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Original Article

Hydrochemical analysis and forecasting of Lesser Zab River discharge using innovative trend analysis and Mann–Kendall method at Dukan dam site, NE of Iraq

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ABSTRACT

Planning and managing water resources successfully requires an understanding of hydrochemistry and hydroclimatic element trends, especially inputs to dams. This research uses surface water sampling and Innovative Trend Analysis (ITA) and the Modified Mann-Kendall (MMK) test to analyze water quality and both inflow and outflow to examine streamflow patterns of the Lesser Zab River at Dukan Dam. To determine the size and importance of trends, monthly, seasonal, and annual streamflow data from 2000-2025 were analyzed. Based on the analyzed samples, all water samples are suitable for drinking and other purposes according to the WHO and Iraqi standards. While January showed a non-significant growing trend, MMK data for inflow showed primarily non-significant falling trends with negative magnitudes over the majority of months, seasons, and the yearly scale. Similarly, neither the annual nor the seasonal outflow study showed any noteworthy changes. ITA data, however, revealed substantial declining patterns in inflow throughout all seasons and months except for January. Outflow ITA data showed falling trends in low and medium flows throughout several months, seasons, and the annual period. Significant trends were not observed on the annual or seasonal scale. Non-significant decreasing trends during some months and seasons. Climate change, rising water demand, and the Iranian Tropical Water Project, which significantly changed regional hydrological regimes and affected water availability in the Lesser Zab River basin. Decision making on the management of water resources is made easier by examining patterns and turning points in dam inflows.

1. Introduction

Water flow shifts have been seen in many regions of the world recently, particularly since the 1970s, in relation to changes in the global climate (Mitof & Pravalie, 2014). Although the most important kind of change in the environment is global warming, statistical studies have also shown this trend (Westra et al., 2012). Changes in rainfall amounts have been the main factor causing changes in flow rates (Mitof & Pravalie, 2014 & Ismaiel, 2018).

For more than thirty years, research has focused on identifying patterns in hydrologic, climatic, and other natural time series (Hamed, 2008). Because of the amount of research being done on water resources and their unpredictability, the topic of trend identification has received even more attention lately. The Intergovernmental Panel on

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Climate Change Report states that by the middle of the century, the average annual river discharge will increase by 10–40% in high latitudes and certain wet tropical regions, while it will decrease by 10–30% in some drier mid-latitude regions and the dry tropics (Lee et al., 2024). Trend analysis will be helpful in removing approximation mistakes when constructing hydraulic structures with fixed hydrometeorological parameters taken into consideration.

An examination of hydroclimatic data through time series methods yields direct insight into hydrological transformations and constitutes a critical component in the comprehension and stewardship of water resources (Antico et al., 2014). Therefore, planning and managing water resources, flood prevention and disaster mitigation, and agricultural activities will benefit from recognizing and evaluating long-term patterns in meteorological and hydrologic data (Alemu et al., 2020; Al-Manmi, & Qader, 2021: Ademe et al., 2022; & Panditharathne et al., 2022).

Trend analysis will be helpful in removing approximation mistakes when constructing hydraulic structures with fixed hydrometeorological variables being considered. There are several techniques that experts have proposed for evaluating trends in hydrometeorological time series. These include Spearman's rho, the Mann-Kendall (MK) test, linear regression analysis, and the Theil-Sen technique (Becker et al. 2006; Sonali & Nagesh Kumr 2013; Asadieh & Krakauer 2015). Trend analysis is a useful method for understanding the shifting trends of hydrological data. Trends in hydrological data are found using various statistical testing techniques, which fall into two categories: parametric and non-parametric tests (Chen et al., 2007).

Mann-Kendall (MK), modified Sen's slope estimator, Mann-Kendall (MMK), and innovative trend analysis (ITA) are the most often used non-parametric techniques. In order to assess the patterns in hydrological time series data, they have been widely used (Pingale et al., 2016; Hu et al., 2019; Adelodun et al., 2022; Paramaguru et al. 2023; Rajput et al., 2023a).

Numerous studies have shown the effectiveness of the ITA approach in identifying and assessing hidden trends (Malik et al., 2019; Caloiero et al., 2020; Wang et al., 2020; Nisansala et al., 2020; Anusty et al., 2024). One benefit of the ITA approach is the ability to identify the "low," "medium," and "high" rainfall clusters (Şişman & Kizilöz, 2021; Kessabi et al., 2025).

This research has examined long-term rainfall and inflow patterns at the Dukan Dam meteorological station and stream gauging station for the years 2000-2025 in order to promote the sustainable management of water and agriculture despite climate change. A dual-method approach is used to identify changes in historical rainfall and stream flow records: the conventional statistical Mann-Kendall (MK) and modified Mann-Kendall (mMK) tests, as well as the graphical Innovative Trend Analysis (ITA) technique.

Sen's slope estimator (Q) was used in this work to calculate the rate of change. Although there was a high degree of agreement (around 90%) between the graphical ITA approach and the MK/mMK Z statistics, their functionality is very different. In contrast to the MK/mMK tests, which are only intended for monotonic trend identification, the ITA technique has the extra benefit of being able to identify sub-trends. The abundant water resources in the research region, which are mostly derived from streams, are very beneficial since they are essential for improving biological variety as well as agricultural and electrical production.

This study's research gap is entirely prior research has mostly concentrated on hydrological trend analysis or hydrochemical evaluations separately, with little integration of both elements in a cohesive framework. Research on the Lesser Zab River is very rare, especially when it comes to trend analysis at the Dukan Dam. There is still little use of the Mann-Kendall test in conjunction with

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innovative trend analysis to identify both monotonic and non-monotonic trends. Additionally, somewhat than using predicting techniques, the majority of studies focus on identifying historical trends not forecasting. Inadequate research has also been done on the impact of dam control and the link between discharge regime, and climate change. The objectives of this research is to analyze historical data on river discharge at the Dukan Dam site to establish baseline conditions and identify river discharge trends over time and predict future patterns.

2. Study Area

The Dukan Subbasin at the Dukan Dam location will be the study's primary focus. Geographically, the research region (Dukan Dam Reservoir) is situated about 60 km northwest of Sulaymaniyah City, south of the town of Ranya, between longitudes 44˚48'00"E and 45˚03'00"E and latitudes 35˚56'00"N to 36˚15'00"N (Fig. 1). The Dukan Dam Reservoir, which consists of two sub-reservoirs, is a natural depression that lies between the dam and the Darbandi Rania (Kewa-Rash Mountains). The reservoir has a maximum capacity of 8.3 billion cubic meters and a regular capacity of 6.8 billion cubic meters. The surface elevation is 515 meters above sea level at that capacity. The surface elevation must be between 469 and 511 meters to run the power plant. The reservoir is 270 square kilometers in size.

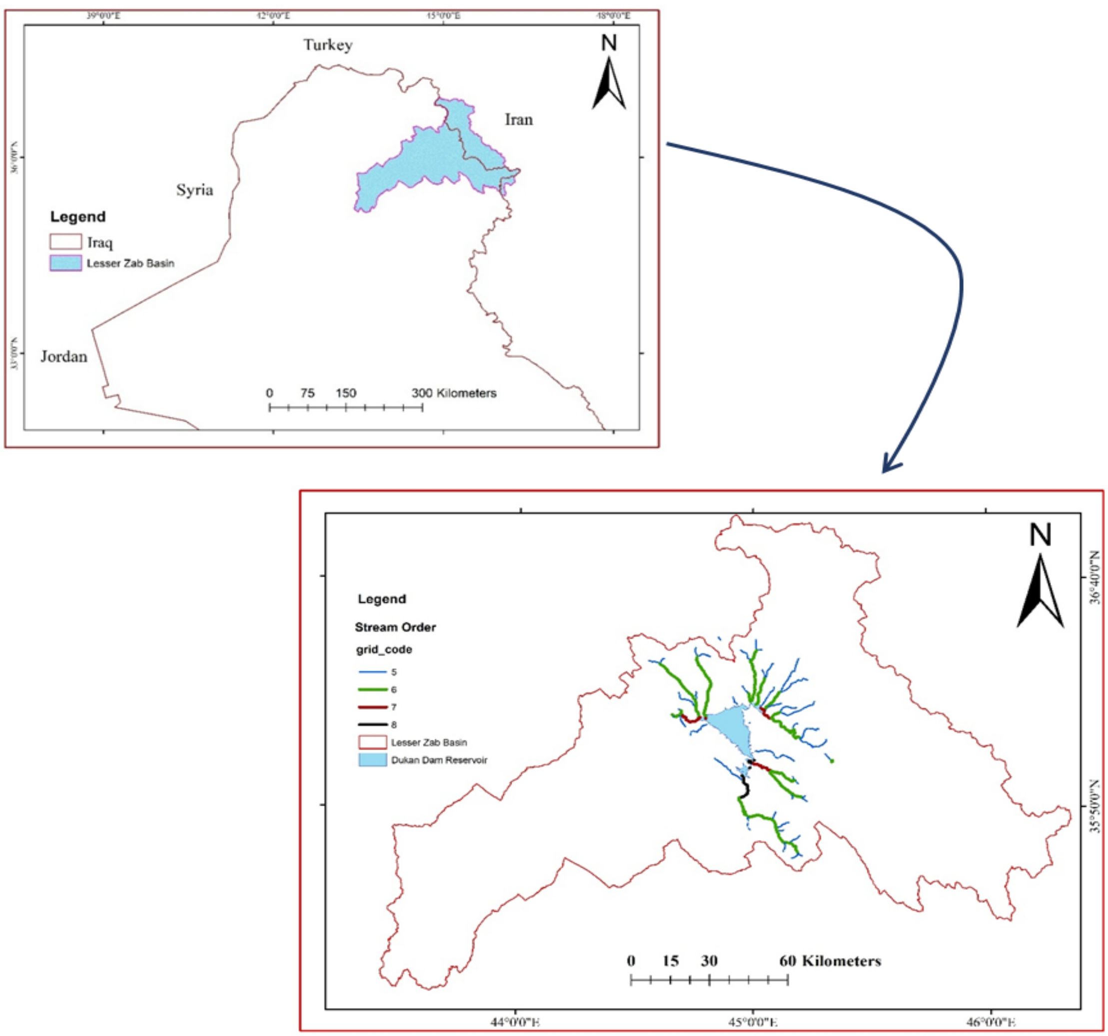

Figure 1. Location map of the study area.

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3. Hydrology

With a surface area of over 25,000 hectares, the Dukan Lake is a major body of water in Iraqi Kurdistan. The Kosrat, Qarasrd, and Sara ranges define its complex terrain, and its elevation ranges from 412 to 868 meters (A.S.L.).

The region features steppe grasslands and scattered oak forests and is surrounded by significant human settlements like Ranya and Qaladza, with concentrated development to the northwest.

Two smaller streams converge in Iran to form the Chami Kalvem stream, which originates in Iran's Azarbayjani Gharbi Region. One of the streams is the Chami Kalvem stream itself and the Baneh River represents a significant watercourse on the left bank of the system. Chami Kalvem stream enters the Kurdistan Region of Iraq close to the town of Mawat and flows south-southeast along the border between Iraq and Iran.

