

WATER SCARCITY CHALLENGE FOR TURKEY: RECOGNITION OF REGIONAL DISCREPANCIES AND URGENT SOLUTION FOR SUSTAINABILITY

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ABSTRACT

This study examines dam fill rates across Turkey between 2010 and 2020 using statistical trend analysis methods, including the Mann-Kendall test and Sen's slope estimation. The results reveal slightly negative national average annual trends reaching -0.47% ($p=0.349$), while also identifying significant social and economic impacts stemming from regional differences. The study observed statistically significant growth trends only in Northeastern Anatolia, with an annual growth rate of $+1.76\%$ ($p=0.005$). Central Anatolia and the Aegean region, however, experienced significant declines, with annual decreases of -1.11% ($p=0.087$) in Central Anatolia and -2.46% ($p=0.062$) in the Aegean region. The provincial-level study confirms strong, statistically significant declines, reaching the 0.05% significance level in 26% of the provinces. While large metropolitan areas like Istanbul maintain high occupancy rates reaching 51.7%, drought-affected regions such as Central Anatolia (26.1%) and the Mediterranean (35.2%) are facing maximum storage capacity. Water scarcity emerges as an environmental problem that engineers must address. The study reveals that Turkey needs to implement urgent policy measures, such as drought-resilient agriculture and reducing urban water loss.

Key words: Climate Adaptation, Dam Occupancy, Regional Inequalities, Water Governance, Water Stress

INTRODUCTION

Dams which function as water storage facilities and flood control systems represent an exceptional engineering achievement that provides optimal water resource management through their construction. The structures create substantial effects on aquatic systems and the organisms inhabiting the region (Chalise et al., 2023; Cho and Qi, 2023; He et al., 2024). The entire system of infrastructure and water resources faces severe danger from climate change. The capacity of reservoirs to receive direct water inputs is restricted by changing rainfall patterns and snowmelt and hot weather conditions (Gruss et al., 2023; Sambou et al., 2023). The dams face two opposing forces which create a situation that will become increasingly difficult for them to manage (Ariffin et al., 2025; Abu-Afifeh et al., 2023; Genç et al., 2026). The Three Gorges Dam operation has increased low-flow events according to research conducted by Wang et al. (2023) which shows that this phenomenon mainly affects vegetation patterns. In Iraq, climate change poses a serious threat to the Al Abila Dam, according to research by Abed et al. (2023). The complex relationship between climate change and dam operations requires the development of flexible water management regulations according to the presented cases. The African continent meets the Mediterranean Basin in Turkey, which will experience the most severe climate change impacts. The occupancy rates of dams serve as the most precise and extensive indicators which show the complete water condition of the basin. The present water stress situation needs evaluation through assessment of rate patterns which demonstrate its progress throughout different time periods and various geographical areas (Disasa et al., 2026; Ji and Senay, 2023; Kong et al., 2023). Erosion risk assessments provide valuable information about how long-term sedimentation affects the occupancy of dam basins (Karaoğlu, 2023; Kholmurodova et al., 2025). The research will establish the national trend while examining regional and provincial variations which stem from different

geographical and climatological characteristics to create scientifically based water management solutions for specific regions. This study would be of significant importance for providing Turkey with the development of a resilient and sustainable water management strategy that can endure the increasing water stress.

METHODOLOGY

This study investigates how reservoir occupancy ratios in Turkey changed over time from 2010 to 2020 and how they differ across different regions. The study used official provincial scale reservoir occupancy data which was supplied by DSI and TÜİK. The dataset went through a preprocessing step which removed all data points that contained errors or missing data or extreme values. The researchers divided provinces into 13 different regions according to their climate and geographic characteristics. The dataset required nonparametric methods because it contained non-Gaussian data along with suspected outlier cases. The researchers used the Mann–Kendall test to study temporal trends while they used Sen's slope estimator to measure the strength of those trends. The researchers determined statistical significance at the $\alpha=0.10$ level. The analysis was conducted at national, regional, and provincial levels using specific hypotheses; H_0 : No trend; H_a : Monotonic trend. Test statistic T is shown in Eq. 1, where N stands for the total number of observations, y_l and y_k are the data at time k and l ; the $\text{sign}()$ function is defined in Eq. 2; the variance of T in Eq. 3, where g is the number of tied groups and r_m is the size of the m -th tied group; the standardized test statistic Z^* is defined in Eq. 4; and the trend slope θ is estimated using Sen's method as presented in Eq. 5, where θ denotes the slope and $t_q - t_p$ represents the time difference.

