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Interannual Variability of Reservoir Occupancy: A Multi-Reservoir Assessment from Çanakkale, Türkiye

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ABSTRACT

Monitoring reservoir occupancy rates is increasingly important under rising water demand and growing hydrological variability. This study evaluates temporal variability in occupancy rates of seven reservoirs (Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey) in Çanakkale Province (Türkiye) over the period 2013–2023. Bray–Curtis similarity and hierarchical cluster analyses were applied to assess interannual and inter-reservoir patterns, while Mann Kendall trend analysis, Sen's slope estimator, and Spearman's rank correlation were also applied to evaluate temporal trends and precipitation occupancy relationships. The results revealed interannual variability, with occupancy rates ranging from 2.7% to 79.2%. Gökçeada, Atikhisar, and Umurbey exhibited relatively similar occupancy dynamics, whereas Bakacak and Taşoluk displayed more distinct patterns. Trend analysis indicated that no statistically significant trends were observed for most reservoirs ($p > 0.05$), whereas a statistically significant decreasing trend was detected only for Umurbey Reservoir ($Z = -2.14$, $p = 0.033$; Sen's slope = -2.45). Correlation analysis did not indicate a statistically consistent relationship between annual precipitation and reservoir occupancy ($p > 0.05$), despite moderate correlation coefficients in some reservoirs. These results indicate that annual precipitation alone does not adequately explain interannual variations in reservoir occupancy. Overall, reservoir occupancy appears to reflect the combined influence of hydroclimatic variability and other unquantified factors rather than a single controlling variable. The results provide a quantitative and comparative assessment of reservoir occupancy dynamics and may serve as a reference for future water management and research efforts in the region.

INTRODUCTION

Water continuously circulates between the Earth's surface and the atmosphere through the hydrological cycle. Although approximately three-quarters of the Earth's surface is covered by water, about 97–98% of it is stored in oceans and inland seas. Due to its salinity, this water is not suitable for drinking, irrigation, or industrial use (Abdelali, 2019). Freshwater, which constitutes only a small fraction of total water resources, is an indispensable component for sustaining biological life and human societies. While a significant portion of freshwater is stored in glaciers and groundwater, the amount of accessible surface water is limited. This limited availability makes freshwater a vital and strategic resource (Gündoğdu, 2025). In addition, hydrological events such as irregular precipitation, floods, and droughts resulting from global warming threaten the availability of freshwater. The conservation and sustainable management of water resources require planned and efficient use of existing supplies, particularly in regions where water demand is steadily increasing. Therefore, monitoring water occupancy rates, especially in dam reservoirs is crucial for ensuring reliable and sustainable freshwater resources.

Dams are basic engineering structures that are built with significant investments and are expected to serve for a very long time (Aşık, 2016). Dams are structures that serve a wide variety of purposes, including domestic and industrial water supply, agricultural irrigation, flood control, hydroelectric energy production and ecosystem regulation (Taş-Divrik, 2022). Regular monitoring of dam water levels is essential for developing water management policies and establishing early-warning mechanisms for potential drought scenarios. Recent searches have increasingly focused on temporal variability in reservoir occupancy rates and their relationship with precipitation, as well as comparative analyses among multiple reservoirs to better understand regional water dynamics (Hou et al., 2022; Steyaert et al., 2022; Demirbaş & Özbaş, 2024; Cui & Liu, 2025; Akiner, 2025). However, despite the presence of several important reservoirs, studies focusing specifically on Çanakkale Province remain limited in the literature.

Located in Çanakkale Province, Atikhisar reservoir, the primary drinking water source for the city center, holds strategic importance. Ayvacık, Bakacak, Tayfur and Umurbey reservoirs provide multi-purpose water supply, particularly for agricultural irrigation. Gökçeada reservoir serves island settlements and their surrounding rural areas, while Taşoluk reservoir supports increased irrigation demand during the summer months.

This study addresses the following research questions:

(i) Are there statistically significant temporal trends in reservoir occupancy rates?

(ii) Does annual precipitation explain interannual variability in occupancy rates?

