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Impacts of Climate Change on the Statistical Trends of Monthly and Annual Flood Discharges in the Kashafrood River Basin Iran

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Abstract

Global warming has caused the climate of the planet to lose its equilibrium in recent decades, so climate change has attracted a great deal of attention in the study of climate change. Long-term statistics can demonstrate dramatic shifts in climate. The purpose of this study is to examine the statistical trends of monthly and annual series, flood discharge of the Kashafrood river basin in Iran. Therefore, the statistical data of the last 65 years related to the monthly and annual series of the station were examined. Mann-Kendall test was used to check whether it was random or non-random, for the trend, type and time of change, which was observed in 5 months of an increasing trend and in 7 months of sudden jump. Mann-Whitney and Kruskal-Wallis tests were used to evaluate the significance of jump points, which were significant in most months except November and June.

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Introduction

Climate is the prevailing weather conditions over a long period of time. In fact, the climate of a region is made up of a set of elements and factors that result from the changes in each element due to climatic factors. This creates special conditions in terms of weather that are unique for each region (Doulabian et al., 2021).

Although the flow regime shows seasonal variations in river flow, it does not provide accurate information on the magnitude and frequency of floods and droughts. The study of flood behavior is very important because they are able to carry significant amounts of sediment and play an influential role in canal formation.

Climate change has led to changes in the worldwide hydrological regime in recent decades, so that the likelihood of exposure to maximum climatic events such as floods has increased. Since increasing this probability for future periods could have detrimental effects on human societies, in recent years, research on this issue has been considered for various catchments around the world (HassanMohammed et al., 2021; Eslaminezhad et al., 2022).

Hydrological hazards occur as a result of changes in the frequency and intensity of rainfall, rising temperatures and changes in land use. Global warming has led to increasing rainfall and decreasing snowfall in winter, rising the river levels and increasing river discharges. This increase causes life and property losses and increases the likelihood of flooding. Therefore, by examining the factors affecting the change in flood intensity and appropriate management practices such as the development of watershed management, forestry, etc., the volume of flood damage can be reduced in the basin. Changes in climatic parameters such as precipitation affect the river flow regime. Given the impact of climate change on human life, an effort to understand more about climate change events is essential. The metropolis of Mashhad has a wide geographical location in the alluvial plain. Being located between the sedimentary heights of Kopehdagh and Hezarmasjed has led to the creation of a special morphology for the alluvial plain of Mashhad. The Kashafrood River drains all the rivers of Mashhad plain and the drainage rivers of the Binalood heights pass through Mashhad city and discharge into the Kashafrood River. The physical development of the city over the years has led to changes in the morphology of the city's rivers, and in some areas on the riverbeds, high-rise structures have been built with high importance and have increased the likelihood of hazards (Azamizade et al., 2021).

The structures that have been created due to the beautiful landscape in the highlands of the metropolis of Mashhad are built exactly on waterways. As a result of the reduction in water infiltration, the runoff volume created is generally high, which in turn increases the likelihood of flooding and its severity in residential and commercial areas. These issues make the city vulnerable to increases periodic floods (Eslaminezhad et al., 2020).

Ghorbani (2002) used 40 years of meteorological statistics at Gorgan Station to study climate change. The rate of change in temperature and precipitation was investigated by the simple linear regression method. According to the results, no significant changes in temperature were observed but rainfall decreased.

In our country Azizi et al. (2004) studied the presence or absence of temperature and precipitation trends.

Asgari et al. (2006) studied the trend of eleven precipitation indices across the country and found that in about two-thirds of countries, the annual precipitation index had a negative and positive trend in wet days and heavy rainfall days, respectively. Hosseinzadeh et al. (2007) investigated the issue of floods and flooding in Mashhad and expressed the indirect effects of urban expansion within catchment areas and the possibility of flood intensification in the urban context.

