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Proceeding Book of 5th International Conference on Engineering and Applied Natural Sciences ICEANS 2024

August 25-26, 2024: Konya, Turkey

PROCEEDING BOOK OF 5TH INTERNATIONAL CONFERENCE ON ENGINEERING AND APPLIED NATURAL SCIENCES ICEANS 2024

PROCEEDING BOOK OF 5TH ICEANS 2024:

25-26 August 2024

Konya, Turkey

Publication date: 03.09.2024

Publisher: All Sciences Academy

All Sciences Academy
https://www.allsciencesacademy.com/
Proceeding Book of 5th International Conference on Engineering and Applied Natural Sciences ICEANS 2024: edited by All Sciences Academy.

ISBN: 978-625-6314-30-6

5th International Conference on Engineering and Applied Natural Sciences

August 25-26, 2024 : Konya, Turkey

https://www.iceans.org/

Using Geographic Information Systems to Analyze the Sustainability of Wetlands under Climate Change in Nurdağı, Gaziantep (Türkiye)

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Abstract – This research examined the impact of climate change and land use changes (LUC) on wetland areas in the Nurdağı district of Gaziantep, utilizing Geographic Information Systems (GIS). Over the period from 1990 to 2018, significant shifts in climate patterns, including rising temperatures and varying precipitation, have led to considerable changes in wetland ecosystems and land use. The study aimed to analyze historical trends and forecast future developments in wetlands and land use due to these climatic shifts and human activities, using GIS analyses with both historical and contemporary climate data, alongside satellite imagery. Noteworthy findings include a significant negative correlation between agriculture and temperature ($p<0.05$) and a positive correlation between wetlands and precipitation ($p<0.05$). Additionally, significant correlations were observed between agriculture and urban areas ($p<0.05$) and between wetlands and swamp areas ($p<0.01$), highlighting the intricate interactions between land use changes and climate factors. The Wetland Sustainability Index (WSI) calculations indicated that rising temperatures, fluctuating precipitation, and increased human activities have had a profound impact on wetland areas. Specifically, the decline in wetland water levels due to rising temperatures and urban growth has further compromised the ecosystem services provided by these wetlands. The study concluded that climate change exerts both direct and indirect effects on the wetlands of Nurdağı, negatively influencing biodiversity and ecological functions. This research provides valuable insights for policymakers and conservationists, stressing the urgent need for effective wetland management strategies at both regional and national levels.

Keywords – Climate Change Index, Geographic Information Systems, Land Use, Wetlands, Wetland Sustainability Index

I. INTRODUCTION

Climate change stands as one of the most urgent environmental challenges we face, profoundly affecting ecosystems across the globe [1]. Wetlands, which are some of the most productive and diverse ecosystems, are especially susceptible to the impacts of climate change [2]. Increasing global temperatures, shifting precipitation patterns, and a higher frequency of extreme weather events have a profound impact on the hydrology, biodiversity, and functioning of wetlands [3,4]. These changes jeopardize the ecological balance and the wide array of ecosystem services that wetlands offer, such as water purification, flood control, carbon sequestration, and providing habitat for numerous species. [5]. Wetlands act as natural water filters, removing pollutants and enhancing water quality [6]. They also function as buffers against flooding and storm surges, providing protection for coastal and inland areas [7]. Moreover, wetlands are vital for carbon sequestration, aiding in climate change mitigation by storing substantial amounts of carbon in their vegetation and soil. They also provide essential habitat for various species, support biodiversity, and serve as breeding grounds for fish, birds, and other wildlife [7–10]. The loss or degradation of wetlands can result in reduced ecosystem services and heightened susceptibility to environmental changes [11]. Worldwide, natural resources are being depleted at a troubling pace, making it essential to adopt advanced conservation and monitoring strategies [12]. Remote sensing technologies have become essential tools for the conservation and monitoring of wetlands [13]. Rising carbon emissions are associated with increasing temperatures, which intensify the threat to these ecosystems [14,15]. Climate change has also caused ocean acidification, adding further stress to marine and coastal environments [16,17]. As a result, there is an increasing demand for sustainable development solutions to address these impacts, such as innovative urban planning strategies and alternative energy sources [18,19]. As global resources continue to deplete, sustainability has become increasingly important, prompting space research to seek out new resources [20].

