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Analyzing trends and exploring the correlation between runoff and precipitation in the Armand River Basin

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ABSTRACT

This study examines temporal trends and discharge patterns over 35 years in the Armand River Basin using data collected from synoptic and hydrometric stations (1986-2020). Statistical analysis and graphical tests like the Mann-Kendall test, Pearson correlation, and Spearman correlation were employed. Results show a notable negative trend in average annual and winter precipitation at the Shahrekord station since 1994 and 1996, respectively, with other stations exhibiting decreasing rainfall trends across all seasons without a clear pattern. The analysis of runoff trends across hydrometric stations in the Armand Basin indicates a significant decrease in both annual and seasonal runoff, particularly notable in the summer season. These trends align with observed changes in precipitation across different seasons, confirming the decreasing runoff trend. Pearson's and Spearman's correlation coefficients show a statistically significant correlation ($p < 0.05$) between runoff and precipitation, with coefficients of 0.612 and 0.595, respectively, supporting this relationship. Regression variance analysis confirms the linear assumption of this relationship, illustrated by scatter diagrams depicting the intensity, direction, and type of relationship between the two variables in the Armand River basin. The linear graphs indicate a positive relationship between precipitation and runoff in the basin. This is evident from the upward slope of the points, moving from left to right. Additionally, the concentration of points around the regression line suggests a strong and intense relationship between runoff and precipitation in the studied basin.

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1. Introduction

The global warming trend, coupled with disruptions in precipitation patterns, has garnered attention from leaders, politicians, scientists, and experts worldwide. Recognizing past, present, and future climate conditions is crucial for accurately planning and executing economic, construction, agricultural, industrial, and other plans at both micro and macro levels. Hence, incorporating climate research into planning is essential. The Armand basin is a sub-basin within the North Karun watershed. Here, the waters of the Vanak River, located to the west of Semirom City in Isfahan province, combine with those of Mashaikh. Seasonal and permanent waterways along the route contribute to the basin's water sources. The basin exits on its western sideClimate variations, including rising temperatures, alterations in precipitation patterns, diminished snow cover, and shifts in runoff, impact the hydrological cycle (IPCC, 2008). Consequently, there is a rise in average annual runoff in high-latitude regions and certain humid tropical areas, while it decreases in some arid areas within middle latitudes and dry tropical zones (IPCC, 2008). Changes in weather conditions contribute to the heightened occurrence of extreme events like floods and droughts.

Over the last century, dry areas worldwide have seen a more than 50% increase, and this trend is anticipated to grow by 30% by the year 2100 (Mata, 2008). In a study conducted by Farajzadeh and colleagues (2012), the impact of rainfall variability on surface runoff fluctuations in the Ferkhes catchment area was examined. The findings revealed a pattern of consecutive droughts in both rainfall and runoff within the basin, with an escalation in the severity of these drought events over recent years. There has been an overall decline in precipitation and discharge trends throughout the basin. Seasonally, the most significant monthly variations in surface runoff were observed during spring, particularly in April, while the fewest fluctuations occurred in late summer, attributed to reduced river flow during this period in the studied years. The Mann-Kendall test detected a negative and declining trend in flow measurements at certain stations, with some stations showing significant deviations beyond the 95% confidence interval, indicating localized climate changes at those stations. Meshkinnejad et al. (2013) examined the influence of climate change on runoff in the Dez Dam region, utilizing atmosphere-ocean general circulation models (AOGCM) for future periods. The IHACRES runoff-precipitation model was applied during the base period (2002-2011), with calibrated and validated results. Future year data were computed using the ClimGen model and CGCM3-AR4 model based on A2 and B1 scenarios. Introducing this data to the runoff-rainfall model yielded a 50% reduction in runoff in the dam area for the period 2091-2100. Farrokhnia et al. (2013) conducted a study assessing the influence of changes in precipitation and temperature on the flow of rivers connected to Lake Urmia. Their findings revealed a decreasing trend in discharge across all investigated stations, with nine showing significant declines. They also observed a direct impact of temperature and precipitation changes, leading to significant trends in discharge. Gandomkar and Raeisi (2013) explored the correlation between precipitation and runoff in the Gojan basin, originating from Karun's headwaters. Analyzing the monthly relationship between average rainfall and runoff at Varkash hydrometric station in the Gojan basin revealed its insignificance. However, a notable relationship emerged when establishing a link between monthly rainfall in the Gojan basin and runoff one month later at the Varkesh hydrometric station. Results from this correlation analysis indicated monthly water storage in the basin. This storage is attributed to two factors: firstly, the majority of precipitation from December to March is in solid form, leading to snow accumulation that transforms into runoff. Secondly, the region's geological structure, characterized by high ground permeability, allows a significant portion of precipitation to infiltrate the ground, causing delayed outflow from the basin. Examination of the annual relationship between rainfall and runoff demonstrated a significant connection, influenced by the same factors observed in the monthly rainfall-runoff relationship. Papadimitriou and colleagues' (2016) research on the mean discharge in five significant European watersheds, employing the RCP8.5 scenario and BC micro rotation method, revealed that the water cycle under this scenario approaches critical levels. Even in basins with minimal changes in average discharge, there is a decrease in discharge, leading to an increase in dry days.Bashir and colleagues (2016) explored the repercussions of climate change on Dinder River runoff in Sudan, employing the SWAT model and four atmospheric general circulation models from the fifth series. Two scenarios (RCP8.5 and RCP4.5) and two methods (CF and QM) were utilized for hydrological simulation. Comparing future runoff with the dry period of 1977-1988 revealed positive impacts of climate change on Dinder National Park's ecosystem. Santoz et al. (2017) examined the effects of 176 rainfall events, encompassing intensity, duration, and frequency, on runoff in three Brazilian basins with diverse uses. They emphasized the substantial influence of rainfall regimes on changes in surface runoff. In their research, Bahata et al. (2019) assessed the SWAT model's performance and altitude bands, quantifying the impact of climate change on flows in the Tamor River basin in the eastern Himalayas of Nepal. The findings indicated that under RCP8.5 scenarios, future climate may lead to a reduction in flow exceeding 8.5% during the 21st century. Radhapyari et al. (2021) highlighted in their study that recent years have seen a shift beyond discussions solely on water quantity and access, with an increasing focus on water quality in the context of climate change induced by global warming and extreme climatic events. They emphasized the undeniable impact of climate change on both the quantity and quality of water resources, concluding that the provision of drinking water will be influenced by this climatic. Phenomenon Ansari et al. (2017) explored temperature, precipitation, and discharge changes in the Cashew River in Sistan and Baluchistan province over a 20-year statistical period using the non-parametric Mann-Kendall test. The results indicated a declining trend in rainfall, an increasing trend in temperature, and a decreasing trend in river flow during this statistical period. Shakrian et al. (2018) examined the changing patterns of rainfall and river discharge in the Karun Begor basin, utilizing the TFPW-MK method across 74 meteorological stations and 46 hydrometric stations over three time periods: monthly, seasonal, and yearly. The findings revealed that, at an annual scale, 82% of the stations exhibited a declining trend. Specifically, the rainiest months (January, February, and March) demonstrated a decreasing trend, with March experiencing a decrease in more than 99% of the stations. The declining trend in rainfall changes within the catchment area corresponded to a reduction in river flow rates.Imani and colleagues (2019) conducted a study on the impact of climate change on the runoff of the Babelroud basin. They employed the WMS rainfall-runoff model to assess the effects of climate change on runoff characteristics. The model underwent calibration and validation using three and two precipitation events, respectively. The findings demonstrated the model's capability to accurately simulate peak discharge and runoff volume. Furthermore, it was observed that in the future, there will likely be an increase in rainfall during colder months and a decrease during warmer months. Overall, under various climate change scenarios, it is anticipated that both the discharge amount and flood volume will increase for rainfall events with different return periods. Naderi (2019) utilized the SWAT model to forecast the impact of climate change on the inflow discharge and reservoir volume of the Darudzen dam, located in the northern region of Fars province. The study indicated that the average annual rainfall in the catchment area is projected to decrease from 751 mm to 653 mm, 630 mm, and 624 mm under the three RCP2.5, RCP4.5, and RCP8.5 scenarios, respectively. Predictions for the dam's inflow under these scenarios suggest a reduction in the average annual inflow from 28.6 cubic meters to 14.9 cubic meters, 14.2 cubic meters, and 14.3 cubic meters. The research attributes this significant decrease to diminishing rainfall and increasing evaporation and transpiration in the dam's catchment area, exacerbating water resource shortages and intensifying crises in downstream areas of the dam. Mireshkaran and colleagues (2021) examined the impact of climate change on precipitation and temperature patterns within the Qarasu watershed in Kermanshah province. Utilizing AR4 models over thirty-year periods (2015-2044) and (2045-2075), the study assessed model accuracy. Findings indicated that the IPCLCM4.0 model displayed the highest accuracy in temperature estimation, while the GISS-ER model exhibited the greatest accuracy in precipitation estimation across the entire Qarasu basin. Analysis of temperature and precipitation changes revealed that summer and spring experienced the most significant increases in temperature, while winter exhibited the highest decline in precipitation.