Avand et al. (2011) Investigated the effects of climate change and land use on flood prone areas in the Tajan watershed of Iran. The results showed that elevation (21.55), distance from the river (15.28), land use (11.1), slope (10.58), and rainfall (6.8) are the most important factors affecting flooding in this basin. The factors were modified according to land use changes and climate changes and the models were revised. Landuse and climate forecasting in this region indicate that land use change, like decreased forest cover (−77.19 km^2) and reduced rangeland (−218.83 km^2) near rivers and downstream, can be expected and rainfall is projected to increase (under both scenarios). These changes would result in increased probabilities of flooding in the downstream portion of the watershed and near the sea.

Darand et al. (2013) investigated the temperature and precipitation behavior at Kermanshah station. The results showed that cold extreme indices in Kermanshah are decreasing while extreme warm indices are increasing.

Sayemuzzaman et al. (2014) examined the trend of seasonal and annual rainfall in North Carolina, USA. In order to analyze the annual and seasonal temporal and spatial trends, they used the Mann- Kendall test for uniform distribution of 249 precipitation data in North Carolina during the statistical period (1950–2009), respectively, to determine its trend and significance. The local trend of precipitation (mountainous, foothills and coastal) was also determined by the tests mentioned above. Before using statistical test, pre-bleaching method was used to eliminate the correlation effect of precipitation data series. The results show a significant increasing and decreasing trend in winter and autumn rainfall, respectively. For annual, spring and summer rainfall, a combined (increasing/decreasing) trend has been identified. Significant trends were detected in only 8, 7, 4 and 10 stations out of 249 stations in winter, spring, summer and autumn, respectively. The amount of annual precipitation varies between 5.5 to 9 mm per year. In spatial trend analysis, increased precipitation has been recorded in mountainous and coastal areas throughout the period except in winter. In the foothills area, the trend is rising in the summer and autumn, but decreasing in the winter and spring. Modarres et al. (2016) studied the great changes in the flood and the severity of drought in Iran for the years 1950 to 2010, with changes in the time interval in some stations. Both increasing and decreasing trends were observed for drought severity and flood magnitude in different climate regions and major basins of Iran using these tests. The increase in flood magnitude and drought severity can be attributed partly to land use changes, an annual rainfall negative trend, a maximum rainfall increasing trend, and inappropriate water resources management policies.

Waikar (2014) has calculated that the rate of water discharge in a drainage basin has an inverse relationship with drainage density. In this case, factors such as walling the banks of floodways and removing the mazes change the characteristics and morphology of the river.

Ahmad et al. (2015) investigated the precipitation changes at 15 stations in Pakistan's Swat River basin over a 51-year period (1961-2011). They used nonparametric Mann-Kendall and Spearman statistical tests to detect monthly, seasonal, and annual precipitation trends. The results of monthly, seasonal, and annual precipitation show a combination of positive (incremental) and negative (detractive) trends. One station in particular, Sayed Sharif station, recorded the most significant monthly rainfall. On a seasonal time scale, the precipitation trend has changed from summer to autumn.

Sayed Sharif station showed the highest positive trend (7.48 mm/year) in annual precipitation. Across the Swat River basin, a statistically significant trend was found for the annual rainfall series. The lower Swat basin, however, showed the maximum increase in precipitation (2.18 mm/year). Also, the performance of Mann-Kendall and Spearman tests was constant at the significantly confirmed level.

