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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

An Overview of the Impacts of Climate Change: Investigation of Precipitation, Temperature Anomaly and Effects on Water Resources in Turkey

Meral KORKMAZ*
Munzur Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü,62, Tunceli, Türkiye

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*: https://orcid.org/0000-0001-5689-2560

***Corresponding author's:**
Meral KORKMAZ
Munzur University, Faculty of Engineering, Department of Civil Engineering, 62, Tunceli, Türkiye
✉: meralkorkmaz@munzur.edu.tr

Abstract: Climate change is a global issue that significantly impacts our daily lives and water resources. Understanding the complex relationship between climate change and water resources is vital for developing effective prevention and adaptation strategies. This study aims to investigate the impacts of climate change on water resources and emphasize the importance of this issue. Water is a finite resource, and its availability and quality have a direct impact on human well-being, agriculture, energy production and ecosystem health. However, climate change is altering the patterns and dynamics of precipitation, temperature and evaporation, leading to significant changes in the availability and distribution of water. Rising global temperatures are causing glaciers to melt, steadily reducing freshwater resources. As water scarcity becomes more widespread, competition for limited resources increases, potentially leading to conflict and social unrest. Given the importance of water resources and the decisive impact of climate change on their availability and quality, it is imperative that we understand this complex relationship in depth. This study aims to assess the socio-economic and environmental impacts of climate change on water resources. In conclusion, the impact of climate change on water resources cannot be overstated. This study examines the impacts of changing precipitation patterns and increasing temperatures caused by climate change on groundwater and surface water resources in Turkey. According to the results, the decrease in winter precipitation and increase in temperature exacerbate drought conditions, especially in the Mediterranean and Southeastern regions. Long-term satellite images of lakes, especially in the Mediterranean region, show a significant decrease. These changes lead to a decrease in groundwater and surface water resources and increase the risk of water scarcity.

Keywords: Climate change, precipitation, temprature, Türkiye, water resources.

İklim Değişikliğinin Etkilerine Genel Bir Bakış: Türkiye'de Yağış, Sıcaklık Anomalisi ve Su Kaynakları Üzerine Etkilerinin İncelenmesi

***Sorumlu yazar:**
Meral KORKMAZ
Munzur Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, 62, Tunceli, Türkiye
✉: meralkorkmaz@munzur.edu.tr

Öz: İklim değişikliği, günlük yaşamımızı ve su kaynklarımızı önemli ölçüde etkileyen küresel bir sorundur. İklim değişikliği ile su kaynakları arasındaki karmaşık ilişkiyi anlamak, etkili önleme ve adapte stratejileri geliştirmek açısından hayati önem taşımaktadır. Bu çalışma, iklim değişikliğinin su kaynakları üzerindeki etkilerini araştırmayı ve bu konunun önemini vurgulamayı amaçlamaktadır. Su, sınırlı bir kaynaktır ve erişilebilirliği ile kalitesi insan refahı, tarım, enerji üretimi ve ekosistem sağlığı üzerinde doğrudan etki etmektedir. Ancak, iklim değişikliği yağış, sıcaklık ve buharlaşma desenlerini ve dinamiklerini değiştirerek suyun erişilebilirliği ve dağılımında önemli değişikliklere yol açmaktadır. Küresel sıcaklıkların artması, buzulların erimesine yol açarak tatlı su kaynaklarını sürekli olarak azaltmaktadır. Su kıtlığı daha yaygın hale geldikçe, sınırlı kaynaklar için rekabet artmakta ve potansiyel olarak çatışmalara ve sosyal huzursuzluğa yol açmaktadır. Su kaynaklarının önemi ve iklim değişikliğinin erişilebilirliği ile kalitesi üzerindeki kesin etkisi göz önüne alındığında, bu karmaşık ilişkiyi derinlemesine anlamamız kaçınılmazdır. Bu çalışma, iklim değişikliğinin su kaynakları üzerindeki sosyo-ekonomik ve çevresel etkilerini değerlendirmeyi amaçlamaktadır. Sonuç olarak, iklim değişikliğinin su kaynakları üzerindeki etkisi abartılamaz. Bu çalışma, Türkiye'de iklim değişikliğinin neden olduğu değişen yağış desenleri ve artan sıcaklıkların yeraltı ve yüzey su kaynakları üzerindeki etkilerini incelemektedir. Araştırma sonuçlarına göre, kış yağışlarında azalma ve sıcaklık artışı, özellikle Akdeniz ve Güneydoğu bölgelerinde kuraklık koşullarını şiddetlendirmektedir. Özellikle Akdeniz bölgesindeki göllerin uzun dönem uydu görüntüleri incelendiğinde ciddi anlamda azalma görülmektedir. Bu değişimler, yeraltı ve yüzey su kaynaklarının azalmasına ve su kıtlığı riskinin artmasına yol açmaktadır.

Anahtar kelimeler: İklim değişikliği, yağış, sıcaklık, Türkiye, su kaynakları.

INTRODUCTION

In recent years, the direct and indirect effects of global climate change are being felt around the planet, with many of these impacts concentrating on our water resources. Climate change goes beyond mere increases in temperature and changes in the severity of weather events, deeply marking the hydrological cycle through alterations in precipitation patterns, evaporation rates, and snowmelt. These changes affect a wide range of water resources from river flow regimes to groundwater levels, and from drinking water supply to agricultural irrigation needs. Water security is already a serious issue for millions of people worldwide, and climate change exacerbates these existing problems and creates new challenges.

Climate change refers to the long-term changes in average weather conditions on Earth (Karaman & Gökalp, 2010). These changes are assessed over long periods, typically decades or longer. The current climate change refers to the changes that have been occurring since the early 1900s. Predominantly, modern climate change stems from human activities such as the burning of fossil fuels and deforestation (Partigöç & Soğancı, 2019; Frederick & Major, 1997). According to Arnell (1999), climate change, a term that has become widespread in recent years, refers to the long-term changes in temperature and typical weather conditions in a specific region or across the entire planet. This phenomenon primarily originates from human activities that release greenhouse gases into the atmosphere, leading to various harmful environmental consequences. These activities emit greenhouse gases that trap heat in the atmosphere, causing the planet to warm to dangerous levels (Arnell, 1999; Şahin et al., 2015). In this context, climate change, which is a very significant phenomenon today, will be presented in this section of the study in terms of its causes, impacts, and possible consequences, and will be assessed from a literature perspective.