Motameduziri and colleagues (2021) investigated the impact of climate change on groundwater recharge in the Karaj watershed. They utilized data from two global models, Hadcm3 and CGCM1, along with SDSM microscale models of climate variables across three periods: 2010-2039, 2040-2069, and simulated 2070-2098. Results from the simulation of climate variables under scenario A2 of climate change revealed an anticipated increase in temperature and solar radiation, along with a decrease in precipitation over the next three periods compared to the base period. Similarly, using the HELP model to simulate groundwater recharge under scenario A2, findings indicated a projected decrease of 9.6%, 15.1%, and 15.6% in recharge over the next three periods compared to the base period. Nami (2022) conducted an investigation into the climatic changes affecting the Jazmurian watershed. The study's findings suggest that over the next 50 years, the region can anticipate a temperature increase ranging from 1.5 to 2.1 degrees Celsius based on various scenarios. Salmanzadeh Yazdi and colleagues (2022) conducted a study titled "Modeling the Hydrological Behavior of the Hossein Abad Watershed in Kerman Province, Affected by Future Precipitation Changes." They emphasized the significant impact of climate change on watersheds, highlighting that the Hossein Abad watershed is expected to undergo changes in the future compared to the current period. The overall findings suggest that in arid ecosystems, shifts in precipitation patterns resulting from global warming will alter the hydrological behavior of basins. This alteration may lead to an increased likelihood of extreme events such as heavy precipitation and floods occurring during the winter and spring seasons. Lake and its surrounding areas utilizing remote sensing alongside the EVI, NDVI, and VCI indices. The findings revealed that by 2020, a greater expanse of land had transitioned into salty and barren classifications compared to 2000. Moreover, upon comparing the classes and values of these indicators between 2020 and 2000, there is a likelihood of a decline in index values, consequently indicating a further escalation of drought conditions in the region. In their research, Rajaei (2023) forecasted the future climate changes in the Tajen watershed. The study utilized statistical data on maximum temperature, minimum temperature, and precipitation from basin stations, alongside data from 14 models derived from general circulation models of the atmosphere under two scenarios. Two distinct time periods were analyzed: 2014-2040 as the future period and 1993-2013 as the base period. The findings indicated a reduction in rainfall during spring, autumn, and winter, coupled with an increase in summer rainfall. A shift in precipitation patterns was anticipated from autumn to summer. These projected changes are expected to impact the river flow regime, peak discharge timing, intensification of the water cycle, occurrence of large floods, frequency and severity of flood and drought events, as well as agricultural crop yields, among other factors. On the Snow Areas of the Northern Alborz Watershed" utilizing the CPA method. Their findings indicated that abrupt changes in global warming and meteorological drought between 2010 and 2014 resulted in significant alterations in the snow-covered area and temperature during these years. Furthermore, they discovered that the rise in temperature and alterations in climatic conditions had led to a decrease in winter precipitation, which typically contributes to snow accumulation. This reduction in snow accumulation is expected to impact summer runoff resulting from winter precipitation.

2. Material and Methods

The Armand River basin encompasses a significant portion of Chaharmahal and Bakhtiari provinces, including the cities of Shahrekord, Kohrang, Ardal, Farsan, Kiyar, Borujen, and Khanmirza, as well as a small section of Semirom city in Isfahan province. This river basin is characterized by several notable tributaries, with the most significant ones being the Behesht Abad River and the Sabzkoh River. The most significant tributaries within the Armand river basin are the Behesht Abad River and the Sabzkoh River. Geographically, the studied Armand basin extends between longitude 49 degrees 34 minutes to 51 degrees 47 minutes east and latitude 31 degrees 18 minutes to 32 degrees 40 minutes north. With a total area of 9961 square kilometers, it serves as the primary water source for Chaharmahal and Bakhtiari province, boasting an average annual rainfall of approximately 100 cubic meters per second. The average elevation of the watershed is 1039 meters above sea level, and its precipitation pattern is characterized as snowy, with an annual average rainfall exceeding 600 mm. Thanks to its rugged terrain and abundant snow catchment areas, this basin is renowned as one of the most water-rich regions in Iran. Notably, it serves as the origin of the country's most significant river, the Karun. As a result, the Armand basin holds a crucial position in the management of Iran's water resources (Consulting engineers, 1988; Natural Resources Research Center, 1999). The Armand river basin, encompassing significant tributaries such as the Behesht Abad River and Sabzkoh River, holds paramount importance as the primary water source for Chahar Mahal and Bakhtiari province. With an average annual rainfall of approximately 100 cubic meters per second, this basin serves as a crucial water reservoir for the region. The average elevation of the basin is 1039 meters above sea level, and its precipitation pattern is characterized by snowfall and rainfall, with an annual average rainfall exceeding 600mm. The Armand watershed boasts a diverse climate owing to its unique geographical and topographic characteristics, encompassing various climatic zones within its boundaries. Rainfall patterns in the region are primarily influenced by Mediterranean atmospheric currents and predominantly the Sudanese low-pressure system. These weather systems typically enter the basin from the west and southwest, exerting their influence over the region for approximately 8 months, spanning from

October to May. The presence of the Zagros mountain range, positioned perpendicular to the direction of these atmospheric currents, intensifies their cyclonic nature, resulting in heavy rainfall occurrences throughout the area. Atmospheric precipitation in the Armand basin typically occurs from early October through May, as noted by Omidvar et al. (2012) and Dastar et al. (2014). The western heights, particularly the Zardkoh Heights, receive the highest average annual rainfall in the basin, amounting to approximately 1600 millimeters. Additionally, the Sabzkoh highlands experience substantial precipitation, averaging around 1400 millimeters annually, while the southwest highlands near Lordegan city receive approximately 900 millimeters of rainfall on average. Conversely, the eastern parts of the basin, including Shahrkord and Borujen stations, receive the lowest annual rainfall, ranging between 250 and 300 millimeters (Omidvar et al., 2013).