Zhou et al. (2019) examined the effects of recent urban development on hydrological runoff and urban flood volume in a large city in northern China, and compare the effects of urbanization with the effects of climate change under two representative focus paths (RCPs 2.6 and 8.5). They then map the urban drainage system to reduce flood volume for future adaptation strategies. The results show that urbanization has led to an annual increase in surface runoff of 208 to 413%, However, changes in urban flood volume can vary greatly depending on the performance of the drainage system during development. In particular, urbanization changes in the expected annual flood volume range from 194 to 942 percent, which is much greater than the effects of climate change under the RCP 2.6 scenario (64 to 200 percent). Sun et al. (2021) examined an urban rainstorm model and a scenario simulation method in downtown Shanghai. First, the flood risks in the study area under the influence of future climate change were investigated using a simulation with different rainfall return periods. They then evaluated the benefits of traditional drainage system adaptation measures and low-impact development (LID) practices in reducing urban flood risks. The results show that the volume of urban floods increases non-linearly with increasing rainfall intensity under climate change. The maximum flood zone increases accordingly and is much more sensitive to smaller rainfall events. Both traditional drainage adaptation measures and LID practices can effectively reduce floods. Pal et al. (2022) explore future floods in India due to climate change and land use. Human activities and related carbon emissions are a major cause of land use and climate change, which has a significant impact on floods. They provide flood sensitivity maps for various future periods (up to 2100) using a combination of remote sensing data and GIS modeling. To quantify future flood susceptibility to various flooding factors, the Global Circulation Model (GCM) of precipitation and land use and land cover (LULC) data are predicted. They evaluated the current flood sensitivity model through the receiver performance characteristic curve (ROC), in which the area under the curve (AUC) shows 91.57% accuracy of this flood sensitivity model and can be used to model future flood sensitivity. Based on the predicted LULC, rainfall and flood sensitivity, the results of the study indicate that the maximum monthly rainfall in 2100 will increase by approximately 40 to 50 mm, while the conversion of natural vegetation into agricultural land and is about 0.071 million m^2 and the area of severe flooding will now increase to 122% (0.15 million km^2).

A flood is considered as one of the Natural disasters and the limiting factor of development, especially along coastlines and river banks. Therefore, studies of flooding and flood prevention are important in water resources management. It is beneficial to identify flood-prone areas in watersheds when planning infrastructure programs for rural, agricultural and industrial development.

Due to the fact that the Kashafrud watershed has critical and supercritical flood potential in some areas, especially in Mashhad and Chenaran, the importance of studying changes in the intensity and duration of floods increases. Kashafrud river basin is a part of Qaraqoom catchment in Iran. This catchment is located in the northeast of the country and in the north of Khorasan Razavi province. It has an area of 15,650 km^2.

In the Kashfrud watershed, several authors conducted studies on flooding. BaniWaheb et al. (2006) investigated regional flooding in the Western Kashafrud river basin. The results showed that among the factors affecting the flood, the average of maximum 24-h precipitation and the percentage of area covered by vegetation had a more significant effect on the maximum instantaneous discharge values than other factors.

Barati et al. (2011) analyzed the regional flood frequency in the Kashafrud catchment using the linear moment method. Based on the linear moment diagram and the Z^{dist} statistic, the distribution of generalized limit values has been identified as an appropriate distribution for the study area.

Sayari et al. (2011) compared two models of general atmospheric circulation in predicting climatic parameters and water needs of plants under climate change in the Kashafrud River basin. The results showed that the average annual rainfall with the model (CGCM2) and two scenarios (A2, B2) decreased by 13 and 16%, respectively. But for the model (HADCM3), the average annual rainfall was increased by 2 and 8%. The model (CCCM2) and two scenarios (A2 and B2) decreased by 13 and 16 percent.

Azamizadeh et al. (2019) investigated the flooding potential of Kashafrud river basin of Mashhad by SCS method in CIS environment. The results showed that 68.25% of total basin area has normal flood potential, 25.5% is critical, 6.25% has supercritical flood potential.

Helmi and Shahidi investigated the impact of drought on the water quality of Kashfroud river using precipitation, temperature, and quality data from six stations over a 30-year period. They found that during drought, water quality parameters such as TDS, EC, Ca, Mg, Na, SO4-, HCO3-, and Cl- increased significantly compared to the long-term average. The concentration of Cl- reached a maximum of 7.66 mg/l at Olang Asadi station. Additionally, the increase in temperature during drought led to the highest water quality changes at Olang Asadi station. Overall, the study concludes that drought, coupled with reduced rainfall and increased temperature, results in decreased water quality, particularly downstream.

The purpose of this study was to examine the statistical trend of monthly and annual series, flood discharges of the Kashafrud river basin. Therefore, statistical data of the last 65 years related to the monthly and annual series of the station were examined using Excel and SPSS software.

Materials and Methods

Case study

This study area is part of the Qaraqoom catchment in Iran, located in the northeast of the country and in the north of the Khorasan Razavi province, with an area of 15,650 km^2.

