# **Analyzing Discharge Changes in the Tigris and Euphrates Rivers (1972-2022): The Role of Damming and Climate**

**Abstract**

The Tigris and Euphrates river basins face unprecedented water resource challenges due to extensive damming, primarily by Turkey, and increasing climate change impacts. This study analyzes the discharge changes in these rivers between 1972 and 2022, aiming to disentangle the roles of damming and drought. Utilizing daily discharge data from 12 sampling stations near major dams and 12 stations located far downstream, along with monthly Palmer Drought Severity Index (PDSI) datasets, we employed time series analysis, correlation analysis, change point analysis, and pre- and post-damming period comparisons. Our findings reveal significant reductions in average annual discharge, altered seasonal flow patterns, and a strong correlation between drought severity and river flow. Notably, the magnitude and timing of discharge changes differed between near-dam and far-from-dam stations, suggesting distinct impacts of damming and climate. Change point analysis indicates abrupt declines in discharge at near-dam stations coinciding with major dam operations, while far-from-dam stations showed a more gradual decline influenced by both damming and regional drought patterns. The study concludes that both damming and climate change have substantially impacted the hydrological regimes of the Tigris and Euphrates rivers, with damming having a more immediate and pronounced effect in closer proximity, while climate change exerts a broader influence across the basin, exacerbating water scarcity in downstream regions.

**1. Introduction**

The Tigris and Euphrates river basins, a region of immense historical and ecological significance in the Middle East, have sustained human civilizations for millennia (Al-Ansari & Knutsson, 2011; Evans, 2021; Kibaroglu & Scheumann, 2013; Zargar & Abbasi Alamooti, 2023). These rivers, originating in Turkey and flowing through Syria and Iraq to the Persian Gulf, are the lifeblood of an arid and semi-arid landscape, supporting agriculture, providing essential water supplies, and sustaining diverse ecosystems (Issa et al., 2014; Kibaroglu & Scheumann, 2013; Zargar & Abbasi Alamooti, 2023). In recent decades, however, the basins have experienced increasing water stress due to large-scale damming projects, particularly within Turkey, and the growing threat of climate change manifested as prolonged and intensified droughts (Issa et al., 2014; UN-ESCWA & BGR, 2013; Zargar & Abbasi Alamooti, 2023).

The Southeastern Anatolia Project (GAP), initiated by the Turkish government, represents a massive undertaking involving the construction of numerous dams and hydroelectric power plants on both the Tigris and Euphrates rivers (Al-Ansari & Knutsson, 2011; Aygun et al., 2013; Hussein et al., 2020; Kibaroglu & Scheumann, 2013; Kucukmehmetoglu, 2013; Salman & Salman, 1992; UN-ESCWA & BGR, 2013). Key structures such as the Atatürk Dam on the Euphrates and the Ilisu Dam on the Tigris have significantly altered the natural flow regimes of these rivers, leading to concerns about water availability and quality in downstream Syria and Iraq (Beaumont, 1995; Kibaroglu & Scheumann, 2013; Salman & Salman, 1992; UN-ESCWA & BGR, 2013). While Turkey emphasizes the benefits of these projects for energy production and irrigation within its borders, the scale of these interventions has raised significant geopolitical and environmental issues in the region (Kibaroglu, 2014; Zargar & Abbasi Alamooti, 2023).

This study aims to provide a comprehensive analysis of the changes in the discharge of the Tigris and Euphrates rivers over a 50-year period (1972-2022). Specifically, it investigates the roles of both upstream damming projects and climate-induced drought conditions in driving these alterations. By employing a combination of hydrological and statistical methods on daily discharge data from 12 sampling stations in close proximity to major dams and 12 sampling stations located further downstream, along with monthly PDSI datasets, this research seeks to quantify the impacts of these factors on the rivers' flow regimes at different spatial scales. Understanding the individual and combined effects of damming and climate change at varying distances from damming infrastructure is crucial for informed water resource management and for mitigating potential conflicts in this water-scarce and politically sensitive region. This paper builds upon the existing literature by providing a detailed analysis of long-term discharge data from spatially differentiated sampling points in conjunction with drought indices to offer insights into the complex interplay of anthropogenic and climatic influences on these vital transboundary rivers.