Another stream, the Sewail Stream, merges into the Jogasur Stream close to Chwarta in the Kurdistan Region, close to the town of Penjween. The Jogasur Stream has only one tributary, the Mawakaba Stream, but the Sewail Stream itself is created by the meeting of the Shler and Qzlja Streams. The Qalachwalan Stream, which eventually empties into the Lesser Zab River near the Iraq-Iran border, is created when these Streams combine, (Fig. 2). The Lesser Zab River flows through the area with the help of this network of tributaries (Hassan, 2021).

The Lesser Zab River Basin has a total area of 19,756 km^2. The northeastern region of Iraq contains the majority of the basin, 15,094 km^2 (76.38%), while Iran contains the remaining fraction, 4662km^2 (23.6%). The Lesser Zab River Basin encompasses approximately 6.5% of the 303,339 km^2 Tigris River Basin.

The reservoir's primary inflow is the Lesser Zab River, which forms part of the Iran-Iraq border before entering from the northeast. Its catchment area upstream of the dam is about 11,700 km^2. Before reaching the reservoir, the Lesser Zab River is fed by several ephemeral tributaries and is joined by the significant Qalachwalan Stream system. Approximately 35% of the Lesser Zab's flow in this region comes from the Qalachwalan, which rises in Iran and flows into a 1,506 km^2 basin. Along with minor streams draining the Ranya Plain, the Hizop and Khdran stream systems supply water to the northwest section of the reservoir.

The hydrological regime is pluvial, relying on seasonal rainfall and snowmelt, primarily from the Baneh and Qalachwalan sub-basins. Geopolitically, 74% of the total catchment lies within Iraq, with 26% in Iran. The rivers' paths through populated and agricultural areas introduce potential anthropogenic pollution, compounded by natural sources like mineralized springs and geological weathering. The reservoir itself now submerges a section of the historically contributory Ranya plain.

Climatologically, the Mediterranean Sea system impacts on the study area, giving the rain a clear yearly cycle. As illustrated in Figure 3, the humid period spans October through May, followed by an arid interval from June to September. Long-term records (2000-2025) from the Dukan Dam meteorological station indicate a mean annual rainfall of 561.11 mm; however, this means is characterized by considerable fluctuation and an overarching trend of reduction. The period witnessed a maximum annual precipitation of 1038.4 mm (2018-2019) and a minimum of 226.4 mm (2024-2025).

4. Methodology

4.1. Hydrochemistry

After gathering available basic data from different sources. Field trips were planned and carried out for a few days in March 2025; the water samples were collected by using 500 ml capacity, unused polyethylene bottles for physiochemical tests. A total of thirty-six samples of surface water has been collected for hydrochemical analysis (Table 1 and Fig. 4).

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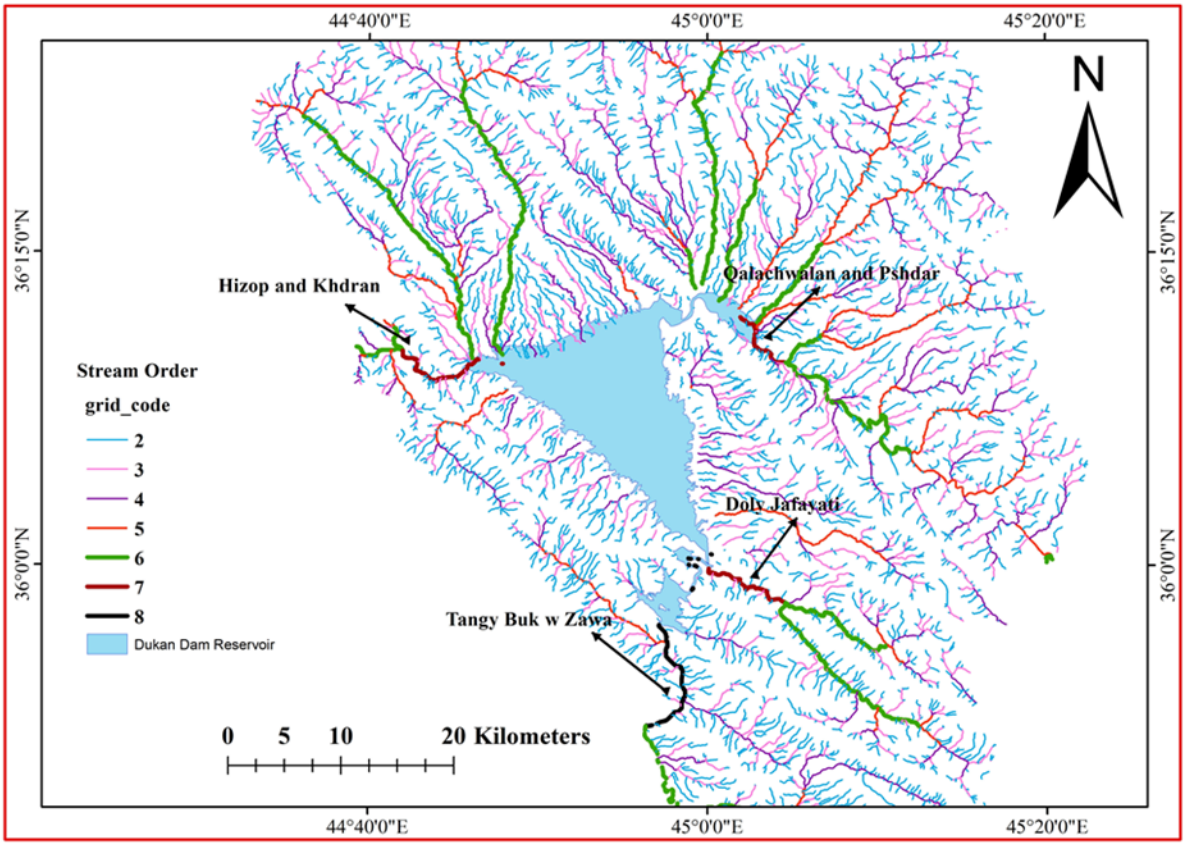

Figure 2. Drainage network of the study area.

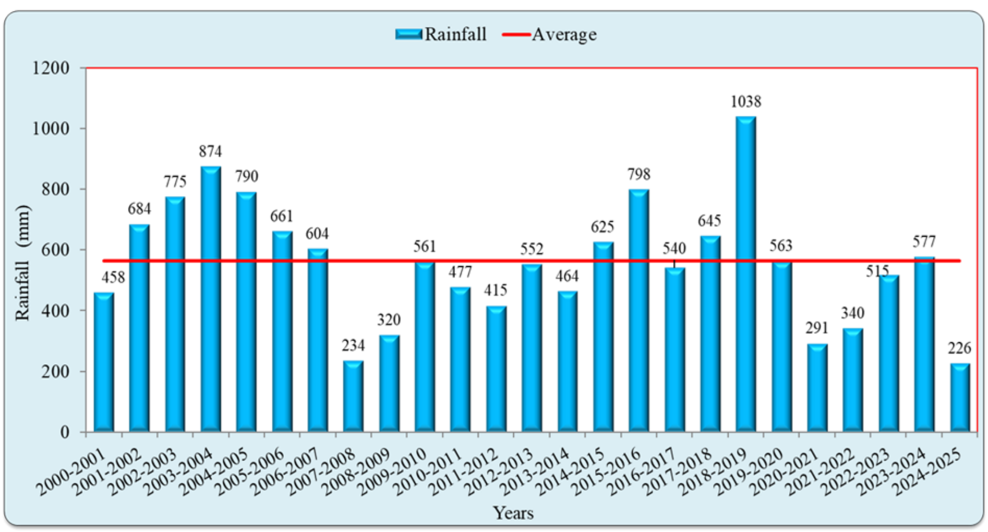

Figure 3. Mean annual rainfall in Dukan Dam Station for the period of (2000-2001 to 2024-2025).

All water samples were filtered through 0.45 µm millipore filters for cation and anion analyses upon return from the field. In situ determination of (T°C, EC, Eh, DO, and pH) was done during sample collection.

Surface water samples hydrochemically tested in Sulaimani Environment Directorate, Table 2 shows the parameter and the analyzing method.

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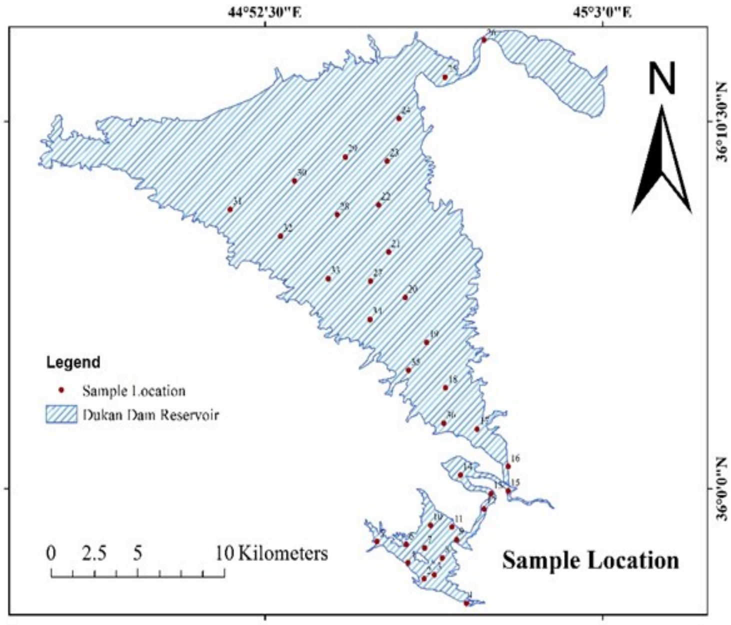

Figure 4. Location map of water samples.

Tables 1. Location of selected sites on Dukan dam reservoir for hydrochemical analysis, when the water level is 477 m.a.s.l

Sample No.	Sample Name	Longitude	Latitude
1	Jublakh	44°56'46"	35°56'43"
2	Near Dam	44°57'27"	35°57'25"
3	Collapsed Cave	44°57'46"	35°57'32"
4	Collapsed Cave space	44°56'57"	35°57'53"
5	Bride and Groom	44°55'59"	35°58'29"
6	Gulneri	44°56'54"	35°58'24"
7	Bang Rayel	44°57'28"	35°58'18"
8	Grda Niska	44°58'01"	35°58'01"
9	Ga Zard	44°58'28"	35°58'32"
10	Palko Village	44°59'19"	35°59'25"
11	White Rock	44°59'32"	35°59'51"
12	Baska Hoj	44°58'35"	36°00'23"
13	Shekhaless	45°00'04"	35°59'56"
14	Khoshaw Village	45°00'04"	36°00'38"
15	Kuna Flusa	44°58'19"	35°58'54"
16	Wate	44°59'06"	36°01'42"
17	Bemusha	44°58'07"	36°02'53"
18	Sewkan	44°57'32"	36°04'11"
19	Nawarast	44°56'52"	36°05'28"
20	Mamandawa	44°56'21"	36°06'46"
21	Baizakha	44°56'02"	36°08'07"
22	Nawrasakan	44°56'18"	36°09'22"
23	Sarsyan	44°56'40"	36°10'35"
24	Joga Sur	44°57'39"	35°58'57"
25	Maly Sarsyan	44°58'06"	36°11'46"
26	Prdy Darband	44°59'19"	36°12'50"
27	Nawarast2	44°55'47"	36°05'56"
28	Nawarast3	44°54'45"	36°07'50"
29	Grdy Nawrasakan	44°55'00"	36°09'29"
30	Pashawy Baizakha	44°53'25"	36°08'48"
31	Baizakha	44°51'25"	36°07'59"

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Tables 1. Location of selected sites on Dukan dam reservoir for hydrochemical analysis, when the water level is 477 m.a.s.l

Sample No.	Sample Name	Longitude	Latitude
32	Kalkan	44°52'59"	36°07'13"
33	Aliqa	44°54'28"	36°06'00"
34	Bngrdan	44°55'46"	36°04'50"
35	Qshlla	44°56'58"	36°03'23"
36	Mirzarostam	44°58'04"	36°01'52"

Table 2. Hydrochemical parameter and methods of analysis.

