Pure Appl. Geophys. 182 (2025), 4303–4318

https://doi.org/10.1007/s00024-025-03794-z

Pure and Applied Geophysics

Check for updates

Resilience to Drought-Affected Areas in a Semi-Arid Agricultural Watershed by Climate Risk: Practical Implications for Sub-Basin Scale Case

Hakan Aydin,[1] Kasim Yenigun,[2] Oznur Isinkaralar,[3] and Kaan Isinkaralar[4]

Abstract—Türkiye is threatened with drought due to climate risk since it is vulnerable to water resources derived from rainfall. This paper was generally carried out in drought-affected areas in a semi-arid agricultural watershed in the provinces of The Western Black Sea Basin, including Düzce, Bolu, Zonguldak, Çankırı, Karabük, Bartın, Kastamonu, and Sinop. It was aimed to meet the need for a coordinated examination of agricultural areas across different basins with hydrological and meteorological data. Life-touching results were revealed by overlay mapping the flow observation station data analysis results and irrigation areas. The importance of agriculture in the world economy, which is in a bottleneck regarding food needs and access to food, is understood better daily. This study evaluated future risks and opportunities in agricultural production in the basin. A better understanding of the future state of water throughout the basin is essential in protecting and improving the basin's economic, social, and demographic structure. The irrigation areas of 43% are currently in operation, and with the addition of the areas under construction, 60% of the currently identified areas will become irrigable. It was observed that land principally occupied by agricultural areas increased by 26.54% with the transformation of irrigated and non-irrigated lands in the basin between 1990–2008 according to CORINE database. Considering the irrigation areas included in the preliminary examination and master plan, planning, and project stages, irrigated agriculture in the basin is not yet at the desired level. By implementing better agricultural policies, the welfare level of the people of the region and the development level of the basin can be increased in general. One of the primary purposes of the study is to shed light on decision-makers. The results were designed to form the basis for basin-wide planning studies.

Keywords: Climate adaptation strategies, drought trend, disaster risk reduction, hydrological droughts, regional development.

1. Introduction

While drought is a natural disaster that has been known for ages, it is the one that has worsened its effects recently. Droughts do not have a universally accepted definition, and they are assessed from many perspectives and in different fields (Orimoloye et al., 2021). Drought can be defined into six main types according to the areas affected: meteorological drought, climatological drought, atmospheric drought, agricultural drought, hydrological drought, and water resources drought (Wang et al., 2015; Zhang et al., 2022). Both the usage and reduction of the drought's adverse effects are issues that relate directly to each other. It is critical to foresee the future plights of our rivers, the effects of the potential changes in drought, and the preemptive measures needed to be taken into account to prevent possible economic and social crises (Gasmi et al., 2024). Drought is an intricate and complex phenomenon that is the product of precipitation in rain, snow, and sleet. It is a natural disaster that significantly affects diverse socioeconomic sectors, especially agriculture, social life, and industry, where extended periods of low precipitation lead to water scarcity (González Tánago et al., 2016; Ourarhi et al., 2022).

During specific periods, when precipitation levels fall below the annual rainfall of many years, drought, a natural weather event, can happen everywhere on Earth. Climate, which has been evolving for millions of years (Mahmoud et al., 2023), is unstable and hovers between the two extremes, making it hard for

[1] Department of Civil Engineering, Graduate School of Natural and Applied Sciences, Kastamonu University, 37150 Kastamonu, Türkiye.
[2] General Directorate of Combating Desertification and Erosion, The Ministry of Environment, Urbanization and Climate Change, 06510 Ankara, Türkiye. E-mail: kasim.yenigun@csb.gov.tr
[3] Department of Landscape Architecture, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Türkiye.
[4] Department of Environmental Engineering, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Türkiye. E-mail: kisinkaralar@kastamonu.edu.tr

scientists to predict it accurately (Han & Singh, 2023). Future climate change cases have been projected to be the following: the temperature may rise in the upper atmosphere, evaporation may increase, snowfall may be less, and the seasons will be disturbed due to the rainfall pattern (Lankford et al., 2023; Mehta, 2024). These fluctuations shall de-terrain the world by decreasing water availability and harvesting (Ourarhi et al., 2024c, 2024d). A drawback in the water budget is associated with the deterioration of crucial benchmarks and threatens different sectors such as agriculture, power, and industry. Shortage of water affects the local economies in various ways (shown in Fig. 1).

