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Research Article

Determining the vulnerability of urban open and green spaces to climate change: The case of Düzce province

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ABSTRACT

Climate change is causing global environmental and social problems through its effects on the Earth's climate system, and cities are intensely feeling these impacts. This study aims to examine the sensitivity and vulnerability of open and green spaces in the city of Düzce to the effects of climate change, and to present strategies to mitigate this damage. Located in an area exposed to the effects of climate change, Düzce presents an important example in terms of the management and protection of open and green spaces. With its location exposed to the effects of climate change, Düzce presents an interesting example in terms of management and protection of open and green spaces. The scope of the study consists of methods such as field research, data analysis, and literature review to determine Düzce's climate characteristics and climate change effects. The open and green spaces of Düzce are vulnerable to the effects of climate change. Climate change impacts such as extreme heat waves, heavy rainfall, flood risks, and drought in the city reveal that these areas are highly fragile. These effects can lead to significant problems in the areas in question. Therefore, local governments, planners, non-governmental organizations (NGOs), the private sector, academic institutions, research centers, and local communities should work in collaboration to increase the region's resilience against climate change. In conclusion, determining management strategies suitable for Düzce's unique climate conditions can provide a roadmap for solving problems both for the city itself and for similar geographies.

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INTRODUCTION

Today, global climate change is disrupting environmental balances, and cities are feeling these effects intensely [1]. Protecting cities from the adverse effects of climate change and increasing their resilience is closely related not only to strengthening buildings and infrastructure but also to the planning and management of open and green spaces. As an indispensable element of urban life, the importance and necessity of open and green spaces is an undeniable fact. More investment is needed to protect these areas, and they are becoming increasingly attractive for stakeholders. Consequently, open and green spaces in cities are gaining much more value [2]. In this context, how open and green spaces in cities can be affected by and protected from climate change constitutes an important research topic [3]. Climate change manifests itself through events such as rising temperatures, extreme rainfall, drought, and floods, and these factors also affect open and green spaces. According to the 2022 data from the United Nations Population Fund, the world population has reached 8 billion. Urbanization rates are rapidly increasing, and for the first time in history, the rural population is falling behind the urban population. For example, it was determined that 55.3% of the world's population lived in

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cities in 2018. According to UN projections, the world population is expected to reach 9.7 billion by 2050, with 70% of this population living in cities. Cities account for 75% of global carbon emissions. Their contributions to greenhouse gas emissions vary depending on the city's level of development, economic structure, and population density. On a global scale, the 100 cities with the highest carbon footprint produce 20% of total carbon emissions. In this ranking, İstanbul is 26th, while Ankara is 80th. Urban green areas such as woodlands, parks, recreational areas, and agricultural lands play a critical role in both improving the quality of life for city residents and preserving environmental balance. However, these areas can be quite sensitive to the effects of climate change. Climate change is emerging as a serious global threat today [4]. Cities are among the regions that intensely feel the effects of climate change. In this context, open and green spaces in cities are seen as an important defense mechanism against the effects of climate change [5]. However, the vulnerability of these areas to climate change and strategies to reduce this damage often require more research and practical work. Research shows that the likelihood of natural hazard types in cities occurring along with climate change will increase, including hydrological (flood, flash flood, extreme wind/coastal flood; mass movement, rock fall, landslide, subsidence), meteorological (such as hurricanes), and climatic (extreme temperatures, drought, fire) hazards [6]. These studies reveal that climate change tends to increase the frequency and severity of natural hazard types in cities. Cities need to take multiple measures to cope with the increasing natural hazards due to climate change. These measures may include a range of strategies such as risk assessment, infrastructure strengthening, early warning systems, green infrastructure, community education, and environmental sustainability. Encompass strategies that include sustainable urban planning, green infrastructure applications, and the protection and expansion of green spaces. These strategies can be implemented through concrete measures such as the widespread adoption of green roof systems [7], conducting ecological restoration works to preserve and enhance the biodiversity of existing green spaces [8] and promoting urban agriculture areas [9]. In this way, cities can be better prepared for future climate change-related hazards. The vulnerability of cities to climate change depends on many factors. These factors include the city's geographical location, infrastructure quality, population density, economic situation, and management capacity. It is critical for cities to make appropriate preparations, strengthen their infrastructure, and adopt climate change mitigation strategies to cope with natural events of increasing frequency and severity. In this process, cooperation between local governments, communities, and businesses is necessary. By taking these measures, cities can become more resilient to the effects of climate change. In this context, adaptation strategies should be developed to cope with the natural effects of climate change, infrastructures should be strengthened, green infrastructure projects should be encouraged, community education should be provided, and emergency preparations should be made. Additionally, effective policies and programs should be implemented to mitigate the social and economic impacts of climate change and protect vulnerable groups.

"Vulnerability" is a term that expresses how sensitive or defenseless an organization or system is to damage caused by a potential hazard or event. This concept is used in a range of areas such as risk management, emergency preparedness, and sustainability strategies [10]. Vulnerability is a multifaceted concept. As different vulnerability situations arise under different conditions, there is no general methodology or common definition for this concept [11]. Vulnerability concepts are interrelated, and this relationship can be illustrated with nested spheres. At the innermost part is human-centered/human-prioritizing vulnerability. In the sphere surrounding this, there are multiple structure vulnerability attributes with a dual approach, such as damage probability experience, exposure, and coping capacity. In the outermost part, there are multidimensional vulnerability attributes including physical, social, economic, environmental and institutional characteristics. In this spherical structure, as one moves from the inside out, the scope of vulnerability expands. As the scope grows, different dimensions emerge; with the addition of attributes such as coping capacity and exposure, the impact area of vulnerability also expands. Figure 1. shows the impact dimension of vulnerability.