---------	Titration	Cl^- , Ca^{2+} , Mg^{2+}, HCO_3^-, CO_3^{2-}
Spectrophotometer	Colorimetric	NO_3^- , PO_4^{-3}, SO_4^{2-}
Flame photometer	Flame photometer	Na^+, K^+

The analytical error is calculated using a charge balance (CB) and the accuracy for most samples are less than 5% except some samples, so it is acceptable for most water analyses (Table 3).

Table 3. Accuracy of the hydrochemical analysis of water samples.

No.	EN%	Type	No.	EN%	Type
S1	0.12	Certain	S19	-2.90	Certain
S2	-7.39	P.Certain	S20	7.01	P.Certain
S3	7.03	P.Certain	S21	-6.70	P.Certain
S4	1.32	Certain	S22	0.89	Certain
S5	3.38	Certain	S23	-3.38	Certain
S6	2.43	Certain	S24	-3.98	Certain
S7	7.21	P.Certain	S25	2.14	Certain
S8	1.35	Certain	S26	0.86	Certain
S9	-0.87	Certain	S27	1.21	Certain
S10	-9.68	P.Certain	S28	-0.34	Certain
S11	-9.13	P.Certain	S29	1.20	Certain
S12	-1.70	Certain	S30	5.03	P.Certain
S13	2.33	Certain	S31	0.59	Certain
S14	1.03	Certain	S32	5.29	P.Certain
S15	2.30	Certain	S33	-1.62	Certain
S16	-0.33	Certain	S34	3.31	Certain
S17	3.60	Certain	S35	-3.54	Certain
S18	1.57	Certain	S36	-1.18	Certain

4.2. Trend analysis

The two primary phases of the approach are data collection and trend analysis utilizing Innovative Trend Analysis (ITA) and Mann-Kendall (MK) test procedures. This methodological process is shown in Figure 5. R software (version 4.5.1) was used to calculate these tests.

4.2.1. Data Collection

The Dukan Dam Directorate provided 25-year statistics on the inflow and outflow of the Dukan Dam Reservoir from 2000 to 2025, as seen in (Figs. 6 & 7). Additionally, this study uses the Innovative Trend Analysis (ITA) approach, which was created by Şen (2012), to analyze the inflow and outflow data of Dukan Dam in order to determine the monthly, seasonal, and yearly patterns within the historical rainfall record. The Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) and its modified form (mMK)

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(Hameed & Rao, 1998) are then used to compare the data obtained from the ITA. Following accepted methodological guidelines, when considerable autocorrelation is found in the data series, the modified Mann-Kendall test (Güçlü, 2020) is used since serial correlation might undermine the assumptions of the normal MK test.

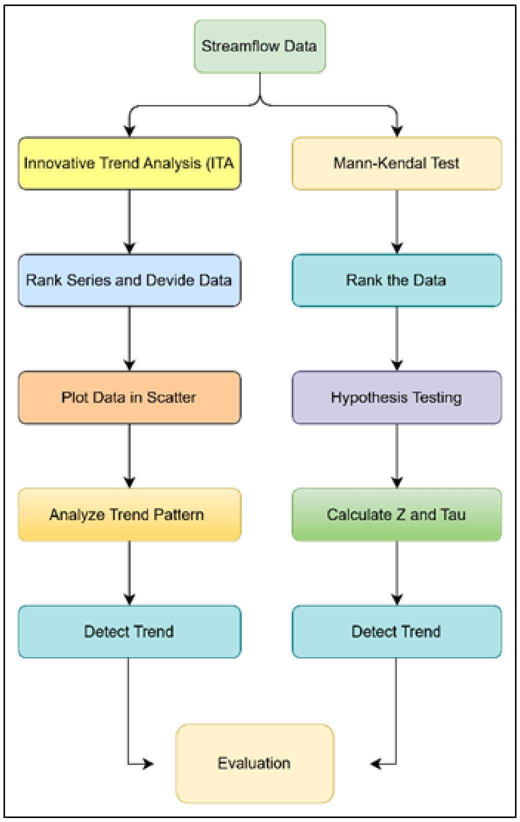

Figure 5. Methodology flow chart for trend analysis for river flow for the study area.

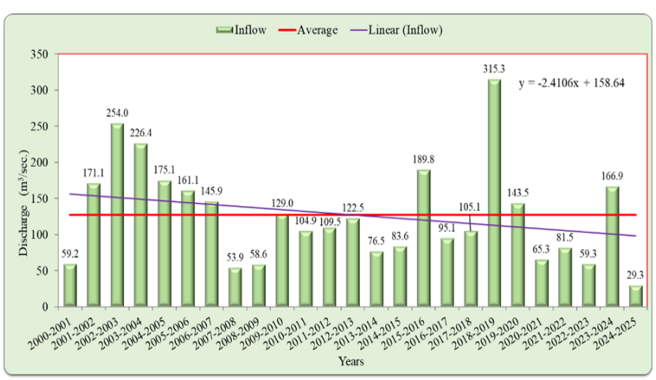

Figure 6. Annual inflow discharge for the period of (2000-2025).

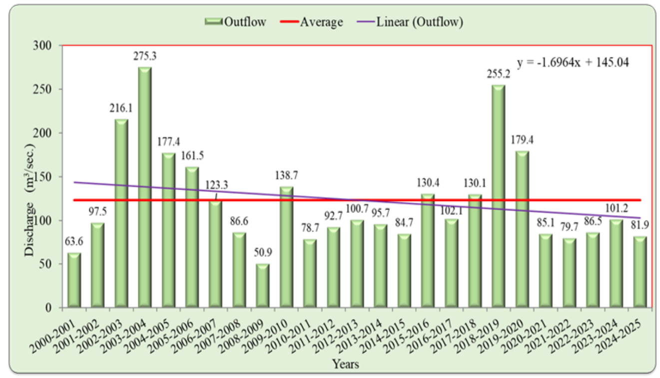

Figure 7. Annual outflow discharge for the period of (2000–2025).

4.3. Methods of trend analysis

4.3.1. Mann-Kendall Test

The non-parametric Mann-Kendall trend test is a rank-based assessment of randomness versus monotonic trends (Mann, 1945; Kendall, 1975). The primary goal of trend analysis is to determine if data values are rising, decreasing, or trendless across time. However, trend detection is a complicated topic due to data characteristics (Kisi & Ay 2014). Trends in hydrologic and climatologic time series are frequently examined using the Mann-Kendall test (Yue & Wang, 2004).

To evaluate and find patterns in a time series, several researchers have used the MK trend test in their data analysis. (Chiew & McMahon, 1993; Burn, 1994; Gan, 1998; Lins & Slack, 1999; Douglas et al., 2000; Pilon & Yue, 2002; Yue et al., 2003; Hamed, 2008; Sharif & Burn, 2010; Jain & Kumar, 2012).

Nonparametric tests include the Mann-Kendall and Sen's Slop estimator tests. As a result, the outcome is unaffected by data outliers. To evaluate the significance of trends in hydro-meteorological records, researchers frequently utilize the non-parametric Mann-Kendall statistical test (Douglas et al., 2000; Yue et al., 2002). This exam has two benefits. First of all, the test is non-parametric, meaning that a normal distribution of the data is not necessary. Second, because of the inhomogeneous time series, the test is not sensitive to sudden breaks

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(Tabari et al., 2011). This test's null hypothesis, H0, presupposes that there isn't a trend in the data.

This explanation is evaluated against the alternative hypothesis (independent and randomly arranged). According to (Onoz & Bayazit, 2003), the alternative hypothesis, H0, assumes the presence of a trend.

The Mann-Kendall test statistic S can be computed for a time series $*m*_1$, $*m*_2$, $*m*_3$... $*m*_n$ with the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\ mj - mk \quad (1)$$

Where n denotes the length of the data sets, and mj and mk denote the observations at times j and k.

Sign (mj-mk) = +1 if mj-mk > 0

Sign (mj-mk) = 0 if mj-mk = 0

Sign (mj-mk) = -1 if mj-mk < 0

A positive value of the Mann-Kendall statistic SS signifies an increasing trend in the time series, whereas a negative value denotes a decreasing trend. The variance of S, denoted as VAR(S), is calculated using the following equation:

$$VAR(S) = 1/18\{n(n-1)(2n+5) - \sum_{j=1}^{\rho} \tau i(\tau i - 1)(2\tau i + 5) \quad (2)$$

In this notation, ρ represents the number of tied groups within the dataset, where a tied group (I) is a set of observations sharing an identical value. The variable τ_i denotes the number of data points within the i^{th} tied group. Following the methodology of (Hamed & Rao, 1998), the estimates for S and VAR(S) are utilized to compute the test statistic Z for sample sizes exceeding 10 (Gilbert, 1987), as defined by the following equation:

$$Z = \frac{S-1}{\sqrt{VAR(S)}}, if\ S > 0 \quad (3)$$

$$Z = \frac{S+1}{\sqrt{\mathrm{VAR(S)}}}, if\ S < 0 \quad (4)$$

A positive Z statistic signifies an upward trend in the data series, whereas a negative value indicates a downward trend.

4.3.2. Modified Mann-Kendall test (mMK)

Hydrological data sets often show a serial relation (Yue et al., 2002; Kulkarni & Storch, 1995). Positive serial correlation can make trends appear more significant than they actually are, and it can even point to trends that don't exist (Hamed & Rao, 1998). Consequently, it is necessary to assess data for serial correlation prior to implementing the Mann–Kendall (MK) test. When serial correlation is detected, the modified Mann–Kendall method introduced by (Hamed & Rao, 1998) should be employed to analyze the time series, thereby removing the influence of autocorrelation.

The modified variance statistic, VAR(S), can be derived using the following equation:

$$VAR\ (S) = (n\ (n - 1)(2n + 5)/18).(n/n * e)$$

A correction factor, expressed as the ratio of the sample size to the effective sample size ($n/n*_e$), is applied to adjust for autocorrelation in the data as follows:

$$(n/n * e) = 1 + \left(\frac{2}{n3 - 3n2 + 2n}\right) \sum_{f=1}^{n-1} (\mathrm{n} - \mathrm{f})(n - f - 1)(n - f - 2)\rho e(f) \quad (5)$$

The term $\rho_e(f)$ denotes the autocorrelation function between the ranks of observations. It can be estimated using the formula:

$$\rho(f) = 2\ sin\left(\frac{\pi}{6} \bullet \rho_e(f)\right) \quad (6)$$

4.3.3. Sen's slope Estimator

Sen's slope estimator (Şen, 1968) was also employed to quantify the magnitude of the trend

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(slope θ). The slope θ is derived from N pairs of data points using the following method:

$$\emptyset i = \frac{(xk - xj)}{k - j}, i = 1,2 \ldots N, K > j \qquad (7)$$

Here, xk and xj are the data values at time points k and j, and θi is the median slope.