Climate change represents long-term changes in weather conditions and patterns worldwide (İclal, 2021). This primarily arises from the increased levels of atmospheric carbon dioxide produced by the burning of fossil fuels. A review of the literature has identified many causes for the emergence of climate change (İclal, 2021; Yılmaz & Navruz, 2019; Zaimoğlu, 2019; Demir, 2009; Şen, 2005; Doğan & Tüzer, 2011; Tuğaç, 2014):

Burning coal, oil, and natural gas releases carbon dioxide and other greenhouse gases into the atmosphere. These gases trap heat from the sun, causing the planet to warm over time. More emissions mean more warming. Globally, as well as in Turkey, the energy sector is the most significant source of greenhouse gas emissions, with this sector's emissions comprising a large portion of the country's total greenhouse gas emissions. Turkey's total greenhouse gas emissions in 2016 showed an increase of 135.4% compared to 1990, calculated as a total of 496.1 Mt CO_2 equivalent. Although Turkey's share of CO_2 emissions is small compared to the global total, as a developing country, it bears significant responsibilities in managing its emissions and transitioning to sustainable energy sources. In this context, the rising trend of emissions in Turkey and the control of this increase will play a critical role in achieving national and global climate targets (Çapar, 2019).

Deforestation contributes to climate change. Trees absorb and store carbon dioxide from the atmosphere. When they are cut down and either burned or left to decay, the stored carbon is released back into the air. Fewer trees mean more accumulation of carbon dioxide. As the human population grows and countries develop, the demand for electricity and transportation also increases. Increased energy demand generally means more burning of fossil fuels, which leads to higher emissions. In summary, human activities such as burning fossil fuels, deforestation, agriculture, and waste production cause an increase in atmospheric greenhouse gas concentrations. This enhances the natural greenhouse effect, leading to higher global temperatures and altering climate patterns worldwide. It can be argued that there is an urgent need for action to reduce emissions and mitigate climate change (Shukla et al., 1990).

Climate change is linked to climatological variables such as temperature and precipitation, causing changes in these factors. These changes lead to excessive rainfall in some regions, droughts in others, and reductions in snow masses, resulting in water scarcity. Climate change continues to have far-reaching impacts on global living conditions (Yılmaz & Navruz, 2019). From increasing global temperatures to extreme weather events, the effects of climate change are becoming more pronounced each day (Köle, 2012). This section of the study will evaluate the impacts of climate change.

One significant consequence of climate change is the rising global sea levels. As the world warms, sea ice melts, oceans expand and warm up. This leads to higher sea levels, causing coastal flooding and erosion, displacing millions of people, and threatening coastal properties and infrastructure. Many islands and coastal cities are already experiencing the detrimental effects of rising sea levels (Öztürk, 2002; Demircan, 2022).

Another significant result of climate change is the increased frequency and intensity of extreme weather events. As the climate continues to change, heatwaves, droughts, wildfires, hurricanes, and severe rainfall events are becoming more intense and more common. These extreme weather events can lead to loss of life, and damage to agriculture, property, and the environment. Some extreme weather events, like hurricanes, can disrupt lives significantly and cause long-term damage (Gleick, 1989; Şahin et al., 2019).

Turkey has substantial water resources that are strategic due to regional water scarcity. Despite considerable efforts in resource planning and development since the mid-20th century, less than half of the potential has been developed. Rapid population growth and expanding agricultural and industrial demands are putting pressure on both the quantity and quality of these resources (Bayazit & Avci, 1997). A comprehensive review of Turkey's water resources reveals key issues including the physical characteristics that shape water resources, usage patterns (domestic, agricultural, hydroelectric), and challenges such as river basin management, legal frameworks, and sustainability concerns (Harmancioglu & Altinbilek, 2020). Evaluation of water resources potential and management practices highlights the need for better management to address challenges related to distribution and sustainability of water resources in Turkey. Critical concerns include the effects of global warming, ancient water works, transboundary basins, and future water needs and management strategies (Selek & Aksu, 2019).

Water is one of the most important natural resources on Earth (Bayraç & Doğan, 2016). All living organisms require water to survive, making the availability of clean and fresh water essential for sustaining life (Çakmak & Gökalp, 2011). It is also necessary for supporting agriculture and food production. The agricultural industry, encompassing irrigation, crop cultivation, industry, energy production, and livestock, critically depends on water. Without adequate water resources, it would not be possible to produce enough food to feed the world's population (Frederick & Major, 1997; İclal, 2021). According to Melese (2016), water resources are crucial as they are the main source of drinking water essential for human health and survival. Wetlands, rivers, ponds, lakes, and oceans provide vital habitats for fish, waterfowl, and countless other species. The conservation of water ecosystems helps prevent the loss of biological diversity (İclal, 2021; Frederick & Major, 1997; Haddeland et al., 2014; Demircan, 2022).

Groundwater resources are critical during drought processes, as they respond to climate changes more slowly than surface water systems. In Turkey, declining trends of groundwater levels in Central Anatolia are closely associated with increasing drought events, reflecting the regional impacts of climate change. Research indicates that spring recharge of many aquifers around the world has shifted towards winter and summer recharge has decreased significantly. These changes show the impacts of climate change on both the quantity and quality of groundwater resources (Şen, 2022).

