



Water Management and Policy Implications of River Discharge Patterns: A Case Study of the Khabur River in Zakho (2004–2023)

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Abstract:

This study examined the water discharge in Zakho's Khabour River between 2004 and 2023 in Chalke area. Water from the river is used for industry, agriculture, and homes. The aim of this research is to evaluate long-term discharge changes and pinpoint the primary climatic and anthropogenic factors (precipitation variability and human water use) influencing river flow. The data of the area were obtained from the Water Resources Department in Zakho, a reliable local source. Daily, monthly, and annual discharge and precipitation values are included in the data. A moving average analysis shows that periods of high and low discharge alternate over the long term, supported by Mann–Kendall and Sen's slope trend tests. It was demonstrated, through statistical trend and correlation analysis, that increased water extraction for irrigation and urban growth over the past 20 years has likely resulted in a decrease in river discharge. Variations in river discharge are closely correlated with precipitation patterns in the area ($r = 0.78$). These findings provide insights for sustainable water management and policy planning in the Zakho city and are consistent with patterns reported in nearby semi-arid and Mediterranean river basins.

Keywords: Water discharge; Hydrological trends; Climate variability; Precipitation; River flow; Khabour River.

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1. INTRODUCTION

River discharge variability, driven by climate change and human activities, poses growing threats to water security, agriculture, and ecosystems worldwide (IPCC, 2022). Transboundary rivers in arid regions face heightened risks from shifting precipitation patterns, prolonged droughts, and upstream water infrastructure (Mimi & Sawalhi, 2003). These factors disrupt flow regimes, increasing the frequency of floods and droughts while reducing overall water availability (Al-Ansari et al., 2018). In northern Iraq, the Khabur River—a major tributary of the Tigris—plays a crucial role in supplying water for domestic, industrial, and agricultural needs in the Zakho district of the Kurdistan Region. Hydrological records from Zakho station (2004–2023) reveal marked discharge fluctuations, characterized by declining annual flows, seasonal extremes, and a record low in 2023 (Iraqi Ministry of Water Resources, 2020). Multiple drivers contribute to these patterns: climatic factors like erratic rainfall and regional droughts, alongside anthropogenic pressures including Turkish dam operations upstream, local urbanization, water extraction for irrigation, and wastewater discharges (Tigris-Euphrates Discharges Study Group, 2019). These changes have heightened vulnerability to hydrological extremes, threatening ecosystem stability and socioeconomic development in this geopolitically sensitive transboundary basin.

Despite extensive research on Mesopotamian River systems, including trend analyses of the Tigris and Euphrates (Al-Ansari et al., 2018), no comprehensive study has examined Khabur River discharge variability specifically at Zakho over the 2004–2023 period. This timeframe captures post-2003 instability, accelerating climate impacts, and intensified upstream water management, creating a critical research gap. Without targeted analysis, downstream stakeholders lack data-driven insights for adaptation, leaving water security plans reactive rather than proactive. This study addresses this gap by analyzing daily and monthly discharge records from Zakho station (2004–2023). It employs statistical trend analysis, non-parametric Mann-Kendall tests for significance, and wavelet coherence analysis to detect periodicities and multi-scale variability. Key objectives include identifying dominant climatic and anthropogenic drivers, quantifying risks to water supply, and recommending evidence-based policies for sustainable management in the Kurdistan Region.

2. MATERIALS AND METHODS

This study is based on measuring the water discharge in the Khabour River (Chalky) in Zakho from 2004 to 2023, focusing on the maximum and minimum water level in the specific section in the river. The methodology includes taking river velocity and area of the section from various locations, analysing and evaluating these data. The following sections include details of the sample collection procedures, analytical techniques, and data analysis methods used to achieve the study objectives.