Expressing drought in such a specific manner has repeatedly skirted issues in this area of research, which deals with drought monitoring and analysis (Salimi et al., 2021). Drought has been examined through extensive research over definitions of drought to the point that it can be categorized into several types, which consist of meteorological, climatic, atmospheric, agricultural, hydrological, and water management (Ji et al., 2015; Orimoloye et al., 2022). These studies further identified drought to be a place of moisture shortage due to the deficient precipitation over a specific period (Cunha et al., 2019; Svoboda et al., 2016) In many acclaimed studies, creative approaches and explanatory methods are employed to deepen, broaden, land use analysis and diversify drought hazards monitoring (Alemu & Dioha, 2020; Meresa, 2020; Ourarhi et al., 2024a, 2024b). It has been shown in research that the early-warning systems, to be exact, in drought are mostly monitors of these activities, assessing, observing, and releasing information associated with hydrological circumstances, water supplies types, and

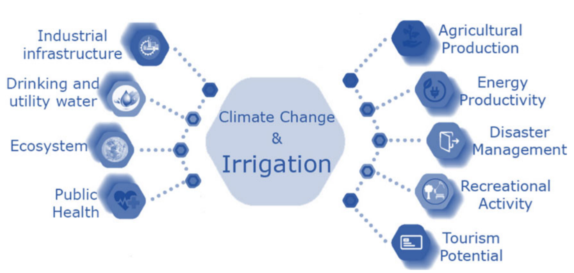

Fig. 1
Various sectors affected by drought

upwards trends (Savari et al., 2022; Wang et al., 2019).

An optimal system would incorporate both monitoring and forecasting elements. Research suggests that providing early information and detecting drought onset is crucial for implementing drought risk management plans to mitigate potential effects (Baudoin et al., 2017; Carrão et al., 2018). For such a gradual hazard, a thorough and integrated approach is essential. Given the wide range of sectors impacted by drought, it's noted that a single method cannot address all situations, and various index combinations should be employed as needed. This paper categorizes drought indices into a) meteorology, b) soil moisture, c) hydrology, d) remote sensing, and e) combined or modeled, characterizing them based on their practicality and types. Lana et al. (2001) examined spatial and temporal rainfall patterns using Standardized Precipitation Index (SPI) in Catalonia northeastern Spain, utilizing data from 99 stations from 1961–1990. Their findings revealed a notable increase in periods of rainfall scarcity. Lloyd-Hughes and Saunders (2002) applied the SPI to monthly data spanning 1901–1999 for a European region (35–70°N, 35°E-10°W). They emphasized that standardized procedures facilitate quantitative comparisons of drought indices across regions and periods. Their study demonstrated an approximate equivalence between the Palmer Drought Severity Index (PDSI) and SPIs over 9–12 months. Analysis of SPI and PDSI trends showed minimal changes in European regions experiencing extreme or moderate drought conditions throughout the twentieth century. Min et al. (2003) investigated drought patterns in Korea and East Asia using the Climatic Research Unit (CRU) monthly precipitation data from 1951–1996. Their SPI analysis revealed significant drought intervals of 2–3 and 5–8 years in Korea, with increasing frequency since the 1980s. Droughts in Eastern China, Manchuria, and northern Japan showed high compatibility with Korean droughts, although temporal durations varied among the regions. Bonaccorso et al. (2003) studied drought in Sicily from 1926–1996 using the NCEP/NCAR Reanalysis dataset and 43 observation stations across the island. They employed SPI methods to identify drought occurrences in the region.