**2. Study Area**

The Tigris and Euphrates rivers originate in the eastern Anatolian highlands of Turkey, traversing southeastward through Syria and Iraq before their confluence at Al-Qurnah in Iraq, forming the Shatt al-Arab, which empties into the Persian Gulf (Al-Ansari & Knutsson, 2011; Kibaroglu & Scheumann, 2013). The river basins exhibit significant climatic and topographic variations, from the mountainous headwaters in Turkey to the arid and semi-arid plains of Syria and Iraq (Issa et al., 2014). These rivers are the primary sources of freshwater in a region characterized by water scarcity, supporting extensive agricultural activities, diverse ecosystems including the critical Mesopotamian Marshes, and the water needs of a large population (Al-Ansari & Knutsson, 2011; Issa et al., 2014). Turkey's GAP project, with its network of dams on both rivers, represents a major water management intervention in the upper reaches of the basin (Kibaroglu & Scheumann, 2013; Kucukmehmetoglu, 2013). The operation of these dams, coupled with the increasing frequency and intensity of droughts in the region, has significantly impacted the hydrological balance and downstream water availability in Syria and Iraq (Beaumont, 1995; UN-ESCWA & BGR, 2013). To better understand the spatial variability of these impacts, this study focused on 12 sampling stations located in close proximity to major dams and 12 sampling stations situated at a considerable distance downstream.

**3. Data**

This study utilized two primary datasets covering the period from 1972 to 2022 to analyze discharge changes and the influence of damming and climate:

* **Daily Discharge Data:** Daily streamflow measurements were collected from 24 key gauging stations located on the Tigris and Euphrates rivers. Twelve of these stations were strategically selected for their close proximity to major dams in Turkey, Syria, and Iraq, allowing for the assessment of the immediate impacts of dam operations. The remaining twelve stations were located at a significant distance downstream from these dams to capture the cumulative effects of damming and the influence of other factors, such as climate variability and tributary inflows. The daily resolution of the data enables the analysis of both short-term flow variability and long-term trends in river discharge volume at different spatial scales.
* **Monthly Palmer Drought Severity Index (PDSI):** Monthly PDSI values for the geographical area encompassing the Tigris and Euphrates river basins were obtained. The PDSI is a widely recognized and used index that integrates temperature and precipitation data to provide a standardized measure of drought severity and duration (Dai, 2011). By using monthly PDSI, this study aims to capture the long-term drought conditions and their potential impact on the discharge of the rivers, and to compare its influence on the near-dam and far-from-dam stations.

**4. Methodology**

To investigate the discharge changes in the Tigris and Euphrates rivers and to determine the respective roles of damming and climate (drought) at different spatial scales, a combination of hydrological and statistical methods was applied to the collected datasets:

* **Time Series Analysis:** The daily discharge data for both the Tigris and Euphrates rivers at the 24 sampling stations were subjected to time series analysis to identify long-term trends and patterns (Issa et al., 2014). Techniques such as moving averages and the fitting of trend lines were used to visualize and quantify shifts in the average flow and seasonal discharge patterns over the 50-year study period for both near-dam and far-from-dam locations. This analysis helps in understanding the overall trajectory of river discharge and identifying periods of significant change at different distances from damming infrastructure.
* **Correlation Analysis:** To assess the relationship between climate variability and river discharge at different locations, correlation analysis was performed between the monthly discharge data from the 24 stations and the corresponding monthly PDSI values (Dai, 2011). Pearson's correlation coefficient was calculated to quantify the strength and direction of the linear association between drought conditions and river flow for both near-dam and far-from-dam stations. This analysis helps to determine the extent to which drought events influence the discharge of the Tigris and Euphrates at varying distances from major dams.
* **Change Point Analysis:** Change point analysis was employed to detect statistically significant points in time where the mean discharge of the rivers experienced abrupt shifts at both sets of sampling stations ( настроения, 2016). These identified change points were then compared with the operational timelines of major dam construction projects in the upper catchments, such as the Atatürk Dam (operational in the early 1990s) and the Ilisu Dam (began filling in 2019) (Kibaroglu & Scheumann, 2013). By comparing the timing and magnitude of change points at near-dam and far-from-dam stations, this method helps to identify the spatial extent and immediate versus delayed impacts of dam construction on river flow.
* **Comparison of Pre- and Post-Damming Periods:** To quantify the impact of damming on the rivers' flow regimes at different spatial scales, the average discharge and seasonal flow patterns were compared between distinct periods: before the operation of major dams and after their significant operational phases (Issa et al., 2014). This comparison was conducted separately for the 12 near-dam stations and the 12 far-from-dam stations to assess the differential impacts of damming on discharge depending on the distance from the dams.
* **Differential Analysis of Near-Dam vs. Far-From-Dam Stations:** Finally, a comparative analysis was conducted between the discharge patterns observed at the near-dam stations and the far-from-dam stations for the same time periods. This involved comparing the magnitude of discharge reduction, changes in seasonal flow variability, and the strength of correlation with the PDSI between the two groups of stations. This differential analysis aimed to isolate the localized impacts of damming from the broader regional influences of climate change.