$$T = \sum_{k=1}^{N-1} \sum_{l=k+1}^N \text{sign}(y_l - y_k) \quad (1)$$

$$\text{sign}(z) = \begin{cases} +1, & z > 0 \\ 0, & z = 0 \\ -1, & z < 0 \end{cases} \quad (2)$$

$$\text{Var}(T) = \frac{N(N-1)(2N+5) - \sum_{m=1}^g r_m(r_m-1)(2r_m+5)}{18} \quad (3)$$

$$Z^* = \begin{cases} \frac{T-1}{\sqrt{\text{Var}(T)}}, & T > 0 \\ 0, & T = 0 \\ \frac{T+1}{\sqrt{\text{Var}(T)}}, & T < 0 \end{cases} \quad (4)$$

$$\theta = \text{median}\left(\frac{y_q - y_p}{t_q - t_p}\right), \forall q > p \quad (5)$$

RESULTS

Decision-making about water management planning needs information about Turkey's dam occupancy ratios. Figure 1 demonstrates that dam occupancy rates in Turkey show extreme variation which results from both climate conditions and distinct water management methods. Malatya, Kayseri, Kırşehir, Isparta, and Van show the lowest average values among all provinces in Turkey. The Central Anatolia and Mediterranean regions approach critical occupancy thresholds, which creates severe hazards to agricultural activities and drinking water supplies. The Aegean region experienced low occupancy rates which showed a clear downward pattern that demonstrated rising water stress levels and drought conditions. Some areas have enhanced their water storage capabilities, but essential agricultural zones and urban water supply regions continue to suffer from reduced water levels. The Black Sea and the Marmara areas experienced more stable occupancy rates, which remained at moderate-to-high levels throughout the study period. The Southeastern Anatolia Region demonstrated substantial yearly variations, which created fluctuations from its average values. A violin plot in Figure

2 displays how occupancy rates change over time. 2015 exhibited both a wide range of values and a substantial increase in its median measurement. The extended lower violin reaches from 2019 to 2020 showed that additional provinces would experience low occupancy rates, which would create severe water shortages. The violin plots show that some years exhibit bimodal or multimodal patterns, which include the years 2012 and 2017. The period from 2010 to 2013 showed a stable distribution which reached a high point but 2014 brought about expanded values which resulted in greater concentration during lower intervals. The Violin plot shows how water stress distribution occurs during dry years and differs between different regions during wet years.

