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Evaluating the Effect of Climate Changes on Runoff and Maximum Flood Discharge in the Dry Area (Case Study: Tehran-Karaj Basin)

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ABSTRACT

Aims The aim of this study was to the prediction and analysis of temporal pattern changes of runoff, maximum discharge, and Drought indexes in the Tehran-Karaj basin.
Materials and Methods In this study, the temperature and precipitation data extracted from Statistical Downscaling Model (SDSM; 2021-2050 and 2051-2080) together with observational runoff data of the Sulghan hydrometric station (1986-2015) were used as input data for IHACRES rainfall-runoff model and discharge rate, runoff volume, and maximum discharge were extracted in the desired scales. Then, drought indexes (SPEI and SRI) were investigated.
Findings In the period of 2021-2050 and 2051-2080, the mean of annual discharge, volume of runoff and annual precipitation will be decreased. While seasonal runoff, discharge, and precipitation will rise in the winter. Moreover, the maximum predicted discharge (In most scenarios) in the return periods less than 5 and more than 50 years is less than the observation period and in the Return Periods of 5 to 50 years it will be more than the observation period. Besides, 48-month SPEI with 48-month SRI (without delay) has a maximum correlation with each other at the level of 99%.
Conclusion In the winter season and return periods of 5 to 50 years, the floods hazards and Rivers overflow in the Future periods (2021-2080) will be more than the observation period. Also, meteorological droughts often have their effect on the drought of surface waters during the same month.

Keywords Climate Change; Statistical Downscaling Model; IHACRES; Maximum Flood Discharge

CITATION LINKS

[1] Evaluating the level and nature of sustainable development for a geothermal ... [2] Climate change 2007-the physical science basis: Working group I contribution to the ... [3] Evaluation and projection of extreme precipitation indices in the Eastern ... [4] Hydrological response to different time scales of climatological drought: An evaluation of the standardized ... [5] Investigating the relationship between hydrological and meteorological droughts in ... [6] Combined analysis of precipitation and water deficit for drought hazard ... [7] Characterization of droughts in humid subtropical region, upper Kafue river basin ... [8] Comparison of the performance of six drought indices in characterizing historical ... [9] Uncertainty and climate change impact on the flood regime of small ... [10] Global warming and changes in the probability of occurrence of floods in Bangladesh ... [11] New estimates of future changes in extreme rainfall across the UK using the regional climate ... [12] A framework for assessing uncertainties in climate change ... [13] Jordan recurrent neural network versus IHACRES in modelling daily ... [14] A methodology to diagnose the effect of climate change and to identify adaptive strategies ... [15] Assessment of climate change impact on river flow regimes in The Red River Delta, Vietnam–A case study of the ... [16] Quantifying different sources of uncertainty in hydrological projections in an Alpine ... [17] Effects of future climate change, CO2 enrichment, and vegetation structure variation on hydrological processes ... [18] Impacts of future land cover and climate changes on runoff in the mostly afforested ... [19] Streamflow response of Belgian catchments to IPCC climate change ... [20] Climate change impacts on streamflow at the upper Jordan river based on an ensemble ... [21] Assessment of the impact of climate change on hydropower potential in the ... [22] Identifying climate change impacts on water resources in Xinjiang ... [23] Bivariate analysis of floods in climate impact ... [24] Landscape- and climate change-induced hydrological alterations in the typically urbanized Beiyun river ... [25] The effects of climate change on the hydrology and water resources ... [26] RCM rainfall for UK flood frequency ... [27] Carbon emission limits required to satisfy future representative concentration ...

Introduction

Climate change is known as one of the most important challenges in the world. It can have serious consequences for the social, economic, agricultural, and environmental infrastructure of human beings [1]. In the future expected an increase in the occurrence of drought in low and middle latitudes, especially in hot seasons [2]. Future climate in the Middle East region is expected to be characterized by possible decreasing precipitation and increasing temperature trends [3]. Several studies have been conducted on the effects of climate change and drought on water resources. Vicente-Serrano and Lopez-Moreno [4] evaluated the temporal relation between the occurrence of meteorological and hydrological droughts in Spain and showed that the maximum correlation between SRI and SPEI is observed in a short-term time scale. Azareh *et al.* [5] showed that in Karaj dam watershed, the maximum correlation between meteorological and hydrological droughts (at 99% confidence level) was found for the 3-month timescale. Tokarczyk and Szalinska [6] employed SPEI, SRI, and Markov chain in Poland and found that meteorological drought was converted to hydrological drought on the same month. Lweendo *et al.* [7] showed that SPEI has a strong link with hydrological conditions at 9-15 months timescale. Bayissa *et al.* [8] indicated that SPI and SPEI had a high correlation with ETDI and SMDI (r>0.62) at 3-month aggregate period, while SPI and SPEI had a better correlation with SRI at 12-month timescale. The impact of climate change on flood regimes has been studied in different parts of the world. Prudhomme *et al.* [9] examined the effects of climate change on the flood regime English rivers. The results of the study indicated an increase in the severity of flood events. Mirza *et al.* [10] studied the effect of climate change on the possibility of a flood event in Bangladesh. The results indicated an increase in mean peak discharge and the occurrence of the flood. In England, Ecstrom *et al.* [11] stimulated maximum rainfalls through RCM model and found that short and long-term events increase in a certain return period. Wilby and Harris [12] evaluated the effect of climate on minimum river flows, they indicated that the uncertainty of AOGCM model and greenhouse gases scenarios respectively had the maximum and minimum share in estimating the probabilistic function of runoff. In Italy, Carla Carcano *et al.* [13] showed that the performance of a simple model such as IHACRES could be better than complicated models provided that the suitable input data are available.

