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Review Article

Review on the use of artificial neural networks to determine the relationship between climate change and the occupancy rates of dams

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ABSTRACT

Climate change has the potential to raise temperatures, alter precipitation patterns, and alter how water resources are distributed globally. The occupancy rates of drinking water supplies may change as a result of these changes. For instance, dwindling water supplies may result from rising temperatures and diminishing precipitation. As a result, the occupancy rates of the reservoirs may drop, making it harder to deliver drinking water. Climate change, however, might highlight regional variations and result in wetter conditions in some places. The occupancy rates in the reservoirs could rise in this scenario. Heavy rains, however, can also result in additional issues like infrastructure damage and floods. Climate change-friendly actions must be taken to manage water supplies in a sustainable manner. In the management of water resources, dams are crucial. It has been observed that when a reliable estimate of a dam's flow is provided, data-based models can produce valuable findings for a variety of hydrological applications. It is obvious that one of the most important problems is the difficulty in getting utility and drinking water as a result of climate change and other things. The purpose of this study is to compile the works that can be offered as a result of the literature review on the impact of climate change on surface water resources and dams, given the importance of this topic. As a result of this study, we can deduce a link between the occupancy levels of the reservoirs used to supply drinking water and climate change. Climate change has the capacity to increase temperatures, modify precipitation patterns, and shift the distribution of water supplies. The relationship between climate change and water supplies is better understood thanks to this study.

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INTRODUCTION

As stated in the United Nations Framework Convention on Climate Change (FCCC), "change in climate as a result of human activities that directly or indirectly disrupt the composition of the global atmosphere, in addition to natural climate change observed over a comparable time period" is considered climate change [1].

With rising population and advancing industry, there have been noticeable increases in greenhouse gas emissions, which have exacerbated global warming by enhancing the atmosphere's already-present greenhouse effect. The earth's climate has changed drastically and quickly as a result of these factors [2–4].

Climate change is a phenomenon that occurs on a long-term scale and over several millennia [5]. Environmental issues brought on by climate change include shifting precipitation patterns, polar ice caps melting, and rising sea levels [6]. Global warming is the primary cause of these changes [7]. Increased greenhouse gas emissions and ex-

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cessive energy absorption by the Earth's atmosphere are the causes of rising global temperatures. The energy balance between the sun and the Earth has been disturbed by rising greenhouse gas levels [8, 9].

Water resources are depleted as a result of climate change, and arid and semi-arid regions are expanding. As a result of excessive evaporation, desertification, salinization, and erosion are becoming more and more prevalent every day. Water stress is brought on by changes in the water cycle brought on by climate change and the unpredictability felt by nations with issues using their water resources [10]. 25.5% of Türkiye's land is at high risk of desertification, while 53.2% is at moderate risk, according to the "Combating Desertification Progress Report" issued in 2018. Climate change: It is predicted that the likelihood of desertification and the length and severity of droughts would both keep rising daily. According to the studies, Türkiye, which is situated in the Mediterranean Basin, is one of the riskier nations. The water resources of Türkiye, which is among the nations that are already experiencing water shortages in terms of usable water potential per capita, are anticipated to be negatively impacted by these changes in tandem with the changes in precipitation and temperatures [11, 12].

By the 2090s, climate change is expected to cause average temperatures in Southern Europe and the Mediterranean region, including Türkiye, to rise by up to 3.0-3.5°C and total precipitation to fall by 15–30% [13, 14]. These modifications are predicted to result in a large decrease in the water potential that is already there. As a result, it is possible to notice reductions in the existing water potentials of over 50% in the Mediterranean region and between 25% and 50% in the Aegean [15].

In order to gather enormous amounts of water or build a reservoir, dams are constructions that are often built on both sides of a river valley [16]. All nations rely on their rivers and lakes to provide water for irrigation or domestic and industrial water supplies. As a result, it is critical to always have enough water in water sources. Since precipitation and snowmelt determine surface water level, seasonality is a deciding element in surface water availability. In fact, there are times of the year when the river flow is high and may even be higher than the demand for water downstream. However, during dry spells, river flow can be extremely low, leading to water shortages. By holding excess water flow in a reservoir and releasing it when the flow is low or insufficient to fulfill full demand, the construction of dams enables the regulation of seasonality [17].