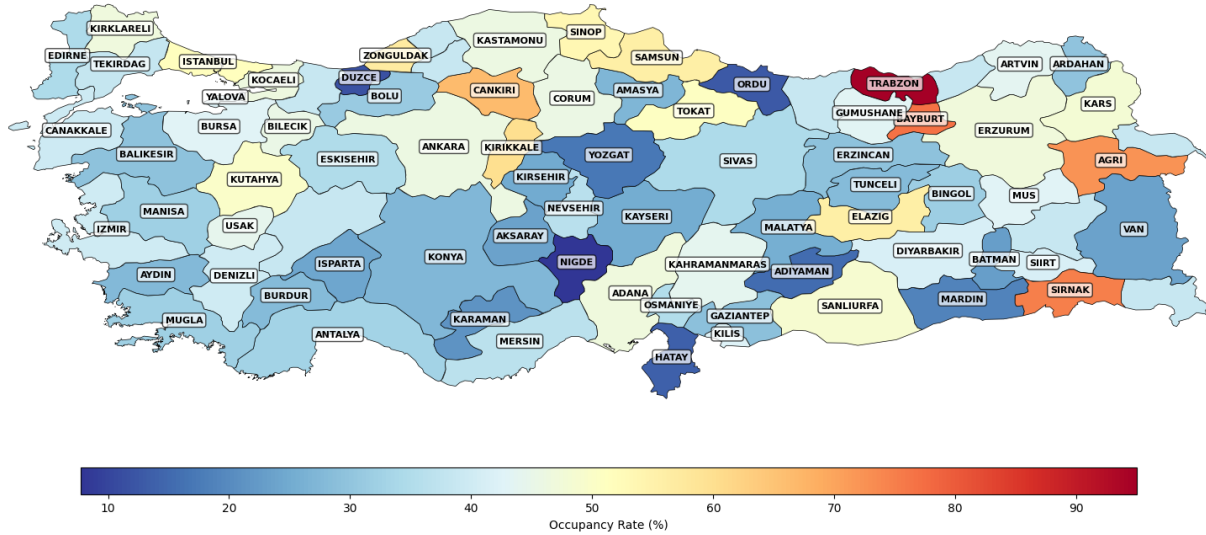


Figure 1: 2010-2020 average dam occupancy rates by provinces of Turkey

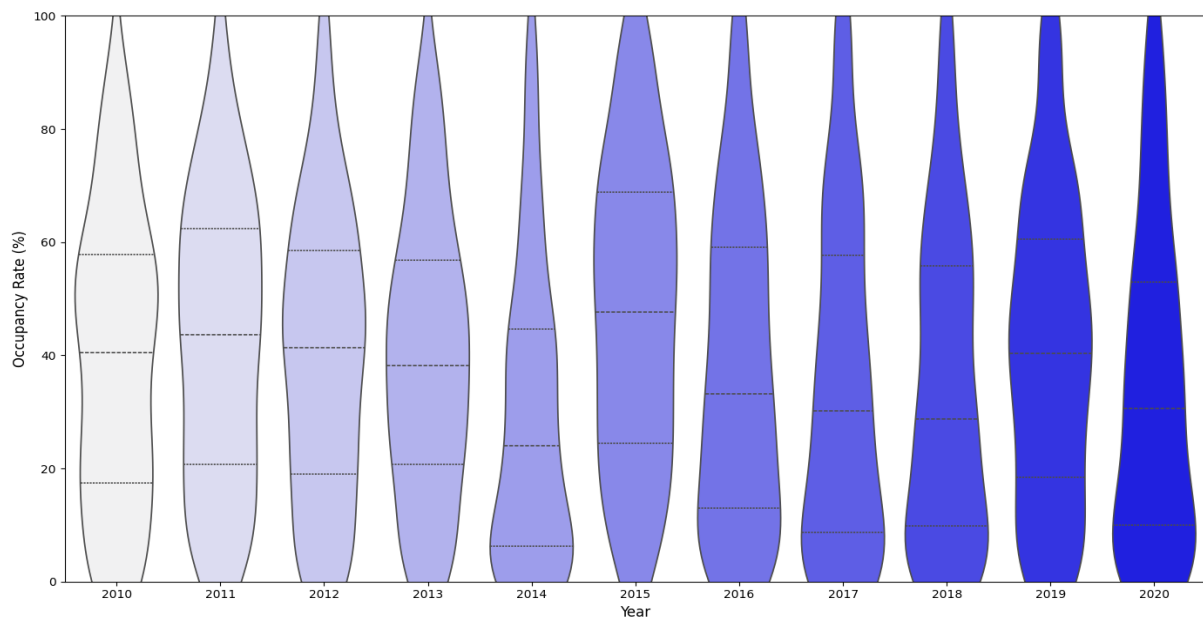


Figure 2: Violin plots depict yearly distribution of dam occupancy rates

The upper panel in Figure 3 displays three data sets, which include original data and three-year moving average data and linear regression model results. The moving average curve shows annual variations in data while it demonstrates the overall long-term trend of the data. The analysis of linear regression shows that the country experiences an annual declining trend of 0.47, which achieves statistical significance at the 90 percent confidence level. The lower panel displays percentage changes, which show green columns for increases and red columns for decreases. The moving average shows that water stress has become a new regular pattern because it has not reached its pre-2014 level.