(iii) Do reservoirs exhibit similar or distinct occupancy patterns? From this perspective, this study analyzed the occupancy rates of the Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey dam reservoirs in Çanakkale Province between 2013 and 2023, using data published by the General Directorate of State Hydraulic Works. This study contributes to the literature by integrating trend analysis (Mann–Kendall and Sen's slope), correlation analysis (Spearman's rank correlation), and similarity based clustering (Bray–Curtis) to evaluate reservoir occupancy dynamics. From an applied perspective, the findings provide information for regional water management.

MATERIAL AND METHODS

Study Area and Data Source

This study analyzed annual reservoir occupancy rate data for seven reservoirs in Çanakkale Province, Türkiye. The spatial distribution of the investigated reservoirs is shown in Figure 1. Occupancy rates (%) for Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey reservoirs were obtained from the General Directorate of State Hydraulic Works of the Republic of Türkiye. The dataset covers the period 2013–2023, which was specifically selected because occupancy records prior to 2013 contained gaps for some reservoirs, preventing a consistent inter-reservoir comparison. The occupancy rates represent annual values (%) as officially reported for each year, providing a complete dataset for interannual analysis. These values represent annual occupancy percentages as officially reported by the State Hydraulic Works (Anonymous, 2025a) and are not derived from monthly or daily averaging within this study. Annual precipitation data for the study region were obtained from the provincial briefing reports of the Provincial Directorate of Agriculture and Forestry, which compile measurements from the Turkish State Meteorological Service (Anonymous, 2025b). These datasets were used to examine temporal variability in reservoir occupancy rates and to investigate potential relationships with precipitation.

Figure 1. Spatial distribution of the investigated reservoirs in Çanakkale Province, Türkiye

Structural Characteristics of the Reservoirs

The structural and operational characteristics of the investigated reservoirs are summarized in Table 1. These characteristics include construction period, body fill type, body volume, reservoir volume, reservoir area, and primary purposes such as irrigation, potable water supply, and flood control. Detailed technical specifications for each reservoir are provided in Table 1.

Data Processing and Statistical Analysis

All percentage-based reservoir occupancy rate data were first examined to ensure completeness and consistency. Microsoft Excel was used for data organization, preprocessing, and calculation of descriptive statistics, including minimum, maximum, mean values, standard deviation (SD), and coefficient of variation (CV) to characterize variability in reservoir occupancy rates.

Reservoir occupancy rates and annual precipitation data were evaluated on a yearly basis throughout the study period (2013–2023) to assess interannual variability.

Monotonic trends in annual reservoir occupancy rates were analyzed for each reservoir using the non-parametric Mann–Kendall trend test implemented in PAST (PAleontological STatistics) software, version 4.17 (Hammer et al., 2001). The magnitude of trends was further estimated using Sen's slope estimator (Sen, 1968). Sen's slope values were calculated in Microsoft Excel using the median of all pairwise slopes between data points, expressed as (Eq. 1):

$$Q = \text{Median}\left(\frac{x_i - x_j}{\text{j}-\text{i}}\right),\ \text{j} > \text{i} \qquad (1)$$

where x_i and x_j represent reservoir occupancy rates at times *i* and *j*, respectively.

The relationship between annual precipitation and reservoir occupancy rates was evaluated using Spearman's rank correlation analysis. Annual precipitation data represent spatially aggregated values at the provincial scale and were used as a regional indicator of climatic conditions influencing all reservoirs. This nonparametric method was selected due to the non-normal distribution and limited length of the dataset.

Similarity analysis among reservoirs was conducted to identify comparable occupancy patterns. Annual occupancy rates (2013–2023) were used to construct a Bray–Curtis similarity matrix based on temporal occupancy profiles. Hierarchical cluster analysis was then applied using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA).

In addition, interannual similarity was assessed by treating each year as a sample and reservoirs as variables. All correlation, similarity and clustering analyses were performed using PAST 4.17.