The structures used for water storage (reservoirs) are the most crucial part of water delivery systems where water needs are satisfied by surface water sources. Reservoirs are run according to operating curves that are designed to provide water storage at desired levels throughout the year. The fundamental goal of reservoir operation is to guarantee that the reservoir is filled up to the designated storage level in line with the operating curve during wet seasons, while still supplying the necessary flow, particularly during dry months. Operating curves were once calculated through trial and error, but today they may be calculated using a variety of optimization approaches [18]. The majority of these techniques reliably calculate the volume of water storage needed to meet the need. Hydroclimatic data must be incorporated into the reservoir operation and decision-making system in order to improve water resource management. A water allocation decision support model that accepts input from climate-based forecasts can help with this integration. By essentially reducing the probability range of potential reservoir flows that can be determined from climatic information, the created decision support system enables better water distribution decisions [19].

An artificial neural network (ANN) is a mechanism for providing parallel information flow between organizations that was created using the same principles as the human brain [20].

The current issues are attempted to be resolved as cells are networked together. Through the relationships forged, information exchange is made possible by these connection values' capacity for learning. ANNs are computer systems that can carry out tasks like knowledge generation and discovery through learning with the aid of sample data. ANNs are designed for actions that cannot be foreseen [20]. ANN is employed in the areas of associating, learning, generalization, classification, reconciliation, and feature determination. It is described as a model that replicates the operation of the brain through a statistical analysis of sample data. By building networks and artificial cells to simulate all of the brain's behavior, scientists are creating a branch of study that acts independently of computer operations in their quest to understand the formula of the brain. As a result, ANN has become a brand-new branch of science. Nerves with several cells are arranged in layers to create ANNs. The first row of the network contains the input layers, while the last row has the output layers. Each layer is arranged in relation to the one beneath it and the one above it. The network topology, activation activities, accuracy rate, and training are all necessary for setting up an ANN.

It is clear that the difficulty in obtaining drinking and utility water due to climate change and other factors is a very critical issue. Given the significance of this topic, the goal of this study is to assemble the works that can be provided as a result of the literature review on the influence of climate change on dams and surface water resources. This study's goal is to support additional research in the future.

EXAMPLES FROM THE LITERATURE

A study on the detrimental impacts of a potential drought on Istanbul's water supplies was undertaken by Gerek et al. in 2007 [21]. A software program created by DSI (State Hydraulic Works) for reservoir operation was used to determine the amount of evaporation from the reservoirs in order to calculate the annual yields of these reservoirs in accordance with the results of the drought analysis. The study's scope included an examination of Istanbul's current water supply system.

In the study done in 2007 by Altunkaynak [22], it was utilized to estimate how the lake's water level changed over time as a result of Van Lake's rising water level and the flooding of the coastal districts. With the help of this study, it was determined that an artificial neural network could be used to estimate the link between precipitation and lake water level as well as the dynamic variations in the lake's water level [22].

Bates et al. [23] stated in a literature summary compiled on behalf of the IPCC that in the European continent, especially in England, the Netherlands, and Germany, adaptation and risk against the uncertainties that climate change will create on their water systems. This was based on studies looking at the effects of climate change on the supply reliability of dam reservoirs. They appear to carry out their calculations [23].

In the study done by Çalım [24], the level change of the dam reservoir was estimated using the 1796-day measurement data of Hatay, Antakya Yârseli Dam and its basin located in the Mediterranean Region. This method used artificial neural networks. The artificial neural network was modeled using the Boyesian organization method. In this instance, the Levenberg-Marquardt (LM) training procedure was used to update the weight and bias coefficients. When compared to data obtained using the conventional method, it has been observed that the estimation findings from the artificial neural network modeling study performed well [24]. The increased amount of reservoir evaporation brought to light by global warming and the rise in greenhouse gas concentration in the atmosphere by Benzaghta et al. [25]. For instance, it is said that 95% of Australia's precipitation has already evaporated. The study looked at both chemical and physical approaches to lowering reservoir evaporation. The results showed that while chemical approaches can impair water quality and reduce evaporation by 20% to 40%, physical methods can efficiently reduce evaporation without having an adverse effect on the environment [25].