The regional trends in Turkey are assessed through four graphs which are displayed in Figure 4. The top-left graph shows the strength of trends that exist in each region's Sen slopes. The graph displays the annual rate of change that exists in Turkey's regions while presenting the statistically significant development patterns. The study identifies Northeastern Anatolia as the region that displays the strongest positive trend since it experiences 1.76% annual growth. The Aegean region experiences its most severe negative trend, which results in an annual decline of -2.46%.

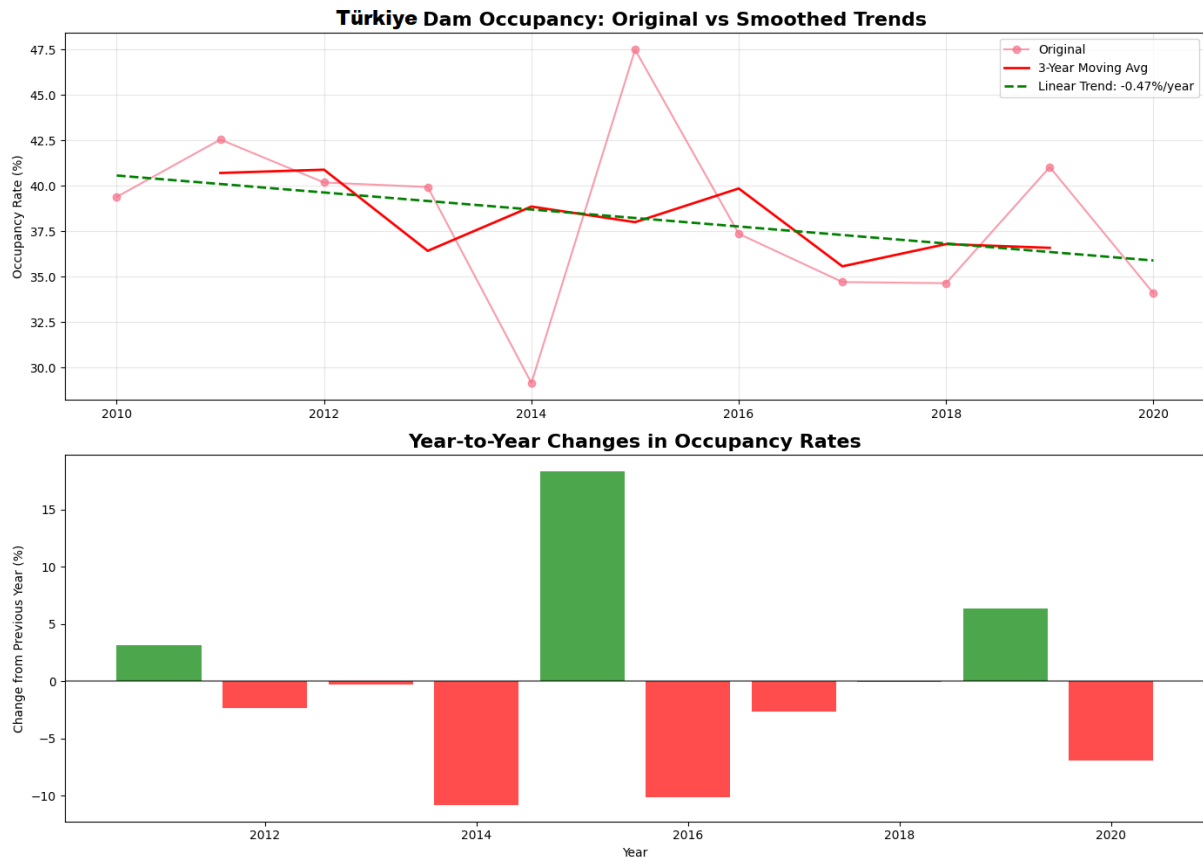


Figure 3: a) Original over smoothed dam occupancy trends for Turkey, b) Yearly changes in occupancy