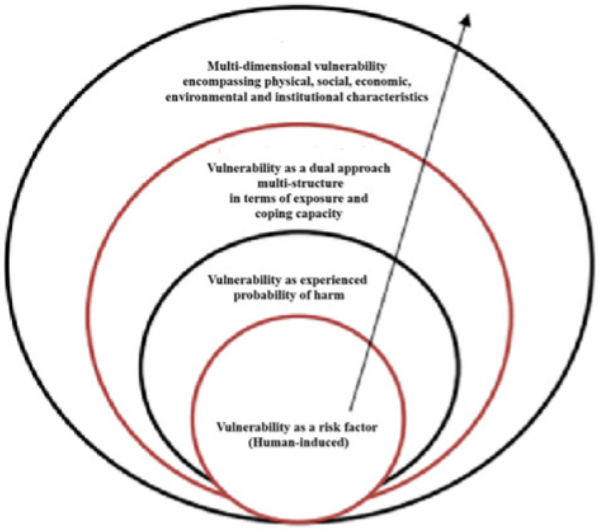

Figure 1. Impact dimension of vulnerability [10]

Towards the end of the 1990s and in the early 2000s, researchers and scientists showed great interest in the vulnerability of humans to environmental changes, particularly climate change. During this period, climate change was increasingly recognized as a global issue, and its potential impacts on people, societies, and ecosystems began to be investigated more intensively [12]. When considering the vulnerability to climate change in the context of cities, a two-way interaction emerges: While activities in cities contribute to climate change, cities are also sensitive to this change and are adversely affected [13]. Events classified as natural hazards can increase the vulnerability of cities. The consequences of climate change, such as temperature increase, sea level rise, changes in precipitation patterns, and extreme weather events, have significant impacts on both the physical and

socio-economic structures of cities [14]. With the spread of the global pandemic in 2020, the effects of climate change continue to be observed in various areas alongside the pandemic [15]. When evaluating articles published on prominent sub-topics in the context of climate change impacts, national-scale studies conducted in Turkey have identified the nature and effects of global climate change [16]. Climate change has been addressed as a social policy and social research subject [17]. Additionally, research has been conducted on the roles of coal, wind, and solar energy in mitigating the effects of climate change [18]. Among local-scale studies, the effects of climate change on precipitation-temperature and drought have been examined in the Akarçay sample [19], its impact on surface water resources, soil moisture, and plant productivity in the Thrace Region sample [20] and the general effects of climate change in the Mediterranean Basin sample [21]. Other prominent studies examine the effects of climate change in various water sub-areas based on scenarios. Examples include estimating irrigation water needs in the Gediz Basin [22], examining the Bartın Stream Basin based on remote sensing and Geographic Information Systems [23] and a study presenting the Southern Aegean Coastline change scenario [24]. Other studies examined in this context focus on the specific effects of climate change and its reflection, drought, on water ecology [25, 26], analysis of drought through the Eğirdir Lake Basin [26] and the effects of drought on the hydrological design of water structures [27]. The 6th and latest Assessment Report of the Intergovernmental Panel on Climate Change states that climate change is clearly visible and rapidly progressing, increasing day by day [28]. The report indicates that human-induced climate change is causing unusual weather events and unexpected climatic changes in many regions of the Earth. Nevertheless, the report emphasizes that there is still time to mitigate the negative effects of climate change. It is also stated that the continuous reduction in emissions of greenhouse gases will rapidly improve air quality and make positive contributions to temperature stabilization over a period of 20-30 years [28].

The significance of this study lies in presenting vital solution proposals for sustainable urban planning by revealing the vulnerability of open and green spaces to climate change, specifically in the city of Düzce. Düzce serves as an important example in climate resilience studies as one of the regions in Turkey most affected by climate change. Urban green spaces are gaining increasing importance in developing resistance against climate change; these areas both preserve environmental balance and provide protection against climate impacts. For instance, while green infrastructure projects in New York aim to reduce the effects of heat waves, parks and green roofs in Singapore maintain the temperature and humidity balance in the city. In Turkey, İstanbul's "Green İstanbul" projects also aim to reduce the risk of increasing temperatures and flooding [29].

The protection of urban green spaces in cities with high climate vulnerability, such as Düzce, plays a critical role in increasing resilience against climate change. All cities worldwide are vulnerable to climate change, which leads to an increase in heat waves due to the urban heat island effect. This creates serious risks that threaten the health and quality of life in cities. Moreover, extreme weather events, rising sea levels, and irregular precipitation lead to a decrease in water resources and food crises [30]. The increase in the number of hot and cold days is one of the biggest risks cities face. This situation affects sectors such as tourism, construction, and transportation. Especially the increase in heat waves poses a risk to urban quality of life and health [31]. In this context, the protection of urban green spaces is vital for creating cities that are more resilient to climate change. Considering Düzce's climate characteristics, developing strategies for the protection of these areas sets an important example for other cities as well.