Nurdağı, with its distinctive geographical and climatic features, is a vital area for wetland research, especially as it lies along the migratory path of numerous bird species. These wetlands are crucial for maintaining local biodiversity and providing essential ecosystem services. However, they face increasing threats from climate change and human activities. On February 6, 2023, the region experienced two severe earthquakes: one with a magnitude of 7.7 Mw in Pazarcık, Kahramanmaraş at 01:17 (UTC), and another with a magnitude of 7.6 Mw in Elbistan, Kahramanmaraş at 10:24 (UTC) (Arslan et al., 2024). These earthquakes resulted in significant environmental damage and alterations in land cover (Dinçer et al., 2024). Understanding these effects is crucial, as future research can compare conditions before and after the earthquakes to provide insights into the resilience and recovery of wetland ecosystems. This study aims to analyze historical changes in wetland areas, forecast future impacts of climate change, and assess the effects of land use changes. It includes examining past changes through historical data and GIS analyses, predicting future scenarios using climate models, and evaluating the impacts of urban expansion and agricultural activities. In light of recent seismic events, this research is essential for understanding how such natural disasters affect wetland dynamics and for informing future conservation and management strategies.

II. MATERIALS AND METHOD

This research was conducted in the Nurdağı district, located in the southeastern part of Gaziantep, Türkiye. Nurdağı is distinguished by its unique climatic and geographical characteristics, making it a vital region for studying wetland ecosystems in Gaziantep (see Fig. 1). The location of wetlands in Nurdağı is detailed in Table 1. On February 6, 2023, at 01:17 (UTC), the area experienced two major and highly destructive earthquakes: one with a magnitude of 7.7 Mw in Pazarcık, Kahramanmaraş, Türkiye, and another with a magnitude of 7.6 Mw in Elbistan, Kahramanmaraş, Türkiye, at 10:24 (UTC) [21]. These earthquakes had considerable environmental impacts [22]. Due to the limitation of Corine Land Cover (CLC) data, which is only available up to 2018, current observations cannot be made. The coordinates of the stations were recorded with a Garmin eTrex Vista® HCx GPS device.