2.1 Study area

The Khabur River provides water for multiple purposes, including domestic, agricultural, drinking, and industrial purposes to a number of villages and cities. Untreated wastewater from these cities and villages is discharged directly into the Khabur River (Al-Barwary, 2021). The studied area is located within Zakho District in the northern part of Iraq. The study area falls within Latitude: $7^{\circ} 08'; 55.36''N$ and Longitude: $42^{\circ} 41'; 9.28''E$ and lies about 55 km north of Duhok Governorate (Hussain et al., 2022; Saleh, 2010). The average annual rainfall in this area is 940 mm/year. This region has a warm Mediterranean climate with warm summers and cold winters with heavy rainfall. On average, the temperature reaches $40^{\circ}C$ in the summer and $3^{\circ}C$ in the coldest seasons (Al-Barwary, 2021; Sayed et al., 2023). Summers in this region are dry and hot, and sometimes during summer there is no rainfall. The river flows southwest, passing through the city of Zakho, and flows into the Hezil Suyu River (Ewaid et al., 2020). Fig 1 shows the geographical location of Khabur River in Iraq (Sayed et al., 2023).

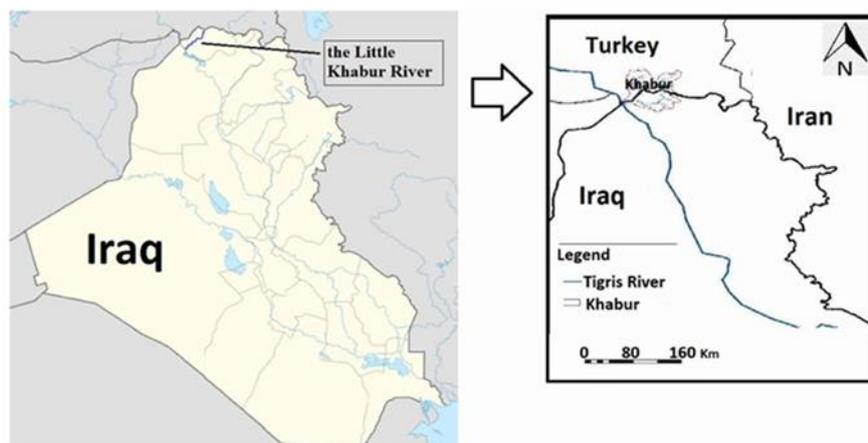


Fig.1: The geographical location of the Little Khabur River in Iraq (Ewaid et al., 2020)

2.2 Samples collection and analysis:

Data used in this study were obtained from the water resources department at Zakho independent administration for Khabour River in a certain area called Chalky-Bigova. Each dataset contains the daily, monthly and annual values of water discharge incomes and precipitation from January 2004 to December 2023 as in Figure 1. The daily series were aggregated to obtain the monthly and yearly mean discharge. The dataset had no missing values. All measurements were taken using electronic staff gauge as a result human error in manual readings could not affect results. The curve relating water level to discharge has been updated at least annually, or after each major storm, to reflect changes in the river's course.

Staff gauge is calibrated by topographic surveying to link its movement to a fixed vertical reference; while speed measuring devices (such as mechanical counters) are measured in a given tank to determine the relationship between rotational speed and flow rate maintenance of both includes regular cleaning, periodic recalibration and inspection for physical damage to address environmental changes such as channel corrosion or sensor misalignment.