To the best of our knowledge, the present study analyses the trends of minimum flows derived from the flow observation points located on the Western Black Sea Basin rivers and assesses the consequences of drought. In addition, the focus is on the evaluation of recommendations for better utilization of water in the basin, particularly in agricultural irrigation.

2. Literature Review

According to the drought indicators, there are three drought indices used in Türkiye: SPI, Percent of Normal Index (PNI), and PDSI (Wambua et al., 2015). In a strict sense, Palmer (1965) reported that drought can be considered a meteorological event and a meteorological anomaly resulting from a long-term and abnormal lack of moisture (Spinoni et al., 2019). In his study, he aimed to correlate drought periods with atmospheric cycle data rather than addressing the leading causes of drought. McKee et al. (1993) stated that five basic points are important in drought analyses. These are: i) time scale, ii) probability, iii) lack of precipitation, iv) soil moisture, groundwater, snow cover, surface water, and reservoir volume, and v) effects of drought and definition relationship. Drought's frequency, duration, and intensity depend directly or indirectly on the time scale. They stated that a single method or definition cannot fully cover all these issues. They reported that many drought definitions and determination methods were applied in the past in America, the most frequently used of which is the PDSI (Shah & Mishra, 2020). However, the weak point of the method is the difficulty in applying it correctly. They defined a new versatile indicator SPI to monitor and analyze drought. This method requires only one variable as input data. Similarly, it can be applied to precipitation, snow cover, stream flow, reservoir volume, soil moisture, and groundwater data. Their published study also included the application they made for data covering 1889–1991 from the Fort Collins region of Colorado. PNI is a method introduced by (Willeke et al., 1994) as a fast and simple index sufficient for a region or season to define the percentage of normal precipitation. It can be calculated for monthly, seasonal, and annual time scales (Wilhite & Easterling, 2019). The PNI methodology demonstrates significant efficacy when applied to a specific geographic area or seasonal period (Hayes, 2006). Throughout the years, considerable discussion has centered on the appropriate drought indices and methodologies suitable for particular climatic conditions. Numerous definitions and indices related to drought have been established, and efforts have been undertaken to offer direction regarding this matter (Tirivarombo et al., 2018).

During some meetings, experts elaborated and adopted concrete terms of the "Lincoln Declaration on Drought Indices." The Declaration recommended using the SPI approach to national meteorological and hydrological services of the world to describe meteorological droughts and other droughts uniformly around the world (Sharma et al., 2022). In June 2011, at the 16th World Meteorological Congress, the Declaration repeated recommendations concerning indices and elaborated users' guides. The SPI Guide was compiled and distributed in all official languages to the United Nations by WMO (2012), following Congress' recommendation. Hayes et al. (1999) commented that SPI takes a sophisticated form compared to the previous indices due to its simplicity and applicability on various time scales. This makes it easier to apply to water resources over different periods (Muzammal et al., 2024). They applied the SPI methodology to the southwestern and southern plains of the United States. Also, the authors carried out mapping studies regarding the efficiency of the SPI method in determining the beginning of the drought conditions. A case study for Texas was also performed, and the drought was investigated in depth. It was indicated that the SPI methodology should be an operational tool for monitoring droughts at the national, regional, and state levels. The SPI method was used in the study, wherein its result indicated the start of drought that was 1 month before the result of the Palmer Drought Severity Index (PDSI). They recognized that the temporal distinction will be important to enhancements that both state and federal entities will make in mitigations and responses in the future within the drought-impacted areas.

3. Materials and Methods

This research analyzes the drought level in basins in 3 dimensions: i) mapping of station trends, ii) analysis of primary product areas and spatial structure of selected agricultural areas in Fig. 2.