DISCUSSION

The Turkish dam occupancy rates experienced their most considerable changes between 2010 and 2020. Turkish water resource management operates through multiple layers and various methods according to the research results. Al-Ansari et al. (2023) attribute water scarcity in Iraq to various factors that include climate change, poor management of water, and increased water demand, leading to water stress. Turkey demonstrates a negative trend through its data which shows results at -0.47% every year though the results lack statistical significance. The water trends in Northeastern Anatolia and Eastern Black Sea Region show increasing patterns because of the area's geographical and climatological characteristics. Central Anatolia and Aegean Regions show downward trends because their water patterns have started to decline. The Kilombero River Basin of Tanzania demonstrates similar hydroclimatic patterns according to Sigalla et al. (2023) who found that the same patterns exist throughout Turkey and other parts of the world. The interrelations among precipitation, runoff, and land use operate as the primary elements that control basin-scale water dynamics according to Carvalho et al. (2023) who established a fundamental system to examine regional water system differences.

Dams lose their ability to store water because of sedimentation which leads to a major decrease in their storage capacity. Ferreira et al. (2023) conducted research on reservoir erosion in a Brazilian

semiarid region using the ^{210}Pb geochronological method to determine sedimentation rates which demonstrated how sediment accumulation decreased both dam operational life and storage capacity. Mostafazadeh et al. (2024) conducted research through an index-based approach which assessed how land-use changes and dam regulations affected river flow patterns. Bai et al. (2024) developed a model which uses hidden information to reduce the harmful effects that hydroelectric dams and climate change create for fish habitats. Sun (2023) demonstrated how hydroelectric dam construction in China affects the environment while he emphasized the requirement for conducting environmental impact assessments to support sustainable water management practices.