Velazquez *et al.* [14] evaluated the effect of climate changes on river flow of watershed in Spain and found that the maximum reduction in medium river flow is in August. Cao Duong *et al.* [15] investigated the effect of climate change on runoff in the red river delta, in the Vietnam. The findings showed that climate change impact on the river flow regimes tend towards a decrease in the dry season and a longer duration of flood flow. Doubler [16] assessed the effect of climate change on flood risk potential in Olefin Lake basin and showed that the intensity of flood would increase in the future.

Zhu *et al.* [17] investigated the effect of climate change on hydrological processes in China and discovered that climate has a maximum effect on runoff, hydrological processes, and evapotranspiration. The Impacts of the future land cover and climate changes on runoff in the north China was evaluated by Yang *et al.* [18] using the SWAT model. The results of this study indicated that the mean annual precipitation and runoff may increase for the period of 2020–2030. The impact of the climate change on streamflow was investigated also by Gellen *et al.* [19] in Belgian, Givatia *et al.* [20] in Jordan ,Wang *et al.* [21] in the Nanliujiang River basin of China, Luo *et al.* [22] in Xinjiang, China, Brunner *et al.* [23] in Switzerland, Zhang *et al.* [24] in china, Christensen *et al.* [25] in the Colorado River Basin, Ecstrom *et al.* [11] in Uk and Alison *et al.* [26] in England.

In this regard, the most important purposes of studying Tehran-Karaj basin are 1) evaluation of temporal pattern changes of runoff and maximum discharge in the study area, 2) analysis of the time intervals between meteorological and hydrological droughts, 3) the prediction of the effect of climate change on, discharge, volume of runoff, and maximum discharge of flood using IHACRES rainfall-runoff model in future.

Material and methods

The study area

Tehran-Karaj basin is located between the latitude 35° 10'S to 36° 17'N and longitude 50° 72'W to 51° 69' E in Tehran and Alborz provinces with an area of 5154.2km^2. This area has a semi-dry and dry climate. The annual precipitation is about 236.27mm (statistic period of 1986-2015). The amount of annual precipitation in the spring, summer, fall, and winter is 38.32%, 2.80%, 17.77%, and 41.09%, respectively. The average annual temperature of the area is 18.25°C; the highest and lowest monthly temperature in the region is reported to be 30.93°C in July and 4.28°C in January. Figure 1 shows the location of the study area in Tehran province and Iran.

Data analysis and collection

In the present study, five important steps were performed as follows: 1) preparation of meteorological and hydrometric information, 2) prediction of rainfall data, temperature, and rainfall in future, 3) calculation of meteorological and hydrological drought indices based on data related to base period and forecast period, 4)estimation of maximum discharge in future period, 5) evaluation of modeling results. Figure 2 represents the research steps in summary.

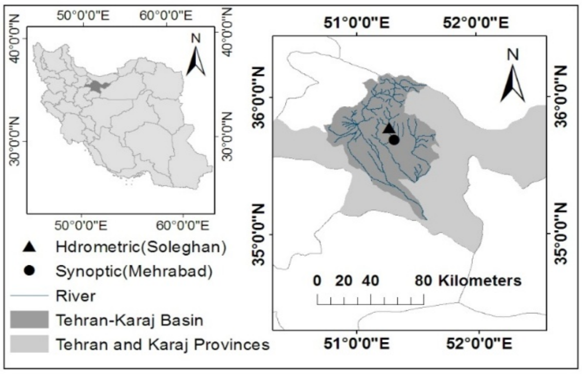

Figure 1) The location of the study area in Tehran province and Iran

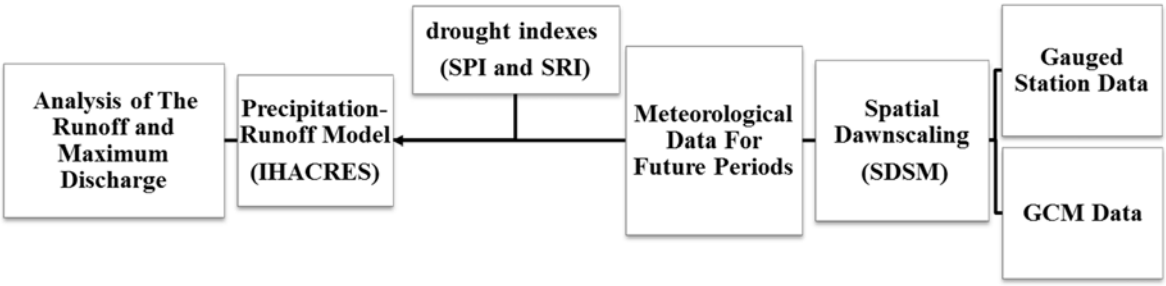

Figure 2) The research steps

Forecasting meteorological data

For this purpose, not only meteorological data of Mehrabad synoptic station and hydrometric data of Sulaghan station statistically evaluated and analyzed in terms of quality and quantity, but also the mentioned periods were separated as observation periods (1986 to 2015) and upcoming periods (2021-2050 and 2051-2080). In order to forecast meteorological data, general circulation model (GCM) and related propagation scenarios were used.

GCM and SDSM: In the present research, CanESM2 model as a comprehensive model and fourth Generation of coupled general circulation models (CGCM4) and series of CMIPS model, as well as the fifth report of Intergovernmental Panel on Climate Change (IPCC) [27]. Besides, RCP 2.6 (the lowest increasing rate of greenhouse gases and radiative forcing scenarios) RCP (constant radiative forcing), and RCP 8.5 (maximum increasing rate of greenhouse gases and radiative forcing scenarios) are representative concentration pathways of various greenhouse gases in optimistic, intermediate, and pessimistic scenarios. Since the predictor variables provide information on the large-scale mode of atmosphere, SDSM of data is necessary at the point and local scale, thus, the SDSM model was used. Input data to the model included daily rainfall data, maximum temperature, and a minimum temperature of Mehrabad synoptic station, and large-scale data of GCM or NCEP.