Turkey's geographical diversity and climatic conditions pose unique challenges for water resources. As the country lies at the intersection of both continental and maritime climatic influences, rainfall and evaporation rates vary greatly from region to region. Most of Turkey's water resources are used for agricultural irrigation, drinking water supply and industrial use. However, factors such as climate change, population growth and urban sprawl put pressure on water resources. Drought periods, especially in the Southeastern Anatolia Region and increasing temperatures in the Mediterranean Region increase water stress and fuel competition for water resources. In combating the impacts of climate change, Turkey's water policies integrate adaptation and mitigation strategies and thus develop long-term plans to protect water resources. These strategies are critical for the protection and management of water resources at both local and national levels. In this process, various scientific research and technological developments are also influential in shaping water management policies (Aktaş, 2014); (Ertürk et al., 2014).

Climate is defined by the average and variability of meteorological elements like temperature, humidity, atmospheric pressure, wind, and precipitation over a long period in a given area. Factors such as latitude, elevation, and proximity to oceans significantly shape a region's climate by influencing these elements. For example, latitude affects solar radiation received, elevation impacts atmospheric pressure and temperature, and proximity to oceans moderates temperature fluctuations and increases moisture availability. These factors collectively define the climatic conditions of a region over time (Flannigan & Wotton, 2001); (Bonacina, 1923).

Climate change significantly impacts water quality by enhancing pollution, increasing salinization, and altering the ecological status of water bodies. These changes necessitate improved management practices and adaptation strategies to safeguard water resources for ecological, agricultural, and human needs. The comprehensive management of water resources is crucial for mitigating the adverse effects of climate change on water quality.

Both drought and floods have significant impacts on water quality. Drought can lead to the concentration of pollutants in water sources, while floods can result in the spread of contaminants and pathogens. This poses a risk to the health and well-being of many people, especially those living in developing countries where access to clean water is already limited (Şen, 2013; Şen, 2005). Climate change also has a significant impact on aquatic ecosystems. Drought can cause rivers and lakes to dry up, leading to habitat and biodiversity loss. Floods, on the other hand, can result in habitat destruction and the displacement of wildlife (Bayraç & Doğan, 2016). Overall, it can be said that climate change has a profound impact on water resources worldwide. The increasing frequency and severity of droughts and floods affect the availability and quality of water, endangering the health and well-being of millions of people and causing serious damage to ecosystems and biodiversity. At this point,

it becomes imperative to take action to mitigate the effects of climate change and to ensure the transfer of water resources to future generations (Taşkın et al., 2022; Partigöç & Soğancı, 2019).

Climate change significantly affects water resources globally, and Turkey, with its geographical and climatic diversity, faces particular challenges. The impact of climate change on Turkey's water resources is increasingly evident, influencing temperature, precipitation, and ultimately the availability of water across different regions. Studies indicate that Turkey, located in the Mediterranean Basin, is experiencing changes in temperature and precipitation patterns due to climate change, which directly affects water resources. Notably, an increase in temperature and variability in precipitation has been observed, leading to water scarcity in some areas and flooding in others (Aktaş, 2014). Climate change affects hydrological cycles in Turkey, necessitating updated water management strategies to cope with decreased river flows and reservoir levels, and increased incidence of droughts and floods. These changes demand a reevaluation of water resource management and infrastructure to ensure sustainability and resilience (Yılmaz & Yazicigil, 2011). Effective governance and policy frameworks are critical in managing the impacts of climate change on water resources. Turkey has been urged to enhance its water management policies, focusing on both mitigation strategies and adaptation measures to better handle the expected changes and to safeguard water resources for future generations (Yılmaz & Imteaz, 2014).

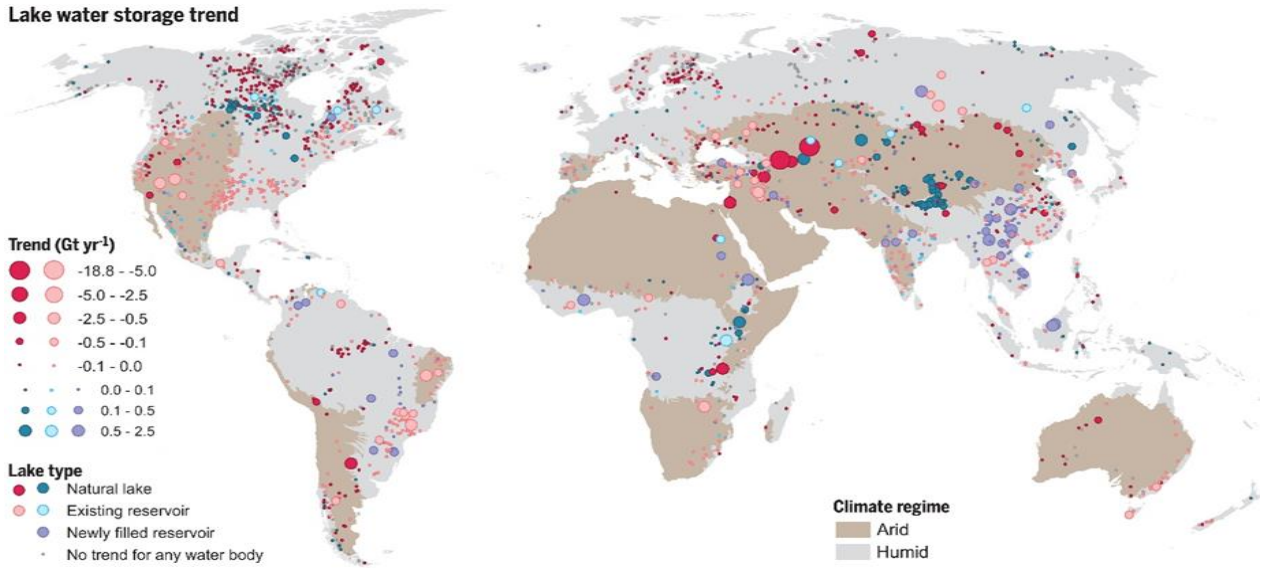

Figure 1. Extensive decrease in water storage in large global lakes from October 1992 to September 2020 (Yao etc., 2023).