Using flow-loss flow, precipitation, evaporation, withdrawn flow, level measurements measured by DSI (State Hydraulic Works) and entering Beyşehir Lake between 1962 and 1990, level values were estimated by artificial neural network in a study conducted by Yarar et al. [26], and the results obtained were compared with the estimation values. By removing the challenges associated with evaluating lake water level readings obtained using conventional techniques, it was hoped that the Beyşehir Lake study would help determine the lake's water level as quickly as possible [26].

Ustaoğlu [27] noted that regional differences, particularly in precipitation amounts, come to the fore, with an increasing trend in the Black Sea Region and a decreasing trend predicted along the Aegean and Mediterranean coasts. His study examined the variability in precipitation amounts in Türkiye. Precipitation amounts are expected to shift, with the southern regions of Türkiye seeing a decrease and the northern sections of Türkiye experiencing an increase. The Aegean and Mediterranean coasts will have the greatest (absolute) precipitation reductions. On the other side, greater precipitation is anticipated for the Eastern Black Sea region. There won't be much of a shift in precipitation in Central Anatolia.

The precipitation results from the future simulation, according to Önol and Ünal [28], show that precipitation declines in almost all regions and in all seasons with the exception of autumn. Türkiye is situated in an area that is very vulnerable to climate change, according to Şen [29]. Future climate change predictions predict that temperatures will rise nationwide and that precipitation will fall, notably in the southern half of the country. It is clear that these changes will have a negative impact on the nation's water resources and reduce water potential, particularly in the southern portion of the basins. According to projections, until the middle of the present century, the reduction in water potential might reach 37% in the Mediterranean basins, 70% in the Konya basin, and 10% in the Euphrates and Tigris basins. The Tahtalı dam basin example was used in the Okkan [30] study to assess the effects of climate change on water resources. In the study, fourteen climate models and various climatic scenarios were used to predict changes in precipitation and temperature in the Tahtalı dam basin. By scaling these changes down to the station scale, local climate variations were discovered. The sensitivity of dam currents to potential changes was also investigated, along with sensitivity analyses to changes in temperature and precipitation. The results indicate that temperatures may rise by 1.5 °C to 2.1 °C, precipitation may drop by 3% to 13%, and flows may decrease by 9% to 22%. The volume of drinking water in this situation is predicted to drop by 11% to 35%, and water supply shortages may develop in the area.

Adeloye et al. [31] assessed how revised conservation-combined reservoir rule curves might affect Pong Reservoir's present and future performance under the influence of climate change in India. The HYSIM precipitation-runoff model's simulations of historical and climate change flow series serve as the foundation for the analyses. Delta changes in temperature (0 °C to +2 °C) and precipitation (10% to +10%) were used due to climatic concerns. A pair of consecutive peaks algorithm and a genetic algorithm optimizer are used to create rule curves for reservoir simulation together with simulated flow situations. Sustainability, dependability, recovery, and the greatest amount of shortages are used to summarize reservoir performance. According to the findings, the prior greatest scarcity has fallen from 61% to 20% below the 25% level that many water consumers can tolerate thanks to conservation efforts. While increased precipitation and more influx were anticipated, climate change fears in precipitation revealed the opposite outcome. Maximum water scarcity was worse than 66% without protection from reduced current; it was improved to 26% with this protection. An important outcome of this study has been the strengthening of operational procedures connected to hedging and the capacity to successfully eradicate the impacts of water scarcity brought on by climate change [31].