Table 1. Structural characteristics of the investigated reservoirs in Çanakkale Province, Türkiye

Reservoir	Purpose	Built Date	Body Fill Type	Body Volume (m^3)	Height (m)	Stream (Outgoing)	Reservoir Volume (hm^3)	Reservoir Area (km^2)	Irrigation Area (ha)
Atikhisar	Irrigation, Flood Control, Potable water supply	1971-1975	Soil	1,990,000	43	Sarıçay Creek	40	3.30	5200
Ayvacık	Irrigation	1997-2007	Soil	1,200,000	53	Tuzla Creek	30	3.42	3900
Bakacak	Irrigation	1991-1999	Rock	1,750,000	65	Koca Creek	139	7.74	9100
Gökçeada	Potable water supply, Irrigation	1977-1983	Soil	561,000	51	Büyükdere Creek	14	1.35	700
Taşoluk	Irrigation	1995-2001	Rock	1,700,000	75	Çınarcık Creek	88	3.10	7924
Tayfur	Potable water supply	1980-1985	Rock, Soil	298,000	39	Tayfur Creek	4.36	0.47	-
Umurbey	Irrigation	1995-2003	Soil	2,400,000	81	Umurbey Creek	24.56	1.70	2445

Table 2. Reservoir occupancy rates of Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey and annual precipitation amounts (mm) for Çanakkale province between 2013-2023

Reservoir	Reservoir Occupancy Rates (%)														
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Max**	**Min**	**Mean**	**SD**	**CV (%)**
Atikhisar	52.7	47.8	55.7	33.1	30.9	61.7	57.5	25.5	79.2	49.1	33.4	79.2	25.5	48.56	16.02	33.47
Ayvacık	60.4	60.9	42	34.6	39.6	36.8	48	4.5	68.3	43.9	35.7	68.3	4.5	42.12	17.16	39.77
Bakacak	33.6	22.4	27.9	2.7	5.6	14	44.3	14.1	11.5	8.7	16.5	44.3	2.7	19.10	12.65	69.15
Gökçeada	65.7	69.1	63.4	43.5	30.3	63.6	68.2	48.8	70.1	56.1	36.7	70.1	30.3	55.07	14.02	25.06
Taşoluk	24.3	24.4	40.1	24.5	23.9	11.4	30.2	27.4	27	18.4	7.7	40.1	7.7	23.62	8.79	37.29
Tayfur	50.9	52.2	44.7	26.1	28.8	63.1	52.6	32.3	35	30.7	18.8	63.1	18.8	39.78	13.85	35.01
Umurbey	43.1	62.2	57.9	43.1	48.6	60.7	49.1	40.7	55.7	35.8	21	62.2	21	46.24	12.21	25.94
Annual precipitation (mm)	650.2	753.3	650.3	570.9	648.6	660.1	581.7	453	749.6	480.7	711.4	453	753.3	624.77	98.80	15.73

RESULTS

In this study, reservoir occupancy rates of Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey reservoirs in Çanakkale Province were analyzed for the period 2013–2023 using the statistical methods. Reservoir occupancy rates varied between 2.7% and 79.2% during the study period (Table 2). Mean values presented in Table 2 represent the arithmetic average of annual occupancy rates for the period 2013–2023. Furthermore, the relationship between reservoir occupancy rates and average annual total precipitation is shown in Figure 2.

All reservoirs exhibited negative Sen's slope values, indicating an overall decreasing tendency in occupancy rates, although these trends were not statistically significant except for Umurbey ($Z = -2.14$, $p = 0.033$; Sen's slope = -2.45) (Mann-Kendall test, $p > 0.05$) (Table 3).

Spearman's rank correlation analysis indicated that correlation coefficients between annual precipitation and reservoir occupancy rates ranged from −0.12 to 0.57 (Table 4). Although moderate positive associations were observed in some reservoirs (e.g., Umurbey, $r_s = 0.57$; Ayvacık, $r_s = 0.52$), none of the correlations were statistically significant ($p>0.05$).