Yao et al. have studied the global lake water storage (LWS) using satellite observations and investigated the trends and causes of changes in lake volumes worldwide. In their study, they identified a widespread decline in global lake water storage over the past 28 years. They observed significant water losses in more than half of the large lakes (53% ± 2%) ($p < 0.1$) (Figure 1). This paper analyzes the changes in water storage of 1,972 large lakes around the world during the period 1992-2020 using three decades of satellite observations, climate data, and hydrological models. The results reveal statistically significant declines in water storage in 53% of the lakes studied. The main causes of water volume declines in natural lakes include climate warming, increased evaporation demand, and human water consumption. Reservoir water losses were found to be mostly due to sedimentation. Additionally, it is estimated that approximately one-quarter of the world's population lives in a drying lake basin. These findings emphasize the need to consider the effects of climate change and sedimentation for the sustainable management of water resources. The study is highly significant for a detailed analysis of natural and human-induced variables that have important impacts on the global water cycle and freshwater resource management (Yao et al., 2023).

Yao et al. also studied the global lake water storage in Turkey using satellite observations and examined changes in lake volumes worldwide. The results reveal statistically significant declines in water storage in 53% of the lakes studied. The main causes of water volume declines in natural lakes include climate warming, increased evaporation demand, and human water consumption. Reservoir water losses were found to be mostly due to sedimentation. Additionally, it is estimated that approximately one-quarter of the world's population lives in a drying lake basin. These findings emphasize the need to consider the effects of climate change and sedimentation for the sustainable management of water resources. The study is highly significant for a detailed analysis of natural and human-induced variables that have

important impacts on the global water cycle and freshwater resource management. The study also indicates that Turkey, except for the Black Sea region, falls within the arid zone (Yao et al., 2023).

The research by Doğrul and Alkan (2022), which examines the water loss in lakes and dams in Turkey as a result of climate change using remote sensing technology, is an important contribution to the existing literature. Using multi-temporal satellite imagery, the researchers documented the changes in different water bodies such as Lake Duden, Gölköy Reservoir, Bademli Reservoir and Lake Burdur. In particular, the calculation of the surface areas of these lakes between 2011, 2015 and 2021 with Google Earth software and the comparison of the measurements obtained with SPI data is remarkable in terms of the methods used to determine the decreases in water resources (Doğrul & Alkan, 2022). This study is considered as a critical reference in understanding the impacts of climate change on water resources and demonstrating the potential uses of satellite technology.

MATERIAL AND METHOD

Study Area: Turkey's annual average rainfall is approximately 574 mm, with a total annual precipitation amount reaching 450 billion cubic meters. The country's surface area has been calculated to be 783,577 km². The annual surface runoff has been determined to be 186 billion cubic meters, with 94 billion cubic meters of this water identified as usable surface water. In terms of groundwater, the annual extractable amount has been determined to be 18 billion cubic meters. In total, surface and groundwater together provide a usable water potential of 112 billion cubic meters (Table 1).

Table 1. Turkey's water resources potential (DSİ, 2022).

Water Resources Potential	Value	Unit
Annual average rainfall	574	mm/year
Area of Turkey	783,577	km²
Annual rainfall amount	450	billion m³
Surface Water		
Annual surface runoff	186	billion m³
Usable surface water	94	billion m³
Groundwater		
Annual extractable groundwater	18	billion m³
Total Usable Water (surface + groundwater)	112	billion m³
Development Status		
Irrigation Water	44	billion m³
Drinking, Usage, and Industrial Water	13	billion m³
Total Used Water	57	billion m³

Turkey's geographical diversity and climatic conditions present unique challenges for its water resources. Positioned at the intersection of continental and maritime climate influences, the country experiences significant regional variations in precipitation and evaporation rates. A large portion of Turkey's water resources are used for agricultural irrigation, drinking water supply, and industrial use. However, factors such as climate change, population growth, and urban sprawl exert pressure on these resources. Particularly, the Southeastern Anatolia Region experiences periods of drought, and rising temperatures in the Mediterranean Region exacerbate water stress, fueling competition over water resources. In the fight against the impacts of climate change, Turkey's water policies integrate adaptation and mitigation strategies, thereby developing long-term plans to protect water resources. These strategies are critical for the preservation and management of water resources at both local and national levels. During this process, various scientific research and technological advancements also play a significant role in shaping water management policies (Aktaş, 2014; Ertürk et al., 2014).

Figure 2. Map of water resources in Türkiye.

In Figure 2, the water resources in Turkey are shown. Turkey hosts 25 distinct river basins, each with its own characteristics. Most of these rivers originate within Turkey's borders and flow into the seas around Turkey. Among the longest rivers in the country are the Kızılırmak (1151 km), Sakarya (824 km), Büyük Menderes (584 km), Seyhan (560 km), Yeşilırmak (519 km), Ceyhan (509 km), Gediz (275 km), and Küçük Menderes (129 km). The Orontes (88 km in Turkey) and Maritsa (187 km in Turkey) rivers originate in foreign countries and reach the coasts of Turkey. The variability of precipitation across seasons and regions in Turkey causes annual fluctuations in the flow and speed of these rivers. The steep gradients of river beds provide great potential for hydroelectric power production, yet these same gradients make river navigation challenging.

Turkey is home to 320 natural lakes, many of which are subject to seasonal variations. The largest lakes include Lake Van (3713 km²), Lake Tuz (1300 km²), Beyşehir Lake (656 km²), and Eğirdir Lake (482 km²). There are 861 operational dams in Turkey. The largest by surface area include the Atatürk Dam (817 km²), Keban Dam (675 km²), Ilısu Dam (313 km²), Karakaya Dam (268 km²), and Hirfanlı Dam (263 km²) (DSİ, 2024).

Table 2. Annual Groundwater Potential by Basins, 2013-2022 (DSİ, 2022).