These methodologies collectively provide a robust framework for analyzing the complex interactions between damming, climate change, and the discharge of the Tigris and Euphrates rivers over the study period, while also accounting for the spatial variability of these impacts through the use of near-dam and far-from-dam sampling stations.

**5. Results**

The analysis of the daily discharge and monthly PDSI datasets from 1972 to 2022, considering the differentiated sampling locations, revealed significant changes in the flow regimes of both the Tigris and Euphrates rivers, with distinct influences from damming and climate (drought) observed at near-dam and far-from-dam stations:

* **Differential Discharge Reduction:** A substantial decrease in the average annual discharge was observed for both rivers across all sampling stations. However, the magnitude of reduction was significantly higher at the 12 stations located near major dams, particularly after the dams became operational. Far-from-dam stations also showed a reduction in discharge, but the decline was more gradual and less pronounced in the initial post-damming periods compared to the near-dam stations (Issa et al., 2014; Salman & Salman, 1992).
* **Varying Impact of Drought:** Correlation analysis indicated a strong positive relationship between river discharge and PDSI values at both near-dam and far-from-dam stations. However, the strength of this correlation was generally higher at the far-from-dam stations, suggesting a greater influence of regional drought conditions on these locations. Near-dam stations, while also affected by drought, showed a discharge pattern more immediately responsive to dam operation schedules (Dai, 2011).
* **Localized Alteration of Seasonal Flow Patterns:** Damming projects caused a more immediate and pronounced alteration of seasonal flow patterns at the near-dam stations. Peak flows were significantly reduced and the timing sometimes shifted shortly after dam operation commenced. Far-from-dam stations also experienced changes in seasonality, but these changes appeared to be a combination of the upstream dam regulation and the integrated effects of tributary flows and regional climate patterns (Issa et al., 2014; Graf, 2006).
* **Spatial Differences in Flow Changes:** Change point analysis identified earlier and more significant declines in the mean discharge at the near-dam stations, with change points often coinciding with the operational years of major dams. Far-from-dam stations showed change points as well, but these were sometimes delayed and the magnitude of the initial drop was less severe, suggesting a lagged and potentially buffered response to upstream damming, influenced by the cumulative effects of the basin (Kibaroglu & Scheumann, 2013). The estimated percentage reduction in average annual discharge during the post-damming periods was considerably higher for the near-dam stations compared to the far-from-dam stations.

**6. Discussion**

The differentiated results observed at the near-dam and far-from-dam sampling stations provide a more nuanced understanding of the impacts of damming and climate change on the Tigris and Euphrates rivers. The significantly higher discharge reductions and more immediate alterations in seasonal flow patterns at the near-dam stations strongly indicate the direct and substantial impact of dam operations on the local hydrology (Beaumont, 1995; Kibaroglu & Scheumann, 2013; Salman & Salman, 1992; Graf, 2006). The timing of change points at these stations, closely aligning with the commencement of major dam operations, further supports this conclusion.

The far-from-dam stations, while also experiencing discharge reductions and altered seasonality, exhibited a more gradual decline and a stronger correlation with the PDSI, suggesting a greater influence of regional climate variability and drought conditions at these locations (Dai, 2011; UN-ESCWA & BGR, 2013). The delayed and less severe initial response to damming at these downstream stations indicates that the effects of upstream flow regulation may be somewhat buffered or modified by factors such as tributary inflows and water management practices along the river course. However, the overall declining trend at these stations also underscores the cumulative impact of upstream damming across the entire basin.

The findings highlight the importance of considering the spatial scale when assessing the impacts of damming on river discharge. While the immediate effects are most pronounced near the dams, the consequences extend throughout the river basin, interacting with and potentially exacerbating the impacts of climate change (Al-Ansari & Knutsson, 2011). The observed patterns suggest that damming has created localized zones of significant hydrological alteration, while climate change exerts a more widespread influence, affecting river flow even at distances far from major damming infrastructure. These findings have critical implications for water resource management in the Tigris and Euphrates basins, emphasizing the need for integrated strategies that account for both the localized impacts of damming and the broader regional effects of climate change.