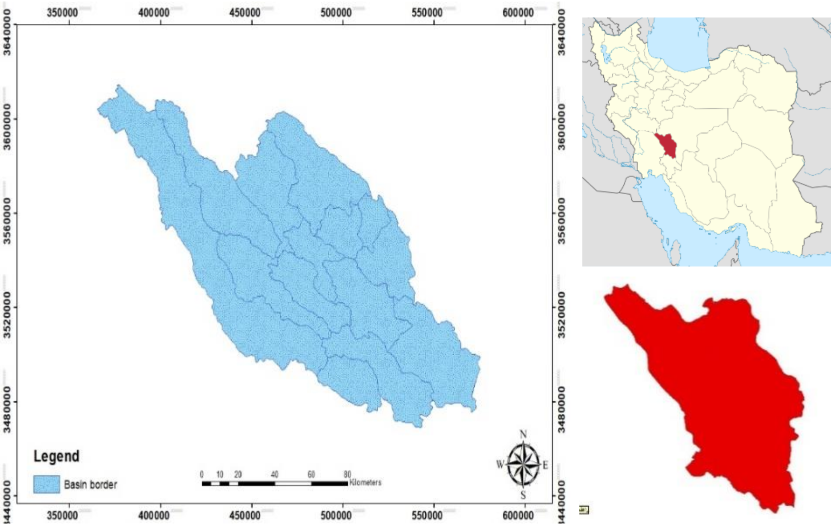

Fig. 1. Depicts the location of the study basin within chaharmahal and Bakhtiari province and its position within the country

2.1. Methods and tools of information gathering

Nonparametric methods are widely employed for assessing significant changes in hydrometeorological time series data. Unlike parametric statistical methods, nonparametric methods are preferred when dealing with data that do not adhere to a normal distribution, which is often the case with many hydrometeorological factors. One commonly used nonparametric method for this purpose is the Kendall rank correlation coefficient (Kendall's tau). This method is robust and does not rely on assumptions about the distribution of the data, making it well-suited for detecting trends or changes in time series data, especially in the context of hydrology and meteorology. To conduct this research, rainfall statistics were gathered from the General Directorate of Meteorology of Chaharmahal and Bakhtiari Province. Additionally, data concerning the discharge of the studied basin were acquired from the General Directorate of Water in Chaharmahal and Bakhtiari Province. In this research, after reconstructing the missing data, the investigated period (1986-2020) was subjected to statistical analysis. Initially, analysis of variance (ANOVA) was conducted to uncover trends in rainfall and runoff changes. Subsequently, non-parametric tests such as the Kendall correlation coefficient were employed to assess the correlation and significance of the relationship between rainfall and runoff. Additionally, the Pearson and Spearman correlation coefficients were utilized for further examination of the relationship between these variables. Moreover, the linear regression method was employed to explore potential linear trends in the data over time. In this study, the method of differences and ratios, as outlined by Alizadeh (2014), was employed for data reconstruction. This method utilizes statistics from base stations, which are stations with complete and reliable data within the region (Eq. 1).

A: The method of ratios to reconstruct rainfall data in which:

$$X = bx\frac{\overline{x}a}{\overline{x}b} \quad (1)$$

X: Rainfall per year without statistics.

$\bar{x}a$: Average rainfall in common statistical years for stations without statistics.
$\bar{x}b$: Average rainfall in common statistical years for the base statio.
bx: amount of rainfall in the desired year at the base station.
Reconstruction of hydrological data.
In order to reconstruct the discharge data of the hydrometric station, the statistics of the upstream station have been used. The statistical method used was the ratio method (Eq. 2):

$$Q = qb\frac{\overline{qa}}{\overline{qb}} \quad (2)$$

Q: The flow rate per month does not have statistics.
$\overline{q}a$: Average discharge in the desired month and in common statistical years for the station without statistics.
$\overline{q}b$: Average discharge in the desired month in common statistical years for the base statio.
qb: Debit in the desired month and in the desired year at the base station.

2.2. The studied meteorological and hydrological stations.

To explore the relationship between runoff and precipitation in the Armand river basin, data from both synoptic and hydrometric stations were utilized over a 35-year statistical period (1986 to 2020). The synoptic stations used for precipitation data collection include Shahrekord, Kohrang, Borujen, and Lordegan. Meanwhile, the hydrometric stations within the basin, namely Armand, Behesht Abad, Kareh Bas, and Koh Sokhte, were employed to analyze runoff patterns. The specifications and locations of these stations are detailed in Table (1), while their spatial distribution is visualized in Fig 2.
In order to extract the average monthly and annual rainfall of the basin during the desired statistical period, the average annual rainfall of the basin was drawn by using the interpolation of the basin's rainfall map in the mentioned statistical period. Using multivariate statistical analysis, especially regression and correlation, the relationship between runoff and precipitation in the basin has been investigate.

Table 1. Characteristics of synoptic and hydrometric stations of the studied basin

Station type	Station name	Latitude utm	Longitude utm	Above sea level	Statistical period
Synoptic	Shahr e Kord	3571851	485875	2048	1986-2020
	Kohrang	3588812	416957	2285	1986-2020
	Borojn	3534932	528352	2197	1986-2020
	lordegan	3486878	482592	1580	1986-2020
Hydrometric	Armand	3503943	478250	1039	1986-2020
	Behesht Abad	3543882	464984	1695	1986-2020
	Karebas	3490299	519563	1790	1986-2020
	Khosokhte	3550398	468545	1977	1986-2020