Rainfall-runoff model IHACRES: Experts have always been interested in the rainfall-runoff model (IHACRES) because it requires low data (temperature and precipitation) and high estimation power. The daily temperature and precipitation values generated by the Statistical Downscaling Method for different scenarios and observational data of daily discharge (cubic meters per second) at the Solghan hydrometric station are the inputs of the model. The IHACRES model converts rainfall to effective rainfall (a part of the rainfall that eventually enters the river) and access rainfall (a part of the rainfall that eventually disappears by evapotranspiration due to impermeability of the watershed) at a certain time scale. Then, by the linear transformation function (or unit hydrograph; UH).

The effective rainfall and simulated runoff are model outputs. In order to calibrate and validate the model, 3 years (2002-2004) of daily discharge data in the observational period were selected as a range that included the wet, drought and normal periods. Then, about 70% of the data (2003-2002) were selected as the calibration period and other data (2004) as the validation period. After that, about 2-3% of the data was selected as Warm-Up (the initial preparation of the model with less data), and the time interval between rainfall and the runoff (Set Delay) was assumed to be zero. In the end, according to the calibrated parameters of **tw** and **f** at the calibration stage, it was attempted to simulate the daily runoff values during the periods of 2050-2050 and 2080-2080. Table 1 shows the values of the parameters in the calibration stage.

Table 1) The output of IHACRES software at the calibration stage

Non Linear Model Modoule Calibration	
Mass balance term (c)	0.0005
Drying rate at reference temperature (tw)	27
Temperature dependence of drying rate (f)	4
Reference temperature (tref)	20
Moisture threshold for producing flow (l)	0
Power on soil moisture (p)	1

The evaluation of model performance: In order to evaluate the efficiency of the IHACRES model, the determination coefficient (R^2), Nash-Sutcliffe coefficient (NSE), and root mean squared error (RMSE) were used. Equations 1 and 2 show these indices:

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(x_s-x_o)^2}{n}} \quad (1)$$

$$\text{NSE(EI)}=1-\frac{\sum_{t=1}^{n}(x_o-x_s)^2}{\sum_{t=1}^{n}(x_o-\bar{x}_o)^2} \quad (2)$$

In the above equations, x_s is simulated data, x_o is observational data, $\bar{x}_o$ is the mean of observational data, and n is the number of data.

Determine the type of climate in the study area: For this purpose, using the SDSM model output and observation station data, the type of climate in the area was determined using Amberge Moisture Coefficient. In this regard, Q_2 Amberge Moisture Coefficient, P Average Annual Precipitation (mm), M Average maximum temperature in the warmest month of the year (Kelvin) and m is the average minimum temperature in the coldest month of the year (Kelvin):

$$Q_2 = \frac{2000\,P}{M^2-m^2} \quad (3)$$

Hydrological (SRI) and Meteorological (SPEI) Indices

In this study, the standardized precipitation-evapotranspiration index (SPEI) and the standardized runoff index (SRI) were applied to characterize the meteorological and hydrological drought conditions of the study area at different time scales (3, 6, 12, 24, and 48 months) using DIC and SPEI software. A critical benefit of the SPEI over other commonly used drought indices that consider the effect of PET on drought severity is that its multi-scalar characteristics permit the identification of the different drought types and impacts in the situation of the global warming. This index uses the difference between rainfall and potential evapotranspiration based on the Thornth Waite approach. SPSS software was used to analyze the relationship between SPEI and SRI indices via Pearson correlation matrix.

The SPEI is based on the original SPI calculation procedure. The SPI is calculated using monthly (or weekly) precipitation as the input data. The SPEI uses the monthly (or weekly) difference (D) between precipitation (P) and the reference crop evapotranspiration (ETo). This difference (D) is the water surplus or deficit for the analyzed month (i), and is calculated using Equation (4):

$$D_n^k=\sum_{n=0}^{k-1} P_{n-1} - ETo_{n-i} \quad (4)$$

ETo, is generally calculated using a simple climatic water balance, and it is expressed as Equation (5):

$$ET_o = 16K\left(\frac{10T}{I}\right)^m \quad (5)$$

Where ETo is the reference crop evapotranspiration, T is monthly temperature, I is the heat index, K is the constant, and m is a coefficient depending on I.

Logarithmic logistic function analysis was performed for exploration of he time series data in different time scales. Therefore, the cumulative distribution function was calculated and converted to the normal values and then the values of the SPEI index are extracted.

Standard runoff index (SRI) is calculated using Equation (6):

$$(SRI_{ik}=\frac{V_{ik}-\bar{V}_k}{S_K}) \quad (6)$$

Where, $\bar{V}_k$ is the average of the total volume of discharge and S_k is the standard deviation of the cumulative flow volume for the standardized runoff index in the Base period k (Table 2)

Table 2) Drought classification for SRI and SPEI Index

Condition	SPEI and SRI
Severe wet	2≤
Moderate wet	1.5 to 1.99
Relatively wet	1 to 1.49
Normal	-0.99 to 0.99
Relatively dry	-1 to -1.49
Moderate dry	-1.5 to -1.99
Severe dry	-2≥

The study of variations in the runoff volume and discharge patterns in the future

Considering the simulated runoff of the IHACRES model, the amounts of monthly, seasonal, annual discharge and runoff volume during the periods of 2021-2050 and 2051-2080 was extracted. Then, the measured values were compared with the measured data at the Solghan hydrometric station and their variations were evaluated in the form of time patterns.