It is bounded to the north by the ridge of the Hezarmasjed Kopehdagh mountains, to the south by the Binalood mountains, to the west by the Khajeh Ali, Poshteh Par and Shah Jahan mountains, and to the east by the Harirod River. The river that drains this basin is called the Kashafrud River. A major tributary originates from Khajeh Ali, Poshteh Par and Shah Jahan Mountain, located in the Hezar Masjed and Binalood Mountains in the east of Quchan city, before flowing from west to east. After crossing the Mashhad plain, the Kashafrood River crosses the Mashhad-Sarakhs road and enters the narrow valley (AqDarband) in the south of the village of Mozdoran. After leaving it, it joins Harirod in a place called Pol Khatun on the border of Turkmenistan and forms the Tajan River.

In order to detect climate change from a statistical point of view, special methods are used. This method provides a comprehensive overview in addition

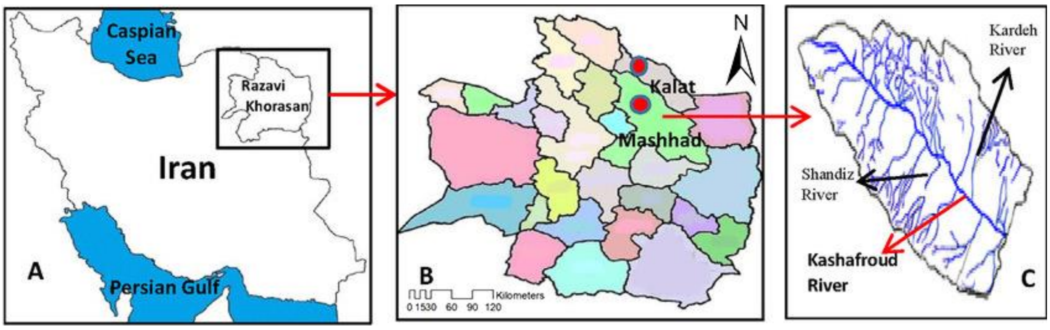


Figure 1. Geographical location of the region in (A) Iran, (B) province and (C) Qaraqoom catchment

to providing many facts, and it is more valuable to study these methods together. In this research, the statistical analysis of monthly and annual floods in Cosford river basin was investigated.

In climate change studies, long-term statistics can show change, how, and its characteristics to a large extent. Monthly and annual flood discharge data for the last 65 years were entered into Excel software and the Mann-Kendall test was used to determine the randomness or non-randomness of the series and then to determine the direction, type and time of change, the Mann- Kendall graphical test was used.

Mann-Kendall test

In this test, first the time series, arranged in ascending order of the year, were entered into Excel software and the flood discharge data related to each series were ranked and Mann- Kendall's statistical equation (1) was entered in Excel software (Shaikh et al., 2022).

$$T = \frac{4p}{n(n-1)} \quad (1)$$

T is the Mann-Kendall statistic and p is the sum of the ranks greater than T=4p/(n(n-1)), and n is the total number of Statistical years. The following equation is used to assess the significance of T-statistic

$$T_t = \mp \tan \sqrt{\frac{4n+10}{gn-1}} \quad (2)$$

Where tg is for the critical value of the normal or standard score (z) with the test probability level and with the 95% probability level, it is equal to1.96. If this value is applied T_t, will be obtained. If$+(T)_t > T > -(T)_t$, no trend is observed in the series and the Serie is random. If $T < -(T)_t$ represents a negative trend in the series and if $T < (T)_t$, the positive trend in the series will prevail (Azizi and Roshani, 2008).

Mann-Kendall graphical test

It is necessary to use the Mann-Kendall graphical test to determine the direction and type of change. For this purpose, a special table is used. In this table, first, the statistical data are entered in the order of the year, and in the second column, the data are given a row number. Then, in the third column, the values of the desired parameter are entered and ranked (to identify the starting points of the time series trend, the time series diagram in terms of the values u(t) and u`(t) is used. There are 12 computational steps for calculating this test, which 6 steps are required for calculating u(t) and six steps are required to calculating u`(t).

Step one: Determine rankings for variables.