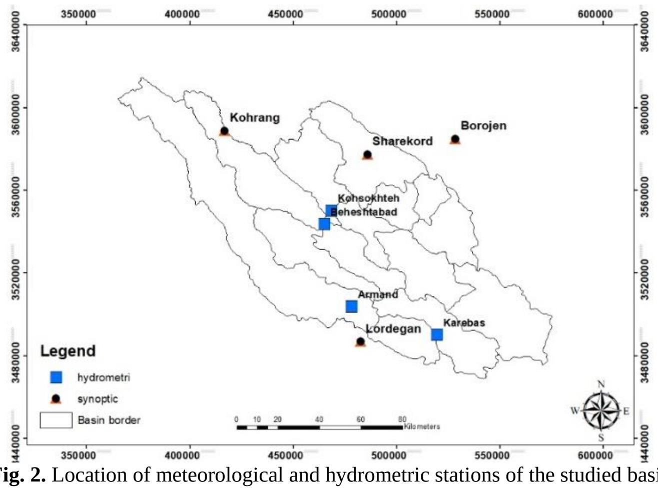

Fig. 2. Location of meteorological and hydrometric stations of the studied basin

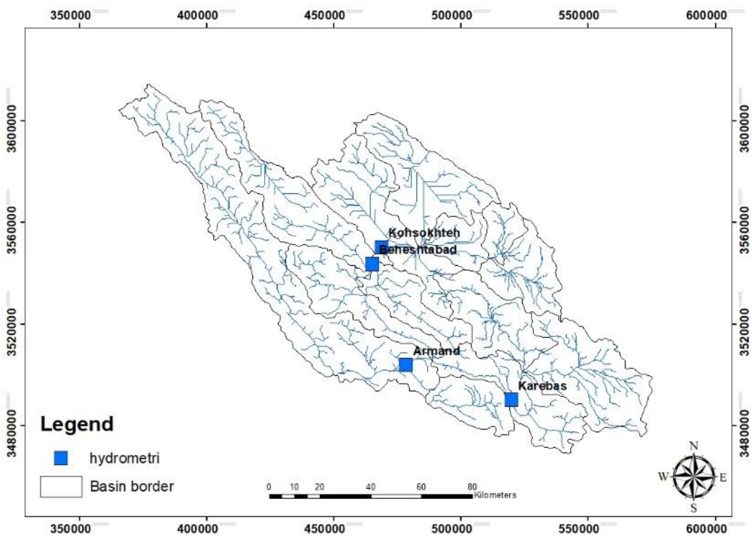

Fig. 3. The waterways network of the studied basin

3. Results and discussion

The Armand River Basin possesses numerous significant tributaries, with the Behesht Abad River and Sabzkouh River ranking as the most notable among them. Serving as the primary water resource for Chahar Mahal and Bakhtiari province, this basin exhibits an average annual rainfall of approximately 100 m^3sec^{-1}, making it a crucial water reservoir for the region. The basin experiences a mixed precipitation regime characterized by snowfall and rainfall, contributing to an average annual precipitation exceeding 600mm.

The analysis of precipitation data for the Armand River Basin was conducted using both graphical and statistical methods, specifically the Mann-Kendall test.

Fig 4 illustrates the trend of precipitation in the basin over a period of 35 years. The z-statistic derived from the Mann-Kendall test is plotted on the vertical axis of the graph. Upon examination of Fig 4, it is observed that the U and U' lines, which commenced in 1987 and 1994 respectively, intersect within the range of +1.96 and -1.96. This intersection indicates that the rainfall series in the Armand basin demonstrates a decreasing trend, albeit without a clear pattern. In summary, the analysis suggests a decreasing trend in precipitation for the Armand River Basin, but without a discernible pattern. This information is crucial for understanding the hydrological dynamics of the basin and informing water resource management decisions in the region.

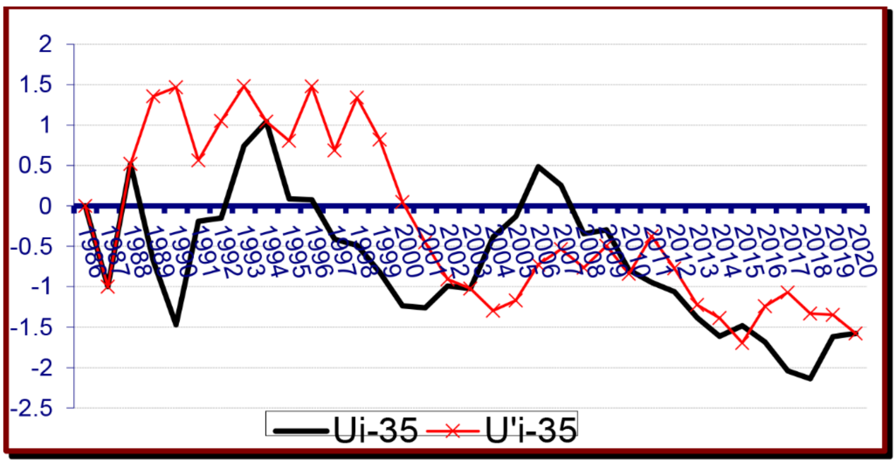

Fig. 4. Illustrates the annual precipitation trend of the studied basin over a statistical period of 35 years

Table 2 presents the statistical analysis of average annual and seasonal rainfall data from four synoptic stations within the Armand basin. According to the results, Kohrang and Boruj stations exhibit the highest and lowest average annual rainfall, with values of 1351.48±62.01

mm and 250.32±12.43 mm, respectively, during the study period. The average annual rainfall for the entire Armand basin is calculated to be 619.53±25.47 mm, with recorded minimum and maximum annual rainfall values of 264.55 mm and 909.35 mm, respectively, over the same period. Furthermore, the average precipitation for each season is estimated as follows: 314.45±19.99 mm for winter, 94.66±7.56 mm for spring, 2.18±0.45 mm for summer, and 208.09±15.64 mm for autumn. These findings provide valuable insights into the spatial and temporal distribution of rainfall within the Armand basin, facilitating informed decision-making and water resource management strategies in the region.

Table 2. Descriptive statistical results of average annual and seasonal precipitation of synoptic stations, Armand watershed (statistical period 1986-2020)

Station	Annual-seasonal	Year	Domain	min	max	Average	S.E	S.D	Variance
	Annual	35	401.00	126.50	527.50	309.6343	16.35658	96.76686	9363.825
	Winter	35	261.40	28.30	289.70	148.2057	10.97160	64.90887	4213.161
Shahr e Kord	Spring	35	126.80	.90	127.70	52.7600	5.39843	31.93751	1020.005
	Summer	35	11.70	.00	11.70	1.6229	.48779	2.88578	8.328
	Autumn	35	244.40	11.30	255.70	107.0457	10.67619	63.16122	3989.340
	Annual	35	367.10	93.60	460.70	250.3207	12.43538	73.56868	5412.350
	Winter	35	226.70	18.50	245.20	124.0565	9.22111	54.55282	2976.010
Borojen	Spring	35	94.60	1.40	96.00	42.5197	4.09257	24.21200	586.221
	Summer	35	15.20	.00	15.20	1.4465	.47096	2.78626	7.763
	Autumn	35	157.60	11.10	168.70	81.5034	7.61840	45.07104	2031.399
	Annual	35	1474.60	565.40	2040.00	1351.4803	62.01955	366.91262	134624.868
	Winter	35	1137.70	243.60	1381.30	697.2144	47.40832	280.47142	78664.217
Kohrang	Spring	35	401.50	13.40	414.90	206.5358	16.90485	100.01042	10002.083
	Summer	35	21.00	.00	21.00	3.9307	.98638	5.83548	34.053
	Autumn	35	874.90	89.60	964.50	443.7995	32.83402	194.24869	37732.552
	Annual	35	567.80	272.70	840.50	566.7086	21.85960	129.32311	16724.467
	Winter	35	432.60	81.20	513.80	288.3257	17.45978	103.29348	10669.543
lordegan	Spring	35	221.80	4.10	225.90	76.8571	8.50098	50.29248	2529.333
	Summer	35	16.50	.00	16.50	1.7429	.57914	3.42622	11.739
	Autumn	35	415.80	21.40	437.20	200.0200	17.44397	103.19993	10650.226
	Annual	35	644.80	264.55	909.35	619.5360	25.47921	150.73704	22721.655
	Winter	35	476.95	95.78	572.73	314.4506	19.99318	118.28127	13990.459
	Spring	35	164.50	4.95	169.45	94.6682	7.56256	44.74072	2001.732
Total basin	Summer	35	10.38	.00	10.38	2.1857	.45715	2.70454	7.315
	Autumn	35	378.58	43.15	421.73	208.0921	15.64266	92.54324	8564.252

Table 3. Calculation of the annual and seasonal precipitation trends of the studied basin based on the Mann-Kendall coefficient during a period of 35 years.