Two separate neural network models were employed in the study done in 2016 (Doğan et al.) [32] to estimate Lake Van's daily water level. Feedforward neural networks (FFNNs) and radial basis function neural networks (RBNNs) are examples of these neural networks. The FFNN algorithm model beat the RBFNN algorithm model when the estimation results were compared using the mean square error (MES) and R^2 (determination) coefficients. A threat won't be posed by an increase in water in the rapidly growing and densely populated areas around Van Lake's coast because it has been determined from the estimation results of this study that the water level of Van Lake will fall in the future [32].

In their 2016 study, Soundharajan et al. [33] looked at the Pong Reservoir in India, which is situated on the Beas River. To explain the uncertainties brought on by climate change in the storage need and reservoir performance, they employed the Monte-Carlo simulation approach. The software simulates calibrated precipitation-temperature and precipitation-runoff scenarios. Due to the future's drier climate, the reservoir capacity in the results revealed a significant coefficient variability of 0.3 [33].

Yang et al. [34] seek to develop adaptive multi-purpose business rules to lessen variability. An adaptive multi-purpose operating model is suggested and built together with the combination of operating rule curves and reservoir operating function. These ideal operating guidelines are created by contrasting and discussing the NSGA-II approach and dynamic programming. The most effective operating rules were chosen using the projection tracking approach. The findings demonstrated that using NGSA-II to develop reservoir operating rules can boost dependability, water resource efficiency, and hydroelectric energy production. In particular, these water resource-focused rules can significantly increase reservoir annual water resource efficiency by 18.7%. This demonstrated the effectiveness of the suggested paradigm for reservoir operation in terms of climate change [34].

In the Zhao et al. [35] study, the Distributed Hydrology Soil Plant Model (DHTBM) included a multi-purpose reservoir module with established complex operation rules. This module has been modified to accommodate conditional operating rules created to improve the consistency of water delivery and lower the risk of floods. Two reservoirs on the Brazos River in Texas (Whitney and Aquilla) were used to assess the effectiveness of this integrated model. The model has been tested and calibrated using data on reservoir storage and observed input and output currents. Daily, weekly, and monthly data for both reservoirs are a summary of inaccurate figures (reservoir capacity, volume of water discharged, hydraulic power). The Nash-Sutcliff Coefficient was 0.75 and the coefficient of determination (R^2) was 0.85 when using the Whitney Reservoir's weekly reservoir storage capabilities. With the addition of new reservoir components, DMTBM has demonstrated that it is a platform that supports equitably managing water resources in the face of growing anthropogenic activity and ongoing environmental change [35].

The impact of weather information on variations in the water level in the Yalova Gökçe Dam dam and the impact of climate change on lake water level were both investigated in the study by Sönmez et al. [36]. Daily rainfall in the dam basin, daily evaporation, lake water level elevations, flow rates into the dam lake, and flow rates out of the dam were all employed for this purpose. The monthly and yearly fluctuations of these values were then looked at. With regard to population and water consumption per person in 2023, it has been stated that the changes in the dam's water level will not be sufficient due to the effects of global warming. [36].

The objective of the study carried out by Abu Salam in 2018 [37] was to determine the water level of the Dibis Dam, which is situated northwest of Kirkuk. The artificial neural network's input data set consisted of 10-year data. These information includes measurements of the initial water level, precipitation, and the flow values going into and out of the dam. The remaining 20% was utilized as test data, and the remaining 80% as training data. All models are fed via the forward back propagation learning technique in artificial neural network modeling. Four alternative analysis models were developed for the analyses. These analytical models include rainy/non-precipitated, initial water level with/without. The beginning water level was shown to be a crucial piece of information in this investigation [37].

The water budgets of the basins that provide Istanbul with drinking water were calculated using hydrological process models in the Cüceloğlu [12] study. Additionally, the effects of climate change on water supplies were examined using the results from global climate models. Analyses of Istanbul's water resources system's current state and potential impacts of climate change have been done. Water budget simulations have shown the future situation of Istanbul's water supply system. Approaches to dynamic modeling have proved successful in evaluating water resource management and watershed systems. In order to assess the existing state of Istanbul's water resources system and investigate the implications of climate change, a modeling infrastructure has been created.