3.1. Information About Sub-Basins

The Western Black Sea Basin lies within the latitudes between 40°34′42“ and 41°27′52” and the longitudes between 30°52′33“ and 35°12′12”. The Western Black Sea Basin covers an area of approximately 2,896,766 hectares (ha). On the southwest side, the Sakarya Basin forms the boundary, while on the southeast lines, the Kizilirmak Basin and the Black Sea form the northernmost sides. A total of 744,215 ha of the basin is agricultural land. The shares of those agricultural lands in various provinces are as follows: Düzce: 74,723, Bolu: 112,773, Zonguldak: 48,645, Bartın: 38,764, Karabük: 37,635, Kastamonu: 147,290, Çankırı: 207,646, and Sinop: 76,739 hectares (TURKSTAT, 2020)—the General Directorate of State Hydraulic Works (GDSHW)-managed irrigation areas in the whole region of the Western Black Sea Basin. Although the irrigation areas are limited to very few locations, with sudden changes in altitude along the shoreline, it is mainly observed in the Bartın Basin, which contains an extensive flat area, and on the high plateaus and plains.

Sampling points were conducted within the scope of the Western Black Sea Basin, and visuals were created by mapping 24 sub-basins and positioning them in the ArcGIS program to evaluate drought's impact on the sectors. Figure 2 presents the stations covering all the records of the basin. Following the station identification activities, the stations were determined, and the basic structure of the research was established by gathering and editing the minimum flow data at the points selected.

It covers an area of 3.7% of the total area of Türkiye, consisting of five main basin sections and many subbasins inside them. Many streams give their names to sub-basins in the basin: for example, Melen, Bartın, Filyos, Devrekani, Alaplı, Gülüç, Aydos, Zerbana, and Güble Streams. Originating from the skirts of mountain chains lining up along the Black