Basin No	Basin Name	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
		Groundwater Recharge (hm³/year)									
1	Meriç-Ergene	508	508	508	508	508	508	508	508	508	508
2	Marmara	242	242	242	242	242	242	242	242	242	242
3	Susurluk	740	780	780	780	780	780	780	780	780	780
4	Kuzey Ege	289	289	289	289	289	289	289	289	289	289
5	Gediz	555	555	1156	1156	1156	1156	1156	1156	1156	1156
6	Küçük Menderes	179	179	179	179	179	179	179	179	179	179
7	Büyük Menderes	1045	1045	1045	1045	1045	1045	1045	1045	1045	1045
8	Batı Akdeniz	473	473	473	473	473	473	473	473	473	473
9	Antalya	1093	1093	1165	1165	1165	1165	1165	1165	1165	1165
10	Burdur Göller	106	106	106	106	106	106	106	106	106	106
11	Akarçay	188	345	345	345	345	345	345	345	345	345
12	Sakarya	2197	2197	2197	2197	2197	2197	2197	2197	2197	2197
13	Batı Karadeniz	442	442	641	641	641	641	641	641	641	641
14	Yeşilırmak	907	907	907	907	907	907	907	907	907	907
15	Kızılırmak	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003
16	Konya Kapalı	2525	2525	2597	2597	2597	2597	2597	2597	2597	2597
17	Doğu Akdeniz	97	97	97	97	97	97	97	97	97	97
18	Seyhan	839	839	839	839	839	839	839	839	839	839
19	Asi	393	393	393	393	393	393	393	393	393	393
20	Ceyhan	985	985	985	985	985	985	985	985	985	985
21	Fırat - Dicle	4737	4737	4995	4995	4995	4995	4995	4995	4995	4995
22	Doğu Karadeniz	491	491	491	491	491	491	491	491	491	491
23	Çoruh	30	30	30	30	30	30	30	30	30	30
24	Aras	304	406	389	389	389	389	389	389	389	389
25	Van Gölü	179	179	179	179	179	179	179	179	179	179
Total		**21548**	**21848**	**23032**	**23032**	**23032**	**23032**	**23032**	**23032**	**23032**	**23032**

Table 2 shows the annual renewable groundwater potential (hm³/year) in different basins in Turkey between 2013 and 2022. Understanding how the potential of groundwater resources in various regions of Turkey has changed over the years is critical for sustainable water management. The table includes both basins that have remained stable and those that have shown marked changes, indicating that changes on water resources are regionally differentiated.

According to the data in the table, significant increases have been observed in some basins over the years. For example, while groundwater potential in Gediz Basin was 555 hm³ in 2013 and 2014, it increased to 1156 hm³ as of 2015.

Euphrates-Tigris, Konya Closed and Kızılırmak basins stand out as the basins with the highest groundwater potential in Turkey. Euphrates-Tigris Basin has a potential between 4737-4995 hm³ from 2013 to 2022. In Konya Closed Basin, this value is between 2525-2597 hm³ and it is one of the largest basins of Turkey and has strategic importance in terms of groundwater. Kızılırmak Basin also offers a high potential with 2003 hm³.

Turkey's total groundwater potential increased from 21,548 hm³ in 2013 to 23,032 hm³ by 2022. When the observed increase in Turkey's total groundwater potential from 2013 to 2022 is evaluated together with the increasing population and demand pressure on water resources, it is necessary to determine the impacts on future water resources. Especially the fluctuations observed in the population growth rate between 2007 and 2023 in the TUİK database once again reveals the importance of population growth on water resources. Considering the increase in population, it emphasises the necessity of long-

term management of groundwater potential and precautions.

This study emphasises the importance of monitoring Turkey's water resources on a regional and annual basis. Especially the protection of basins with high potential will play a critical role in adaptation to climate change impacts.

Research Methods and Dataset: For this study, meteorological data such as temperature and precipitation have been sourced from the Turkish State Meteorological Service (MGM) and various international climate databases. This information is crucial for understanding the climatic trends across different regions of Turkey. Additionally, data on surface and groundwater levels, as well as flow regimes, have been obtained from the State Hydraulic Works (DSİ).

The collected data were analyzed to assess long-term climatic and hydrological trends. This involved a detailed examination of the tendencies in the meteorological variables and their impact on water resources. The methodology employed includes both statistical analysis to identify trends and anomalies in the climate data and hydrological assessments to evaluate changes in water regimes.

Furthermore, remote sensing technologies and satellite imagery have been utilized to gather data on water coverage and land use changes. This data has been processed and analyzed using ArcGIS software, allowing for precise mapping and analysis of spatial and temporal changes in water resources and land use patterns.

This comprehensive approach ensures a robust analysis of the impacts of climate change on Turkey's water resources, providing valuable insights into the regional variations and trends over time.

Describe the geographical location and characteristics of the study area in Turkey, focusing on its climatic conditions, hydrological features, and relevant environmental aspects.

RESULTS AND DISCUSSION

Investigation of the Effects of Climate Change on Temperature and Precipitation

Detailed Analysis of Temperature: Studies on temperature trends and climate change in Turkey show a clear warming trend, especially in the last half century. The figure 3 shows Turkey's annual average temperature values between 1971 and 2023 in order (MGM, 2024). The horizontal axis of the graph shows years and the vertical axis shows temperature values (°C). On the far left, the red bar for 2023 shows the highest annual average temperature with a value of 15.1 °C. This is the most striking element of the visual. Another red bar representing the average between 1991 and 2020 is marked with 13.9°C. This represents the long-term average temperature and indicates that 2023 is significantly higher than this average.

This ranking illustrates the temperature increase in Turkey and clearly shows how temperature values have changed in recent years. In particular, the year 2023 seems to have set a record with a temperature well above the long-term average.