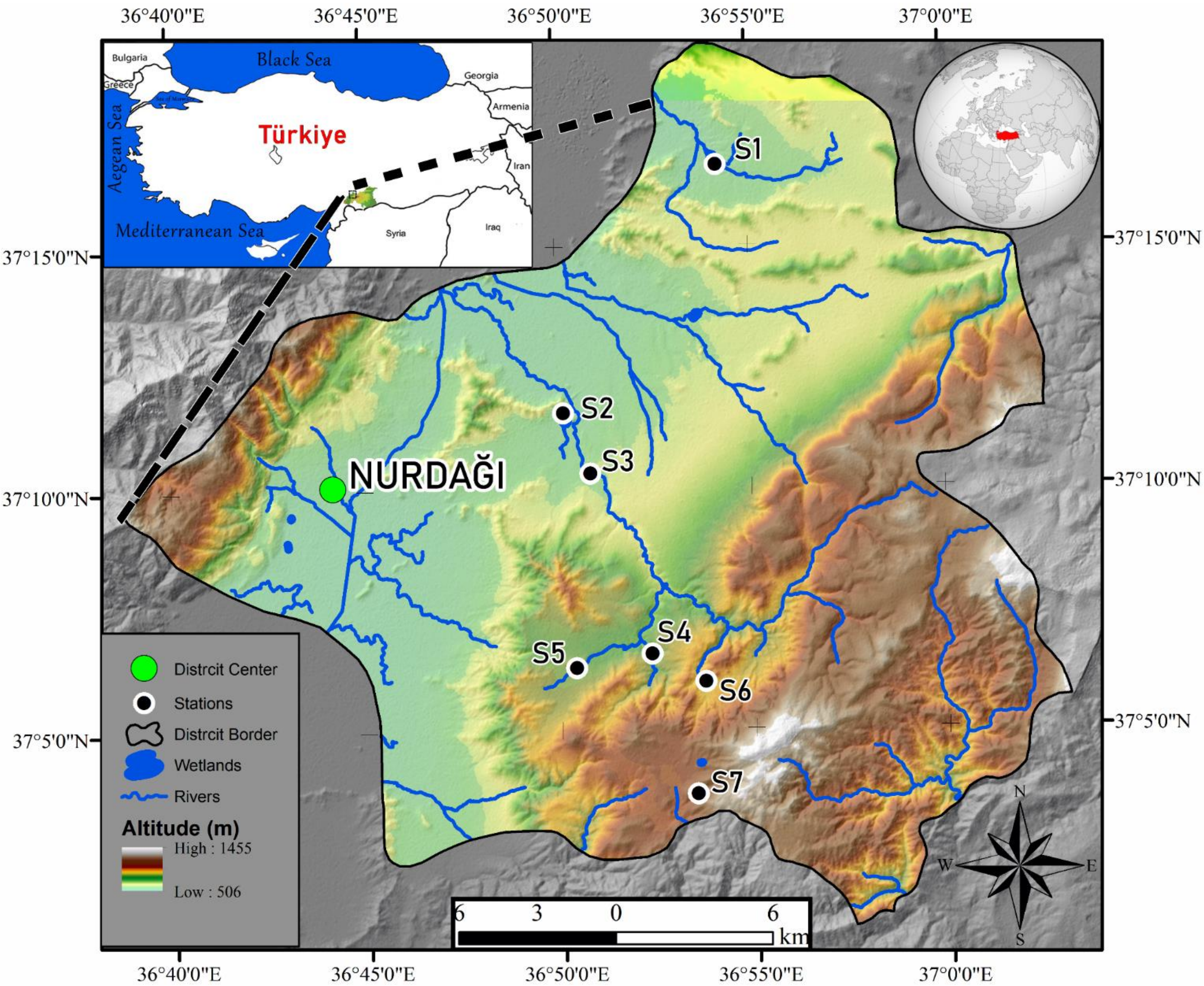

Fig. 1. Map of Nurdağı displaying the location of critical wetlands. S1- Balıkalan Pond, S2- Çakmak Pond, S3- İçerisu River, S4- Karanlık River, S5- Hamidiye Pond, S6- Yemişerli River, S7- Kuzoluk Pond

Historical climate data, covering temperature and precipitation records from 1990 to 2022, were collected to analyze long-term climate trends and their potential effects on the wetlands. The primary source of climate data was the NASA Power data archive. [23]. Missing and inconsistent data were supplemented and verified using Climate Data and Tutiempo datasets [24,25]. Population data were obtained from the Turkish Statistical Institute [26]. Existing datasets from the Corine Land Cover (CLC) were used for this purpose. [27]. Land use data for categories such as Agriculture, Forest, Swamp, Wetlands, and Urban were collected for the years 1990, 2000, 2006, 2012, and 2018. To ensure consistency, land classifications were conducted under broad categories rather than detailed sub-headings. Data for newly constructed artificial ponds and reservoirs were excluded due to their recent establishment. Satellite imagery and GIS data were employed to map and analyze the spatial distribution of wetlands and other land use categories in Nurdağı, offering a visual representation of changes in wetland areas over time. The mapping and analysis were performed using ESRI ArcMap 10.7 software.

The Spearman rank-correlation test was used to identify significant correlations among the studied environmental variables. This analysis clarifies both the direct and indirect effects of climate change on wetlands. Statistical analyses and visualizations were conducted using R and Python [28,29]. Principal Component Analysis (PCA) was performed to identify key factors influencing changes in wetland areas, reducing data dimensionality and highlighting significant variables [30]. Data were transformed using the ln(x+1) function to address skewness. Z-score standardization was applied to all indices to normalize the data and ensure comparability. This method, commonly used in scientific research, standardizes variables across different scales, facilitating meaningful comparisons [31].

The Wetland Sustainability Index (WSI) was calculated to assess the health and sustainability of the wetlands. The formula used for WSI is:

$$\text{WSI} = (W_{wetland} \times Wetland) + \left(W_{temperature} \times (1 - Temperature)\right)$$

$$+(W_{precipitation} \times Precipitation)$$

$W_{wetland}$, $W_{temperature}$, and $W_{precipitation}$ are the weights assigned to the wetland area, temperature, and precipitation, respectively. $Wetland$ represents the wetland area for a given year. Temperature represents the temperature for a given year. Precipitation represents the precipitation for a given year. $(1 - Temperature)$ indicates the inverse effect of temperature, suggesting that an increase in temperature negatively impacts wetland sustainability. The WSI formula combines the impacts of wetland area, temperature, and precipitation to provide a comprehensive assessment of wetland sustainability. This index is crucial because it encompasses the complex effects of climate change and human activities on wetland ecosystems. By including temperature and precipitation, the WSI illustrates how these climatic factors affect wetland health. The weights $W_{wetland}$,$W_{temperature}$, and $W_{precipitation}$ are crucial as they allow for the adjustment of the relative importance of each factor based on their impact on wetland sustainability. This index helps understand the current state of wetlands and aids in making informed decisions for their conservation and sustainable management [33].