	Annual-seasonal	**Statistical period**	**Test Z**	**The significance level**
Total basin	Annual	35	-1.56	It is not meaningful
	Winter	35	-1.65	It is not meaningful
	Spring	35	0.68	It is not meaningful
	Summer	35	1.14	It is not meaningful
	Autumn	35	-0.48	It is not meaningful

To analyze the trend of runoff series in the Armand River Basin, statistical and graphical tests of Mann-Kendall were conducted. The average annual discharge of the Armand River Basin over the 35-year statistical period was calculated as 29.3 cubic meters per second. Throughout the same timeframe, the average minimum and maximum annual discharge for the basin were reported as 0.7 and 84.785 cubic meters per second, respectively. Furthermore, the average discharge for each season during the investigated period was determined as follows. Winter: 41.79 cubic meters per second. Spring: 46.28 cubic meters per second. Summer: 12.21 cubic meters per second. Autumn: 17.3 cubic meters per second. These findings provide valuable insights into the hydrological characteristics of the Armand River Basin. Analyzing the trend of runoff series using statistical and graphical tests such as Mann-Kendall can help in understanding any potential changes or patterns in discharge over time. During the statistical period, the Armand station exhibited the highest discharge among all stations in spring, averaging 137.7 $m^3 sec^{-1}$. Conversely, the Koh Sokhteh station recorded the lowest discharge among all stations during the same season, with an average of 6.74 cubic meters per second. Analysis of the hydrometric data revealed that April and March were the wettest months, while October and September were the least wet months of the year across the stations in the studied basin. Specifically, the Armand station experienced the highest water levels in April, while the Koh Sokhteh station had the lowest water levels in the same month. These findings highlight the variability in discharge levels among different stations within the Armand River Basin, with certain stations exhibiting significantly higher or lower discharges compared to others during specific seasons. Such insights are crucial for understanding the hydrological dynamics of the basin and for effective water resource management planning. Fig. 6 illustrates the annual runoff trend of the entire Armand River Basin. Analysis of the U and U' components for the average annual runoff during the period from 1986 to 2020 indicates a significant decrease in the amount of runoff in the Armand River.

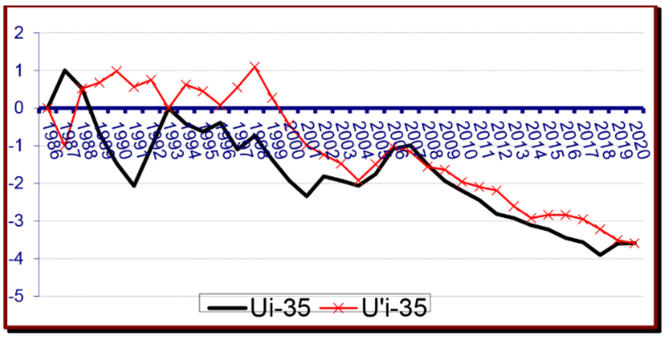

Fig. 5. Depicts the annual trend of Armand River discharge over the 35-year statistical period

The results of the Mann-Kendall test indicate a decreasing trend in the average annual and seasonal runoff of the Armand River across all hydrometric stations within the studied basin. The decreasing trend is evident even at the Armand hydrometric station. The Z-statistics for average annual runoff and the winter, spring, summer, and autumn seasons were -3.35, -2.90, -3.18, -4.32, and -4.18, respectively. This indicates a significant decrease in discharge across all seasons, with the most substantial decline observed in the summer season (Z = -4.32). At the BeheshtAbad station, there has been a consistent decrease in average annual runoff as well as during different seasons (winter, spring, summer, and autumn). The Z-statistics for average annual discharge and the winter, spring, summer, and autumn seasons were -3.21, -2.67, -2.95, -4.35, and -3.38, respectively. This indicates a significant decline in discharge across all seasons, with the most notable decrease observed in the summer season (Z = -4.35), followed by the autumn season. At the Koh Sokhte station, there is a consistent decreasing trend in both average annual and seasonal runoff. The Z-statistics for average annual runoff and the winter, spring, summer, and autumn seasons were -4.69, -4.18, -3.78, -5.20, and -3.79, respectively. Among these seasons, the most significant decrease in runoff occurred during the summer season (Z = -5.20), which represents the highest decline among all stations within the Armand basin (refer to Table 3). At the Kare Bas station, similar to other stations within the basin, there has been a notable decrease in both average annual and seasonal runoff (winter, spring, summer, and autumn). The Z-statistics for the average annual discharge and the winter, spring, summer, and autumn seasons were estimated as -3.49, -3.24, -3.18, -3.64, and -4.57, respectively. The most substantial decrease in discharge was observed during the autumn season (Z = -4.57), followed by the summer season. Overall, the average annual and seasonal runoff across the studied basin has exhibited a significant decreasing trend. The Z-statistics for the average annual runoff and the winter, spring, summer, and autumn seasons across the entire basin are estimated as -3.68, -3.24, -3.27, -4.37, and -3.98, respectively. This indicates that the highest decrease in Armand River runoff occurred during the summer season (Z = -4.37), followed by the autumn season. The descriptive statistics of the average annual and seasonal runoff of the Armand Basin are presented in Table 5, while Table 6 illustrates the type and timing of changes in the annual and seasonal runoff of the Armand Basin based on the Mann-Kendall graphic test. Additionally, Fig 7 illustrates the discharge trend of the Armand hydrometric station over a 35-year period. The graphical test results and examination of changes in the U and U' components reveal a significant and decreasing trend in the amount of annual runoff during the investigated period from 1986 to 2020. This decreasing trend commenced in 1988 and persisted until 2020.

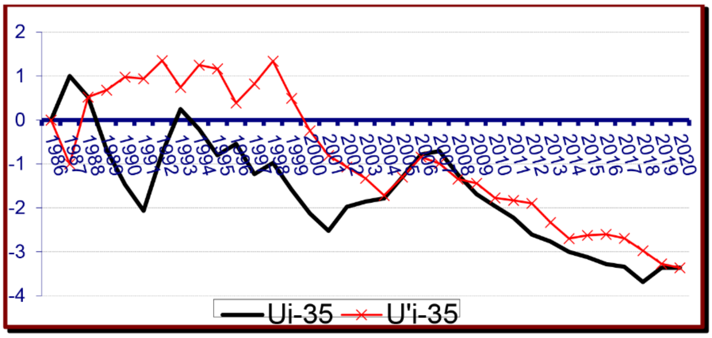

Fig. 6. Depicts the annual discharge trend of the Armand hydrometric station over the 35-year statistical period within the Armand River Basin

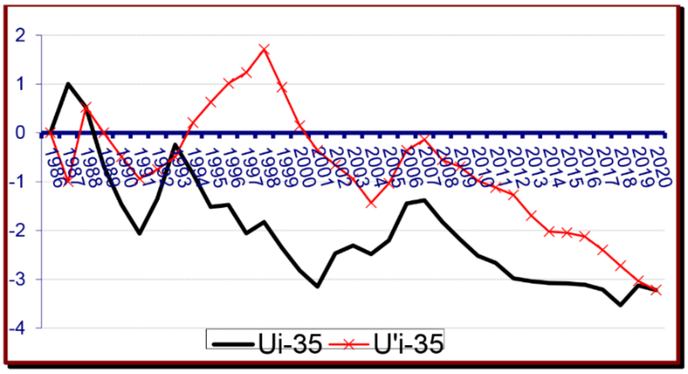

Fig. 7. Illustrates the discharge trend of the Armand River at BeheshtAbad station over a period of 35 years.