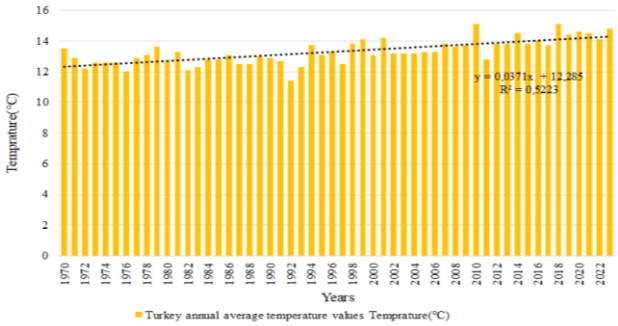

Figure 3. Annual average temperature data obtained from 239 major climate stations across Turkey from 1970 to 2023.

Figure 3 shows how the annual average temperature data from 239 major climate stations across Turkey changed between 1970 and 2023 (MGM, 2024). The horizontal axis shows years and the vertical axis shows temperature values (°C). The red line in the graph represents Turkey's annual average temperature and the blue line represents the periodic trend (linear regression line) of these values. Equation of the trend line y=0.0372x+12.285. This means that there is a positive slope (0.037) indicating that temperature values increase as the years progress. In other words, Turkey's average temperature has increased by about 0.037°C every year. The graph shows a significant temperature increase especially since the 1980s. The fluctuations in temperature values in recent years are also noteworthy; these fluctuations may be due to seasonal effects, natural climate events or other environmental factors. In conclusion, the graph shows that temperatures in Turkey have been on an upward trend in the long term and this trend has become more pronounced in recent years.

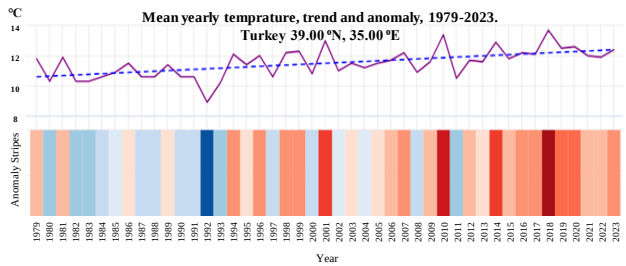

Figure 4. Mean yearly temperature, trend and anomaly, 1979-2023.

Figure 4 shows the average annual temperatures, temperature trend, and anomalies in Turkey from 1979 to

2023 (Meteoblue, 2024). Upon examining the graph, it is evident that the trend of annual average temperatures has increased over time. Analyzing the annual temperature anomalies, the blue bars indicate years below the average temperature, while the red bars indicate years above the average temperature. In recent years, particularly after 2010, there has been a general upward trend in temperature anomalies. This increase in temperature anomalies can be attributed to the effects of climate change.

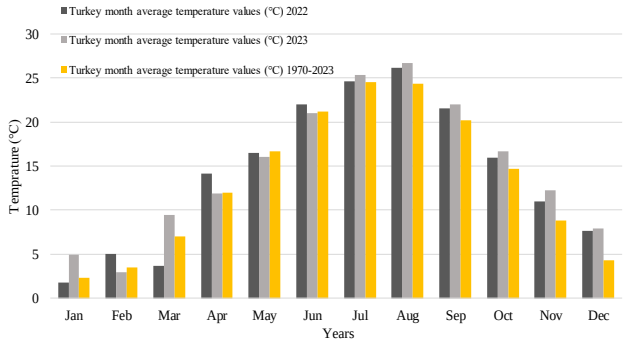

Figure 5. Comparison of the average temperature values of Turkey in 2023 and 2022 with the long-term average between 1991-2020.

Figure 5 shows that when examining the monthly average temperature values for the years 2023 and 2022 in Turkey, higher temperatures are observed compared to the long-term average from 1970 to 2023. The temperature differences are particularly more pronounced during the summer months and in May, the last month of spring. July exhibits the highest temperature increase. These temperature rises demonstrate the effects of climate change, indicating long-term changes.

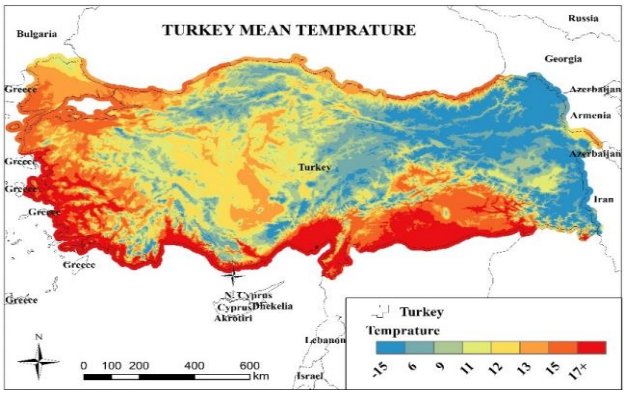

Figure 6. Turkey's average temperature distribution between 1970-2023.

Figure 6 shows the average temperature distribution of Turkey between 1970 and 2023. The southern and southwestern regions, especially the Mediterranean coast, have higher temperatures (shades of red and orange), while the eastern regions and the northeastern highlands have lower temperatures (shades of blue). The Mediterranean region, showing high temperatures (shades of red), is generally recognized as one of the hottest regions of Turkey. Central Anatolia and Eastern Anatolia have colder temperatures (shades of green and blue), especially in high altitude areas. The Black Sea Region, on the other hand, is in the middle temperature range (shades of green) and exhibits temperate climate characteristics due to both the sea effect and high humidity.

In conclusion, the average temperature in Turkey for the year 2023 was 15.1°C, which is 1.2°C above the 1991-2020 average of 13.9°C. Since 2007, there have been positive temperature anomalies in Turkey's average temperatures, except for the year 2011. The average temperatures for 2023 have been above the long-term averages.

Detailed Analysis of Precipitation: Approximately 40% of the annual total precipitation in Turkey occurs in winter, 27% in spring, 10% in summer, and 23% in autumn, with regional variations. Changes in winter and spring precipitation significantly impact water quantities. The precipitation patterns during these seasons are crucial for the continuity of water resources. Long-term precipitation data across Turkey indicate significant decreases in winter precipitation. There are slight, non-significant increases in precipitation during spring and autumn, with regional differences. It is well-known that prolonged droughts over the past 20-30 years have greatly affected water resources in Turkey (Demir et al., 2008). Therefore, understanding and examining precipitation trends is vital when conducting studies related to climate change.