Step two: the number of ranks smaller than each row ti that is placed before it.

Step three: Use this formula to calculate this step E_i. In terms of the null hypothesis, its distribution function is asymptotically equal to the mean and variance.

n_i: Row number of each variable

$$E_i = \frac{n_i(n_i - 1)}{4} \quad (3)$$

Step four: To calculate the variance v_i, we will use the following equation.
n_i: Row number.

$$v_i = \frac{(n_i(n_i - 1).(2 \times n_i + 5)}{72} \quad (4)$$

Step five: Calculate the cumulative density of T_i, add each number to the previous number. This is called zt_i

Step Six: The following equation is used to obtain u(t).

$$u(t) = \frac{(zt_i - E_i)}{v_i 0.5} \quad (5)$$

These six steps are just calculation of u (t). In order to determine the time of change, in addition to u (t), the component of u´ (t) must be calculated. To calculate u´(t), simply reverse the rating of the data and perform the above six steps to obtain u´(t). The successive values of u_i and u'_i obtained from the Mann-Kendall test are displayed graphically (Excel). If the values of u_i and u'_i overlap several times, there is no trend or change, but where the curves intersect each other's, the trend or changes are seen. If the curves intersect each other's within the critical range, they indicate the time of onset of sudden change, and if they intersect each other's outside the critical range, they indicate a trend in the time series.

Extent and significance level of changes

Regression analysis is a statistical process for estimating the relationships between variables. This method includes many techniques for modeling and analyzing specific and unique variables.

When determining the amount of changes in trends and sudden jumps, the linear regression method was used for the series that showed changes in the test to examine the correlation between the independent and dependent variables. The statistical method of regression analysis is used to investigate the trend of meteorological parameters. The purpose of regression analysis is to predict the dependent variable through the independent variable. Therefore, the application of regression analysis in climate studies is measurement, analysis and prediction.

In the measuring stage, the data should be evaluated for regression analysis. Then, the conditions in each station should be evaluated. Finally, the relationship and the degree of change of the variables should be predicted. The coefficient of determination (R to the power of 2) shows the percentage of changes in the dependent variable by the independent variables and is explained by this regression model.

The level of significance (type 1 error) is a measure known as the significance level. If the relationship between the variables is less than 0.05, the probability of the relationship being by chance is very low and the relationship is significant, However, if it is more than 0.05, the relationship is likely to be random and not significant. Sig is the amount of error we commit in rejecting the initial assumption. The confidence level shows the frequency of the confidence interval that includes the desired parameter. In this research, the calculations were done at a significance level of 5% and a confidence level of 95%. The significance of jump points was evaluated by Mann-Whitney and Kruskal-Alice tests.

Mann-Whitney test for one jump and Kruskal-Wallis test for multiple jumps were used to evaluate the significance of jump points. These tests are available in SPSS software and performed with SPSS. The Mann-Whitney test is one of the hypothetical statistical tests between two independent groups. This test is a nonparametric and is not suitable for data with a normal distribution. The Kruskal-Wallis test is a nonparametric test used to compare three or more independent groups, which are measured at three rating levels.

Results and Discussion

Results of series randomness

In all the monthly and annual series for the last 65 years, the Mann-Kendall statistical value is greater than the critical value at the AqDarband Station, which shows trends and changes.