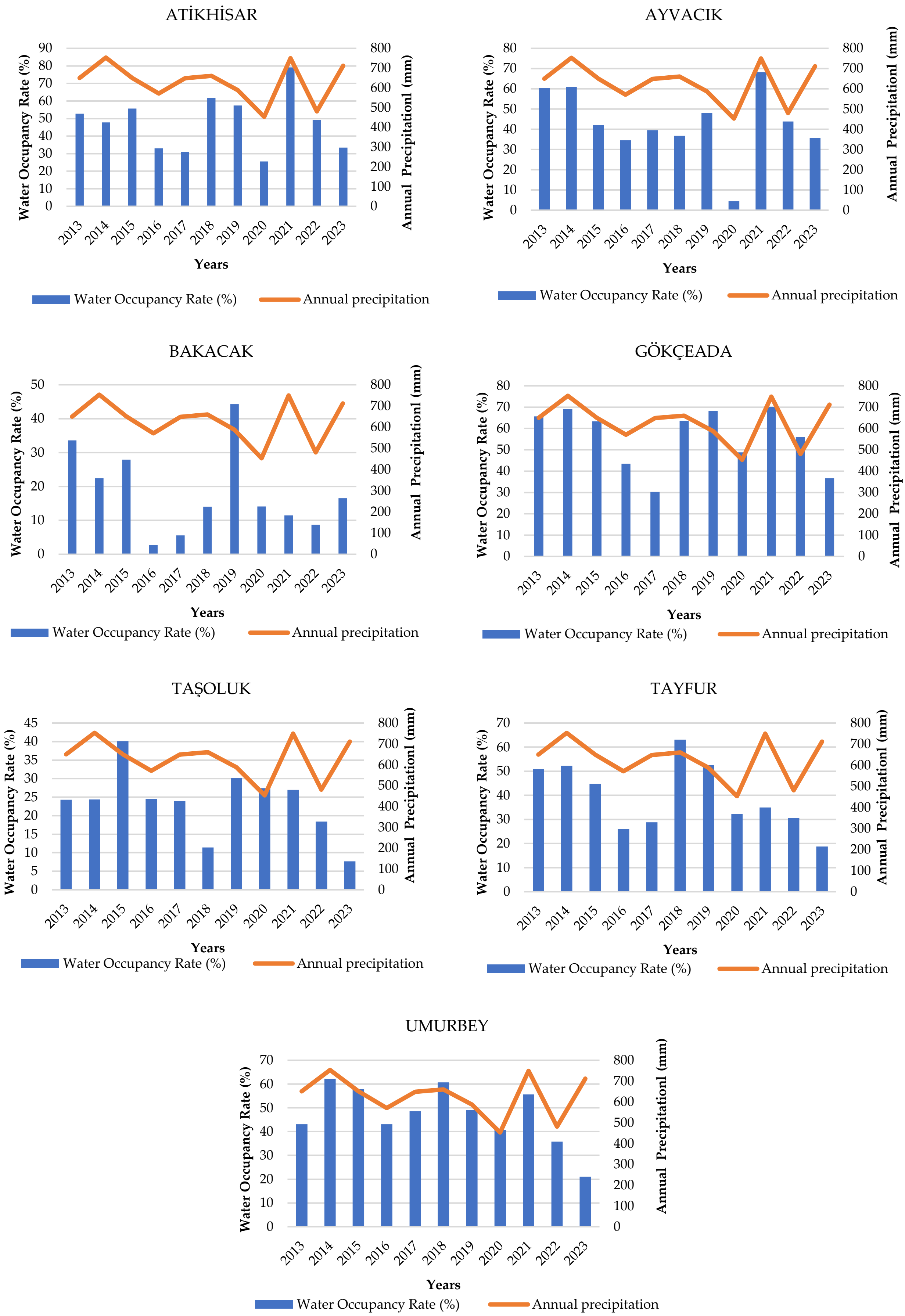

Figure 2. Total precipitation and occupancy rates of Atikhisar, Ayvacık, Bakacak, Gökçeada, Taşoluk, Tayfur, and Umurbey reservoirs between 2013 and 2023

Table 3. Mann–Kendall trend test and Sen's slope results for reservoir occupancy rates (2013-2023)

Reservoir	n	S	Z	p value	Sen's slope	Trend
Atikhisar	11	-5	-0.27	0.783	-0.40	No significant trend
Ayvacık	11	-17	-1.10	0.271	-1.73	No significant trend
Bakacak	11	-7	-0.41	0.680	-1.43	No significant trend
Gökçeada	11	-17	-1.10	0.271	-1.07	No significant trend
Taşoluk	11	-23	-1.51	0.130	-0.75	No significant trend
Tayfur	11	-27	-1.79	0.074	-2.48	No significant trend
Umurbey	11	-32	-2.14	**0.033**	-2.45	Decreasing trend