4.3.4. Innovative trend analysis (ITA)

In 2012, Zekâi Şen created the ITA technique, which claimed advantages over the MK and SR tests. It doesn't require any presumptions like serial correlation or normalcy (Şen, 2017).

The monthly weather series for a specific division (j) must first be divided into two equal-length, temporally independent series in order to use Innovative Trend Analysis (ITA) (Kessabi et al., 2025). Each subseries is then displayed with the other in a Cartesian coordinate system after being sorted in in decreasing order (Girma et al., 2020; Alifujiang et al., 2021), with the first half indicating the x-axis and the second half the y-axis. To determine whether a monotonic trend exists, a straight line is fitted to the resulting scatter plot the number of data points above the 1:1 (45°) line shows a rising trend, whereas an amount below this line shows a dropping trend (Cui et al., 2017). Conversely, equally spaced data points along the 1:1 line suggest the absence of a statistically significant trend (Şen, 2012). Finally, the Trend Indicator (TI), which measures the extent of the identified trend, is calculated using the following formula (Şen, 2012):

$$B = \frac{1}{\mathrm{n}} \sum_{i=1}^{n} \frac{10(\mathrm{xi} - \mathrm{xk})}{\mathrm{x}^{-}} \qquad (8)$$

The slope obtained from the Innovative Trend Analysis (ITA) is represented by the quantity B in this equation. Each subseries' length is represented by the variable *n*, and the data values in the two successive subseries are represented by the variables x_j and x_k. Lastly, $\bar{x}$ represents the first subseries' mean value (x_k).

A growing trend in the time series is shown by a positive value of the slope parameter B, whereas a falling trend is indicated by a negative value.

A utility in the R environment called trend change version 1.2 is used to calculate the trend ITA, with slope significance thresholds set at 95% and 99%.

5. Results and Discussion

5.1. Hydrochemical evaluation

Results: The results of the analysis are tabulated in the Tables (4 and 5). All water samples are colorless, tasteless, and odorless. Ca^{2+} and Mg^{2+} are the dominant cations present in the Dukan Lake samples, next to Na+ and K+. Bicarbonate is the predominant anion with the mean value; sulfate and chloride are also present in considerable amounts. The water samples are Ca-HCO_3 type. According to IQS, (2009) and WHO, (2022), all water samples are in the range and suitable for drinking purposes.

5.2. Descriptive Analysis of monthly, seasonal, and annual Inflow

Presents key statistical parameters including minimum, maximum, mean, standard deviation (SD), and coefficient of variation (CV), skewness (CS), and kurtosis (CK) for the monthly, annual and seasonal Inflow for water years (2000-2001 to 2024-2025) recorded at the Dukan Dam meteorological station, Table 6.

5.3. Monthly, Seasonal and annual trends in inflow as estimated from Mann-Kendall and Sen's slope statistics

With a particular focus on the Dukan Dam Reservoir, it has conducted a thorough investigation to look into the patterns in dam inflow throughout the Lesser Zab River Basin. Several well-known techniques, including the MK test, MMK test, Sen Slope estimator, and ITA, are used to achieve this. An investigation of homogeneity was carried out after the trend analysis.

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Table 4. pH, EC, T°C, DO, NO_3, and total hardness values of selected samples from Dukan Dam Reservoir.

Sample No.	D.O mg/l	NO3 mg/l	Total Hardness mg/l	Sample No.	D.O mg/l	NO3 mg/l	Total Hardness mg/l
S1	6.3	5.06	168	S19	3.6	3.83	154
S2	3.3	3.42	154	S20	3.3	3.69	176
S3	3	3.5	164	S21	3.5	3.69	162
S4	2.7	3.59	156	S22	3	3.59	156
S5	3	3.52	162	S23	3.3	2.91	158
S6	2.8	3.61	154	S24	3.2	4.85	192
S7	3	3.5	162	S25	3	3.49	198
S8	2.5	3.51	150	S26	2.9	3.57	188
S9	3.1	3.42	142	S27	2.6	3.38	154
S10	3	3.93	130	S28	2.5	3.93	140
S11	2.8	3.4	160	S29	2.8	3.47	138
S12	2.6	3.5	150	S30	2.7	4.24	156
S13	2.5	3.21	152	S31	2.6	3.78	152
S14	2.4	3.26	150	S32	2.5	3.5	156
S15	3	3.68	154	S33	2.7	3.04	142
S16	3.5	3.28	154	S34	2.6	3.3	150
S17	4	3.32	162	S35	3	3.33	150
S18	3.5	3.66	160	S36	3	5.06	144
Min.	2.4	2.91	130				
Max	6.3	5.06	198				
Avr.	3.1	3.64	157				

Table 5. Major Cations and Anions concentrations of selected samples from Dukan Dam Reservoir.

No.	T°C	pH	EC	TDS	unit	Cations				SUM	Anions				SUM
			µs/m	mg/l		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		SO_4^{2-}	Cl^{-}	HCO_3^{-}	CO_3^{2-}	
					ppm	48.8	11.2	6.0	1.4	67.4	28.0	12.9	165.8	0.0	206.70
S1	14.5	6.59	331	222	epm	2.44	0.93	0.26	0.04	3.67	0.58	0.36	2.72	0.00	3.66
					%epm	66.5	25.4	7.1	1.0	100.00	15.9	9.8	74.3	0.0	100.00
					ppm	41.6	12.2	7.0	1.8	62.6	57.0	15.4	145.0	0.0	217.40
S2	11.2	7.15	295	198	epm	2.08	1.01	0.30	0.05	3.44	1.19	0.43	2.38	0.00	3.99
					%epm	60.4	29.4	8.8	1.3	100.00	29.7	10.7	59.5	0.0	100.00
					ppm	44.0	13.1	6.0	1.4	64.5	29.0	11.2	134.4	0.0	174.60
S3	10.5	7.26	289	194	epm	2.20	1.09	0.26	0.04	3.59	0.60	0.31	2.20	0.00	3.12
					%epm	61.3	30.5	7.3	1.0	100.00	19.4	10.0	70.7	0.0	100.00
					ppm	40.8	13.1	6.0	1.4	61.3	27.5	11.0	150.2	0.0	188.70
S4	11	7.29	289	194	epm	2.04	1.09	0.26	0.04	3.43	0.57	0.31	2.46	0.00	3.34
					%epm	59.5	31.9	7.6	1.0	100.00	17.1	9.1	73.7	0.0	100.00
					ppm	45.6	11.7	6.0	1.4	64.7	23.5	16.3	144.8	0.0	184.60
S5	11	7.30	294	197	epm	2.28	0.97	0.26	0.04	3.55	0.49	0.45	2.37	0.00	3.32
					%epm	64.3	27.4	7.4	1.0	100.00	14.8	13.7	71.6	0.0	100.00
					ppm	42.4	11.7	6.0	1.5	61.6	23.0	11.1	149.0	0.0	183.10
S6	11.2	7.36	291	195	epm	2.12	0.97	0.26	0.04	3.39	0.48	0.31	2.44	0.00	3.23
					%epm	62.5	28.7	7.7	1.1	100.00	14.8	9.5	75.6	0.0	100.00
					ppm	45.6	11.7	6.0	1.4	64.7	22.1	11.0	140.6	0.0	173.70
S7	11.2	7.36	291	195	epm	2.28	0.97	0.26	0.04	3.55	0.46	0.31	2.30	0.00	3.07
					%epm	64.3	27.4	7.4	1.0	100.00	15.0	10.0	75.1	0.0	100.00
					ppm	40.8	11.7	6.0	1.4	59.9	18.6	16.3	145.2	0.0	180.10
S8	11.3	7.4	284	190	epm	2.04	0.97	0.26	0.04	3.31	0.39	0.45	2.38	0.00	3.22
					%epm	61.7	29.4	7.9	1.1	100.00	12.0	14.1	73.9	0.0	100.00
					ppm	38.4	11.2	6.0	1.4	57.0	25.1	10.0	146.6	0.0	181.70
S9	11.1	7.41	329	220	epm	1.92	0.93	0.26	0.04	3.15	0.52	0.28	2.40	0.00	3.20
					%epm	61.0	29.6	8.3	1.1	100.00	16.3	8.7	75.0	0.0	100.00
					ppm	32.0	12.2	6.0	1.4	51.6	27.3	17.0	152.0	0.0	196.30
S10	11.5	7.38	391	262	epm	1.60	1.01	0.26	0.04	2.91	0.57	0.47	2.49	0.00	3.53
					%epm	55.0	34.8	9.0	1.2	100.00	16.1	13.4	70.5	0.0	100.00