Table 1. Mann-Kendall statistics values for AqDarband station

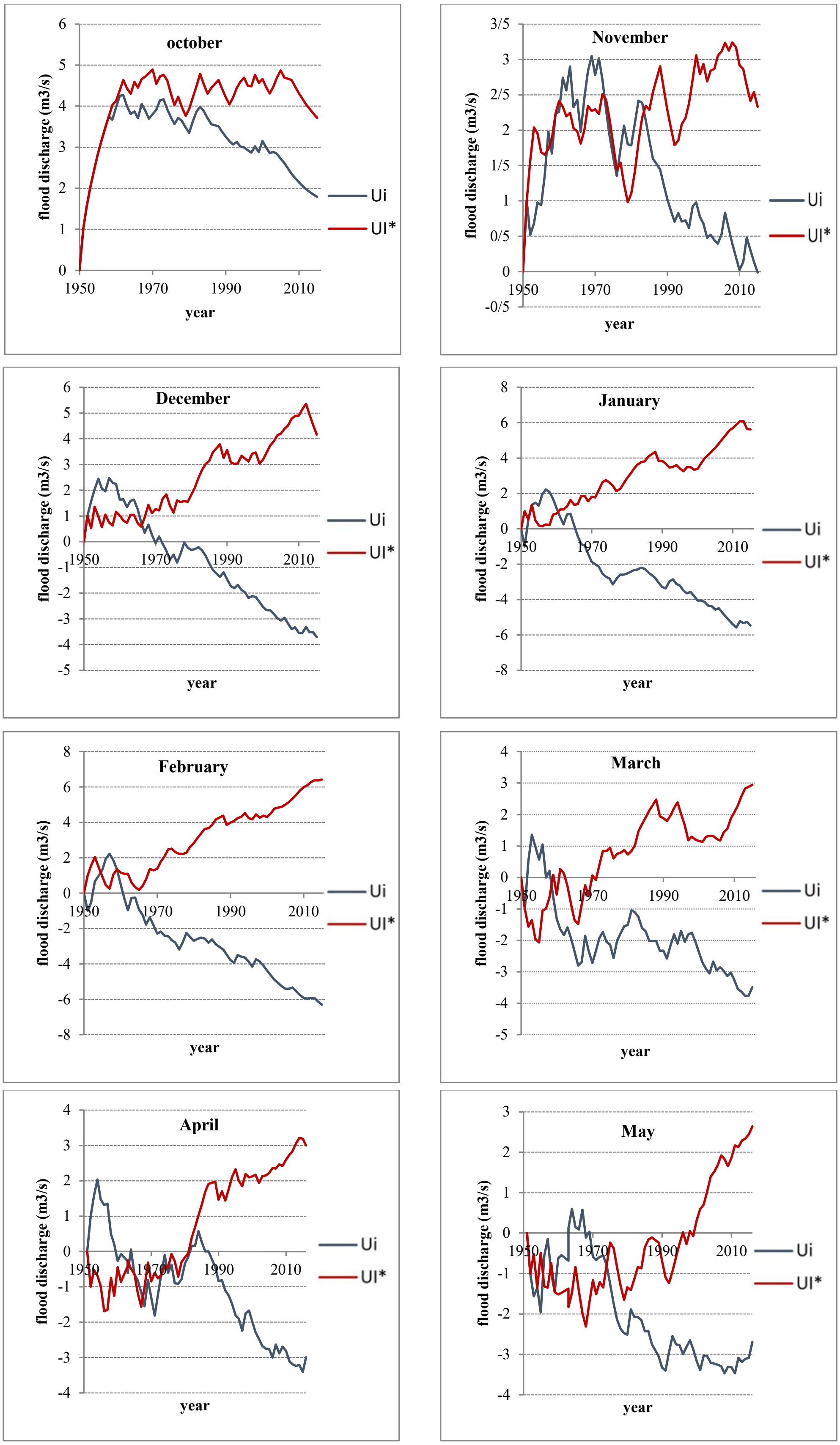
month	AgDarband station
January	0.539
February	0.469
March	0.704
April	0.749
May	0.779
June	0.807
July	0.882
August	1.035
September	1.117
October	1.17
November	0.981
December	0.684
Annual	0.691
critical	0.166

Mann- Kendall Graphical test

The results of the Mann- Kendall Graphical Test are presented in Table 2 and Figures 2-14. If the UV prime lines intersect within the critical range, it indicates a sudden jump, and if they intersect outside the critical range, it indicates a trend.