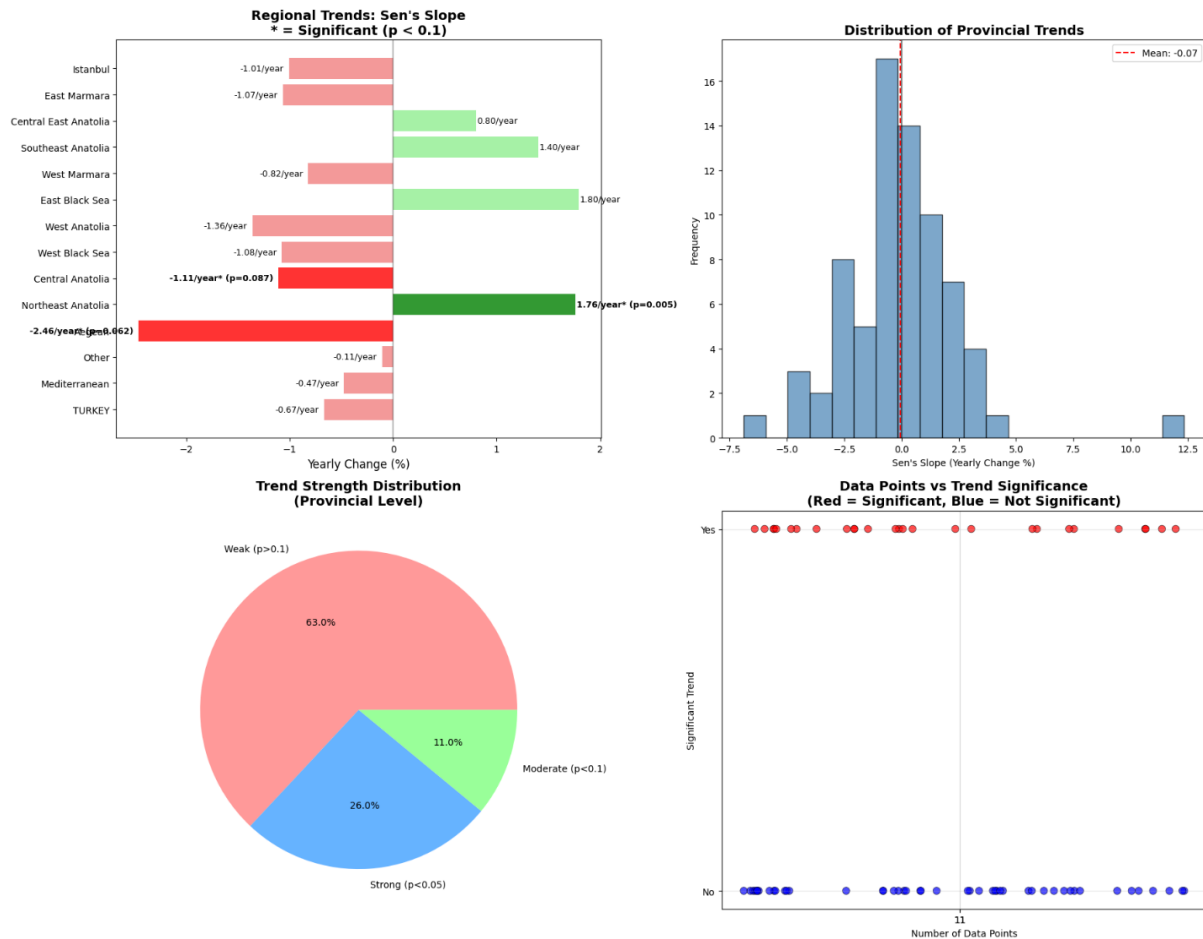


Figure 4: Statistical significance and yearly change trends of dam occupancy

Provincial authorities need to establish water management policies which require consideration of specific characteristics present in each individual region. Water resources management includes multiple components which connect together through their functions in dam construction, safety operations, and flood control activities (Yameogo et al., 2023). Samsudin et al. (2023) used GIS methods to study dam-break flood events which proved valuable for developing emergency management response plans. Lee et al. (2023) developed an ensemble model which uses multiple data sources to forecast water flow at the Soyang River Dam. The study establishes hydrological forecasting as an essential component necessary for effective water management. The research conducted by Yakar et al. (2023) studied the fatty acid composition of fish from Atatürk Dam Lake which demonstrated that ecological health assessment requires monitoring of aquatic ecosystems. Muddasir and Dondaş (2023) examined the connection between housing prices and economic indicators in Turkey which helped them show how water resource management interacts with economic growth. The research results show that Turkey needs to create new water management approaches which should include flexible policies to develop climate change resilience.

The study suffers from its major constraint which restricts research to a particular time period. The period from 2010 to 2020 which lasts ten years is insufficient to study extended climate changes. According to Mostafazadeh et al. (2024) researchers require extended time periods to study changes in river flow patterns. The research conducted by Ferreira et al. (2023) in Brazil demonstrates that sedimentation rates impose a critical impact on the capacity of dams to store water. The study presents another limitation because it failed to combine climate change predictions with forecasts of water requirements. The assessment method developed by Bai et al. (2024) which evaluates how hydroelectric dams and climate change together affect ecosystems can be used to study ecological impacts in Turkey. The study excluded both groundwater level measurements and measurements of surface water quality attributes.

CONCLUSION

The study's findings about water management showed important results which water management policy makers used to make their decisions. The study identified important trends which affected 27 out of 73 provinces because they developed at an average rate of -0.066% every year. Central Anatolia and Mediterranean regions which provide essential water supply for agriculture and urban areas have reached critical occupancy levels because they already have 26.1% and 35.2% occupancy rates respectively. The results require the country to establish water resources management policies which should be designed to address climate change effects through regional-specific solutions. The study findings show that ongoing conditions will lead to serious issues which will impact farming activities, drinking water distribution in cities, and the well-being of ecosystems. The main solutions for this situation require farmers to switch to drought-resistant farming methods and water supply systems to minimize their water distribution losses and all stakeholders to work together for effective water management throughout the entire basin while they establish new water sources and enhance their water collection techniques and increase public knowledge. The study uses scientific evidence to support its recommendation that Turkey needs to revise its water management strategies and create flexible solutions which will help the country handle climate change. The next studies need to use long-term data and create integrated modeling methods while they build partnerships with other disciplines at their most effective level. Turkey requires effective water resource management to accomplish its development objectives and create a future that can withstand climate change impacts.

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