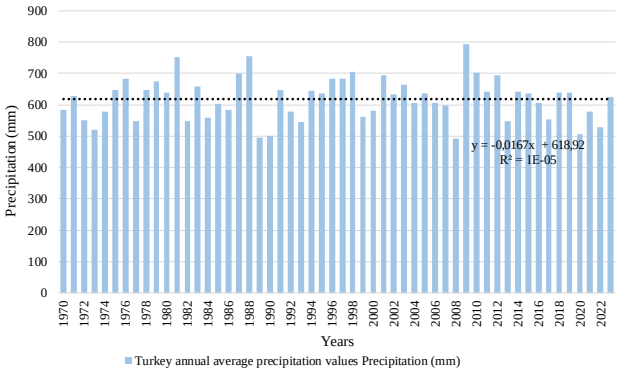

Figure 7. The annual average precipitation data from 224 major climate stations across Turkey changed between 1970-2023.

Figure 7 shows the distribution and trend of the annual total precipitation amounts obtained from 224 major climate stations across Turkey from 1970 to 2023. It is observed that precipitation amounts have fluctuated since 1970. Some years have seen significantly high precipitation (e.g., 1974, 1981, 1998, and 2010), while others have experienced notably low precipitation (e.g., 2001, 2007, and 2014).

The precipitation trend equation is given as $y = -0.0592x + 620.64$. This indicates that, on average, precipitation amounts decrease by 0.0592 mm each year, and this negative slope shows a decline in Turkey's long-

term precipitation trend. This trend could be particularly concerning for sectors such as water resource management and agriculture. Decreasing precipitation amounts may require additional measures in regions experiencing increased water stress. Furthermore, these data should be considered when developing climate change mitigation and adaptation strategies.

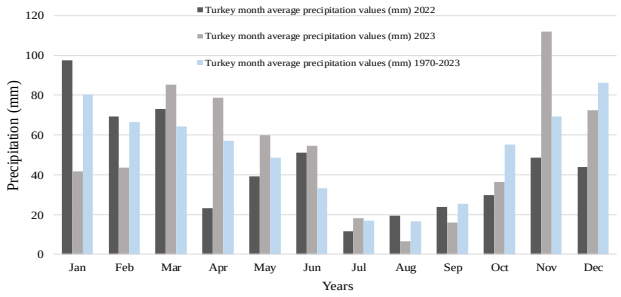

Figure 8. Compares Turkey's monthly avarage precipitation amounts for the year 2023 with those of 2022 and the long-term average from 1970 to 2023.

Figure 8 compares Turkey's monthly total precipitation amounts for 2023 with the long-term average between 2022 and 1970-2023. When the graph is examined, it is seen that 2023 received higher rainfall in March, April and May compared to 2022. However, it has become clear that the precipitation in 2023, especially in June and August, will be lower than both 2022 and the long-term average. It is noteworthy that the precipitation in September 2023 is significantly higher, well above the long-term average. These data are important to observe the effects of climate change on precipitation distribution. Additionally, it is among the variables that should be taken into account when planning in areas such as water resources management, agriculture and urban planning.

Figure 9. Turkey's average precipitation distribution between 1970-2023.

Figure 9 shows the annual total precipitation distribution according to geographical regions of Turkey between 1970-2023. The color scale expresses the total amount of precipitation in each region in mm, with increasing precipitation amounts from light green to dark green. It reflects the typically humid and rainy climate of the Black Sea. Central Anatolia and Southeastern Anatolia regions are shown in lighter shades of green. These regions are generally drier and annual rainfall is less. The Aegean and Mediterranean coasts also appear with dark green tones, indicating that these regions receive high rainfall. However, the amount of precipitation decreases as you move inland. Such data is of great importance for the development of water management strategies and the planning of rainfall-dependent agricultural activities, especially in the central and southeastern regions where water resources are scarce.

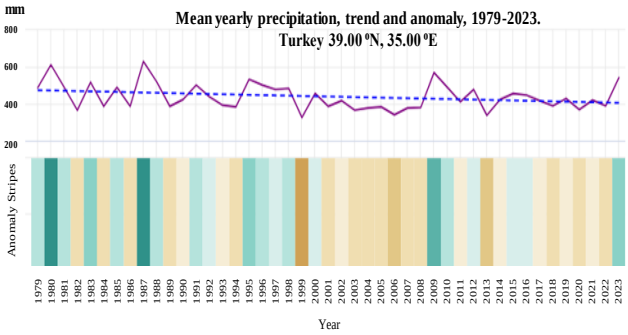

Figure 10. Mean yearly precipitation, trend and anomaly, 1979-2023.

Figure 10 shows Turkey's average annual precipitation, precipitation trend and anomalies from 1979 to 2023. When the graph is examined, it is seen that the annual average precipitation trend decreases over time. It can be said that this decrease in precipitation anomaly is the effects of climate change.

As a result, the areal average precipitation in 2023 was 641.5 mm, approximately 12% above the long-term average (1991-2020 period) of 573.4 mm.

Lake Boundary Changes Under Climate Change in Turkey: The effects of climate change on lake areas in Turkey over the years were analysed using satellite images. Within the area of the study, the boundary changes of Salda, Burdur, Beyşehir, Eğridir, İznik, Hazar, Gölbaşı, İnekli and Azaplı lakes in Turkey were analysed by comparing satellite images of 1988 and 2024. This analysis reveals the potential consequences of the decreases in lake water levels caused by climate change on ecosystem, agriculture and economic activities. On the map, the lake boundaries of 2024 are shown with blue lines, while the boundaries of 1988 are shown with red lines.