Düzce, with its unique geographical location, climate structure, and urban fabric, provides an example that allows us to observe the effects of climate change more clearly. This study aims to determine the vulnerability of open and green spaces in cities to climate change, specifically in the case of Düzce city, and to offer suggestions for reducing this damage. Examining the characteristics of Düzce is of great importance in terms of understanding how open and green spaces can be affected by climate change. In this context, examining the potential impact of climate change on Düzce's open and green spaces will reveal the causes of the effects and enable the proposal of possible solutions for sustainable urban planning. The findings obtained from the Düzce example may contribute to the development of strategies to increase the resilience of cities against climate change.

Climate change is recognized as one of the greatest global threats of our time, and its multifaceted impacts on urban living spaces are becoming increasingly evident. In this context, examining the sensitivity and resilience of open and green spaces to climate change through the specific example of a city like Düzce is an extremely important and timely research topic. This study is of great importance not only from an academic perspective but also in terms of practical applications. The research can play a critical role in shaping the policies and strategies of local governments regarding measures to be taken against climate change. Furthermore, it can serve as a guide in urban planning and design processes for adaptation to climate change and developing resilience.

MATERIALS AND METHOD

Study Area and Main Characteristics

The study area, Düzce province, is located in the western part of the Black Sea Region. The Düzce Plain, with an area of 360 km², is situated at the center of the Düzce basin. The province is bordered by the Bolu Mountains to the east, Sakarya to the west, the Orhan Mountains and the Black Sea to the north, and the Abant Mountains to the South. According to TURKSTAT data from February 4, 2021, Düzce has 8 districts including the Central district, 10 municipalities, 115 neighborhoods affiliated with these municipalities, and 278 villages.

In this study, various data from different sources were collected to examine the effects of climate change in Düzce. Precipitation and humidity data were obtained from the website of the Turkish State Meteorological Service, while drought data were acquired from the Ministry of Agriculture and Forestry. Wind speed and direction information were collected from the Turkish State Meteorological Service, seismicity data from Kandilli Observatory, flood and inundation data from the General Directorate of State Hydraulic Works, and landslide data from the Chamber of Geological Engineers and local government reports. Additionally, prepared by the Düzce Governorship Provincial Disaster and Emergency Directorate also formed a data source for this study [32]. These data were analyzed to determine the vulnerability of Düzce's open and green spaces to climate change and to provide recommendations for sustainable urban planning. The study was prepared as a qualitative research using the document analysis method. The examined sources include national and international reports, scientific books, articles, and theses. Furthermore, as examples of best practices, the websites, strategic plans, activity reports, and action reports of metropolitan municipalities in New York and Singapore worldwide, and İstanbul in Turkey, were also reviewed.

Natural environment

The province of Düzce is one of the most beautiful corners of our country with its bowl-shaped geographical structure, forests, climate, nature that remains green in every season, streams, and highlands. Thanks to its natural and cultural assets, Düzce's eco-tourism potential is increasing day by day. The plant and animal diversity unique to the region is also quite rich within this green nature. According to the final report prepared within the scope of the National Biological Diversity Inventory and Monitoring project carried out by the DKMP General Directorate, 9th Regional Directorate, Düzce Branch Directorate, 1294 flora species and 272 non-seed plant species belonging to 109 families, including 66 endemic and 14 rare species, have been identified in the region. Additionally, 54 mammal species, 7 amphibian species, 17 reptile species, 24 fish species, 180 bird species, and 782 invertebrate animal species have been determined [33]. As shown in Figure 2, the location map of meteorological stations is provided.

Figure 2. Location map of meteorological stations [34]

Temperature

According to the long-term average values (1960-2012) of the General Directorate of Meteorology, seasonal temperature variations in Düzce are distinct. Winters are generally mild, but temperatures can drop below 0 °C and snowfall can occur. Summers are hot and humid; temperatures can exceed 30 °C. The annual average temperature in Düzce typically varies between 15-17 °C, depending on regional differences. The coldest month is January (3.7 °C), while the hottest month is July (22.6 °C). Sudden temperature changes are rare in Düzce, but unexpected weather events can occasionally occur. The city's precipitation regime is closely related to temperature; summer months are rainier, while winters are drier. Climate change is affecting temperature and precipitation patterns in Düzce. This situation is increasing the frequency and intensity of extreme heat waves along with rising temperatures, while also causing changes in the precipitation regime, thereby elevating the risk of drought.

Precipitation

The amount of precipitation is 817.7 mm. Winter and autumn seasons are the periods with the highest rainfall; summer is the driest season. The distribution of precipitation across seasons is as follows: winter 32%, autumn 26%, spring 23%, and summer 19%. The annual average humidity rate is 77.5%. The number of days with snowfall is 6, the duration of snow cover on the ground is 5 days, and frost occurs for 44 days. Fog occurs for a total of 23 days in a year, with the highest incidence in November 8 days [35].

Wind

The annual average wind speed of Düzce city is 1.2 m/s. In simulations prepared for the years 2011 and 2050 to determine the future wind speed of Düzce, it was observed that there was no change in wind speed throughout the province and in the city. The results of wind speed, prevailing wind direction, and seasonal distribution, which are the most important factors in the transport of emissions from the source, are given in Figure 3.