The goal of the study by Damla et al. [38] was to use an artificial neural network to predict the water level of the Yalova Gökçe Dam. The Sellimandra stream flow rate, basin precipitation and evaporation values, dam water discharges, leachate volume, and dam water level statistics have all been used to try and estimate the water level in 2019. The findings collected indicated that the artificial neural network model's predictions were rather accurate in describing the actual water level. The estimated water level and the measured water level converged, with the determination rate determined at 94.14%. In general, it was found that the estimates were higher than the measured values, but in July and September, it was found that the estimates were lower than the measured values. The findings of this study indicate that using artificial neural network methods to estimate water levels can be advantageous for dam operations.

The Sono, Manuel Alves da Natividade, and Palma basins in the Cerrado region of Brazil were the subject of an investigation by Rodrigues et al. [39] on the hydrological impacts of climate change under several emission scenarios for the 21st century. In order to achieve this, the HadGEM2-ES and MIROC5 global climate models, along with the RCP4.5 and RCP8.5 scenarios, were used to run the SWAT hydrological model throughout three time periods (2011-2040, 2041-2070, and 2071-2099). Droughts were defined using the Standardized Precipitation Index (SPI) and the Standardized Stream Flow Index (SSFI). Overall, the findings indicate that future periods are likely to see an increase in the length, severity, and frequency of meteorological and hydrological droughts. However, it is anticipated that hydrological droughts will be more severe than meteorological droughts. Reduced stream flows are seen in both scenarios and over all future time periods, especially during dry spells. This could have a negative impact on the Cerrado biome's ecological processes, diminish aquifer recharge, and increase the risk of producing electricity in northern Brazil. The Sono, Manuel Alves da Natividade, and Palma Cerrado basins' hydrological behavior in the current climate was successfully reconstructed by the SWAT model. These findings demonstrate that it is possible to investigate how stream flow in the basins of the Cerrado Region is affected by climate change. Reductions in the annual water budget (P-ET) have been predicted by the Eta/HadGEM2-ES and Eta/MIROC5 climate models for the whole 21st century. The SWAT model expected declines in monthly stream flow throughout the year under these conditions. The dry season (June to August) had the largest monthly stream flow fluctuations, with decline rates reaching 90.1%. The RCP8.5 scenario (Eta/HadGEM2-ES) predicts the greatest changes in mean annual flow at the end of the twenty-first century, with 81.9% (412.2 mm), 75.4% (411.6 mm), and 81.9% (411.6 mm) in MRB, PRB, and SRB, respectively. A reduction of 74.7% (443.3 mm) is visible. A rise in the length, severity, and frequency of climatic and hydrological droughts is also predicted for the foreseeable future. However, it is anticipated that hydrological droughts will be more severe than meteorological droughts. Generally speaking, the outcomes from the various climatic scenarios used show large variations. The findings indicate that the availability of water in Brazil's Cerrado region may be significantly impacted by climate change. Therefore, it is important to draw attention to the hazards for decreased aquifer recharge, northern Brazil's electrical power production, and the Cerrado Region's environment.

According to the most recent IPCC 6th Report [40], droughts would negatively affect Türkiye in the coming years, notably in Türkiye, according to model results obtained in accordance with SSP scenarios. There is a trend toward rising temperatures and falling precipitation, as shown by the scenarios and models customized for Türkiye in the report Climate Projections for Türkiye issued by the General Directorate of Meteorology [41]. Ayva et al. [42] attempted to analyze the existing impact of climate change and its potential future implications in the Kirazdere basin, a sub-basin of the Yuvacık Dam, a significant water resource in the Kocaeli province. The Mann Kendall trend analysis results show that there has been a significant increase in temperatures, particularly after the 2000s, and that temperatures have been growing throughout the analyzed time. While there was no discernible trend in the precipitation, the flow was seen to be diminishing. Additionally, the analysis of the Standardized Precipitation Index (SPI) revealed that there were times of drought. Drone photographs showed that there had been drops in water level in the dam lake as a result of the drought. Some scenarios forecast an increasing trend in temperature and a declining trend in precipitation based on climate models and scenarios. The results of the drought analysis indicate that the basin will experience both short-term and long-term droughts in the future.