The study of variations in the maximum discharge patterns in the future

For this purpose, using the extracted discharge values of the IHACRES runoff rainfall model, the maximum annual discharge was determined in predicted periods. The best statistical distribution (Log-Pearson Type III) was selected appling l-moment method via a computer program that was written in the quick basic environment. Then, the maximum annual discharge in the certain return periods, according to the best-selected distribution was calculated. Finally, maximum discharge values were compared in the observation and predicted periods and their corresponding curves were extracted.

Findings

The prediction of Meteorological Data

According to the results of SDSM, the average winter and summer precipitation will increase in the periods of (2020-2051) and (2051-2080) in all three scenarios. But in general, the annual precipitation decreases for all three scenarios in both periods (for RCP 2.6, RCP 4.5, and RCP 8.5, during the 2021-2050 period, respectively, 6.17%, 8.02%, and 8.48%, and during the period of 2051-2080, 9.43%, 7.98%, and 8.56%, respectively). Despite the fact that the average annual temperature does not show significant changes compared to the observational period, the study of temperature data trends in different scenarios suggests an upward trend of the average annual temperature in the predicted upcoming periods (79%-1.12%). Table 3 shows the monthly mean rainfall and temperature values in observational and future periods (Table 3).

Evaluating climate change in the study area: Considering the Amberge Moisture Coefficient, the type of climate in the studied area will change from Cold arid climates to Moderate arid climate (Table 4).

Table 3) Observational and predicted mean precipitation (P) and temperature values (T) from SDSM model

Scale	1986-2015		2021-2050						2051-2080					
			scenario 2.6		scenario 4.5		scenario 8.5		scenario 2.6		scenario 4.5		scenario 8.5	
	T	P	T	P	T	P	T	P	T	P	T	P	T	P
Jan	4.78	31.27	4.73	30.30	5.19	31.35	4.94	31.22	4.93	31.01	5.08	33.22	5.18	34.97
Feb	6.85	32.26	6.38	38.29	6.67	37.84	6.42	38.59	6.63	38.14	6.47	40.04	6.55	42.45
Mar	11.44	44.20	10.21	49.12	10.38	45.68	10.39	42.66	10.97	44.40	10.27	43.89	10.41	35.32
Apr	17.74	31.98	17.87	21.27	18.56	20.67	17.96	18.88	17.84	17.60	18.17	15.05	18.49	11.95
May	22.96	14.38	22.83	9.24	23.53	9.44	22.81	9.87	23.00	8.94	23.18	8.18	23.49	6.94
Jun	28.45	2.10	27.89	0.73	28.03	0.65	27.88	0.68	28.11	0.61	27.88	0.47	27.82	0.20
Jul	30.93	2.72	31.08	6.42	31.25	6.70	31.09	7.80	31.18	6.85	31.18	9.18	31.27	12.47
Aug	30.31	1.80	30.46	0.53	30.67	0.40	30.51	0.33	30.18	0.39	30.52	0.30	30.55	0.05
Sep	26.21	1.00	26.36	1.02	26.58	1.04	26.33	1.14	26.15	1.07	26.40	1.16	26.70	1.71
Oct	19.85	13.79	19.42	7.20	20.02	7.09	19.60	6.30	19.50	7.72	19.51	5.81	19.92	3.11
Nov	12.20	27.20	12.10	22.75	12.52	23.24	12.09	24.41	12.11	24.12	12.29	24.49	12.68	29.06
Dec	6.75	33.57	7.33	34.83	7.54	33.24	7.41	34.36	7.08	33.15	7.57	35.62	7.73	37.82
Spring	17.37	90.56	16.96	79.63	17.01	75.78	17.05	71.41	17.13	70.95	17.20	67.12	17.45	54.22
Summer	29.92	6.62	29.83	7.69	29.82	7.75	29.85	8.82	29.86	7.85	29.88	9.95	29.90	12.71
Autumn	19.42	41.99	19.29	30.97	19.24	31.37	19.34	31.85	19.23	32.90	19.40	31.47	19.77	33.87
Winter	6.11	97.09	6.14	####	6.21	####	6.25	####	6.23	####	6.37	####	6.48	####
Year	18.26	####	18.11	####	18.13	####	18.18	####	18.14	####	18.27	####	18.46	####

Table 4) Determine the type of climate in Observation and forecast period

Statistical	Amberje Method	
Period	Moisture Coefficient	Type of Climate
1986-2015	17.69	Cold arid
2021-2050	21.07	Moderate arid
2051-2080	20.91	Moderate arid

The study of the climate change impact on runoff rate

Evaluation of the IHACRES model: The results of the performance evaluation of the model showed that IHACRES was acceptably accurate in estimating runoff. Thus, the determination coefficient, root mean square error, and Nash-Sutcliffe coefficient in the calibration step were 0.73, 1.95, and 0.72, and in the validation phase, 0.75, 1.5 and 0.74. diagram 1 shows the modeling accuracy in the calibration and validation steps.

The impact of climate change on discharge and runoff volume: The predicted discharge and runoff volume values for RCP 2.6, RCP 4.5, and RCP 8.5 are presented in two periods of 2021-2050 and 2051-2080 in Table 5. According to the results and unlike the observational period, the mean annual discharge and runoff volume over the period of 2021-2050 in RCP 2.6, RCP 4.5, and RCP 8.5 will decrease by 38.65, 42, 42.56%. The decreasing of the mean annual discharge and runoff volume over the period of 2051-2080 in RCP 2.6, RCP 4.5, and RCP 8.5 will be 43.29, 41.61, and 42.90%, respectively.