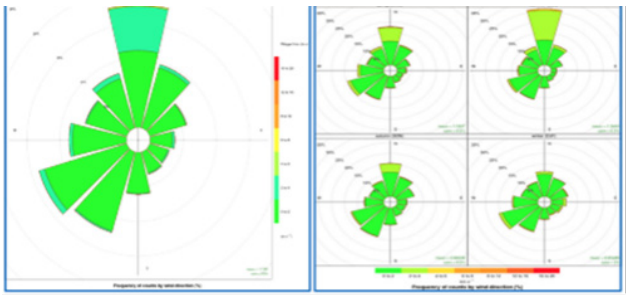

Figure 3. Prevailing wind direction and seasonal change graph [36]

Wind speed and direction are among the most important factors in the transport of emissions from their source. According to speed ranges, winds are examined in 6 different classes: calm (0-0.2 m/s), light air (0.3-1.5 m/s), light breeze (1.6-3.3 m/s), gentle breeze (3.4-5.4 m/s), moderate breeze (5.5-7.9 m/s), and fresh breeze (8.0-10.7 m/s). When ex-

amining the annual variation of wind categories for Düzce province, the highest wind speed of 4-8 m/s is observed most frequently at 15% in summer months, and at 5% frequency in spring and autumn months. The prevailing wind direction in the province is predominantly from the north with 18% frequency, and from the southeast with 12% frequency. Besides these, it can be said that northeast, west, northwest, and south winds are also effective with 8% frequency. In seasonal variation, the prevailing wind direction in summer, spring, and autumn seasons shows the same characteristics as the general prevailing direction, with the frequency of blowing varying depending on the directions. However, especially in winter months, the highest blowing frequency is observed in southeastern winds, followed by western and northern winds in second place [35].

Method

The city of Düzce, due to its location in the Black Sea region of Turkey, is an important area in terms of climate change impacts. In the methodology of the study, indicators suitable for the national database were prepared within the framework of main headings describing social, economic, and environmental systems, based on the World Bank's approach. The main headings and contents of the indicators that reveal the vulnerability of the city's open and green spaces to climate change are shown in Table 1 [37].

These indicators can be used to assess the vulnerability and susceptibility of cities to the impacts of climate change. City managers and planners can develop strategies to combat climate change and make cities more resilient by monitoring and analyzing these indicators.

The study has some limitations. These are:

•Limited Climate Change Research: The scarcity of research on climate change and its effects on Düzce is one of the main constraints of the study. This means there is limited available data for collection and analysis processes. More local studies and data collection on the impacts of climate change are needed.

•Lack of Comparative Data: The absence of data from other cities to compare and evaluate the data of Düzce city narrows the scope of the study and limits the general validity of the analyses.

•Data Access Problems: The inability to obtain certain data that should be acquired from institutions is one of the limitations of the research. This lack of data affects the analyses and results of the study. Therefore, improving the data collection process or finding alternative data sources is important.

•Change in Address-Based Population Registration System: The transition to the Address-Based Population Registration System and the collection or non-collection of certain data at the provincial level is one of the significant limitations of the study. This situation highlights the difficulty of accessing more detailed data at the local level.

Clearly stating these limitations is important for readers interpreting the research results. This can help future researchers take these limitations into account when conducting similar studies and contribute to the development of better data collection methods.

Table 1. Indicators revealing the vulnerability of urban open and green spaces to climate change

1. General Characteristics of the City	2. Socio-Economic Structure	3. Environmental structure
Location of the city	The proportion of the population aged 0-4 in the total population	**Green Infrastructure and Open Space Accessibility Indicators** •Amount of green space per capita •Balance of open-green space distribution in the city •Access to open green spaces •Green infrastructure projects
Resident Population	The proportion of the population aged 65 and over in the total population	
Per person GSYIH	Proportion of the disabled population	
	Unemployment rate	**Flood and Inundation Indicators** •Flood frequency •Infrastructure damage •Emergency preparedness •Residential areas located within flood/inundation zones •Industrial areas located within flood zones •Main transportation link(s) that will become inaccessible during flood/inundation events
	Percentage of population below the poverty line	**Temperature and Air Quality Indicators** •Average temperature changes •Frequency and duration of heat waves •Air pollution levels •Incidence of asthma and respiratory diseases **Water Resources Indicators** •Precipitation changes •Frequency and severity of droughts •Water levels and bodies •Rate of depletion of water resources **Sea Level Rise Indicators** •Rate of sea level rise •Coastal erosion •Coastal infrastructure **Biodiversity and Natural Area Indicators** •Diversity of plant and animal species •Habitat loss •Protection of natural areas
	Proportion of population below the hunger threshold	

FINDINGS

Identifying the potential impacts of global climate change in the city of Düzce and assessing the risks associated with these changes is crucial for understanding the city's vulnerability. In this section of the study, the potential effects and risks of climate change on the city of Düzce are first examined, followed by an analysis of the city's vulnerability based on its social and economic structure and land use decisions. The hazards that may arise due to climate change will be addressed under the following headings [32].

Natural Hazard Risks of Düzce City

The natural disaster that causes the most loss of life in Düzce province is earthquakes. According to the Turkey Earthquake Hazard Map, it is located in the High-Risk Earthquake Zone based on the maximum ground acceleration value. Düzce, which has been affected by destructive earthquakes in historical periods, is under the influence of the North Anatolian Fault Zone (NAF), Düzce Fault Zone, Hendek Fault Zone, and Çilimli Fault Zone. Environmental conditions caused by climate change, especially the decrease in green spaces and inadequate infrastructure, further increase these risks. This situation demonstrates that earthquake-related risks are not limited to seismic hazards alone, but also have profound effects on the city's ecosystem dynamics and social resilience. Consequently, environmental vulnerabilities triggered by climate change increase Düzce's susceptibility to disasters and highlight the necessity of developing an effective green space management strategy in this context.