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					ppm	44.8	11.7	6.0	1.4	63.9	68.7	14.0	146.0	0.0	228.70
S11	12	7.70	294	197	epm	2.24	0.97	0.26	0.04	3.51	1.43	0.39	2.39	0.00	4.21
					%epm	63.8	27.7	7.4	1.0	100.00	34.0	9.2	56.8	0.0	100.00
					ppm	40.8	11.7	6.0	1.4	59.9	21.1	19.0	149.8	0.0	189.90
S12	12	7.76	278	186	epm	2.04	0.97	0.26	0.04	3.31	0.44	0.53	2.46	0.00	3.42
					%epm	61.7	29.4	7.9	1.1	100.00	12.8	15.4	71.7	0.0	100.00
					ppm	43.2	10.7	6.0	1.3	61.2	22.4	12.1	145.8	0.0	180.30
S13	12.2	7.77	274	184	epm	2.16	0.89	0.26	0.03	3.35	0.47	0.34	2.39	0.00	3.19
					%epm	64.6	26.6	7.8	1.0	100.00	14.6	10.5	74.9	0.0	100.00
					ppm	40.8	11.7	6.0	1.4	59.9	22.4	13.7	146.0	0.0	182.10
S14	12	7.80	281	188	epm	2.04	0.97	0.26	0.04	3.31	0.47	0.38	2.39	0.00	3.24
					%epm	61.7	29.4	7.9	1.1	100.00	14.4	11.7	73.9	0.0	100.00
					ppm	44.0	10.7	6.0	1.4	62.1	21.4	11.9	150.0	0.0	183.30
S15	11.3	7.8	282	189	epm	2.20	0.89	0.26	0.04	3.39	0.45	0.33	2.46	0.00	3.24
					%epm	64.9	26.3	7.7	1.1	100.00	13.8	10.2	76.0	0.0	100.00
					ppm	44.0	10.7	6.0	1.6	62.3	28.2	13.5	149.6	0.0	191.30
S16	15.5	7.79	289	194	epm	2.20	0.89	0.26	0.04	3.39	0.59	0.38	2.45	0.00	3.41
					%epm	64.8	26.3	7.7	1.2	100.00	17.2	11.0	71.8	0.0	100.00
					ppm	44.8	12.2	6.0	1.4	64.4	22.8	12.1	152.0	0.0	186.90
S17	16.9	7.78	281	188	epm	2.24	1.01	0.26	0.04	3.55	0.48	0.34	2.49	0.00	3.30
					%epm	63.1	28.5	7.3	1.0	100.00	14.4	10.2	75.4	0.0	100.00
					ppm	45.6	11.2	7.0	1.4	65.2	22.8	19.0	148.8	0.0	190.60
S18	18	7.81	283	190	epm	2.28	0.93	0.30	0.04	3.55	0.48	0.53	2.44	0.00	3.44
					%epm	64.2	26.2	8.6	1.0	100.00	13.8	15.3	70.9	0.0	100.00
					ppm	43.2	11.2	7.0	1.4	62.8	23.3	21.4	156.0	0.0	200.70
S19	15.8	7.88	298	200	epm	2.16	0.93	0.30	0.04	3.43	0.49	0.59	2.56	0.00	3.64
					%epm	62.9	27.1	8.9	1.0	100.00	13.3	16.3	70.3	0.0	100.00
					ppm	55.2	9.2	7.0	1.5	72.9	23.0	11.7	156.2	0.0	190.90
S20	17.7	7.86	302	202	epm	2.76	0.77	0.30	0.04	3.87	0.48	0.33	2.56	0.00	3.36
					%epm	71.3	19.9	7.9	1.0	100.00	14.2	9.7	76.1	0.0	100.00
					ppm	46.4	11.2	7.0	1.5	66.1	63.0	12.1	150.2	0.0	225.30
S21	17	7.87	277	186	epm	2.32	0.93	0.30	0.04	3.59	1.31	0.34	2.46	0.00	4.11
					%epm	64.5	25.9	8.5	1.1	100.00	31.9	8.2	59.9	0.0	100.00
					ppm	44.0	11.2	7.0	1.5	63.7	20.3	14.4	158.0	0.0	192.70
S22	16.7	7.84	288	193	epm	2.20	0.93	0.30	0.04	3.47	0.42	0.40	2.59	0.00	3.41
					%epm	63.3	26.8	8.8	1.1	100.00	12.4	11.7	75.9	0.0	100.00
					ppm	44.8	11.2	7.0	1.3	64.3	40.0	11.8	158.2	0.0	210.00
S23	17	7.88	283	190	epm	2.24	0.93	0.30	0.03	3.51	0.83	0.33	2.59	0.00	3.75
					%epm	63.8	26.5	8.7	0.9	100.00	22.2	8.7	69.1	0.0	100.00
					ppm	57.6	11.7	7.0	1.2	77.5	42.2	14.0	199.2	0.0	255.40
S24	14.5	7.71	302	202	epm	2.88	0.97	0.30	0.03	4.19	0.88	0.39	3.27	0.00	4.53
					%epm	68.8	23.2	7.3	0.7	100.00	19.4	8.6	72.0	0.0	100.00
					ppm	60.0	11.7	7.0	1.3	80.0	34.2	12.5	187.2	0.0	60.0
S25	21	7.72	351	235	epm	3.00	0.97	0.30	0.03	4.31	0.71	0.35	3.07	0.00	4.13
					%epm	69.6	22.5	7.1	0.8	100.00	17.3	8.4	74.3	0.0	100.00
					ppm	56.0	11.7	8.0	1.4	77.1	31.8	10.0	191.8	0.0	233.60
S26	20.5	7.6	358	240	epm	2.80	0.97	0.35	0.04	4.16	0.66	0.28	3.14	0.00	4.08
					%epm	67.4	23.4	8.4	0.9	100.00	16.2	6.8	77.0	0.0	100.00
					ppm	41.6	12.2	8.0	1.5	63.3	21.0	14.2	156.4	0.0	191.60
S27	15.7	7.8	285	191	epm	2.08	1.01	0.35	0.04	3.48	0.44	0.39	2.56	0.00	3.40
					%epm	59.8	29.1	10.0	1.1	100.00	12.9	11.6	75.5	0.0	100.00
					ppm	39.2	10.2	7.0	1.4	57.8	21.2	11.8	146.6	0.0	179.60
S28	15.8	7.86	286	192	epm	1.96	0.85	0.30	0.04	3.15	0.44	0.33	2.40	0.00	3.17
					%epm	62.2	27.0	9.7	1.1	100.00	13.9	10.3	75.7	0.0	100.00
					ppm	38.4	10.2	8.0	1.4	58.0	20.9	12.8	139.6	0.0	173.30
S29	14.7	7.88	279	187	epm	1.92	0.85	0.35	0.04	3.15	0.44	0.36	2.29	0.00	3.08
					%epm	60.9	27.0	11.0	1.1	100.00	14.1	11.5	74.3	0.0	100.00
					ppm	44.0	11.2	7.0	1.4	63.6	21.8	13.7	140.6	0.0	176.10
S30	14.2	7.9	257	172	epm	2.20	0.93	0.30	0.04	3.47	0.45	0.38	2.30	0.00	3.14
					%epm	63.4	26.8	8.8	1.0	100.00	14.5	12.1	73.4	0.0	100.00
					ppm	43.2	10.7	7.0	1.5	62.4	22.2	13.2	154.0		189.40
S31	14.8	7.85	272	182	epm	2.16	0.89	0.30	0.04	3.39	0.46	0.37	2.52	0.00	3.35
					%epm	63.6	26.3	9.0	1.1	100.00	13.8	10.9	75.3	0.0	100.00
					ppm	44.0	11.2	7.0	1.5	63.7	21.7	11.5	143.6		176.80
S32	14.3	7.86	294	197	epm	2.20	0.93	0.30	0.04	3.47	0.45	0.32	2.35	0.00	3.13
					%epm	63.3	26.8	8.8	1.1	100.00	14.5	10.2	75.3	0.0	100.00
					ppm	39.2	10.7	7.0	1.4	58.3	26.0	12.3	147.2	0.0	185.50
S33	15.5	7.86	293	196	epm	1.96	0.89	0.30	0.04	3.19	0.54	0.34	2.41	0.00	3.30
					%epm	61.4	27.9	9.5	1.1	100.00	16.4	10.4	73.2	0.0	100.00
					ppm	41.6	11.2	7.0	1.4	61.2	21.2	11.7	144.6	0.0	177.50
S34	15.3	7.74	295	198	epm	2.08	0.93	0.30	0.04	3.35	0.44	0.33	2.37	0.00	3.14
					%epm	62.1	27.8	9.1	1.1	100.00	14.1	10.4	75.6	0.0	100.00
S35	14.5	7.75	293	196	ppm	42.4	10.7	7.0	1.4	61.5	20.9	22.0	155.6	0.0	198.50

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					epm	2.12	0.89	0.30	0.04	3.35	0.44	0.61	2.55	0.00	3.60
					%epm	63.3	26.6	9.1	1.1	100.00	12.1	17.0	70.9	0.0	100.00
					ppm	38.4	11.7	7.0	1.6	58.7	20.2	12.1	156.0	0.0	188.30
S36	14.5	7.79	276	185	epm	1.92	0.97	0.30	0.04	3.24	0.42	0.34	2.56	0.00	3.31
					%epm	59.3	30.0	9.4	1.3	100.00	12.7	10.1	77.2	0.0	100.00
Min.	10.5	6.59	257	172.2		32	9.2	6.0	1.2		18.6	10.0	134.4		
Max.	21	7.9	391	262		60.0	13.12	8.00	1.8		68.7	22.0	199.2		
Mean	14.3	7.65	295.4	197.9		44.1	11.4	6.6	1.43		27.9	13.6	152.9		

The objective of this analysis is to elucidate the overarching trajectory and scale of temporal changes in dam inflow, identify the exact junctures at which these changes manifested, and thereby improve comprehension of water availability dynamics and the key trends within the Dukan Dam Reservoir, as presented in Table 7.

The results by using Mann-Kendall test and Sen's slope estimator, summarized in Table 2, indicate no statistically significant trends at any scale. Non-significant decreasing trends during the months (Oct., Nov., Dec., Feb., Mar., April, May, July, Aug. and Sept.), in annual and seasons (annual, and all seasons) were seen with magnitudes of (-0.3775115, -0.1890351, -0.9293879, -4.081076, -6.597452, -8.884479, -5.591421, -2.550937, -0.5501882, -0.1165, -0.6646111, -4.136988, -8.751296, -1.220456, -0.3090482, -2.312717) mm.S-1/yr respectively. In month (January) showed non-significant increasing trends with magnitudes of (0.08869318) mm.S-1/yr.

In the case of the monthly, seasonal and annual trend, no positive sign of Tau values was observed, which revealed the presence of an increasing trend. Negative signs of Tau values for all the months, seasons, and annual (except January) showed that there is a declining trend in monthly, seasonal, and annual inflows. Sen's slope toward zero indicated a negligible rate of change of inflow for monthly flow. Regarding annual inflows, the MK test indicated no significant decreasing trend (P-Value = 0.09728 > 0.05), with a tau value of (-0.240) and a Sen Slope value of (-4.136988) that reflects the magnitude of the decrease.

5.4. Innovative trend analysis (ITA) technique for inflow

As shown in Figure 8 to 11, monthly trend analysis using ITA revealed that (except for January) all other 11 months showed a significant downward trend in the decrease in the "low, medium and high" inflow amounts. Annual trend analysis using ITA showed a highly significant decreasing trend.

Seasonal trend analysis using ITA indicated a range of significance from low to high, demonstrating a consistent downward trend.

5.5. Descriptive Analysis of monthly, annual and seasonal outflow

Presents key statistical parameters, including minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), skewness (CS), and kurtosis (CK) for the monthly, annual and seasonal outflow for water years (2000-2025) recorded at the Dukan Dam Directorate, Table 8.

5.6. Monthly, Seasonal and annual trends in out flow as estimated from Mann-Kendall and Sen's slope statistics

The Dukan Dam Directorate provided monthly, seasonal, and yearly outflow data for the Dukan Dam Reservoir. Kendall's tau nonparametric test (Kendall, 1938) was used to find important patterns in this data. At the 90% confidence level, a trend was considered statistically significant if the computed Kendall's tau value was equal to zero, as indicated by a probability value (p-value) of < 0.10.

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Table 6. Statistical properties of monthly, annual and seasonal Inflow for water years (2000-2001 to 2024-2025).

Time	Mean	Max.	Min.	Stdev.	Kurtosis	CV	Skewness
Oct.	24.36	68.58	2.29	15.27	1.87	62.67	1.39
Nov.	53.05	196.67	13.50	42.95	4.64	80.97	2.14
Dec.	100.19	407.19	30.19	89.72	5.06	89.55	2.12
Jan.	164.83	526.74	31.81	139.19	0.61	84.44	1.23
Feb.	252.55	734.00	36.50	168.26	1.13	66.63	1.04
Mar.	289.01	654.74	45.00	163.70	0.24	56.64	0.91
Apr.	284.21	942.17	41.00	201.60	3.53	70.94	1.57
May.	181.66	436.35	24.60	102.66	-0.03	56.51	0.46
Jun.	81.82	343.77	14.80	68.44	8.63	83.65	2.59
Jul.	38.57	70.97	5.52	20.64	-1.37	53.51	-0.14
Aug.	26.20	49.84	2.90	12.67	-0.75	48.36	-0.16
Sept.	31.13	272.94	2.13	52.85	20.11	169.75	4.35
Annual	127.30	315.27	29.33	69.04	0.94	54.24	1.00
Spring	251.62	658.31	36.87	144.34	1.40	57.37	0.97
Summer	48.86	147.92	14.97	29.57	4.09	60.51	1.55
Autumn	36.18	118.60	10.74	26.55	3.19	73.37	1.85
Winter	172.52	478.60	38.18	109.47	0.90	63.45	1.03

Table 7. Significant trends by using Mann-Kendall test and Sen’s slope Estimator in monthly, annual and seasonal Inflow for water years (2000-2025).