III. Results

In 1990, the average temperature in Nurdağı was 15.7°C, with a total annual precipitation of 226.76 mm. By the year 2000, the temperature slightly decreased to 15.33°C, while precipitation significantly increased to 543.16 mm.

In 2006, the temperature rose to 17.36°C, with a corresponding decrease in precipitation to 469.34 mm. In 2012, the temperature was recorded at 16.37°C, accompanied by a further increase in precipitation to 743.55 mm.

Finally, in 2018, the temperature peaked at 17.45°C, with a slight decrease in precipitation to 685.55 mm (Table 1).

Table 1. 1990-2018 Nurdağı climate data

Year	Temperature (°C)	Precipitation (mm)
1990	15,7	226,76
2000	15,33	543,16
2006	17,36	469,34
2012	16,37	743,55
2018	17,45	685,55

The Corine Land Cover (CLC) data for Nurdağı (Fig.2) reveals significant variations in land use categories from 1990 to 2018. Table 2 presents the CLC data for Nurdağı across five different land use categories. Over the past two decades, there have been noticeable shifts, particularly in agriculture, forest, and wetland areas. In Nurdağı, agricultural areas have experienced a decline, decreasing from 54.43% in 1990 to 46.70% in 2018, reflecting a reduction in cultivated lands. Conversely, forest areas have shown consistent growth, increasing from 44.27% in 1990 to 50.09% in 2018, indicating a long-term expansion of forested regions. Wetland areas, although constituting a small percentage of the land, have fluctuated slightly, with the most significant increase observed in recent years, from 1.26% in 1990 to 3.17% in

2018. This suggests that some wetlands have been restored or expanded during this period. Swamp areas remained relatively stable, showing minimal change over the years, holding steady at around 0.04% throughout the period. These data points illustrate the dynamic nature of land use in Nurdağı, where agricultural lands are decreasing while forest and wetland areas are gradually increasing, possibly due to natural reforestation or conservation efforts.