According to the predicted data, the mean annual discharge and runoff volume should be decreased in the spring, summer and fall, but it should be increased in the winter (Table 5).In the monthly scale, in all scenarios, the mean of the monthly discharge and runoff volume values will be decreased compared to the observation period for the period of 2021-2050 except in January and February (Table 5; Diagram 2)

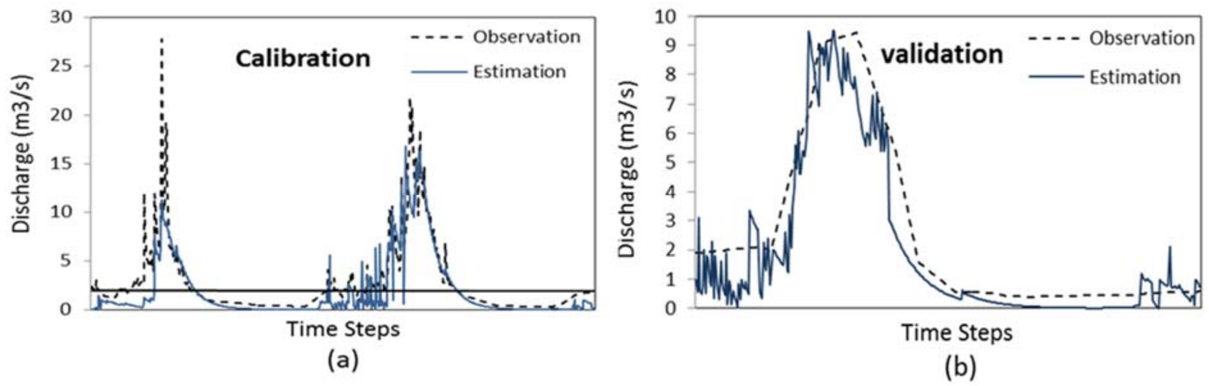

Diagram 1) Observed and calculated values of the IHACRES model during the calibration (a) and validation (b) periods

Table 5) Comparison of the mean discharge (Q) and runoff volume (million cubic meters) (V) in observed and predicted periods

Scale	1986-2015		2021-2050						2051-2080					
			2.6		4.5		8.5		2.6		4.5		8.5	
	Q (M3/S)	V(M3)	Q (M3/S)	V (M3)	Q (M3/S)	V (M3)	Q (M3/S)	V (M3)	Q (M3/S)	V (M3)	Q (M3/S)	V (M3)	Q (M3/S)	V (M3)
Jan	1.42	3.80	1.71	4.57	1.66	4.45	1.78	4.77	1.69	4.53	1.88	5.02	2.15	5.75
Feb	2.35	5.68	3.17	7.67	3.16	7.63	3.21	7.76	3.17	7.67	3.44	8.32	3.90	9.43
Mar	5.99	16.04	5.34	14.30	5.05	13.53	4.93	13.20	5.04	13.50	5.27	14.10	4.84	12.97
Apr	10.39	26.92	4.45	11.54	3.98	10.31	3.81	9.87	3.70	9.58	3.68	9.55	3.13	8.11
May	4.75	12.72	1.81	4.86	1.69	4.53	1.61	4.31	1.54	4.14	1.42	3.79	1.19	3.18
Jun	0.99	2.58	0.51	1.32	0.48	1.24	0.46	1.19	0.43	1.12	0.39	1.02	0.33	0.84
Jul	0.26	0.70	0.13	0.36	0.13	0.34	0.12	0.33	0.11	0.31	0.11	0.28	0.09	0.25
Aug	0.17	0.44	0.04	0.09	0.03	0.09	0.03	0.09	0.03	0.08	0.03	0.08	0.03	0.07
Sep	0.11	0.29	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02
Oct	0.41	1.11	0.02	0.05	0.02	0.04	0.01	0.04	0.02	0.04	0.01	0.03	0.01	0.02
Nov	1.64	4.25	0.22	0.56	0.23	0.58	0.23	0.61	0.24	0.62	0.23	0.60	0.26	0.68
Dec	1.37	3.66	0.90	2.42	0.88	2.37	0.94	2.51	0.94	2.52	0.97	2.59	1.12	3.00
Spring	7.04	55.97	3.87	30.75	3.57	28.40	3.45	27.41	3.43	27.24	3.46	27.46	3.05	24.26
Summer	0.47	3.77	0.23	1.80	0.21	1.70	0.21	1.63	0.19	1.52	0.18	1.40	0.15	1.18
Autumn	0.72	5.68	0.08	0.64	0.08	0.66	0.09	0.67	0.09	0.69	0.08	0.65	0.09	0.73
Winter	1.71	13.30	1.93	14.99	1.90	14.78	1.97	15.35	1.93	15.04	2.09	16.28	2.39	18.57
Year	2.49	78.43	1.53	48.12	1.44	45.49	1.43	45.05	1.41	44.48	1.45	45.79	1.42	44.79

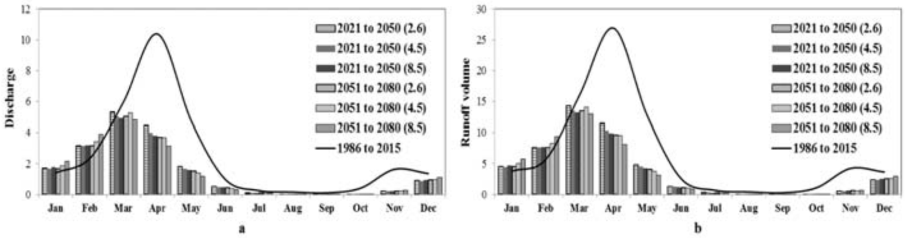

Diagram 2) Variation of the monthly mean discharge (a) and runoff volume (b) in baseline and predicted

The study of the temporal relationship between meteorological and hydrological droughts

As can be seen Table 6 (a) and Table 7, during the observational period (1968-2015) and the predicted statistical periods of 2021-2050 and 2051-2080, meteorological droughts can affect the drought of surface waters during the same period, and the Pearson correlation coefficient is significant at 0.99 level for the standardized runoff index, without delay, and the amount of correlation decreases with delay.