Trend	tau	p-value	Z	Sen's slope	Trend
Oct.	-0.187292	0.1987	-1.2852	-0.3775115	NSDT
Nov.	-0.05695214	0.7084	-0.37399	-0.1890351	NSDT
Dec.	-0.147158	0.315	-1.0048	-0.9293879	NSDT
Jan.	0.000	1	0	0.08869318	NSIT
Feb.	-0.1333333	0.3624	-0.91084	-4.081076	NSDT
Mar.	-0.220	0.129	-1.5181	-6.597452	NSDT
Apr.	-0.2266667	0.1176	-1.5648	-8.884479	NSDT
May.	-0.260	0.07212	-1.7983	-5.591421	NSDT
Jun.	-0.320	0.02651	-2.2187	-2.550937	SDT
Jul.	-0.1133333	0.4409	-0.77071	-0.5501882	NSDT
Aug.	-0.04666667	0.7614	-0.30361	-0.1165	NSDT
Sep.	-0.2370621	0.102	-1.6353	-0.6646111	NSDT
Annual	-0.240	0.09728	-1.6582	-4.136988	NSDT
Spring	-0.280	0.05257	-1.9385	-8.751296	NSDT
Summer	-0.2133333	0.1412	-1.4714	-1.220456	NSDT
Autumn	-0.1266667	0.3875	-0.86413	-0.3090482	NSDT
Winter	-0.09333333	0.5283	-0.63058	-2.312717	NSDT

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, NT refers to no trend.

The Kendall's tau (τ) statistic, which ranges from -1 to +1, quantifies the degree and direction of monotonic correlation. A perfect positive monotonic correlation is represented by a value of $\tau = +1$, a perfect negative monotonic correlation by a value of $\tau = -1$, and the lack of any monotonic connection by a value of $\tau = 0$. Thus, an upward monotonic trend is indicated by a positive Kendall's tau (τ) value, whereas a downward monotonic trend is shown by a negative τ value.

The Dukan Dam Reservoir's monthly, seasonal, and yearly outflow trends are described in depth in the next subsections. The Kendall's tau test was used to identify periods that showed statistically significant trends at the annual scale. Throughout the water years (2000-2025), the Dukan Dam Reservoir's monthly, yearly, and seasonal outflow was examined for statistically significant patterns.

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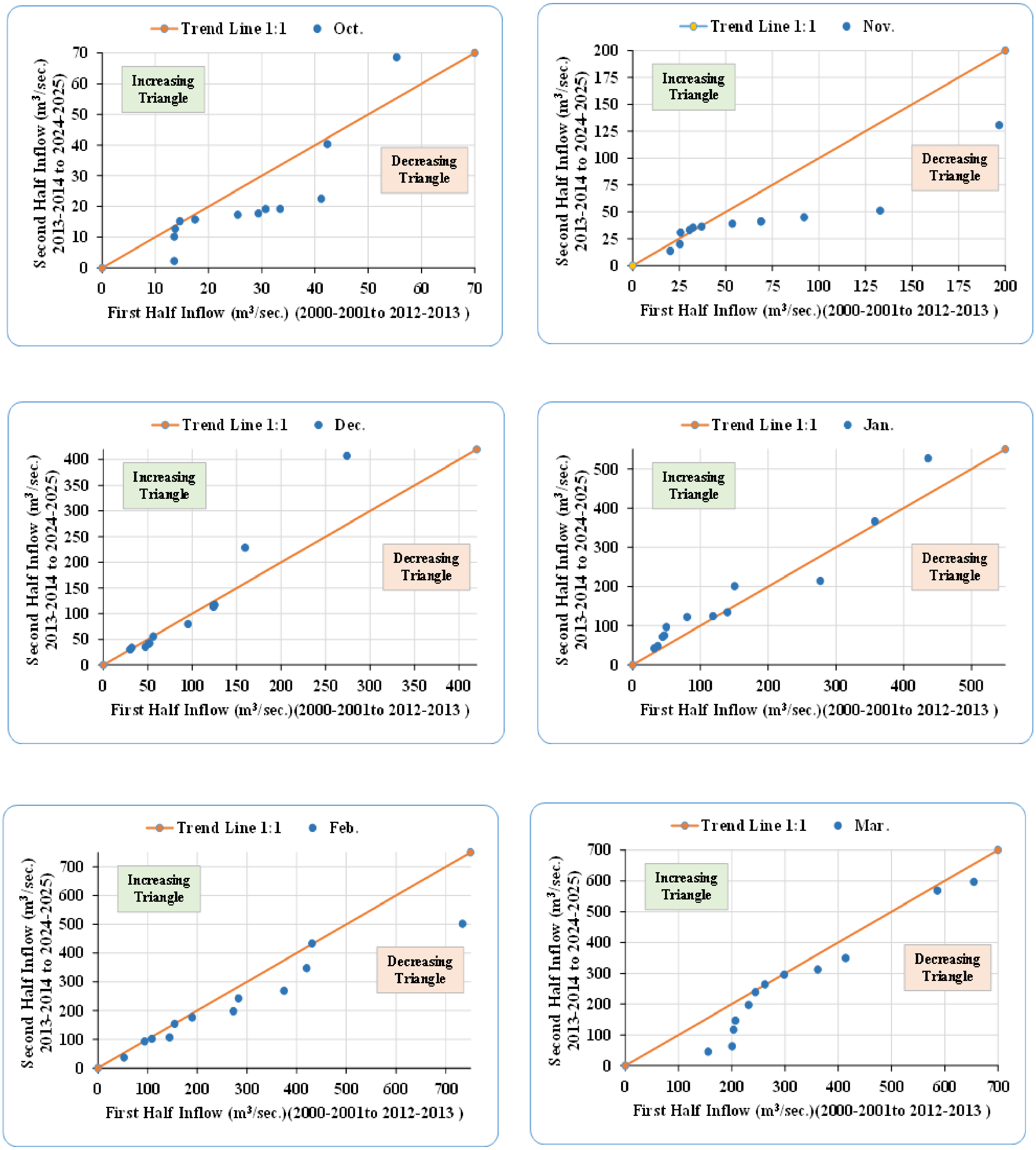

Figure 8. Innovative trend analysis (ITA) for monthly inflow (Oct. to Mar.) for water years.

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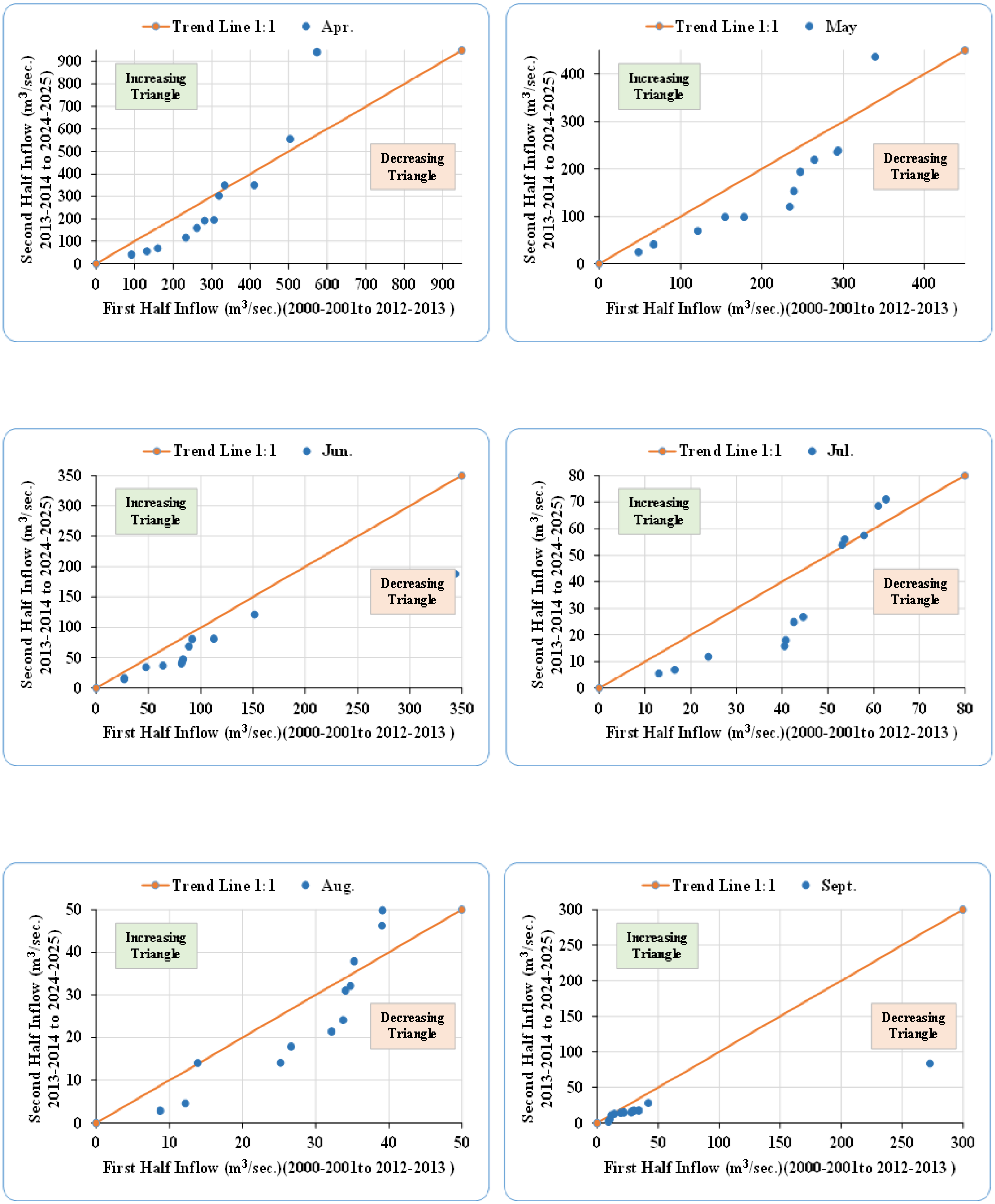

Figure 9. Innovative trend analysis (ITA) for monthly inflow (Apr. to Sep.) for water years.