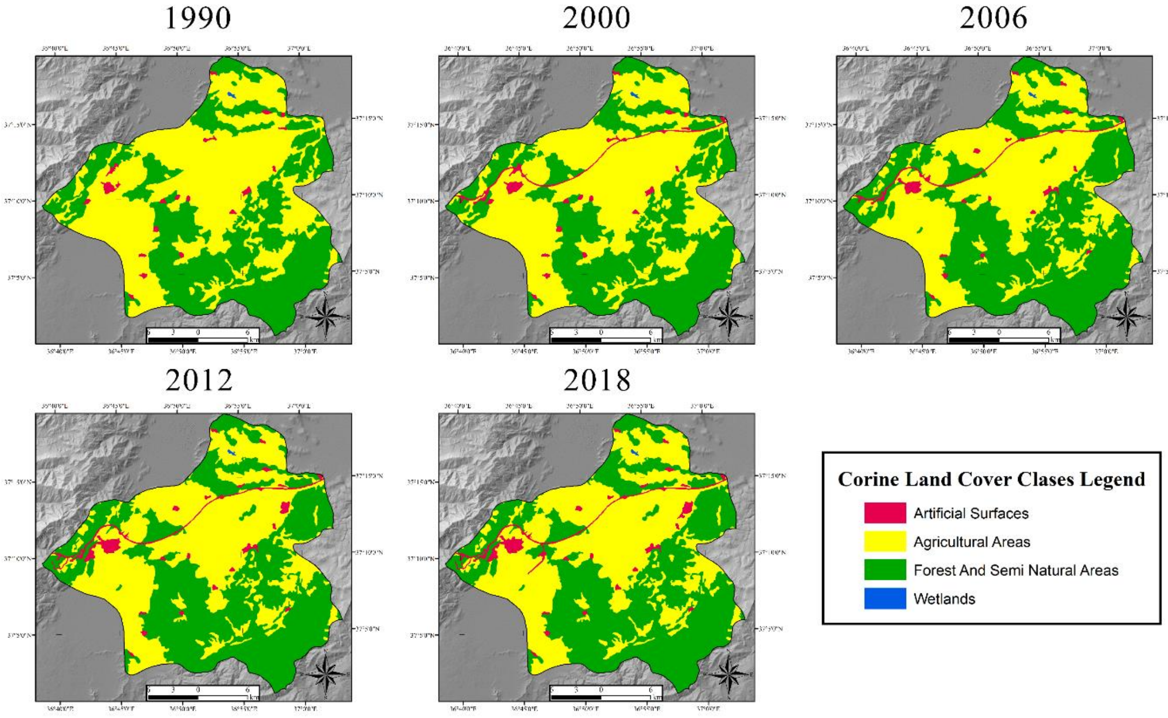

Fig2**.** Corine Land Cover (CLC) Map of Nurdağı (1990-2018)

Table 2. Corine land cover changes of Nurdağı

Region	Code	Year (%)				
		1990	2000	2006	2012	2018
Nurdağı	1	1.26	2.39	2.25	2.93	3.17
	2	54.43	53.72	47.45	46.83	46.70
	3	44.27	43.84	50.26	50.20	50.09
	4	0.05	0.05	0.04	0.04	0.04

1: Urban Areas, 2: Agricultural Areas, 3: Forest, 4:Wetlands

The Spearman rank correlation test for Nurdağı indicates several significant relationships between climate variables and land use categories (Table 3). A significant negative correlation was found between agricultural areas and temperature (r = -0.88, p<0.05), suggesting that higher temperatures are associated with reduced agricultural land. Additionally, a strong negative correlation exists between agricultural and urban areas (r = -0.96, p<0.05), indicating that urban expansion is likely occurring at the expense of agricultural land. Urban areas demonstrated significant positive correlations with both temperature (r = 0.82, p<0.05) and precipitation (r = 0.80, p<0.05), highlighting the close relationship between urban growth and these climate factors. Forest areas showed significant positive correlations with temperature (r = 0.88, p<0.05) and urban areas (r = 0.95, p<0.01), while also exhibiting a very strong inverse relationship with agricultural areas (r = -1.00, p<0.001). This suggests that as forests expand, agricultural lands diminish, possibly due to land-use changes or reforestation efforts. Swamp areas displayed a significant negative correlation with precipitation (r = -0.96, p<0.05), indicating that increased precipitation levels are associated with a reduction in swamp areas. Wetland areas were significantly negatively correlated with swamp areas (r = -0.97, p<0.01), implying that these two land types may be competing for space or resources. Additionally, wetlands showed a significant positive correlation with precipitation (r = 0.89, p<0.05), suggesting that higher precipitation levels contribute to the expansion or preservation of wetland areas.

Table 3. Spearman rank correlation calculated among environmental variables for Nurdağı

Variable	Temperature	Precipitation	Urban	Agriculture	Forest	Swamp	Wetland
Temperature							
Precipitation	0.38						
Urban	0.82	0.80					
Agriculture	-0.88*	-0.68	-0.96*				
Forest	0.88*	0.66	0.95*	-1.00***			
Swamp	-0.12	-0.96*	-0.64	0.49	-0.48		
Wetland	-0.08	0.89*	0.47	-0.30	0.29	-0.97**	

*: p < 0.05, **: p < 0.01, and ***: p<0.001

The Wetland Sustainability Index (WSI) values indicated significant fluctuations in the sustainability of wetlands in Nurdağı over the studied period (Figure 3). There was a notable increase in WSI from 1990 to 2012, followed by a slight decrease in 2018, reflecting the complex interplay between climatic factors (temperature and precipitation) and wetland areas. The highest WSI value in 2012 (218.47) suggested that increased precipitation and larger wetland areas positively contributed to wetland sustainability despite higher temperatures. Conversely, the lower WSI in 1990 (63.64) and a decrease in 2018 (200.75) highlighted periods where the combined effects of temperature, precipitation, and wetland area were less favorable for wetland health.