The Düzce basin is located on the North Anatolian Fault (NAF), one of the most important active faults in our country. This fault extends from the Karlıova region in the east, traversing the northern half of the country in an east-west direction. This fault, which is generally observed in a narrow zone consisting of single fractures up to the Bolu region, bifurcates in the west of Bolu (Dokurcun Valley) and extends towards the Sea of Marmara by splitting into two main branches. The Hendek faults in the Sakarya-Düzce region also join the NAF system, and the width of the fault zone reaches 40 km [38]. As shown in Figure 4, Düzce earthquake hazard map is provided.

The August 17, 1999 İzmit Gulf earthquake occurred on 17.08.1999. The maximum intensity of the earthquake was determined to be Io=X, with a magnitude of Ms=7.4 and an epicenter at 40.70K, 29.19D. In this earthquake, 270 people lost their lives and 1157 people were injured in Düzce.

The November 12, 1999 Düzce earthquake occurred in approximately 35 km of the North Anatolian Fault Zone (NAFZ) stretching between Lake Efteni in the west and the Bolu viaducts in the east, with the largest right-lateral offset measured as 4.0 m and the largest vertical offset around 1.0 m - 1.5 m along the surface faulting. This earthquake, which occurred about three months after the İzmit Gulf Earthquake, had a magnitude of Mw=7.2, a focal depth of 11 km, and its epicenter was determined to be at 40.79K and 31.21D. The maximum intensity of this earthquake, observed on the Düzce fault in the south of the Düzce basin, was determined to be X. In Düzce, 710 people lost their lives and 2679 people were injured. Lastly, there was no loss of life in the Düzce (Gölyaka) earthquake on November 23, 2022. The AFAD report prepared in December 2022 examined the deficiencies experienced in different areas following the 5.9 Mw magnitude earthquake that occurred in Düzce on November 23, 2022. This 20-page report was prepared to contribute to disaster management in our country, where disaster risks are very high.

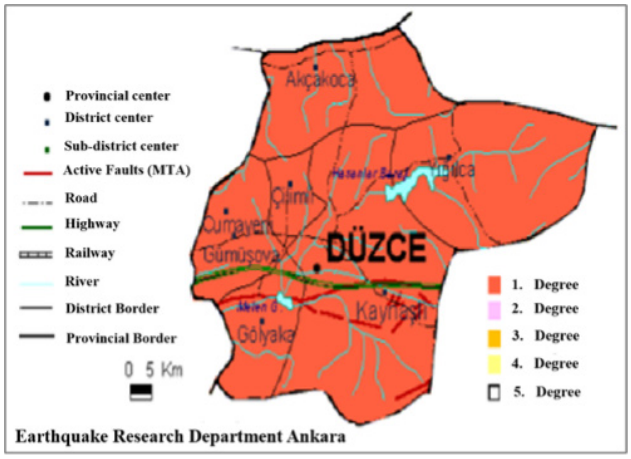

Figure 4. Düzce earthquake hazard map

Flood, inundation and landslide

Düzce province is one of the provinces that has flood and inundation potential in terms of precipitation regime and experiences these events seriously at regular intervals. Significant flood and inundation disasters occurred on July 1, 1961, July 12, 1995, July 25, 1995, August 11, 1997, May 21, 1998, and September 17, 2019. The most recent flood disaster took place on July 10, 2023.

On July 1, 1961, 90 villages were submerged, primarily including Topçular, Hasanlar, Arabacı, Hatip, Fideni Kürtler, İhsaniye, Hacıkadirler, Kahveleryanı, Adaköy, Hademiye, and Şaziye.

In the Kaynaşlı flood on July 12, 1995, 3 houses were destroyed, 8 houses were moderately damaged, and 34 houses were slightly damaged. A total of 25,000 m3 of sediment was removed from the city by DSİ (State Hydraulic Works), with 15,000 m3 from the July 12 flood and 10,000 m3 from the July 25, 1995 flood. The damage was calculated at 150 billion TL ($3,354,180) at the prices of that day. As shown in Figure 5 images of the July 12, 1995 Kaynaşlı flood disaster is provided.

The preservation of green spaces plays a critical role in reducing flood risk. These areas allow for the natural collection of rainwater and contribute to balancing groundwater levels. Moreover, the filtering properties of green spaces improve water quality. In this context, a detailed analysis of the status and quality of green spaces in Düzce is extremely important for the effective management of flood and landslide risks.

Figure 5. Images of the July 12, 1995 Kaynaşlı flood disaster

On August 11, 1997, a flood disaster in Yığılca, Akçakoca, and Düzce resulted in one fatality and damage to 84 homes and businesses. These areas suffered significant damage, with bridges collapsing. In Düzce and Gölyaka, 5,700 hectares of land were submerged, damaging agricultural products. A large amount of sediment flowed into Lake Efteni, with observations indicating that the lake bottom was filled with 30-40 cm thick sediment. According to the Governor's Office, the total damage amounted to 3,000,000,000,000 TL ($17,834,573).