Graphical Mann- Kendall Test

In October 1954, the diagrams of u and u ́intersect each other out of the critical range, which indicates an increasing trend. In November 1960 and 1971, the diagrams of u and u ́ were overlapped each other which shows that there is no trend. In November 1981, the diagrams of u and u ́ intersected each other outside the critical range, which shows an increasing trend. In December 1966, the diagrams of u and u ́intersect each other within the critical range, which shows a sudden jump and change. In February 1954 and 1960 the diagrams of u and u ́intersect within the critical range, indicating a sudden jump and change. In March 1960, the diagrams of u and u ́intersect each other within the critical range, which shows a sudden jump and change. In April 1964, 1970, 1974 and 1981, the diagrams of u and u ́intersect each other within the critical range, which shows a sudden jump with oscillation. In May 1956, 1960 and 1974, the diagrams of u and u ́intersect each other within the critical range, which shows a sudden jump. In June1961 and 1971, the diagrams of u and u ́intersect each other within the critical range, which shows a sudden jump and change. In July1955, the diagrams of u and u ́intersect each other each other outside the critical range, which shows an increasing trend. In August 1956, the diagrams of u and u ́ intersected each other outside the critical range, which shows an increasing trend. In September 1956, the diagrams of and u ́intersect each other outside the critical range, which shows an


october
flood discharge (m3/s)
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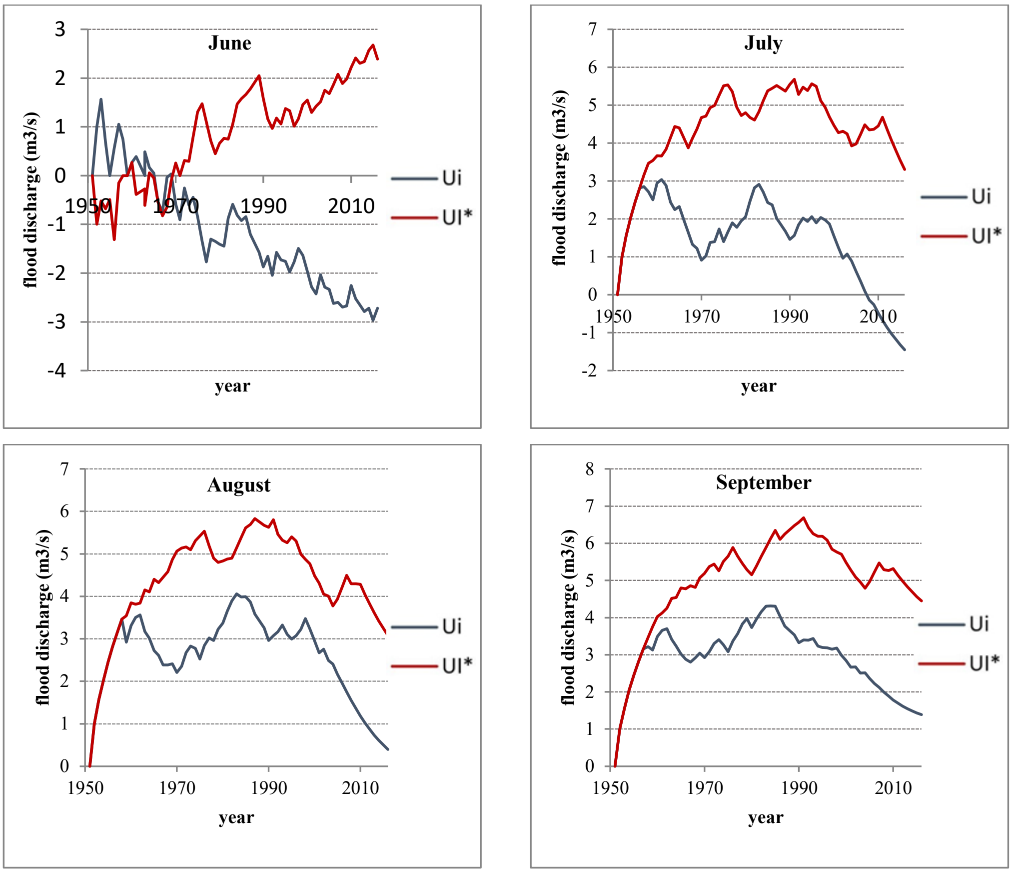