In the second stage, the correlation between standardized runoff index with no delay and standardized drought index was studied at the time scales of 1, 3, 6, 12, 24, and 48 months. As shown in Table 7 (b) and Table 8, in the observational period and the statistical period of 2021-2050, the highest correlation was found between the 6-month standardized drought index (SPI-6) and the standardized 3-month runoff index (SRI-3) at the level of 99% (at a rate of 0.808 for the observational period and 0.914 (RCP 2.6, RCP 4.5) and 0.915 (RCP 8.5) for the period of 2021-2050).

This correlation is also significant in the statistical period of 2051-2080 for the 6-month standardized drought index (SPI-6) and the one-month standardized runoff index (SRI-1) at the level of 99% (0.917 for RCP 2.6, 0.925 for RCP 4.5 and 0.932 for RCP 8.5). Here, the highest correlation in the statistical period of 2021-2050 belongs to RCP 8.5 and the lowest is equally related to both RCP 4.5 and RCP 2.6. Also, in the statistical period of 2051-2080, RCP 8.5 and RCP 2.6, have the lowest and the highest correlation between meteorological and hydrological droughts (Tables 6, 7, 8; Diagram 3)

Analysis of maximum discharge in predicted periods

The comparison of the curves (Diagram 4) shows that with the exception of RCP 8.5 (2051-2080), in the return periods less than 5 years and more than 50 years, the maximum predicted discharge is less than the observational period. However, in the return periods of 5 to 50 years, the maximum predicted discharge would be more than the observational period. These changes for RCP 8.5 (2051-2080) are such that the maximum discharge of above scenario would be lower than the observation period in return periods of less than 10 years, but in return periods of more than 10 years, it would be more than the observation period.

Table 6) Correlation between Standardized Precipitation-Evapotranspiration Indexand standardized runoff index with desired delays in predicted periods

Drought Index	Scenario	2021-2050 SRI	SRI-1 (Delay)	SRI -2 (Delay)	SRI-3 (Delay)	2051-2080 SRI	SRI-1 (Delay)	SRI -2 (Delay)	SRI-3 (Delay)
SPEI-1	2.6	0.046	0.001	-0.006	0.008	0.043	0.004	0.002	-0.001
	4.5	0.044	-0.002	-0.016	-0.011	0.047	-0.002	-0.005	0.001
	8.5	0.062	0	-0.006	-0.014	0.061	0.002	-0.009	-0.027
SPEI-3	2.6	0.109*	0.072	0.029	0.009	0.117*	0.076	0.027	-0.004
	4.5	0.092	0.048	0.002	-0.021	0.110*	0.064	0.012	-0.01
	8.5	0.135*	0.088	0.034	-0.008	0.120*	0.084	0.029	-0.018
SPEI-6	2.6	0.141**	0.125*	0.108*	0.09	0.143**	0.125*	0.103	0.08
	4.5	0.114*	0.095	0.075	0.055	0.144**	0.127*	0.107*	0.082
	8.5	0.164**	0.148**	0.127*	0.097	0.163**	0.147**	0.122*	0.087
SPEI-12	2.6	0.115*	0.115*	0.118*	0.123*	0.116*	0.119*	0.117*	0.114*
	4.5	0.086	0.08	0.077	0.08	0.121*	0.118*	0.115*	0.113*
	8.5	0.133*	0.130*	0.132*	0.128*	0.158**	0.160**	0.158**	0.152**
SPEI-24	2.6	0.078	0.078	0.077	0.082	0.063	0.063	0.065	0.069
	4.5	0.053	0.057	0.061	0.065	0.07	0.067	0.066	0.068
	8.5	0.088	0.086	0.087	0.082	0.049	0.054	0.061	0.069
SPEI-48	2.6	0.046	0.05	0.054	0.06	0.044	0.04	0.035	0.035
	4.5	0.022	0.025	0.026	0.027	0.082	0.08	0.081	0.081
	8.5	0.073	0.07	0.067	0.066	0.071	0.072	0.073	0.074

Table 7) Correlation between Standardized Precipitation-Evapotranspiration Indexand standardized runoff index with delay (a) and standard runoff index without delay in desired scales (b) during the observation period

(a)					(b)						
	1986-2015					1986-2015					
Drought Index	SRI	SRI-1 (Delay)	SRI-2 (Delay)	SRI-3 (Delay)	Drought Index	SRI-1	SRI-3	SRI-6	SRI-12	SRI-24	SRI-48
SPEI-1	0.210**	0.033	0.033	-0.003	SPEI-1	0.210**	0.114*	0.087	0.152**	0.076	-0.04
SPEI-3	0.320**	0.254**	0.147**	0.022	SPEI-3	0.320**	0.309**	0.249**	0.283**	0.164**	-0.03
SPEI-6	0.306**	0.293**	0.267**	0.229**	SPEI-6	0.306**	0.352**	0.434**	0.469**	0.308**	0.048
SPEI-12	0.265**	0.240**	0.227**	0.216**	SPEI-12	0.265**	0.288**	0.415**	0.807**	0.548**	0.214**
SPEI-24	0.187**	0.200**	0.204**	0.201**	SPEI-24	0.187**	0.243**	0.654**	0.736**	0.841**	0.426**
SPEI-48	0.115*	0.124*	0.123*	0.120*	SPEI-48	0.115*	0.170**	0.270**	0.601**	0.793**	0.805**