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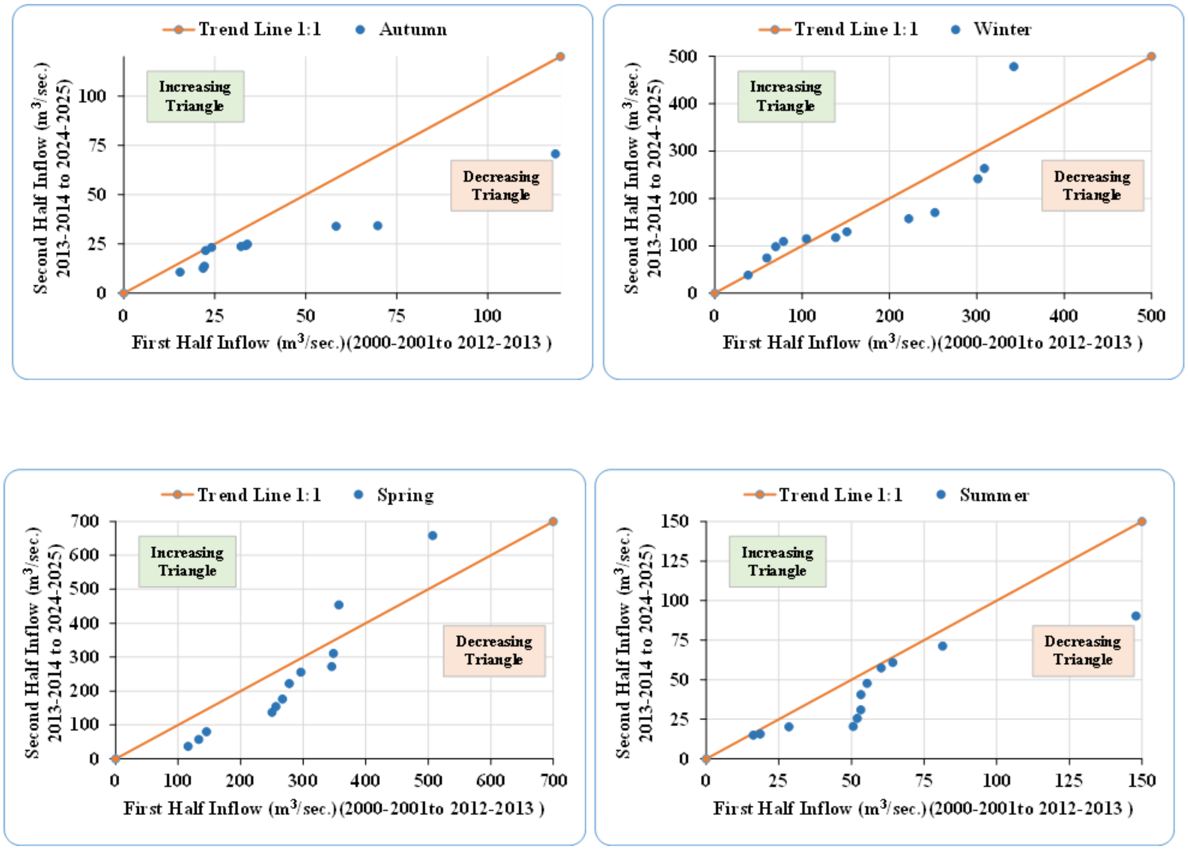

Figure 10. Innovative trend analysis (ITA) for seasonal inflow for water years.

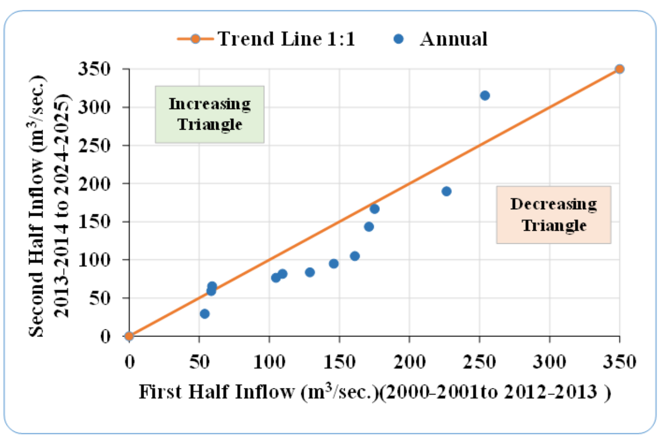

Figure 11. Innovative trend analysis (ITA) for annual inflow for water years.

The yearly streamflow at Dukan Dam station showed significant- changes (p-value < 0.10), according to the study (Table 9).

The analysis of outflow trends revealed almost no statistically significant changes over time. A trend analysis was conducted at monthly, seasonal, and annual scales using the Mann-Kendall test and Sen's slope estimator. The results, summarized in Table 3. However, several non-significant trends were identified. Significant trends were not observed on the annual or seasonal scale. Non-significant decreasing trends during the months (Nov., Dec., May., June., July., Aug. and Sept.), in annual and in seasons (Summer, Autumn and Winter) were seen with magnitudes of (-1.235741, -0.4895427, -0.7704301, -3.384167, -4.487404, -4.941935, -1.381517, -1.001438, -4.072917, -0.5338091, -0.4687662) mm.S-1/yr respectively. In months (Oct., Jan., Feb., March, and April) and in seasons (Spring) showed non-significant increasing trends with magnitudes of (0.1963252, 0.383871, 0.09391762, 1.020283, 0.9839869, 0.3054809) mm.S-1/yr respectively.

5.7. Results of innovative trend analysis (ITA) technique for outflow

The graphical results of ITA (Figs. 12-14) reveal three categories. First, for the first category where

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lower outflow is declining, this reduction in outflow of "medium" and "low" amounts (October, May, June, July, August, September, Summer, Autumn, winter, and annual). The second category is concerned with the absence of a trend in the "lower" outflow, such as in the cases of Nov., Dec., Feb., April, spring, and winter. The third category includes those where the trend of high outflow clusters is unclear. There are upward and downward trends and even unclear ones. An upward trend appears, as noticed in Jan. and March, with the increase in the "medium" outflow amounts.

Table 8. Statistical parameters of monthly, annual and seasonal outflow for water years (2000-2025).

Time	Mean	Max.	Min.	Stdev.	CK	CV	CS
Oct.	111.55	278.23	41.71	67.31	1.00	60.34	1.26
Nov.	108.95	325.97	41.33	67.80	3.49	62.23	1.75
Dec.	111.83	362.03	30.00	75.56	3.69	67.57	1.70
Jan.	97.20	381.65	29.13	75.54	8.38	77.71	2.72
Feb.	93.52	374.52	16.90	74.32	8.32	79.47	2.60
Mar.	84.88	275.35	23.03	56.70	4.82	66.80	2.03
Apr.	102.50	793.90	25.63	146.62	23.06	143.04	4.72
May.	99.74	505.87	31.00	91.78	17.19	92.02	3.89
Jun.	138.79	285.57	55.70	71.31	-0.32	51.38	0.82
Jul.	181.79	415.81	55.00	85.61	0.72	47.09	0.78
Aug.	200.71	344.13	68.60	81.01	-1.05	40.36	0.11
Sept.	144.37	311.73	54.07	70.01	-0.11	48.49	0.73
Annual	122.99	275.30	50.94	58.05	1.30	47.20	1.37
Spring	95.70	497.34	31.52	90.62	17.35	94.69	3.93
Summer	173.76	347.26	60.27	75.61	-0.45	43.51	0.49
Autumn	121.62	303.55	49.85	59.20	2.53	48.68	1.47
Winter	100.85	372.73	29.59	71.70	8.43	71.10	2.63

Table 9. Significant trends by using Mann-Kendall test and Sen's slope Estimator in monthly, annual and seasonal outflow for water years (2000-2025).

Time scale	tau	p-value	Z	Sen's slope	Trend
Oct.	0.033445	0.8334	0.21031	0.1963252	NSIT
Nov.	-0.08695701	0.5591	-0.58419	-1.235741	NSDT
Dec.	-0.120402	0.4134	-0.81787	-0.4895427	NSDT
Jan.	0.06666667	0.6572	0.44374	0.383871	NSIT
Feb.	0.02666667	0.8701	0.16348	0.09391762	NSIT
Mar.	0.1466667	0.3153	1.0043	1.020283	NSIT
Apr.	0.160	0.2723	1.0977	0.9839869	NSIT
May.	-0.08666667	0.5593	-0.58387	-0.7704301	NSDT
Jun.	-0.2266667	0.1176	-1.5648	-3.384167	NSDT
Jul.	-0.2466667	0.08821	-1.7049	-4.487404	NSDT
Aug.	-0.240	0.09728	-1.6582	-4.941935	NSDT
Sep.	-0.080	0.5912	-0.53716	-1.381517	NSDT
Annual	-0.1333333	0.3624	-0.91084	-1.001438	NSDT
Spring	0.07333333	0.6238	0.49045	0.3054809	NSIT
Summer	-0.2466667	0.08821	-1.7049	-4.072917	NSDT
Autumn	-0.040	0.7973	-0.2569	-0.5338091	NSDT
Winter	-0.04666667	0.7614	-0.30361	-0.4687662	NSDT

* NSIT refers to a non-significant increasing trend, NSDT refers to a non-significant decreasing trend, NT refers to no trend.

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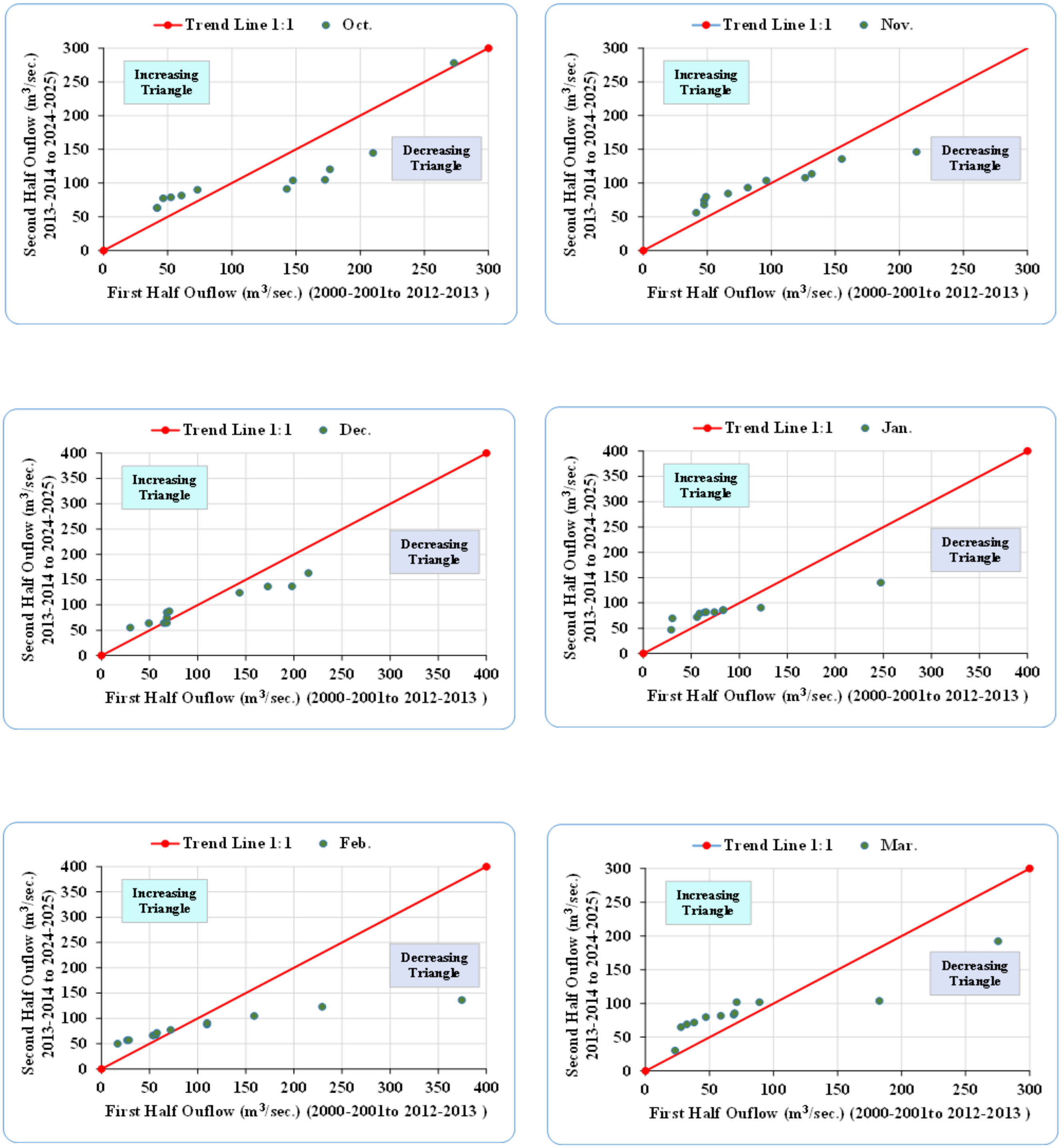

Figure 12. Innovative trend analysis (ITA) for monthly outflow (Oct. to Mar.) for water years (2000-2025).