The results of Kendall's graphic test and the changes in the U and U' components in this station also indicate a negative and significant trend in the amount of annual runoff of the Armand River, which began in 1993. The Mann-Kendall graphic test for the amount of runoff (discharge) reveals a negative and significant jump in the years 1991, 1992, and 1988, respectively.

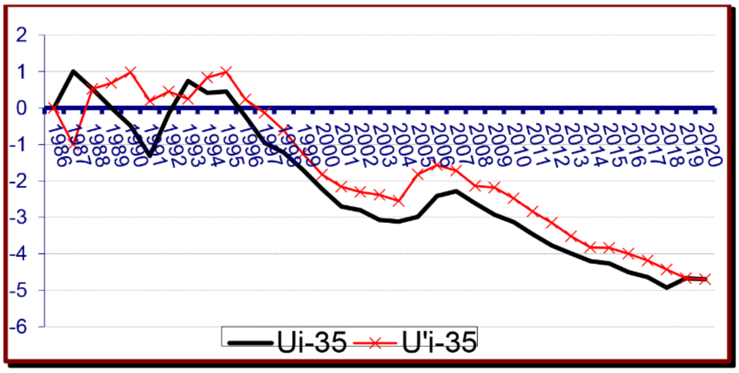

Fig. 8. Illustrates the discharge trend of the Armand River at Kouh Sukhateh station over a period of 35 years**.**

The results of Kendall's graphical test and the changes in the U and U' components of the Kouh Sukhateh hydrometric station in Fig 8 indicate a significant and decreasing trend in the annual runoff of the Armand River during the study period. This trend began in the year 1992 and persisted until 2020. The examination of river runoff at the kare Bas station for other months of the year has revealed a significant decreasing trend at the probability level of 1%. Fig. 9 illustrates the results of the graphical test and examination of the changes in the U and U' components at the Kareh-Bas station, indicating a negative and significant trend in the amount of annual runoff during the studied period. This trend occurred in 1991. The Mann-Kendall graphic test for the amount of runoff (discharge) in winter, spring, summer, and autumn also reveals a significant and decreasing trend in 1992, 1993, 1993, and 1991, respectively, over the period from 1986 to 2020.

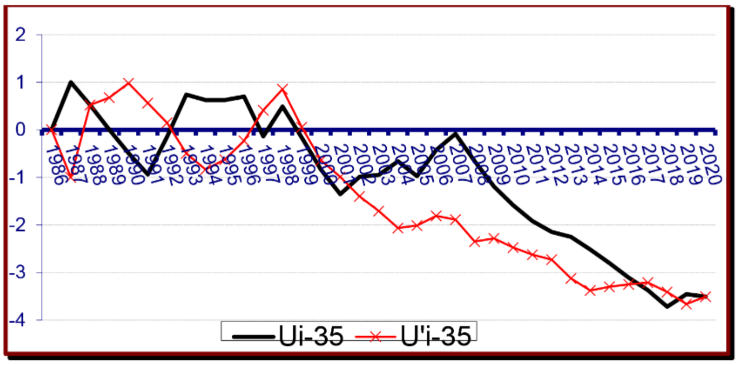

Fig. 9. Depicts the annual discharge trend of the Kareh-Bas hydrometric station over the 35-year statistical period.

Table 4. Results of Mann-Kendall test for the average annual and seasonal runoff of the studied basin.

station	Annual Seasonal	Kendall's tau	Alpha	Test interpretation
	Annual	-3.35	0/05	Decreasing trend
Armand	Winter	-2.90	0/05	Decreasing trend
	Spring	-3.18	0/05	Decreasing trend
	Summer	-4.32	0/05	Decreasing trend
	Autumn	-4.18	0/05	Decreasing trend
	Annual	-3.21	0/05	Decreasing trend

Beheshtabad	Winter	-2.67	0/05	Decreasing trend
	Spring	-2.95	0/05	Decreasing trend
	Summer	-4.35	0/05	Decreasing trend
	Autumn	-3.38	0/05	Decreasing trend
	Annual	-4.69	0/05	Decreasing trend
Kouh Sukhateh	Winter	-4.18	0/05	Decreasing trend
	Spring	-3.78	0/05	Decreasing trend
	Summer	-5.20	0/05	Decreasing trend
	Autumn	-3.79	0/05	Decreasing trend
	Annual	-3.49	0/05	Decreasing trend
Kareh Bas	Winter	-3.24	0/05	Decreasing trend
	Spring	-3.18	0/05	Decreasing trend
	Summer	-3.64	0/05	Decreasing trend
	Autumn	-4.57	0/05	Decreasing trend
	Annual	-3.68	0/05	Decreasing trend
Total basin	Winter	-3.24	0/05	Decreasing trend
	Spring	-3.27	0/05	Decreasing trend
	Summer	-4.37	0/05	Decreasing trend
	Autumn	-3.98	0/05	Decreasing trend

Table 5. Descriptive statistical results of average annual and seasonal runoff of Armand basin

Station	**Annual Seasonal**	**Statistical eriod**	**Min**	**Max**	**Average**	**Standard error**
Total basin	Annual	35 years	5.28	84.85	29.39	2.16
	Winter	35 years	1.19	250.6	41.79	3.58
	Spring	35 years	1.17	350.3	46.28	3.94
	Summer	35 years	0.022	101.7	12.21	.90
	Autumn	35 years	0.54	25.21	17.3	1.33

Table 6. Descriptive statistics table of precipitation and discharge of Armand Basin

Precipitation and discharge at the stations	**Average**	**Standard deviation**	**Year**
Precipitation at Shahr-e Kord station	309.6343 mm	96.76686	35
Precipitation at Boroujen station	250.3207 mm	73.56868	35
Precipitation at Kouhrang station	1351.4803 mm	366.91262	35
Precipitation at Lordgan station	566.7086 mm	129.32311	35
Total basin precipitation	619.5360 mm	150.73704	35
The station discharge at Beheshtabad	15.9058 m^3/s	7.93813	35
The station discharge at Koh Sokhte	5.2827 m^3/s	3.63154	35
The station discharge at Armand	84.8514m^3/s	34.64570	35
The station discharge at Kareh Bas	11.5349 m^3/s	5.99968	35
The total basin discharge	29.3937 m^3/s	12.79934	35

To analyze the relationship between runoff and precipitation in the Armand river basin, both Pearson and Spearman correlation tests were conducted.

The correlation relationship examines the relationship between two or more variables and calculates its coefficient. The correlation between variables may be positive or negative. If the changes of one variable are accompanied by the changes of another variable and the increase of one is accompanied by the increase of another or the decrease of one is accompanied by the decrease of another, the correlation between them will be positive. Pearson's correlation test is one of the most common correlation coefficient tests and the following formula is used to calculate its coefficient (Eq. 3):

$$R_{x,y} = \frac{\sum xy}{NSxSy} \quad (3)$$

In this formula, rx, y is the correlation between x and y variables, N is the number of subjects, Sx is the standard deviation of x scores and ∑xy scores, the sum of the difference between the scores from the mean and Sy is the standard deviation of y scores.