Table 8) Correlations between Standardized Precipitation-Evapotranspiration Indexand standardized runoff index without delay in the desired scales in predicted period

Drought Index	Scenario	2021-2050						2051-2080					
		SRI-1	SRI-3	SRI-6	SRI-12	SRI-24	SRI-48	SRI-1	SRI-3	SRI-6	SRI-12	SRI-24	SRI-48
SPEI-1	2.6	0.046	0.019	0.021	0.003	-0.032	-0.044	0.043	0.022	0.017	0.046	-0.037	0.02
	4.5	0.044	0.011	0.003	0.004	-0.064	-0.081	0.047	0.02	0.026	0.023	0.017	-0.079
	8.5	0.062	0.025	0.02	0.108*	0.074	0.163**	0.061	0.022	0.015	-0.007	-0.105	-0.048
SPEI-3	2.6	0.109*	0.081	0.076	0.158**	0.074	-0.004	.117*	0.088	0.063	.171**	0.025	0.079
	4.5	0.092	0.055	0.034	0.08	-0.026	-0.099	.110*	0.076	0.065	0.063	0.093	0
	8.5	0.135*	0.099	0.074	0.232**	0.164**	0.322**	.120*	0.091	0.064	0.037	-.154**	-0.061
SPEI-6	2.6	0.141**	0.142**	0.156**	0.384**	0.209**	0.092	.143**	.143**	.153**	.336**	.145**	.176**
	4.5	0.114*	0.106*	0.101	0247**	0.141**	-0.014	.144**	.143**	.146**	.133*	.229**	0.086
	8.5	0.164**	0.167**	0.171**	0.436**	0.346**	0.470**	.163**	.164**	.155**	.221**	-.142**	0.032
SPEI-12	2.6	0.115*	0.130*	0.196**	0.802**	0.530**	0.359**	.116*	.133*	.195**	.673**	.370**	.316**
	4.5	0.086	0.092	0.133*	0.595**	0.374**	0.209**	.121*	.131*	.184**	.184**	.445**	.281**
	8.5	0.133*	0.148**	0.210**	0.711**	0.618**	0.636**	.158**	.178**	.247**	.680**	0.082	.313**
SPEI-24	2.6	0.078	0.086	0.130*	0.641**	0.827**	0.473**	0.063	0.071	.110*	.464**	.686**	.396**
	4.5	0.053	0.064	0.105	0.683**	0.708**	0.578**	0.07	0.074	.108*	.108*	.753**	.457**
	8.5	0.088	0.096	0.134*	0.556**	0.759**	0.759**	0.049	0.06	0.1	.532**	.684**	.410**
SPEI-48	2.6	0.046	0.056	0.092	0.466**	0.673**	0.814**	0.044	0.046	0.064	.264**	.493**	.804**
	4.5	0.022	0.028	0.046	0.294**	0.394**	0.732**	0.082	0.092	.133*	.132*	.507**	.777**
	8.5	0.073	0.078	0.104	0.404**	0.510**	0.855**	0.071	0.081	.117*	.422**	.393**	.586**