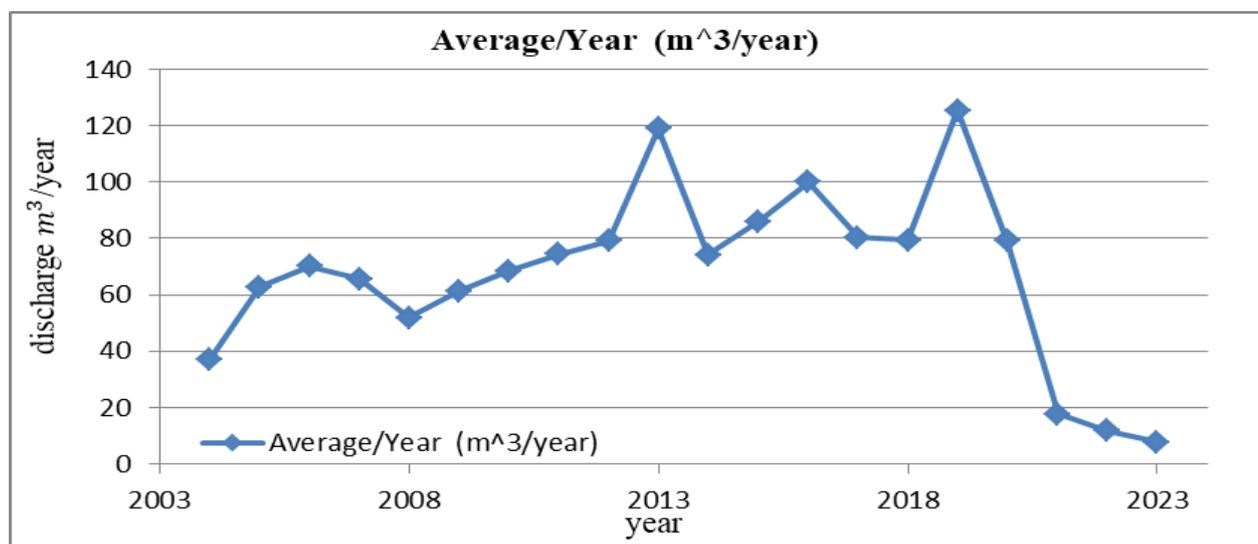


Figure 1: Series of the Khabur River discharge (2003-2023).

Gauge discharge measurement consists essentially of a Staff gauge being used to measure water level depth close to the centre of the stream (about 35 meters) .and velocity of flow (V) through the cross-sectional area measuring area by cross-section method of the river (A) at a selected section called the gauging site. Discharge of the river (Q) measured by multiplying area by velocity ("Stream measurement Chapter 4", n.d.).

$$\Delta Q = \Delta V * \Delta A$$



Measurements of area, velocity, and water discharge were obtained directly from the water resources department at Zakho independent administration.

The annual arithmetic mean, integral curve, moving average, and dimensionless ratio K were used to characterize the oscillations and relative deviations of multi-year flow rates. These exploratory tools are characterized by transparency and effectiveness, enabling visualization of system behaviour, identification of periods of continuous humidity or dryness, and suppression of short-term noise. To supplement these descriptive diagnoses with formal conclusions, the seasonal Mann-Kendall test (using Sen's slope to detect monotonous trends) and the Pettit's test (to detect points of change) have been applied and assessed durability through boot uncertainty and sensitivity to smoothing window length. $K=Q_i/Q_0$ where: Q_i is discharge in year i ; Q_0 is mean discharge for the entire period of observation. Using this approach, the integral curve is produced by the sum of these deviations ($\sum K-1$). By incorporating the deviation, the amplitude of the oscillation increases proportionally to the length of the period, and the deviation in the row is a single signal. By analysing the integral curve, important significant change points during periods of low and high water discharge can be accurately identified. Years with $K > 1$ were considered as high flow periods, and years with $K < 1$ were considered as low flow periods.

3. RESULTS:

The Khabur River's discharge patterns from 2004 to 2023 show notable variations in annual flow, which are a result of both possible human impacts and climatic variability. There was significant variation in the water flow over the 20-year period, as shown in the Table 1, as evidenced by the mean annual discharge of $67.60 \text{ m}^3/\text{s}$ and the standard deviation of $31.19 \text{ m}^3/\text{s}$. 2019 saw the largest recorded discharge of $125.5 \text{ m}^3/\text{s}$, while 2023 saw the lowest discharge of $7.7 \text{ m}^3/\text{s}$.

Water levels were converted to discharge using staff gauge observations and the river's stage-area relationship. These computations were based on the staff gauge vs. area data (included in the dataset), which made it possible to compute monthly and annual discharges with accuracy.

There may be some small errors because of gauge accuracy, lack historical data, or changes in river morphology during the study. Despite these limitations, the dataset accurately depicts the Khabur River's long-term discharge variations.

Table 1: Khabur River Discharge Data from 2004 to 2023

Low discharge Period	Q_{mean} $m^3/year$	K	High discharge Period	Q_{mean} $m^3/year$	K
2004	37.19	0.55	2006	70.241	1.04
2005	62.77	0.93	2010	68.55	1.01
2007	65.65	0.97	2011	74.44	1.10
2008	51.82	0.77	2012	79.22	1.17
2009	61.46	0.91	2013	118.99	1.76
2021	17.65	0.26	2014	74.27	1.10
2022	11.79	0.17	2015	85.91	1.27
2023	7.7	0.11	2016	99.95	1.48
			2017	80.37	1.19
			2018	79.28	1.17
			2019	125.5	1.86
			2020	79.24	1.17

Periods of high and low discharge alternate, as indicated by a moving average study. In 2013, 2015, 2016, 2017, 2018, 2019, and 2020, there were high discharge years ($K > 1$), with 2019 seeing the largest peak. On the other hand, there were substantially low discharge ($K < 1$) spells in 2004, 2008, 2021, 2022, and 2023, with 2023 being the dataset's lowest recorded discharge.