On May 21, 1998, a flood affecting the entire Western Black Sea region also impacted the Melen Basin. This flood caused a total damage of 10,904,988,000,000 TL ($43,619,952) in Düzce province [39].

Heavy rainfall in Düzce on July 17-18, 2019, severely affected the districts of Cumayeri and Akçakoca. It particularly led to flooding in Cumayeri's Dokuzdeğirmen village, Akçakoca town center, and the villages of Dilaver, Esmahanım, Uğurlu, Melenağzı, and Kurukavak in Akçakoca. In these areas, a quarter of the annual rainfall fell within two days, with 160 kg of rain per square meter. As a result of the rain turning into a flood and causing disaster, seven citizens from two families, including four children, lost their lives. The flood disaster's damage included: electricity cut off in 24 villages, roads closed in 40 villages, 141 km of roads affected by landslides, 91 small and 4 large bridges and culverts destroyed, drinking water networks damaged in 41 villages, and 72 cattle, 177 sheep and goats, and thousands of poultry perished. As shown in Figure 6 images of the July 17, 2019 Düzce flood disaster is provided.

As a result of the flood disaster, seven citizens from two families (four of them children) lost their lives. The damages from the disaster can be summarized as follows:

-Electricity cut off in 24 villages

-Roads closed in 40 villages

-141 kilometers of roads affected by landslides

-91 small and 4 large bridges and culverts destroyed

-Drinking water networks damaged in 41 villages

-72 cattle, 177 sheep and goats, and thousands of poultry perished.

Figure 6. Images of the July 17, 2019 Düzce flood disaster

Figure 7. Flood images of Düzce industrial site

Figure 8. Images of the flood disaster in Fındıklı Aksu village

Due to the floods and inundations caused by heavy rainfall between 17-18.07.2019, the Ministry of Interior's Disaster and Emergency Management Presidency issued a "General Life Impact Approval" dated 23.07.2019 with the number E.107744. However, as a result of examinations conducted by the technical personnel of the Provincial Disaster and Emergency Directorate, it was determined that landslide disasters also occurred in some settlements due to the same rainfall. Therefore, in addition to the previous Approval, the Düzce Governorship obtained a "General Life Impact Approval" dated 29.08.2019 with the number E.124334.

On 10.07.2023, the Düzce Industrial Site, established on approximately 250 acres of land along the D-100 highway in the Mergiç and Çerkez Taşköprü locations, was submerged following the overflow of the Melen River after two days of heavy rainfall in the city. The same incident also affected the village of Fındıklı Aksu, located about 25 kilometers from the center with 125 households, resulting in the destruction of 5 houses and 2 bridges, and rendering 11 houses uninhabitable. Figure 7. shows flood images of Düzce Industrial Site, and Figure 8. presents flood disaster images of Fındıklı Aksu village.

Drought

Climate change can lead to an increase in drought events in some regions. This situation can result in problems accessing water resources and negatively affect agriculture. Due to global climate change, increasing temperatures and decreasing precipitation worldwide are intensifying the persistence and potential negative impacts of drought [39]. There are a total of 31 types of natural disasters in the world, and 28 of them are known to be related to meteorology. Among these natural disasters, drought is one of the most dangerous [40].

Distribution and Status of Open and Green Spaces

There are various studies evaluating open green space systems in the study area. For instance, it is stated that intensive urbanization leads to fragmentation in natural areas [41]. Despite the presence of dense green areas, it is noted that due to the abundance of residential areas in the city center and the insufficiency of open-green spaces, urban residents' relationships with nature have reached a breaking point, drawing attention to the fragmented structure of the current system [42]. It is mentioned that unsustainable urbanization causes existing open and green spaces to fail in meeting the city's needs [43]. For this reason, it has been argued that open and green spaces should be transformed into qualified areas and interconnected during the urbanization process [44]. It is stated that urban open green spaces should be the product of systematic planning [45]. It is emphasized that these areas are important not only as a source of recreation but also for the urban ecosystem [46]. It has been determined that the amount of green space in Düzce Bahçeşehir (Permanent Housing) neighborhoods is adequate in size when compared to standards for the study areas [47].

The amount of active green space in Düzce city center is 1.43 m^2 per person, with only a 3.9 m^2 increase over the past 14 years [47]. The amount of active open and green space per person across the entire study area was determined to be 5.33 m^2, while in 18 of the 56 neighborhoods, active open and green space below the standard of 10 m^2/person was proposed [42]. Urban sprawl has been evaluated as a growth pattern that disregards natural factors such as disaster risk, water resources, and agricultural lands [48]. It has been noted that urbanization has occurred in the plain where earthquake and flood risks are high [49]. When examining the 2017 Development Plan of the study area, it is observed that 81.48% of the area consists of structural areas (settle-

ments, single-family housing, industrial and commercial units, industry). The remaining areas are open green spaces (agricultural lands, forests, urban open green spaces, waterways, etc.). Open green spaces are generally fragmented or surrounded by structural areas. Large open green spaces are found along some streambeds and in some northern neighborhoods where elevation increases (Bahçeşehir, Tokuşlar, Kazukoğlu, Orhangazi).