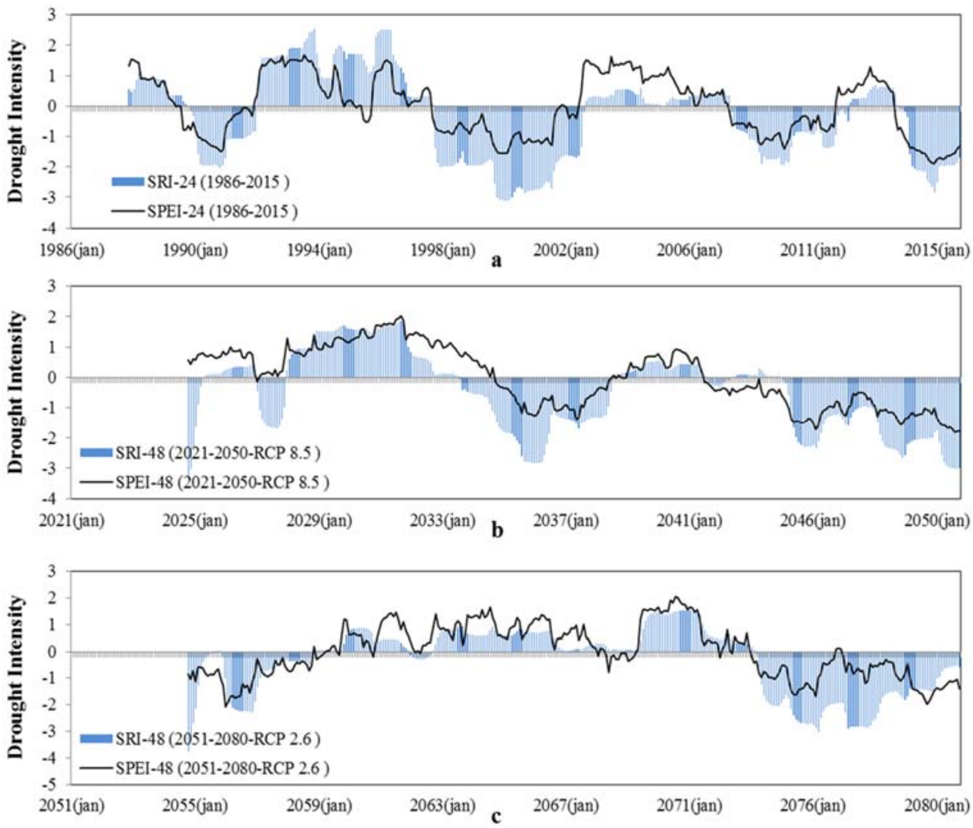

Diagram 3) Comparison of Selected Indices in the baseline and predicted period

Although the hydraulic behavior of the maximum flood discharge has a slight fluctuation in the predicted periods, the studies show that with the exception of RCP 8.5 (2051-2080), in the return periods of less than 5 years and more than 50 years, RCP 2.6 and RCP 8.5 (2021-2050) and RCP 4.5 (2051-2080) increased more than RCP 4.5 (2021-2050) and RCP 2.6 (2051-2080). Nevertheless, in the return periods of 5 to 50 years, these changes are contrary to the previous one. For RCP 8.5 (2051-2080), the change process is slightly different. As for return periods of less than 10 years, the maximum discharge of RCF8.5 (2051-2080) is less than other scenarios and in the return periods of more than 10 years, the maximum discharge of above scenario is more than other scenarios. Regardless of how much data is available, this indicates the quality of flood discharge variations in the future (Table 9; Diagram 4).

Table 9) Indicators for the observed and predicted maximum discharge values by the IHACRES model

Parameter	1986 to 2015	2021 to 2050			2051 to 2080		
		2.6	4.5	8.5	2.6	4.5	8.5
Min	4.03	6.56	6.02	4.55	4.68	6.32	4.55
Max	131.50	12.64	11.88	14.61	12.62	11.91	12.71
Mean	34.93	9.22	9.01	8.72	9.08	8.68	8.01
STDEV	29.46	1.52	1.14	1.95	1.89	1.39	1.91

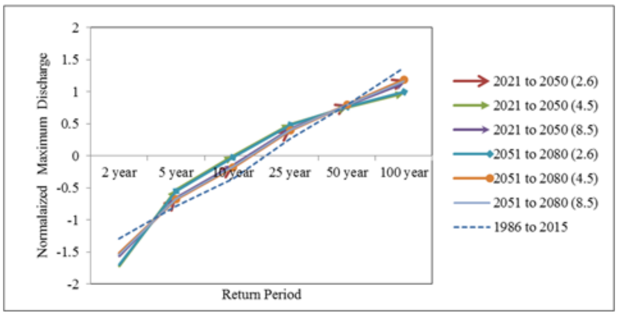

Diagram 4) Normalized values of the maximum flood discharge in certain return periods by Log-Pearson Type III distribution in the observed and predicted Periods

Discussion and Conclusion

According to the findings, in the study area, the mean annual discharge and runoff volume over the period of 2021-2050 and 2051-2080 would be decreased. Also, the mean discharge and runoff volume would be decreased in the spring, summer, and fall and increased in the Winter. These results are in line with the findings of Cao Duong *et al.* [15] in Kelang basin in the Vietnam, Givatia *et al.* [20] in the Jordan and Christensen *et al.* [25] in the Colorado River Basin.

The results of the time interval of meteorological and hydrological droughts in the studied area indicate that the meteorological droughts often affect the hydraulic droughts during the same period. These results are in line with the results obtained by Vicente Sarano and Lopez Murner [4] and Tokarczyk and Szalinska [6]. This is justified by the geographic and hydrological conditions of the study area (high slope and range of impenetrable surfaces). Also, in the predicted periods of 2021-2080, the highest correlation was observed between SPEI-48 and SRI-48 (at the level of 99%).

However, the study of the maximum annual discharge in different return periods with the Log-Pearson type III distribution shows a significant difference between the minimum and maximum data of the maximum flood discharge values.

The reason is that the average and standard deviation of the simulated runoff values by IHACRES model are significantly modified and normalized compared to its measured values. The comparisons show that except for RCP 8.5 (2051-2080), in the return periods of less than 5 years and more than 50 years, the maximum predicted discharge is less than the observational period. Also, the study of the data trend in different scenarios shows that the hydraulic behavior of the flood is independent of the amount of greenhouse gas emissions and they do not have a significant relationship with each other.

According to the results, the mean annual rainfall should decrease by more than 8% in the future. Consequently, it leads to a decrease in annual discharge and runoff volume. The results can help managers and policymakers to better define qualification and adaptation strategies for basins in similar climates.

Thsese results are useful for water management considering the various sources of water in the studied area rather than just taking into account the flood. The results can be used to find the best management systems to avoid drought stresses. Appling the new methods of irrigation and changes in cultivation patterns should be proposed for the study area.

According to the results, the necessity of using the rainwater collection systems and modern methods of collecting urban runoff in the high rainfall seasons is inevitable. Also, it is necessary to use flood forecasting and warning systems in the tourist places of the region (north of Tehran and rivers leading to it) as well as flood control based management and urban watershed management (in residential areas of Tehran) is necessary (especially in the winter season and Return Periods of 5 to 50 years).

Since previous studies in several basins have shown that effects of land use change on water flow is significant, it is suggested that the effect of land use change on annual discharge and runoff volume in the study watershed can be investigated in the further studies.

The limitations of this research include: 1) Using only one Synoptic weather stations as an input into the SDSM model, 2) The problem of uncertainty in forecasting meteorological parameters. The suggestions include: 1) Increasing of the meteorological stations near the hydrometric station, 2) Evaluation of uncertainties in meteorological forecasting meteorological parameters, 3) Use other rainfall-runoff models, with more input layers, to improve the accuracy of the results.

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