است. از این نتایج می‌توان استدلال کرد که تغییر اقلیم باعث کاهش بارندگی‌ها شده است. نتایج حاصل از مدل‌سازی رواناب نیز نشان داد که شبکه اصلی زهکشی شهری منطقه مورد مطالعه گنجایش لازم برای انتقال رواناب‌ها را دارد ولی نتایج حاصل از مطالعات عرصه‌ای نشان دهنده سیل‌گیر بودن بعضی از مناطق شهری مورد مطالعه می‌باشد که این امر می‌تواند ناشی از طراحی نامناسب و یا بسته شدن مسیر رواناب‌ها از طریق رسوبات و ضایعات شهری باشد.

کلمات کلیدی: بارش طرح، سیلاب، منحنی شدت-مدت- فراوانی بارش، رواناب، مدل SWMM

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