Table 7. The correlation between rainfall and discharge as determined by Pearson's correlation coefficient

		precipitation	runoff
precipitation	Pearson Correlation	1	.612**
	Sig. (2-tailed)		.000
	N	35	35
runoff	Pearson Correlation	.612**	1
	Sig. (2-tailed)	.000	
	N	35	35

** Correlation is significant at the 0.01 level (2-tailed).

The provided results display the Pearson correlation coefficient along with the significance level (sig) and the number of data points. With a sig value below 0.05, the null hypothesis (H_0) is rejected, indicating acceptance of the correlation between runoff and precipitation in the Armand basin. This suggests that the reduction in rainfall in this basin has led to a decrease in river flow and runoff during the specified statistical period. Consequently, the correlation coefficient of 0.612 for 35 data points is significant, affirming the existence of a correlation between runoff and precipitation.

Table 8. The association between precipitation and discharge assessed using Spearman's correlation coefficient.

			run	per
Spearman's rho	run	Correlation Coefficient	1.000	.595**
		Sig. (2-tailed)	.	.000
		N	35	34
	per	Correlation Coefficient	.595**	1.000
		Sig. (2-tailed)	.000	.
		N	34	34

** Correlation is significant at the 0.01 level (2-tailed).

The provided output presents Spearman's correlation coefficient along with the significance level (sig) and the number of data points. The results obtained from Spearman's method are akin to those from Pearson's method, with a correlation coefficient of 0.595. With a significance level below 0.05, the null hypothesis (H_0) is rejected, indicating acceptance of the correlation between runoff and precipitation in the Armand basin. Consequently, the correlation coefficient of 0.595 for 35 data points is significant, affirming the existence of a correlation between runoff and precipitation.

Linearity of the relationship between rainfall and runoff variables in Armand river basin (scatter diagram)

To assess the linearity of the relationship between rainfall and runoff variables in the Armand river basin, a scatter diagram can be constructed. This type of plot is a straightforward method to visually inspect the correlation and relationship between two variables. By plotting rainfall values on the x-axis and runoff values on the y-axis, each data point represents a pair of values for a specific time period. The scatter diagram provides a visual representation of the relationship between the variables. By examining the distribution of points on the plot, you can determine the type (linear or non-linear) and direction (positive or negative) of the relationship, as well as its intensity. If the points on the scatter plot form a clear pattern or trend that follows a straight line, it suggests a linear relationship between rainfall and runoff variables. On the other hand, if the points are scattered randomly without following a distinct pattern, it indicates a weak or non-linear relationship. By analyzing the scatter diagram, you can gain insights into the nature of the relationship between rainfall and runoff variables in the Armand river basin.

Table 9. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2082.898	1	2082.898	19.711	.000[b]
	Residual	3487.086	33	105.669		
	Total	5569.984	34			

a. Dependent Variable: KolRun
b. Predictors: (Constant), Kolpercipitation

The above Fig contains regression variance analysis in order to check the certainty of the existence of a linear relationship between the two variables of discharge (runoff) and precipitation of the Armand River basin. The statistical hypotheses of the significance test of the entire regression model are as follows:

H0: There is no linear relationship between two variables

H1: There is a linear relationship between two variables

Considering that sig is less than 5% in the upper output, therefore, the linearity of the relationship between the two variables of runoff and precipitation in Armand basin confirmed. The distribution of points in the following scatter diagrams showed the intensity, direction and type of relationship between two variables. In the graphs below, considering that the slope of the points is from left to right and upwards (ascending), the relationship between precipitation and runoff is positive. Likewise, due to the density of points and their concentration around the regression line, it indicates the existence of intensity and strong relationship between runoff and precipitation in hydrometric stations of the studied basin. Indeed, the upward (ascending) slope of the points on the graphs indicates a positive relationship between precipitation and runoff. This means that as precipitation increases, runoff also tends to increase, which is consistent with what one would expect intuitively. Moreover, the density of points and their concentration around the regression line further support the notion of a strong and intense relationship between runoff and precipitation in the hydrometric stations of the studied basin. When points are tightly clustered around the regression line, it suggests that the majority of data points are closely aligned with the predicted values of the regression model. This alignment indicates that the model accurately captures the relationship. Between the variables and that the observed variations in runoff can largely be explained by changes in precipitation. In summary, the positive slope and the tight clustering of points around the regression line in the graphs provide evidence of a strong and positive relationship between precipitation and runoff in the Armand River basin.

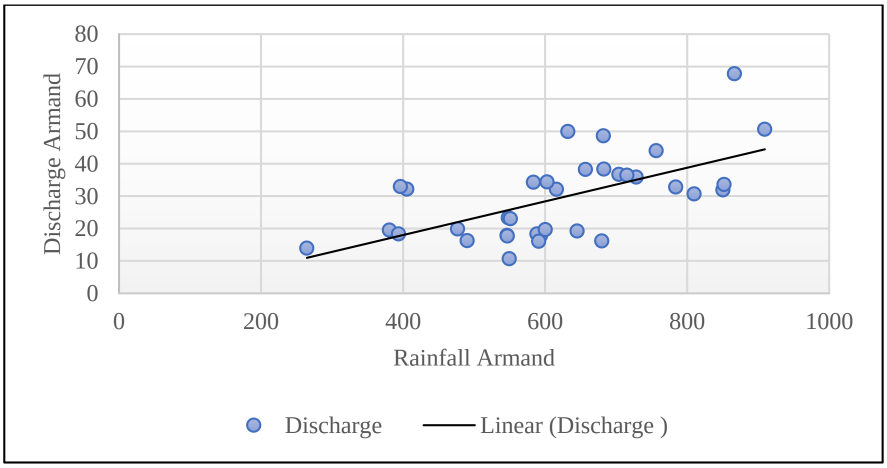

Fig. 10. The relationship diagram between discharge and rainfall in the Armand River basin

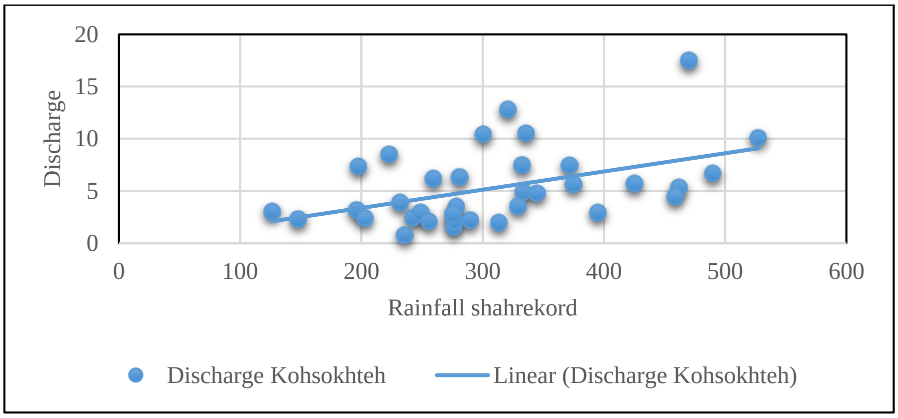

Fig. 11. The relationship diagram between discharge at Koohsokhte station and rainfall in Shahrekord