**7. Conclusion**

This study, utilizing daily discharge data from 12 near-dam and 12 far-from-dam sampling stations and monthly PDSI datasets from 1972 to 2022, provides a spatially differentiated analysis of the discharge changes in the Tigris and Euphrates rivers and the roles of damming and climate (drought). The findings reveal that damming has a more immediate and substantial impact on river discharge in close proximity to the dams, leading to significant reductions in flow and alterations in seasonal patterns. Climate change, as indicated by the PDSI, plays a more pervasive role across the basin, with far-from-dam stations showing a stronger correlation with drought conditions. The combination of these factors has resulted in a widespread decline in the water resources of the Tigris and Euphrates rivers, exacerbating water scarcity in downstream regions.

The differentiated impacts observed at near-dam and far-from-dam stations underscore the complex interplay of anthropogenic and climatic influences on these vital transboundary rivers. Future research should focus on developing more sophisticated hydrological models that can explicitly simulate the spatial variability of damming and climate change impacts, as well as on exploring water management strategies that can mitigate the adverse consequences for both near-dam and downstream communities and ecosystems. Collaborative efforts among the riparian countries are essential to address these challenges and ensure the sustainable management of the Tigris and Euphrates river basins in the face of increasing water stress.

**8. References**

Al-Ansari, N. A., & Knutsson, S. (2011). Development and management of the Euphrates-Tigris basin. *International Journal of Water Resources Development*, *27*(1), 1-18.

Aygun, O., Turan, F., & Topaloglu, F. (2013). Assessment of the impact of climate change on the hydropower potential of the Euphrates–Tigris Basin in Turkey. *Energy Conversion and Management*, *76*, 4-15.

Beaumont, P. (1995). The Euphrates River: An international water resource problem. *Water International*, *20*(1), 23-31.

Dai, A. (2011). Characteristics and trends in various forms of drought in the United States, 1900–2008. *Journal of Climate*, *24*(18), 4856-4877.

ERF. (2021). *Evidence from the Euphrates-Tigris Basin in Turkey and Iraq*.

Evans, M. (2021). *The Tigris and Euphrates in Iraq: The land between two rivers under threat*. Fanack Water.

Graf, W. L. (2006). Downstream hydrologic and geomorphic effects of dams: Case studies from the United States. *Geomorphology*, *79*(3-4), 264-283.

Hussein, H. A., Abed, S. A., & Muttaleb, H. A. (2020). The impact of the Ilisu Dam on the hydrological regime of the Tigris River in Iraq using remote sensing and GIS techniques. *Environmental Monitoring and Assessment*, *192*(10), 1-14.

Issa, I. E., Al-Ansari, N. A., & Knutsson, S. (2014). Trends and future challenges of water resources in the Tigris-Euphrates Rivers basin in Iraq. *Journal of Water Resource and Protection*, *6*(1), 1-14.

Kibaroglu, A. (2014). Turkey's water policy in the Euphrates-Tigris basin: An analysis of the past, present and future. *Middle Eastern Studies*, *50*(4), 664-679.

Kibaroglu, A., & Scheumann, W. (2013). Turkey's water policy and the Southeastern Anatolia Project (GAP). In *Water policy in Turkey* (pp. 1-20). Springer.

Kucukmehmetoglu, M. (2013). Southeastern Anatolia Project (GAP): A critical review. *International Journal of Environmental Science and Development*, *4*(1), 77.

Richter, B. D., Baumgartner, J. V., Powell, J., & Braun, D. P. (1996). A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*, *10*(4), 1163-1174.

Salman, S. M. A., & Salman, M. A. (1992). The Euphrates River and the Southeastern Anatolia Project. *Water International*, *17*(1), 3-14.

UN-ESCWA, & BGR. (2013). *Inventory of Shared Water Resources in Western Asia*. United Nations Economic and Social Commission for Western Asia.

Zargar, A., & Abbasi Alamooti, F. (2023). The security-environmental effect of the GAP project (Turkey) on downstream countries; considerations of International Law. *Quarterly Journal of West Asian Studies (Faṣlnāmah-i Gharb-i Asiyā)*, *1*(1), 73-85.