Table 4. Spearman's rank correlation coefficients (r_s) and associated p-values between annual precipitation and reservoir occupancy rates (2013–2023)

Reservoir	r_s	p value
Atikhisar	0.4636	0.1509
Ayvacık	0.51818	0.10249
Bakacak	0.24545	0.46692
Gökçeada	0.47273	0.142
Taşoluk	-0.12325	0.71807
Tayfur	0.28182	0.40114
Umurbey	0.56948	0.067443

According to the similarity analyses results, the years 2013 and 2014 exhibited the highest degree of similarity, with a similarity coefficient of 93.95%. These two years form a distinct cluster, indicating comparable reservoir occupancy conditions. In addition, 2019 was included within this cluster, showing a high similarity value of 91.84% (Figure 3; Table 5).

In contrast, the lowest similarity was observed between the years 2021 and 2023, with a similarity coefficient of 63.80%, indicating pronounced interannual differences in reservoir occupancy rates. The dendrogram further reveals a gradual divergence among the years, reflecting increasing variability in reservoir water levels over time. These patterns are consistent with the variability observed in Figure 2, where reservoir occupancy rates fluctuate across years.

Cluster analysis revealed a main group consisting of Gökçeada, Atikhisar, Ayvacık, Umurbey, and Tayfur reservoirs, which exhibited relatively high similarity coefficients. In contrast, Bakacak reservoir displayed lower similarity values with the other reservoirs, particularly with Gökçeada (0.49), indicating more distinct occupancy dynamics. Taşoluk reservoir also showed relatively lower similarity values compared with the main group. Similarity coefficients among the seven reservoirs are presented in Figure 4 and Table 6.

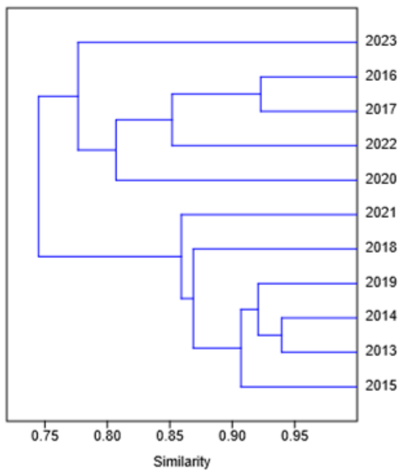

Figure 3. Dendrogram of reservoir occupancy rates for the period 2013–2023

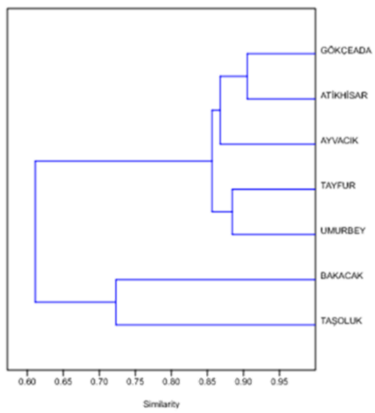

Figure 4. Dendrogram of reservoirs based on similarity matrix

Table 5. Similarity matrix of reservoir occupancy rates for the period 2013–2023

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
2013		93.9525	90.006	77.0574	75.1114	84.891	93.5351	72.5954	86.4059	84.6529	67.8521
2014			90.2341	75.9239	75.9832	88.1132	90.6082	71.501	88.7722	82.9981	66.7453
2015				76.9887	77.0115	88.3048	91.8427	73.6381	85.5711	83.844	67.7169
2016					92.2706	74.9663	74.4753	83.562	74.8918	86.2536	81.929
2017						74.1426	74.4978	79.4514	74.9143	84.103	79.4702
2018							86.2069	70.2338	83.7867	82.5271	69.549
2019								71.1708	85.0581	81.9102	65.3454
2020									70.4684	79.0826	70.6692
2021										82.341	63.8018
2022											78.5455
2023											