The boundaries of Salda, Iznik and Hazar Lakes, which were examined within the scope of this study, have changed over the years, revealing the significant changes observed in the lake surface areas. It was observed that there was no change in the boundaries of Iznik and Hazar Lake. In Salda lakes, the maps of 1988 and 2024 show the shrinkage in the boundaries of the lakes in detail. The fact that the boundaries of Salda Lake in 2024 are narrower compared to previous years shows that there is a decrease in water level due to climate change-related factors such as

increased evaporation rates and decreased precipitation. This indicates that the amount of water in the lake is decreasing over time and that this change is potentially due to climate change. At the same time, this also indicates a decline in the water resources of the Mediterranean region.

(a)

(b)

(c)

Figure 11.a.b.c. Satellite views of Salda, Hazar and İznik lakes in 1988 and 2024.

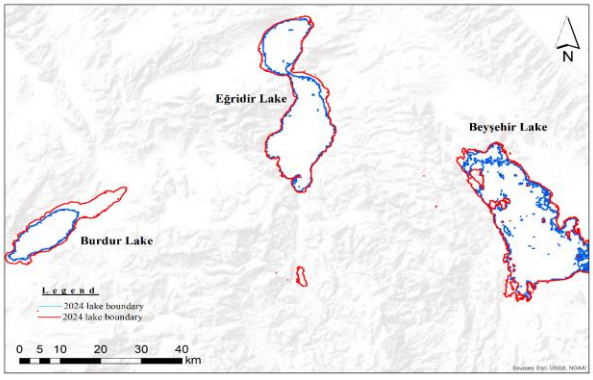

Figure 12. Satellite views of Burdur, Eğridir and Beyşehir lakes in 1988 and 2024.

Figure 12 shows how lake ecosystems have been affected by factors such as climate change, drought and the use of water resources when satellite images of Burdur, Eğridir and Beyşehir lakes from 1988 and 2024 are analyzed. Water losses or narrowing of shorelines, especially at the borders of Lake Burdur, may indicate that these lakes have experienced serious declines in water levels. Such changes can have significant consequences for local ecosystems, agriculture and economic activities based on water resources. Furthermore, these findings may contribute to identifying the necessary steps for sustainable management and conservation of water resources.

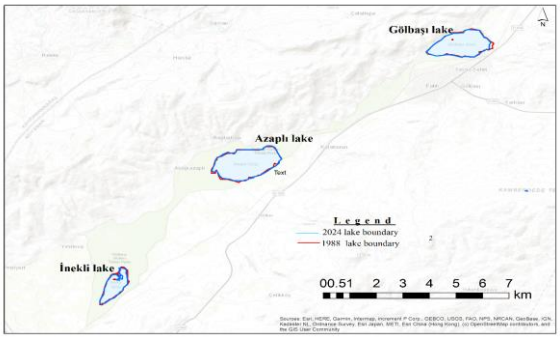

Figure 13. Satellite views of İnekli, Azaplı and Gölbaşı lakes in 1988 and 2024.

Figure 13 shows the boundaries of Gölbaşı, Azaplı and İnekli lakes in 1988 and 2024. Looking at the map, it can be observed that there is a shrinkage in the water areas around the lakes. This could be an indication of a drop in the water level or a shrinking lake area. These shrinkages around the lakes may indicate the decline of water resources and the impact of factors such as evaporation, reduced precipitation or human interventions on the lakes.

These observed changes have important implications for the ecological balance around the lakes and the management of water resources. Changes in lake boundaries can have direct impacts on water quality and regional climatic conditions. These impacts of climate change on natural water reservoirs are critical in determining the measures to be taken for the sustainable management and conservation of water resources.

In conclusion, these changes in the boundaries of lakes in Turkey provide a better understanding of long-term environmental trends and the impacts of climate change

CONCLUSION

As a result, this study has highlighted the significant impact of climate change on global water resources. Increasing global temperatures lead to changes in precipitation patterns, an increase in the frequency of droughts and floods, melting glaciers, and reduced snow

cover. These changes threaten the availability and quality of water essential for drinking, agriculture, industry, and ecosystems.

To better understand these effects, further research is needed in several key areas. Firstly, long-term monitoring of rainfall, soil moisture, river flow, and groundwater levels in various regions will provide more information for evolving hydrological models. Secondly, studies are needed on how climate change affects water quality through increased water temperatures, sedimentation, and pollutant concentrations. Thirdly, assessments are critical on how water management systems and policies can be adapted to enhance resilience against the impacts of climate change. Models integrating climate, hydrological, ecological, and socioeconomic factors will be beneficial for water resources planning and management.

Examining the effects of climate change on Turkey in this study, recent meteorological data shows increasing temperatures and decreasing rainfall. This reflects the impacts of global warming, and recent studies also indicate Turkey experiencing drought conditions. Groundwater use in Turkey will reduce the capacity of water resources to regenerate, increasing pressure on basins. Additionally, increasing per capita water consumption will exacerbate pressures on basins. Efforts should focus on the effective and efficient use of water resources to alleviate these pressures.

In this study, the changes in lake areas in Turkey over the years were examined and the effects of climate change on these natural water reservoirs were revealed. Water losses observed especially in important lakes such as Salda, Burdur and Beyşehir lakes are associated with climate change, increased evaporation rates and decreased rainfall. These changes emphasize the need to take urgent measures for the sustainable management of water resources. Understanding the long-term impacts of climate change on lakes is critical for future water management strategies.

The findings of this study emphasize the urgency and importance of taking action to mitigate these changes and adapt to them. It is evident that a comprehensive approach involving not only governments and policymakers but also individuals, communities, and organizations at all levels is necessary.

On a broader scale, aggressive reduction policies for greenhouse gas emissions and limiting global temperature rise are crucial. Conserving water, improving irrigation techniques, harvesting rainwater, recharging aquifers, water reuse and recycling, and public education can help reduce sensitivity to the impacts of climate change on water. Addressing climate change and its effects on water resources will require determined and coordinated efforts from governments, industries, agriculture, communities, and individuals at all levels. Through informed and timely action, we can work to preserve this most valuable resource.

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