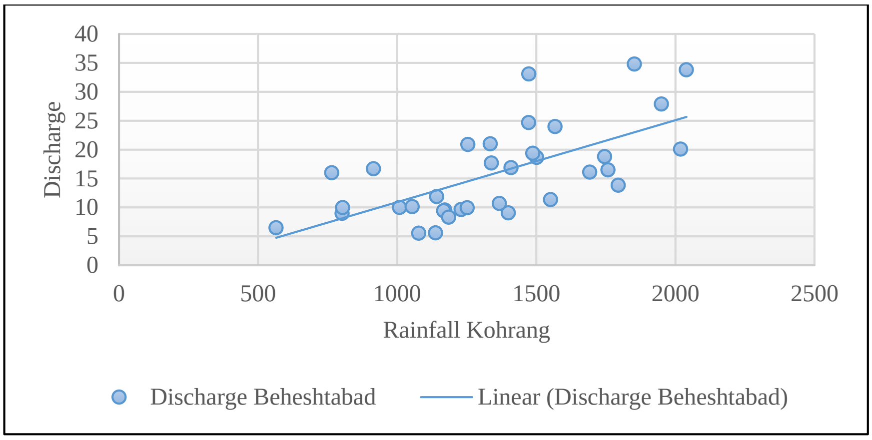

Fig. 12. The relationship diagram between discharge at Kareh bas station and rainfall in Borojen

4. Conclusion

Climate change is characterized by a variety of interconnected phenomena, including rising temperatures, shifts in precipitation patterns, diminishing snow cover, and alterations in runoff and the hydrological cycle. These changes have diverse impacts across different regions and climatic zones. In high latitude areas and certain humid tropical regions, the average annual runoff is on the rise. Conversely, in some medium latitude dry areas and dry tropical regions, runoff is experiencing a decline. These variations in runoff reflect the complex interplay of factors influenced by changing weather patterns and climate dynamics. The consequences of these shifts in climate conditions extend beyond more changes in runoff. They also contribute to the heightened occurrence of extreme weather events such as floods and droughts. These extreme phenomena can have far-reaching implications for ecosystems, water resources, agriculture, and human communities, underscoring the urgent need for proactive measures to mitigate and adapt to the impacts of climate change. The analysis of precipitation trends in the studied basin, conducted using the Mann-Kendall test, resulted in significant findings. It was observed that the average annual precipitation and winter season precipitation exhibited a negative and significant trend, with their starting points identified as 1994 and 1996, respectively. Further examination of the U and U' components for other synoptic stations across all seasons revealed that the precipitation series displayed no discernible trend and lacked a consistent pattern. Statistical analysis comparing the average annual and seasonal rainfall of the studied years in the synoptic stations of the Armand basin indicated a decrease in rainfall, although in some instances, no significant trend was observed. The winter season experienced the highest percentage of rainfall reduction. Based on these results, the Kohrang and Boruj stations were identified as the most and least rainy stations in the studied basin, with average annual rainfall values of 1351.48±62.01 and 250.32±12.43 mm, respectively. The average annual rainfall for the entire Armand basin during the study period was calculated to be 619.53±25.47 mm, with minimum and maximum annual rainfall recorded as 264.55 and 909.35 mm, respectively. Additionally, the average precipitation for the winter, spring, summer, and autumn seasons was estimated at 314.45±19.99, 94.66±7.56, 2.18±0.45, and 208.09±15.64 mm, respectively. These findings provide valuable insights into the precipitation patterns and trends within the Armand basin, highlighting the variability and changes experienced over the study period. The trend analysis of runoff, conducted using both the (Z) test and the Mann-Kendall graphic test, revealed a consistent and significant decrease in runoff across the hydrometric stations of the studied basin. The decreasing trend in runoff observed at the hydrometric stations signifies a decline in the amount of water flowing through the basin's watercourses over time. This trend may have significant implications for various aspects of the basin's hydrological system, including water availability, ecosystem health, and human activities reliant on water resources. The identification of a decreasing and significant trend in runoff underscores the importance of continued monitoring and management efforts to address the potential impacts of declining water availability within the studied basin. Effective water resource management strategies will be essential to mitigate the consequences of this trend and ensure the sustainability of water resources in the face of changing environmental conditions.

The investigation into the trend and changes of runoff in the hydrometric stations of the Armand basin, including Armand, Behesht-Abad, Koh-Sokhte, and Kareh-Bas, has revealed a significant decreasing trend in both annual and seasonal runoff. Among the seasons, the summer season exhibited the most pronounced decrease in runoff compared to other seasons. The average annual runoff for the studied basin during the statistical period was determined to be 29.3 cubic meters per second. Additionally, the average minimum and maximum runoff recorded during the same period were 0.7 and 84.785 cubic meters per second, respectively. These variations in runoff can largely be attributed to the quality of rainfall in the basin. Given these findings, it is suggested that the substantial resources currently allocated to the construction of dams in these areas be redirected towards more fundamental initiatives, such as the implementation of watershed and land management projects. By controlling and managing rainfall instead of allowing it to flow uncontrolled into the watershed, such projects can mitigate the damages caused by floods. Furthermore, they can contribute to the replenishment of underground aquifers in the studied basin, thereby enhancing water resource reserves and promoting sustainability in water management practices. The results obtained from both Pearson's and Spearman's correlation coefficients between runoff and precipitation in the Armand basin indicate that the null hypothesis (H0) is rejected, as the significance level (sig) is less than 0.05. Consequently, the correlation between runoff and precipitation variables in this basin is accepted. This suggests that the decrease in rainfall in the basin has led to a corresponding decrease in river flow and runoff during the statistical period. Therefore, the correlation coefficient between these two variables is deemed significant, confirming the existence of a correlation between runoff and precipitation. Pearson's correlation coefficient was found to be 0.612, while Spearman's correlation coefficient was 0.595. Both coefficients suggest a moderate to strong positive correlation between runoff and precipitation in the Armand basin. Furthermore, the linear assumption of the relationship between runoff and precipitation in the Armand basin is confirmed through regression variance analysis.

Examining the scatter diagrams depicting the distribution of points further reveals insights into the intensity, direction, and type of relationship between runoff and precipitation variables in the Armand river basin. The scattering of points in the diagrams provides visual cues: if the points are clustered along a diagonal line from the bottom left to the top right, it indicates a positive linear relationship between the variables. Additionally, the density and dispersion of points around this line can provide information about the strength of the relationship. In this case, the confirmed linear relationship between runoff and precipitation, along with the moderate to strong correlation coefficients, suggests a significant and meaningful association between the two variables in the Armand basin.

The results depicted in the linear graphs confirm a positive relationship between precipitation and runoff in the Armand basin. This positive relationship is evident from the upward (ascending) slope of the points, indicating that as precipitation increases, runoff also tends to increase. Additionally, the density of points and the concentration of most points around the regression line further underscore the intensity and strength of the relationship between runoff and precipitation in the studied basin. The clustering of points around the regression line suggests that the majority of data points closely adhere to the predicted values of the regression model. This alignment indicates a robust and consistent association between precipitation and runoff variables in the Armand basin.

In summary, the confirmed positive slope of the points and the clustering of data around the regression line provide compelling evidence of a strong and intense relationship between precipitation and runoff in the Armand basin.

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