Table 6. Similarity matrix among reservoirs

Reservoir	Atikhisar	Ayvacık	Bakacak	Gökçeada	Taşoluk	Tayfur	Umurbey
Atikhisar		0.88165385	0.55309795	0.90517468	0.65504517	0.87876897	0.87774055
Ayvacık			0.56715976	0.8537883	0.64414169	0.82162875	0.85029216
Bakacak				0.49289912	0.72297004	0.6325216	0.55978865
Gökçeada					0.59282122	0.82840011	0.8815952
Taşoluk						0.74672426	0.66726711
Tayfur							0.88448222
Umurbey							

DISCUSSION

Maintaining adequate water occupancy in surface reservoirs is essential, as water levels are generally influenced by seasonal hydroclimatic factors such as precipitation and snowmelt (Demirbaş & Özbaş, 2024). Previous studies have reported notable interannual variability in reservoir occupancy, particularly during drought periods. Furthermore, long term drought predictions and decreasing precipitation forecasts further complicate water management in dams (Ayyıldız & Erdoğan, 2022). For example, Dirican (2021) reported considerable fluctuations in Çermikler Dam, the potential roles of hydroclimatic variability and water use pressures in shaping reservoir dynamics (Dirican, 2023a, 2023b, 2024, 2025). Similar variability has also been reported for reservoirs supplying metropolitan areas such as Istanbul. Analyses of Istanbul's dams highlight that climate change is increasing volatility in water levels (Nalici & Akbaş, 2022; Akiner, 2025). Considering projections of increasing drought frequency and altered precipitation regimes on water resources, such variability may become more pronounced in the future (Türkeş, 1998; Taş-Divrik, 2022).

In the present study, the occupancy rates of seven reservoirs in Çanakkale Province showed marked interannual variability between 2013 and 2023 (Table 2, Figure 2). Reservoir occupancy values ranged from 2.7% to 79.2%, indicating substantial fluctuations across years (Table 2). Spearman's rank correlation analysis indicated that, although weak to moderate positive correlations were observed between annual precipitation and reservoir occupancy, these relationships were not statistically significant ($p > 0.05$) (Table 4). This suggests that annual total precipitation alone may not fully account for variations in reservoir occupancy during the study period. Consistent with this finding, the results of the Mann–Kendall trend test and Sen's slope estimator indicated that no statistically significant trends were observed in the majority of the reservoirs during the period 2013–2023 (Table 3). The calculated Z values were generally low and the corresponding p-values remained above the 0.05 significance level. However, all reservoirs exhibited negative Sen's slope values, indicating an overall decreasing tendency in occupancy rates. This decreasing trend was statistically significant only for Umurbey Reservoir ($Z = -2.14$, $p = 0.033$; Sen's slope = −2.45), while Tayfur Reservoir showed a near-significant trend ($Z = -1.79$, $p = 0.074$) (Table 3). Comparable findings were reported by Zulkiflie et al. (2024), who similarly concluded that precipitation alone is insufficient to explain reservoir storage variability. In a study conducted by Serifoglu Yilmaz (2025) in Artvin Province, Türkiye, reported non-significant trends ($p > 0.05$) using Mann–Kendall analysis, supporting the interpretation that observed variations may not represent statistically robust trends within comparable study periods.

In addition to hydroclimatic factors, reservoir occupancy is influenced by site-specific characteristics such as inflow variability, storage capacity, and water use patterns. Therefore, reservoirs should be evaluated individually. In this study, Bray–Curtis similarity and cluster analyses revealed clear differences among reservoirs based on their occupancy dynamics (Table 6, Figure 4). According to the similarity matrix, a main group consisting of Gökçeada, Atikhisar, Ayvacık, Umurbey, and Tayfur reservoirs exhibited relatively high similarity values (generally above 0.80), indicating comparable temporal occupancy patterns (Table 6). In contrast, Bakacak reservoir showed consistently lower similarity values with other reservoirs (approximately 0.49–0.56), clearly distinguishing it as the more divergent system in terms of occupancy behavior. Taşoluk reservoir exhibited intermediate similarity levels (approximately 0.59–0.67), suggesting partial separation from the main group but not as distinct as Bakacak (Table 6). These patterns should be interpreted as descriptive groupings derived from occupancy based similarity rather than direct evidence of causal relationships. However, the clustering structure is directly supported by both the similarity matrix (Table 6) and dendrogram (Figure 4), indicating that reservoirs may exhibit different temporal responses despite being subjected to similar hydroclimatic conditions. This variability likely reflects reservoir specific characteristics such as inflow variability, storage capacity, water demand, and operational practices.