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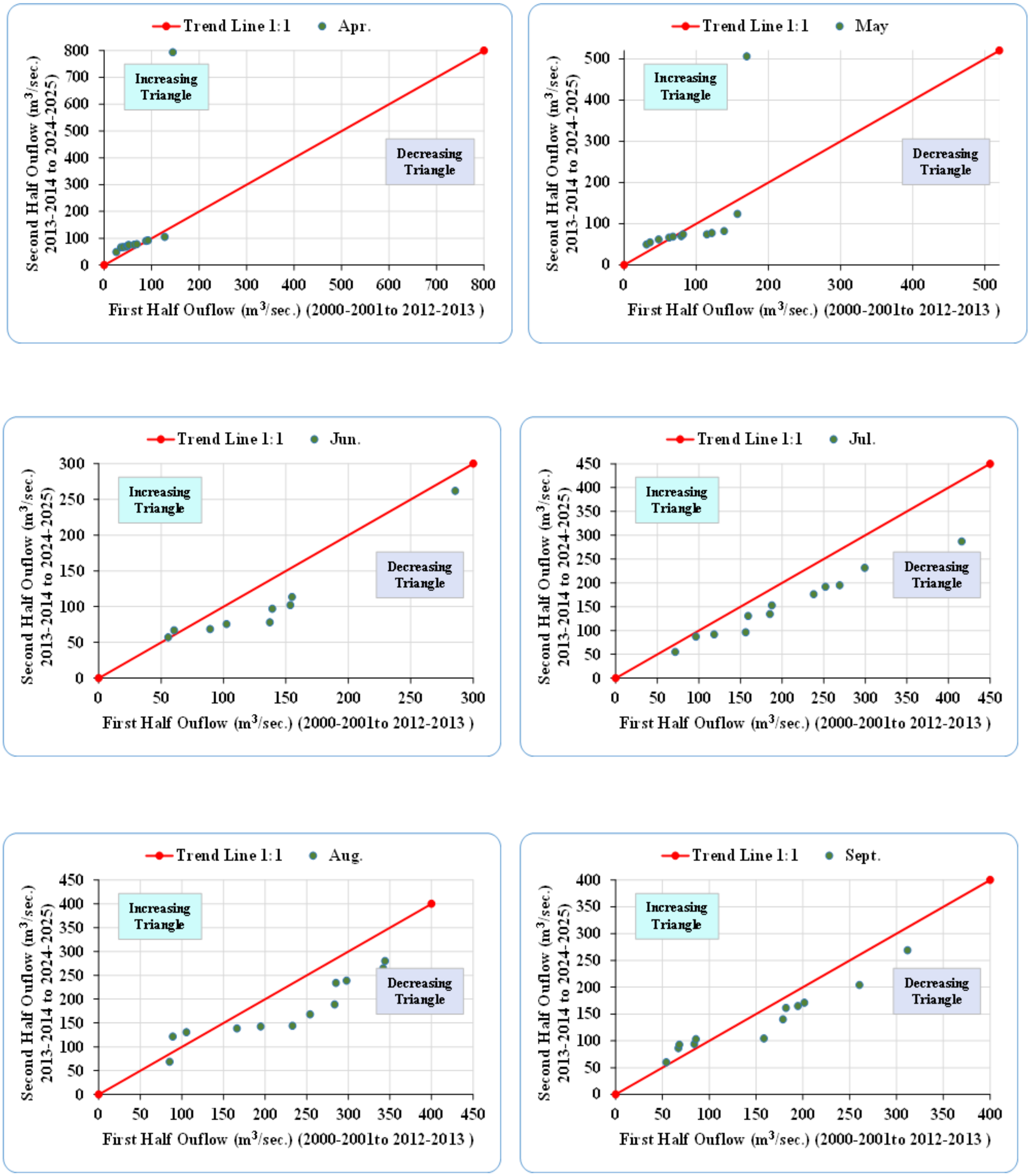

Figure 13. Innovative trend analysis (ITA) for monthly outflow (Apr. to Sep.) for water years (2000-2025).

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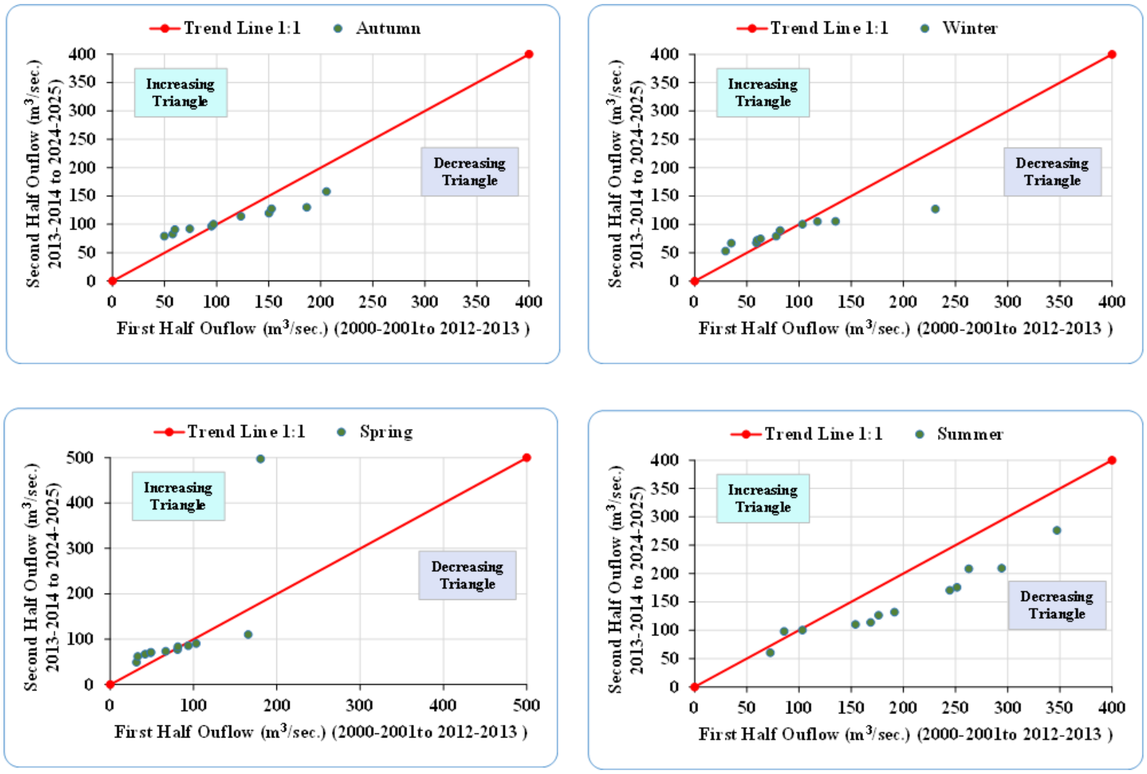

Figure 14. Innovative trend analysis (ITA) for seasonal outflow for water years (2000-2025).

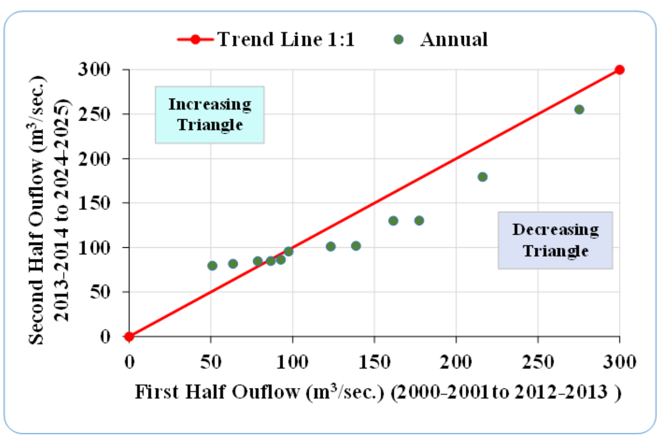

Figure 15. Innovative trend analysis (ITA) for annual outflow for water years (2000-2025).

6. Conclusions

This study analyzed the hydrochemical properties and trends of streamflow for Lesser Zab River discharge at Dukan Dam using various techniques. Measured physiochemical parameters of water samples collected from the 36 Dukan lake water samples show that all water samples are suitable for drinking according to the WHO (2022) and Iraqi (2009) standards. The water type belongs to the calcium bicarbonate type. Inflow and outflow from the dam were analyzed. According to the MMK test, for inflow, non-significant decreasing trends during the months (Oct., Nov., Dec., Feb., Mar., April, May, July, Aug. and Sept.) and in annually and seasonally (annual, and all seasons) were seen with negative magnitudes. While January showed non-significant increasing trends with magnitudes of (0.08869318) mm. S^{-1}/yr. For outflow, several non-significant trends were identified. Significant trends were not observed on the annual or seasonal scale. Non-significant decreasing trends with negative magnitudes were observed during the months (Nov., Dec., May, June, July, Aug., and Sept.) and in the seasons (Summer, Autumn, and Winter). Non-significant increasing trends with positive magnitudes were observed in the months of October, January, February, March, and April, as well as in the season of Spring. ITA results for inflow revealed all months (except for January) and seasons with significant decreasing trends: “low, medium and high.” Furthermore, the annual trend analysis showed a highly significant decreasing trend. For

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outflow, it revealed three categories. First, for the first category where lower outflow is declining, this reduction in outflow of "medium" and "low" amounts occurs in October, May, June, July, August, September, Summer, Autumn, winter, and the annual period. The second category is concerned with the absence of a trend in the "lower" flow, such as in the cases of Nov., Dec., Feb., April, spring, and winter. The third category includes those where the trend of high outflow clusters is unclear. The decreasing trend of streamflow for the last years is due to climate change, increasing demand, and the Iranian Tropical Water Project (TWP). This project has significantly altered local waterways, leading to unpredictable patterns in water availability. This disruption of the ecological balance affects both agriculture and natural habitats in the region.

Conflict of interest

The authors declared no conflicting interests.

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CRediT authorship contribution statement

Sherko Mustafa: Methodology, statistical analysis and investigations, writing original draft, editing. **Diary Al-Manmi**: supervision, review, and editing.

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