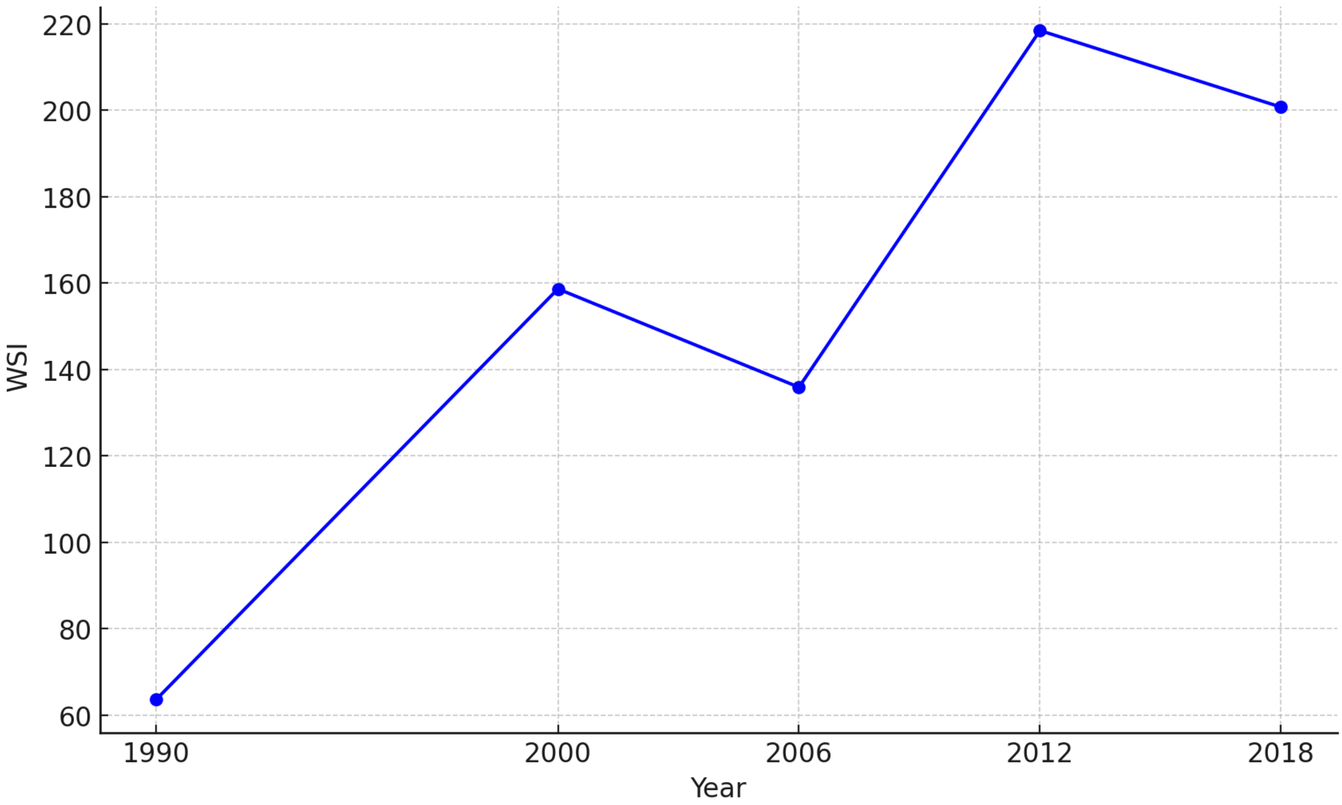

Fig.3. The Wetland Sustainability Index (WSI) trend in Nurdağı

IV. DISCUSSION

This study provides a comprehensive analysis of the sustainability of wetlands in Nurdağı, Gaziantep, through the lens of climate change and land use changes (LUC) over the period from 1990 to 2018. By integrating Corine Land Cover (CLC) data, the Wetland Sustainability Index (WSI), and the correlations between climate variables and land use categories, several critical insights emerge. The CLC data reveals significant shifts in land use, with forest areas expanding notably at the expense of agricultural lands. Forest cover increased from 44.27% in 1990 to 50.09% in 2018, while agricultural areas declined from 54.43% to 46.70%. This shift suggests possible reforestation efforts or natural regrowth in areas previously used for agriculture, potentially influenced by changing land management practices or policies favoring forest conservation. However, wetland areas showed minimal fluctuation, indicating relative stability despite broader changes in the landscape. The Wetland Sustainability Index (WSI) values highlight fluctuations in wetland health, with a marked increase in WSI from 1990 (63.64) to 2012 (218.47), followed by a slight decline in 2018 (200.75). The peak in 2012 suggests that increased precipitation (743.55 mm) during this period played a crucial role in enhancing wetland sustainability, despite higher temperatures.