A similar pattern was observed in the interannual similarity analysis (Table 5, Figure 3), where certain years (e.g., 2013–2014: 93.95% and 2015–2019: 91.84%) exhibited high similarity, whereas others (e.g., 2021–2023: 63.80%) showed markedly lower similarity. This indicates that both temporal variability and reservoir-specific dynamics contribute to the observed clustering patterns.

Overall, these findings indicate that reservoir occupancy rates are characterized by weak and mostly statistically insignificant decreasing tendencies. This suggests that reservoir occupancy is influenced not only by hydroclimatic variability within the study period but also by interannual hydrological variability, water demand, and reservoir operation practices. In addition, drought conditions, defined as deviations from average precipitation levels, may significantly affect agriculture, ecosystems, and water resources (Li et al., 2021). Increasing variability between certain years may indicate growing sensitivity of reservoir systems to climatic fluctuations and water use pressures.

Therefore, reservoir dynamics in the region are likely governed by multiple interacting factors, including hydroclimatic variability, evaporation losses, water abstraction, and reservoir-specific operational conditions. However, these factors were not directly quantified in this study, which represents an important limitation. Nevertheless, the findings provide a useful basis for future studies, which may benefit from incorporating additional variables and alternative analytical approaches to achieve more comprehensive and robust results.

CONCLUSION

This study examined temporal variability in reservoir occupancy rates across seven reservoirs in Çanakkale Province between 2013 and 2023**.** The main contribution of this study is the integrated application of trend analysis (Mann–Kendall and Sen's slope), correlation analysis (Spearman's rank), and similarity-based clustering (Bray–Curtis) to evaluate reservoir dynamics at a regional scale.

The results showed that reservoir occupancy rates varied between 2.7% and 79.2% during the study period. Mann–Kendall analysis indicated that no statistically significant trends were observed for most reservoirs ($p > 0.05$), whereas a statistically significant decreasing trend was detected only for Umurbey Reservoir ($Z = -2.14$, $p = 0.033$; Sen's slope = -2.45). In addition, Spearman's correlation analysis revealed no statistically significant relationships between annual precipitation and reservoir occupancy rates ($p > 0.05$), despite moderate correlation coefficients in some reservoirs. Overall, the results indicate that reservoir dynamics in the region are shaped by multiple interacting influences rather than a single controlling factor, such as annual precipitation alone.

In this context, it is recommended that sustainable water resource management strategies be strengthened at both regional and local levels. The findings demonstrate that management strategies should not rely solely on annual precipitation but should also consider temporal variability, reservoir specific dynamics, and water demand patterns. Integrated planning that considers climatic variability, reservoir operation policies, and demand management is crucial for ensuring sustainable water security over time. Stable reservoir levels are important not only for water supply but also for aquatic ecosystems. Variations in occupancy may affect habitat conditions and water availability. Therefore, sustainable reservoir management and consideration of climatic variability are important for maintaining ecological balance.

Increasing public awareness of water conservation and encouraging responsible water use may help reduce pressure on reservoir systems. In the context of projected changes in precipitation and drought frequency in Türkiye, adaptive management approaches may become increasingly important for regional sustainability.

This study has some limitations. The analysis was based on annual reservoir occupancy and precipitation data. Operational variables specific to each reservoir (e.g., water withdrawals, release regimes, and evaporation) were not explicitly considered. In addition, the study period represents a limited temporal scale for detecting long term hydroclimatic trends. Future studies should incorporate higher temporal resolution data and additional hydrological and management-related variables to provide a more comprehensive assessment of reservoir dynamics.

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Compliance with Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Not applicable.

Data Availability

The author confirms that the data supporting the findings of this study are available within the article.

AI Disclosure

AI-assisted technology was not used in the preparation of this work, except for grammar and spelling checks.

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