Integrated Assessment of Urban Planning, Infrastructure Management, and Climate Change Impacts in Düzce

Examining the natural environment of the city of Düzce and its climate change-related risks requires a more in-depth assessment of the nature of management actions. While natural disaster risks such as floods, landslides, and droughts may increase due to climate change impacts, inadequate urban planning and infrastructure management can further exacerbate these risks. The province of Düzce has become a settlement where green spaces have gradually decreased during the urbanization process. Existing parks, gardens, and natural conservation areas are not adequately protected against climate change-related risks. Green areas, which are highly dependent on water resources, suffer greatly during periods of drought, and local governments are not sufficiently effective in protecting these areas. According to local government studies, floods and inundations frequently occur after heavy rainfall due to infrastructure deficiencies. Düzce's rapid urbanization, flawed settlement planning, and failure to protect green areas have further complicated these problems. It has been determined that structures built on floodplains increase the risk of flooding, and adequate regulations have not been implemented in this regard. The climate change mitigation and adaptation policies of Düzce's local governments have not yet reached sufficient maturity. The municipality's climate change adaptation plans remain limited, and concrete actions for infrastructure renewals and protection of green areas are lacking. In this context, more comprehensive strategies should be developed for managing climate change-related risks. Public institutions and local governments should collaborate more on climate change adaptation and implement long-term projects. This process will not only reduce current risks but also make it possible to build resilient cities against future climate impacts.

Potential Impacts and Risk Analysis of Global Climate Change in Düzce

This section addresses the potential impacts of climate change on Düzce province. Natural disaster risks and particularly short-term and long-term effects on green spaces are examined. The findings are presented classified according to types of climate impacts.

Heavy rainfall, flooding, and floods

Risk Description: The province of Düzce frequently experiences heavy rainfall, flooding, and inundation events due to changes in precipitation patterns. These disasters affect infrastructure, disrupting daily life and causing economic losses.

Past Flood Events:

•July 1, 1961: 90 villages were submerged underwater.

•July 12, 1995: In Kaynaşlı district, 3 houses were destroyed and 42 houses were damaged.

•July 17-18, 2019: 7 people lost their lives in Cumayeri and Akçakoca districts, and infrastructure was damaged.

Impacts on Green Spaces:

•Short-Term Effects: Damage to vegetation after flooding, destruction of infrastructure and parks.

•Long-Term Effects: Soil erosion, loss of green spaces, disruption of ecological balance.

Management Recommendations:

•Flood-resistant infrastructure projects should be developed.

•Green areas and parks with water retention capacity should be created.

Drought and water resource access issues

Risk Definition: Global warming, temperature increases, and irregularities in precipitation patterns are increasing the risk of drought in Düzce. This situation is making agricultural production and access to water resources more difficult.

Drought Trend: Rising temperatures and decreasing precipitation are causing a reduction in water resources and damage to agricultural activities.

Impacts on Green Spaces:

•Short-Term Effects: Increased irrigation needs for green spaces, plant species struggling to resist drought.

•Long-Term Effects: Reduction of biodiversity in green areas, extinction of some tree and plant species.

Management Recommendations:

•Drought-resistant plant species should be preferred.

•Sustainable irrigation methods (such as drip irrigation) should be used.

•Water storage and recovery systems should be implemented.

Extreme temperatures and heat waves

Risk Definition: Climate change is leading to more intense heat waves in Düzce, creating pressure on energy consumption, health, and environmental sustainability.

Heat Wave Trend: Average temperatures are increasing during summer months, with extreme heat posing health risks especially for vulnerable groups.

Impacts on Green Spaces:

•Short-Term Effects: Rapid water loss in plants, increased irrigation needs, stress on plants in green areas.

•Long-Term Effects: Loss of plant species that are not resistant to drought and extreme heat, reduction of biodiversity in green areas.

Management Recommendations:

•Cooling green areas should be created by increasing tree shades.

•Heat-resistant plant species should be preferred.

•Urban climate adaptation projects such as shading structures should be implemented throughout the city.

Earthquake hazard

Risk Definition: Düzce is located on the North Anatolian Fault Line, one of Turkey's most active fault lines, and carries a high earthquake risk. Although climate change does not directly create an earthquake risk, earthquake-related infrastructure damage can indirectly complicate post-disaster management.

Significant Earthquake Events:

•August 17, 1999 İzmit Earthquake: Magnitude Ms=7.4, 270 fatalities.

•November 12, 1999 Düzce Earthquake: Magnitude Mw=7.2, 710 fatalities.

Impacts on Green Spaces:

•Short-Term Effects: Damage to parks, roads, and infrastructure, post-disaster use of existing green spaces.

•Long-Term Effects: Loss of green spaces due to structural reinforcement or reconstruction, inability to preserve green areas.

Management Recommendations:

•The use of open spaces after an earthquake should be planned.

•Earthquake-resistant infrastructure and urban planning should be implemented.

CONCLUSIONS

This study aims to determine the vulnerability of open and green spaces in cities to climate change and develop strategies to reduce this vulnerability, using the example of Düzce city. The findings emphasize the importance of open and green spaces in combating climate change and guide local governments in strengthening planning and measures in this area. As a result of the study, recommendations have been presented to increase the resilience of open and green spaces in Düzce against climate change.