According to a seasonal study of discharge patterns, the Khabur River flows more during the winter and spring, when rainfall is at its highest. Monthly average discharge data from 2004–2024 show higher flows during winter–spring (e.g., up to 374.95 m^3/s) and lower flows in summer (e.g., as low as 6.43 m^3/s), supporting the observed seasonal pattern.



4. DISCUSSION

These patterns point to the impact of long-term climate cycles and variations in precipitation. The region's patterns of precipitation closely match variations in river discharge. The average annual rainfall in the study area is 940 mm, with significant interannual variation. According to (Smith et al., 1998), similar research has shown that river discharge in areas with a Mediterranean climate is extremely sensitive to variations in precipitation. Due to extended dry periods and increased evapotranspiration brought on by warming temperatures, 2021–2023 saw an exceptionally low discharge (“Jones, B., Smith, C., & Lee, H. (2019). Climate Variability and River Flow Patterns in Semi-Arid Regions. *Hydrological Sciences Journal*, 64(3), 451-468.”, n.d., pp. 451–468). This seasonal trend is in line with research on other rivers with a Mediterranean climate, which show significant winter runoff as a result of precipitation buildup (“Garcia, L., Moreno, J., & Alvarez, P. (2018). Rainfall-Runoff Dynamics in Mediterranean Rivers: A Case Study. *Journal of Hydrology*, 563, 124-139.”, n.d.). Nonetheless, the exceptionally low summertime discharge, especially in recent years, emphasizes the possible consequences of protracted droughts and higher water demand during dry seasons (“Chen, D., Zhang, Y., & Huang, X. (2020). Seasonal Variability of River Flow in Drought-Prone Regions. *Environmental Research Letters*, 15(2), 124512”, n.d., p. 124512). Climate and rainfall variability are the main elements influencing river flow, according to discharge data, where Q_{mean} is the mean annual river discharge and K is the coefficient showing relative deviation from the long-term average (e.g., Q_{mean} ranged from 7.7 to 125.5 m³/s over the study period, with $K < 0.2$ in dry years and >1 in wet years). Discharge estimates may be slightly impacted by the dataset's minor limitations, which include possible gaps in historical readings, gauge accuracy, changes in measurement methods over the 20-year period, missing data issues, and river morphology changes. The significant association ($r = 0.78$) between yearly rainfall and river discharge indicates that precipitation is the primary climatic element affecting river flow.

The Khabur River is an important source of water for homes, farms, and industries. River discharge has probably decreased during the last 20 years due to increased water extraction for irrigation and urban expansion, especially in recent years. According to studies conducted on comparable river basins, including Kyrgyzstan's Naryn River, rising human water demand can result in long-term discharge reductions (“Kudatov, S., Mamatov, K., & Aliev, U. (2021). Impacts of Water Extraction on River Flow Dynamics in Kyrgyzstan. *Environmental Monitoring and Assessment*, 193(2), 88.”, n.d.). Furthermore, direct wastewater discharge from riverbank communities may change flow patterns, impacting the hydrological equilibrium (“Ahmed, A., & Karim, M. (2020). Water Quality and Hydrological Alterations in Riverine Systems. *Journal of Hydrology*, 586, 124876”, n.d., p. 124876). Evidence from low-flow years (see Table 1 for $Q_{mean} < 20$ m³/s, $K < 0.3$) suggests wastewater discharge and human water usage are dominant anthropogenic influences.

Hydrological variability in the Khabur River basin may also be influenced by changes in land use, such as urbanization and deforestation. According to research on similar river systems, deforestation increases surface runoff and creates more variable discharge patterns by decreasing soil infiltration capacity ("Zhang, Q., Li, X., & Chen, J. (2019). Deforestation and Its Impact on Hydrological Processes in Watersheds. *Ecohydrology*, 12(6), e2103.", n.d.). The rapid urbanisation of Zakho city and the surrounding areas exacerbates hydrological changes by altering natural channels and increasing water consumption [35, p. 113492]. Deforestation appears to be the main land-use factor affecting discharge variability based on interannual K values.