Figure 2. flood discharge (graphical Mann-Kendall test) in all months

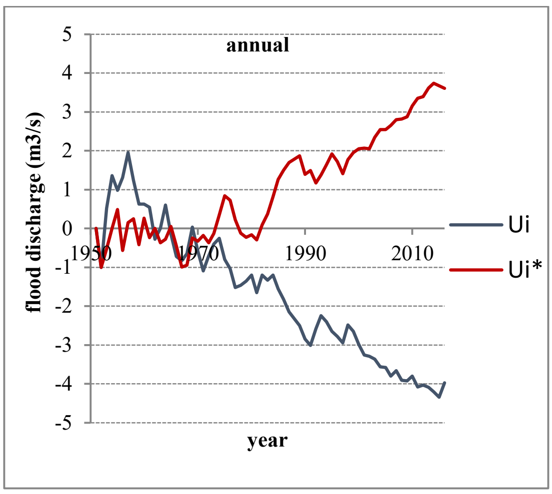

Figure 3. Annual chart of flood discharge (graphical Mann-Kendall test)

increasing trend.
In the annual series, the diagrams u and u´ in 1960 and 1968 intersect each other within the critical range, which shows a sudden jump and change.

Table 2. Summary of the Mann- Kendall test results

month	October	November	December	January	February	March	April	May	June	July	August	September	Annual
Aqdarband	TI	TI	CI	CI	CI	CD	CD	CD	CD	TI	TI	TI	CD
station	1954	1981	1966	1954	1954	1960	1960	1956	1961	1955	1956	1956	1960

*T indicates the trend, C indicates its sudden jump, I and D are symbols that shown increase and decrease of each

The extent and significance level of variation

The results obtained from the regression method are presented in Table 3. The value of r refers to the simple correlation between the two variables and in other words indicates the intensity of the correlation between the two variables. The value of R to the power of 2 indicates how much of the dependent variable by the independent variable. In most months, there is a moderate to weak correlation between the independent and dependent variables. The value of sig of the regression model shows that if the value obtained is less than 0.05, we conclude that the model used was a good predictor, In the monthly series of December, January, February and March and the annual series of the used model, it has been a good prediction. The results of Kruskal-Wallis and Mann-Whitney tests are presented in Table 4. Kruskal-Wallis and Mann-Whitney tests are used to evaluate the significance of the jump points. The value of sig of the Kruskal-Wallis and Mann-Whitney tests shows that if the value obtained is less than 0.05, the jump is significant. In most months, except November and June, the jump points are significant which shows that the jump points are not random and the effect of climate change is confirmed.

Table 3. Summary Results of Linear Regression Method

month	R^2	Sig
October	0.007	0.506
November	0.006	0.54
December	0.247	0.000
January	0.267	0.000
February	0.233	0.000
March	0.122	0.04
April	0.031	0.162
May	0.039	0.115
June	0.00	0.990
July	0.16	0.309
August	0.037	0.127
September	0.049	0.077
Annual	0.136	0.003

Conclusion

The planet's climate has lost its balance in recent decades, so the issue of climate change has attracted a lot of attention. In the study of climate change, long-term statistics can show changes to a large extent. The purpose of this study was to investigate the statistical trend of monthly and annual series, flood discharge of Kashafrood river basin . Therefore, statistical data of the last 65 years related to the monthly and annual series of the station were examined.

Table 4. The Summary of Mann-Whitney and Kruskal-Wallis Tests Results

month	Mann-Whitney test	Kruskal-Wallis Test
October	0.03	-
November	-	0.107
December	0.012	-
January	-	0.000
February	-	0.000
March	0.04	-
April	-	0.029
May	-	0.02
June	-	0.147
July	0.004	-
August	0.005	-
September	0.017	-
Annual	-	0.007

Increasing urban population along with climate change has led to an increased risk of flooding in cities. Therefore, assessing the impact of future climate change on floods and taking effective flood management measures is becoming increasingly important.

Mann-Kendall test was used to determine if the trend, type, and time of change were random or not. It was found that in 5 months of the year the upward trend and in 7 months of the year a sudden jump occurred. Mann-Whitney and Kruskal-Wallis tests were used to evaluate the significance of jump points, which were significant in most months except November and June.

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Conflict of Interest

The authors declare that they have no conflict of interests.

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