The decline in 2018 reflects the complex interplay between rising temperatures (17.45°C) and reduced precipitation (685.55 mm), which together began to exert a more significant negative impact on wetland health. The correlation analysis further elucidates these dynamics. A significant negative correlation between agricultural areas and temperature ($r = -0.88$, $p<0.05$) indicates that higher temperatures are associated with reduced agricultural land, likely due to the expansion of urban areas, which showed strong positive correlations with both temperature ($r = 0.82$, $p<0.05$) and precipitation ($r = 0.80$, $p<0.05$). This urban expansion is a concerning trend as it suggests increased pressure on wetlands through land conversion and habitat fragmentation. Conversely, forest areas benefited from the warmer climate, as indicated by their significant positive correlations with temperature ($r = 0.88$, $p<0.05$) and urban areas ($r = 0.95$, $p<0.01$), though this expansion came at the expense of agricultural lands. The relationship between climate variables and swamp and wetland areas is particularly complex. Swamp areas showed a significant negative correlation with precipitation ($r = -0.96$, $p<0.05$), suggesting that higher precipitation may convert swamps into other wetland types. Meanwhile, wetlands showed a positive correlation with precipitation ($r = 0.89$, $p<0.05$), underscoring the critical role of rainfall in sustaining these ecosystems. The negative correlation between wetlands and swamp areas ($r = -0.97$, $p<0.01$) indicates competition or a shift in wetland types under varying climatic conditions. In conclusion, this study underscores the intricate interplay between climate change, land use dynamics, and wetland sustainability in Nurdağı. While the expansion of forest areas and the relative stability of wetlands are positive signs, the ongoing challenges posed by increasing temperatures, urbanization, and fluctuating precipitation levels require attention. The findings emphasize the need for integrated land use planning and climate adaptation strategies to ensure the long-term sustainability of Nurdağı's wetlands, safeguarding their ecological functions and biodiversity for future generations.

V. CONCLUSION

This study explored the complex interactions between climate change, land use dynamics, and wetland sustainability in the Nurdağı district of Gaziantep, Türkiye, from 1990 to 2018. Using Geographic Information Systems (GIS) alongside Corine Land Cover (CLC) data, Wetland Sustainability Index (WSI) calculations, and correlation analysis, the research provided critical insights into the factors influencing wetland health in the region. Key findings revealed significant land use changes, particularly the expansion of forested areas and the decline of agricultural lands. Despite these shifts, wetland areas remained relatively stable, although the Wetland Sustainability Index indicated fluctuations in wetland health over the studied period. The highest WSI recorded in 2012 underscored the positive impact of increased precipitation on wetland sustainability, even as temperatures continued to rise. However, the slight decline in WSI by 2018 highlighted the growing challenges posed by the combination of higher temperatures and urban expansion, which threaten the long-term sustainability of wetlands. The correlation analysis provided further evidence of the intricate relationships between climate variables and land use categories. The significant negative correlation between agricultural areas and temperature, alongside the positive correlations between urban areas and both temperature and precipitation, emphasized the ongoing pressure on agricultural lands and wetlands due to urbanization. Meanwhile, the expansion of forest areas, although beneficial from a conservation perspective, underscored the competitive nature of land use changes in the region. Overall, this study concludes that climate change and land use dynamics are having profound effects on the wetlands of Nurdağı. The findings stress the importance of adopting integrated land management and climate adaptation strategies to mitigate these impacts and ensure the preservation of wetland ecosystems. Policymakers and conservationists must prioritize the development of sustainable land use practices and effective wetland management plans that consider both current and future climatic conditions. These efforts are essential to protect the ecological functions and biodiversity of wetlands in Nurdağı, ensuring their resilience in the face of ongoing environmental changes.

ACKNOWLEDGMENT

This study was supported by TUBITAK (The Scientific and Technical Research Council of Turkey) under the 2209-A—Research Project Support Programme for Undergraduate Students, project No: 1919B012331232.

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