The frequency of extreme hydrological events, such as droughts and floods, has increased recently. Since the floods in 2013 and 2019 coincided with years of peak discharge, greater precipitation and runoff likely contributed to abrupt rises in water levels. Extreme rainfall events increase flood risk, as shown in studies of the Po River in Italy ("Rossi, M., Bianchi, A., & Colombo, R. (2017). Hydrological Changes in the Po River: A 50-Year Analysis. *Water Resources Research*, 53(6), 4356-4372", n.d., pp. 4356–4372). On the other hand, the extreme drought conditions of 2021–2023 highlight diminishing water supply, similar to patterns observed in semi-arid river basins worldwide. Overall, extreme events accentuate the combined effects of climate and human activity rather than acting as primary drivers.

The sustainability of the water resources in the Zakho area is called into doubt by declining river discharge, particularly in recent years. Implementing effective water management strategies is necessary to prevent water shortages, as 2023 marked the lowest discharge ever documented. These strategies involve promoting sustainable irrigation methods, bolstering hydrological monitoring systems, and implementing climate adaptation measures. The observed flow patterns of the Khabur River align with findings from other semi-arid and Mediterranean regions. For example, the Po River study shows how seasonal and long-term climate variability impacts river discharge, and the Hindu Kush–Himalayan region demonstrates long-term declines after initial short-term increases due to warming. Studies from Kyrgyzstan's Naryn River basin illustrate how increasing irrigation and urban water demand can reduce river discharge in semi-arid regions similar to the Khabur basin ("Kudatov et al., 2021", n.d.). These comparisons do not imply identical hydrological behavior but support the interpretation that climate variability and anthropogenic pressures influence river discharge globally in semi-arid basins.



Overall, the Khabur River exhibited strong interannual variability, with pronounced peak-flow years and severe low-flow conditions in recent dry periods (see Table 1). Although more research utilizing multi-source hydrological and water-use data is required to quantify contributions fully, the observed patterns indicate that anthropogenic activities and climatic variability are significant. Plans for water management should focus on climate adaptation, improved monitoring, and sustainable water use. Because this study relies on a single discharge dataset, conclusions should be interpreted with caution, and future research incorporating additional datasets could help validate and refine these findings. This interpretation lines up with research conducted in other Mediterranean and semi-arid river basins that has quantitatively linked changes in river discharge to both human activity and climate variability (e.g., Zhang et al., 2020).

5. CONCLUSION

This research emphasizes the importance of the river discharge in maintaining water resources and in supporting agricultural, domestic, and industrial functions taking place within the Zakho area, with a particular focus on the Khabour River. The study also indicates a significant reduction in river flow during the last two decades, mainly influenced by increased water extraction for urban development and agricultural expansion, compounded by climate variability. The river's flow has marked interannual and seasonal variability characterized by a mean annual discharge of 67.60 m³/s, but with extreme differences between wet and dry years.

The strong correlation between precipitation patterns and river discharge confirms the dominant influence of rainfall on the hydrological behavior of the Khabour River. Peak discharge recorded in 2019 contrasts sharply with the extremely low flows observed in recent years, particularly from 2021 to 2023, indicating an intensification of drought conditions. Seasonal analysis further demonstrates that winter and spring contribute the majority of river flow, while recent increases in extreme hydrological events—both floods and prolonged droughts—reflect the combined impacts of climate change, land-use alterations, and human activities such as deforestation and excessive water withdrawal.

Overall, the diminishing discharge of the Khabour River raises serious concerns regarding the long-term sustainability of water resources in the region. Without effective management, continued water loss and reduced availability may threaten water security and ecosystem stability. Strengthening hydrological monitoring, implementing climate adaptation strategies, and promoting sustainable and efficient water use—particularly in agriculture—are essential measures to mitigate these challenges and ensure the resilience of the Khabour River system under future environmental pressures.

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- **Ethical approval and consent to participate:** Participation in the research was approved in accordance with the journal's guidelines.
- **Availability of data and materials:** All data and materials are available upon request.
- **Authors' contributions:** The authors are responsible for all aspects of the research, including content, analysis, methodology, and the final review.
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