•Increasing plant diversity by using different plant species and supporting local plant diversity can enhance the resilience of open and green spaces. Increasing plant diversity has the potential to enhance ecosystem health and resilience against climate change. Various plant species, with their different root depths and leaf structures, absorb rainfall more effectively and retain soil moisture. This situation reduces the risk of flooding while ensuring more efficient use of water resources during periods of drought. Research shows that biodiversity plays a critical role in mitigating the effects of climate change. In particular, multi-layered vegetation covers have been proven to have a better capacity for storing atmospheric carbon. For example, there is evidence that carbon storage capacity increases by 30-40% in areas with perennial plants [50]. Such practices offer important strategies for sustainable environmental management in regions like Düzce that are combating climate change. Research can assess the effects of climate change on vegetation and examine its impacts on local biodiversity. In particular, how plant species in natural areas may change and what measures should be taken to preserve biodiversity can be discussed.

•Sustainable water management strategies can be developed for rainwater harvesting and efficient water usage as part of water management strategies.

•Measures can be taken against extreme heat waves. These include afforestation, artificial shading, and the use of cooling systems. These methods can provide effective shading and cooling.

•The relationship between excessive rainfall and climate change is leading to significant environmental problems in Turkey. Increasing rainfall amount and intensity are causing soil saturation, overflow of rivers, and consequently, the occurrence of flood events. This situation has the potential to cause loss of life and property, damage to infrastructure, and harm to agricultural lands in the future. Research evaluating flood and inundation risks is of critical importance for green space planners. In flood and water management, drainage systems and proper water routing can be planned for open and green spaces to reduce flood risks. These studies can help them understand the interaction of green spaces with residential areas and develop strategies to prevent potential floods. For example, green space planners can design green infrastructure projects that provide natural water storage using data obtained from these studies. Additionally, expanding and improving existing green spaces can be seen as an important step in reducing flood risks that may be caused by excessive rainfall. Thus, incorporating scientific data into planning processes will ensure that cities become more resilient to climate change.The research can assess the risk of flooding and inundation that the city of Düzce may face due to increased rainfall caused by climate change. In this context, factors such as water permeability of open areas, drainage systems, and flood risk can be examined.

•Sustainable soil management strategies can be implemented for soil conservation and productivity, to prevent soil erosion and increase fertility. The effects of climate change on soil erosion and how this erosion can damage open and green spaces can be examined. The strategies that should be applied in preventing soil erosion can be addressed. Green infrastructure applications, particularly green roofs and gardens, can significantly reduce erosion by allowing rainwater to reach the soil surface directly [51]. Increasing vegetation cover and selecting appropriate plants help protect the soil while mitigating the adverse effects of precipitation [52], [53]. Another strategy recommended is the implementation of soil management techniques that can better retain water, reduce erosion risk, and increase permeability [54]. The inte-

grated application of such methods is of great importance in terms of reducing urban soil erosion and creating a sustainable environment.

•In the research on heat waves and green areas, the impact of extreme heat waves on the green spaces of Düzce city can be examined. For example, the effects of temperature increase on vegetation in these areas and whether these effects allow for human use can be analyzed.

•In the research conducted for public participation and awareness, the awareness and participation of the local population in Düzce city regarding climate change and the future of open-green spaces can be evaluated. An analysis can be made on how the public can contribute to the protection and sustainable use of these areas. Seminars and workshops organized by local governments can increase citizens' knowledge about the maintenance and protection of green spaces. It is also possible to encourage active participation of individuals by creating community projects such as "Green Space Volunteers". While increasing social awareness, such programs also strengthen the local population's sensitivity to environmental issues [55]. The integration of technology and social media can create platforms that allow the public to express their views and provide feedback about green spaces. For example, online surveys and mobile applications can enable citizens to share their thoughts and make suggestions about the condition of local green spaces. While helping local governments make more inclusive and effective decisions in green space management, these participation mechanisms will also reinforce social solidarity [56].

•Realistic and feasible measures for public authorities and municipalities to protect and improve open and green spaces in Düzce require a comprehensive approach. First and foremost, the condition of existing open and green spaces should be regularly monitored and evaluated. To this end, field studies and surveys should be conducted to determine which areas need protection or improvement. Additionally, meteorological data and biodiversity studies should be continuously updated to track the effects of climate change. To strengthen the city's green infrastructure, green corridors should be created and integrated with pedestrian and bicycle paths. To prevent flooding, measures such as improving existing drainage systems, rainwater harvesting, and protecting natural waterways should be implemented.

•For sustainable maintenance, a calendar should be created that includes watering, pruning, and general maintenance operations for green spaces, and this calendar should be regularly updated. Collaborating with local volunteers to form groups that will take on the maintenance of open spaces is also an important step. Funds and sponsors should be found for the development of open spaces through public and private sector cooperation. Scientific research and applications should be supported by developing joint projects with the private sector. Additionally, community education campaigns should be organized to raise awareness among local residents about the importance of protecting green spaces, and programs on nature education and environmental awareness should be established in schools.

•Processes should be developed to assess the environmental impacts of new projects, introducing restrictions aimed at protecting green areas. The creation of long-term strategic plans in collaboration with local communities will ensure better identification of local needs and increase participation in decision-making processes. Allocating a special fund from the municipal budget for the protection and development of green areas, and the establishment of grant and support programs by public institutions, will contribute to the sustainability of these areas. Addressing these suggestions holistically will reduce the vulnerability of open and green spaces in Düzce to climate change and poor urban planning and help create a sustainable environment.

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

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

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

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