In their study from 2023, Salmona et al. [43] assessed how land development and climate change affected 81 watersheds in Brazil's Cerrado ecosystem. A future deforestation and climate scenario up to 2050 was projected, and their impact on land and water was estimated, based on a thorough examination of field and secondary data collected between 1985 and 2018. It has been noted that river flows are more strongly impacted by the direct effects of large-scale deforestation on the production of irrigable agricultural crops than climate changes. According to estimates, the flow reduced because of deforestation and climate change by 8.7% and 6.7%, respectively. Due to changes in land use and land cover, the majority of the observed changes (56.7%) took place in the last ten years. The Cerrado basins have had a total water reduction of 19,718 m^3/s as a result of changes in climate, land use, and land cover. Assuming current deforestation rates, the total amount of water lost by 2050 will be 23,653 m^3/s, which translates to a 33.9% reduction in river flows in the study area. This will severely alter numerous rivers' flows and have a negative impact on agriculture, the production of electricity, biodiversity, and water supplies, especially during the region's dry seasons. The findings demonstrate how changes in land use and the climate have a direct impact on the amount of surface water in Brazil's Cerrado habitat, which tends to get worse over time. Future projections reveal that the growth of agricultural areas tends to limit water flow in more than 90% of the basins in the Cerrado biome. This could result in repeated levels of water shortages during dry spells in the research area, it was highlighted in the study. The availability of water in the Cerrado biome is impacted by changes in land use and the climate, it was concluded.

CONCLUSIONS

We can infer a connection between climate change and the occupancy levels of the reservoirs used to supply drinking water. Climate change has the potential to raise temperatures, alter precipitation patterns, and alter how water resources are distributed globally.

The occupancy rates of drinking water supplies may change as a result of these changes. For instance, dwindling water supplies may result from rising temperatures and diminishing precipitation. As a result, the occupancy rates of the reservoirs may drop, making it harder to deliver drinking water.

However, there may be regional variations in the correlation between climate change and drinking water reservoir occupancy rates. Extreme weather conditions including increasing rainfall and flooding could occur in some locations. In this scenario, reservoir occupancy rates would climb, but other difficulties, such excessive flooding and infrastructure issues, might also appear.

The occupancy rates of drinking water reservoirs and climate change are intricately related, in our opinion. Understanding how climate change affects water resources will help us modify our water management plans. Future drinking water supplies, resource protection, and efficient water use should all be goals of sustainable water resource management.

Precipitation patterns may alter as a result of climate change. Less precipitation may fall in some areas, while heavy rain and flooding may occur in other areas. Future precipitation patterns will be impacted by climate change, according to climate models. The occupancy rates of reservoirs holding potable water may be impacted by this.

Although drinking-use water consumption accounts for a small portion of global and national consumption, it is claimed that surface water resources provide the majority of the drinking-use water required in major cities. Due to shifting climatic conditions, rapid population increase, and changes in land use, it is challenging to obtain drinking-use water from surface water resources. As a result, it is imperative to manage and evaluate the effects of water resources using dynamic approaches that take both human activities and the hydroclimate's effects into consideration. To ensure the sustainable use of water resources, it is crucial to develop policies that are favorable to climate change. To do this, strategies for reducing water usage should be developed and put into practice, such as changing patterns of water consumption, calculating water footprint reduction, disseminating appropriate water utilization technology, and regulating water use in the industrial sector.

Due to their capacity to contain water and regulate flow, dams are valued assets for flood avoidance as well as for water supply and hydroelectric power. They play a significant role in the management of water resources. This is a crucial function because of the recent rise in extreme occurrences brought on by climate change, and future decades will depend heavily on our capacity to reduce flood damage. For water management or early warning systems, having a reliable estimate of a dam's flow might be advantageous. Data-based models have shown to be an effective tool for a variety of hydrological applications when historical data is available.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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