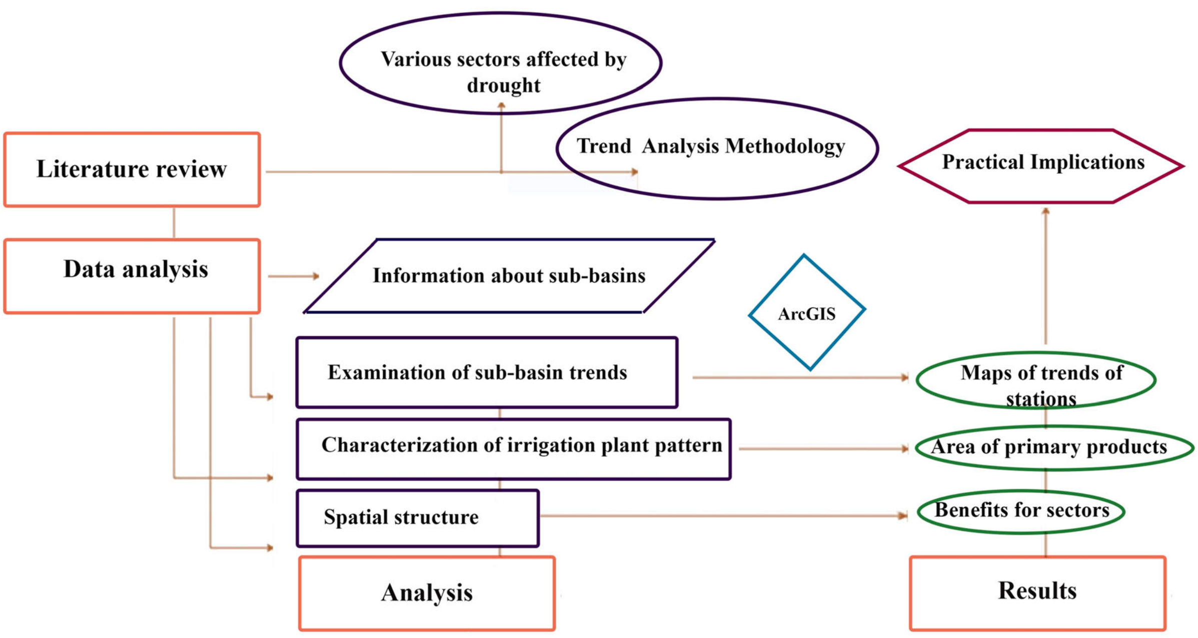

Fig. 2
The framework of the research

Sea, the streams run through the valleys to directly pour into the Black Sea. Further streams that should be mentioned in this context are the Ezine, Sarımsaklı, Helaldi, İnebolu, Akçay, Ayancık, and Güzelçay—Kanlıçay Streams. There are just so many types of teas. Several tributaries and streams in the basin join together to form major streams and rivers. All or parts of the provinces of Ankara, Bartın, Bolu, Çankırı, Düzce, Karabük, Kastamonu, Sakarya, Samsun, Sinop, and Zonguldak fall within the basin. The Black Sea bounds the western Black Sea Basin in the north, and the delineation of the water divide happens to lie along Çangal, Zindan, Küre, Ilgaz, Benlidağ, Bolu Mountains, Karadağ, Işık, and Elmacık Mountains from the east.

Most of the irrigation areas in the basin are located within the provincial borders of Bolu and Kastamonu. Great economic opportunities arise with irrigation in agricultural areas located on wide plains. The phased amounts of irrigation areas operated by GDSHW in the Western Black Sea Basin are shown in Table 1. As can be seen, 43% of the irrigation areas are in operation. With the addition of the areas under construction, 60% of the currently identified areas will become irrigable. Considering the irrigation areas included in the preliminary examination and master plan, planning, and project stages, irrigated agriculture in the basin is not yet at the desired level in Fig. 3. It can be said that the basin promises potential in terms of agricultural economy.

According to irrigation methods, when all irrigation from the preliminary examination master plan stage to the operation phase is considered, it can be seen in Fig. 4 that only 35% of the irrigation in the basin is done by flood irrigation method. However, considering the active situation in the field rather than the irrigation works in the preliminary examination and master plan, planning, project, and construction stages. It has been determined that the current irrigation method is flood irrigation, with a predominant rate of 78%. In this context, this paper focuses on some crucial sub-basins, as seen in Fig. 5. There are six selected areas as follows: β1: Düzce Efteni, β2: Çerkeş-Akhasan, β3: Karabük, β4: Devrekani-Beyler β5: Sinop and β6: Bartın sub-basins.

Table 1

Plant patterns of dams (GDSHW Regional Directorate)

Dams	Product	Ratio (%)	Area (da)
Beyler	Sugar beet	82.74	42,842.77
	Vegetable	0.03	15.53
	Potatoes	1.51	781.88
	Onion–Garlic	0.01	5.18
	Sunflower	1.43	740.45
	Sweetcorn	12.79	6622.66
	Forage Plant	1.35	699.03
	Fruit	0.14	72.49
	Total	100	51,780
Kulaksızlar	Sugar beet	82.30	42,203.44
	Potatoes	1.87	958.94
	Onion-Garlic	0.26	133.33
	Sunflower	0.32	164.10
	Sweetcorn	12.51	6415.13
	Forage Plant	2.66	1364.05
	Fruit	0.08	41.02
	Total	100	51,280
Düzce	Wheat	1.21	
	Hazelnut	84.00	
	Whole Corn	6.14	
	Barley	0.05	
	Paddy	0.29	
	Silage Corn	5.87	
	Forage crops	0.88	
	Clover	0.53	
	Vegetable	1.15	
Kozcağız	Cereals	20	4296
	Fruit	5	1074
	Clover	8	1718.40
	Potatoes	3	644.40
	Sweetcorn	20	4296
	Bean	5	1074
	Sunflower	6	1288.80
	Truck farm	6	1288.80
	Vegetable	19	4081.20
	Onion	3	644.40
	Poplar	5	1074
	Total	100	21,480

3.2. *Examination of Sub-Basin Trends*

Aydin et al. (2025) applied the Mann–Kendall Test, Spearman's Rho Test, Sen's Trend Slope Method, and Şen's Innovative Trend Analysis Test to the basin. The sampling and detailed studies were carried out for the sub-basins deemed essential to monitor and evaluate the response to the drought effect in the field. Below, the station regions are examined in more detail, taking into account the plant patterns and irrigation areas of the irrigation areas.

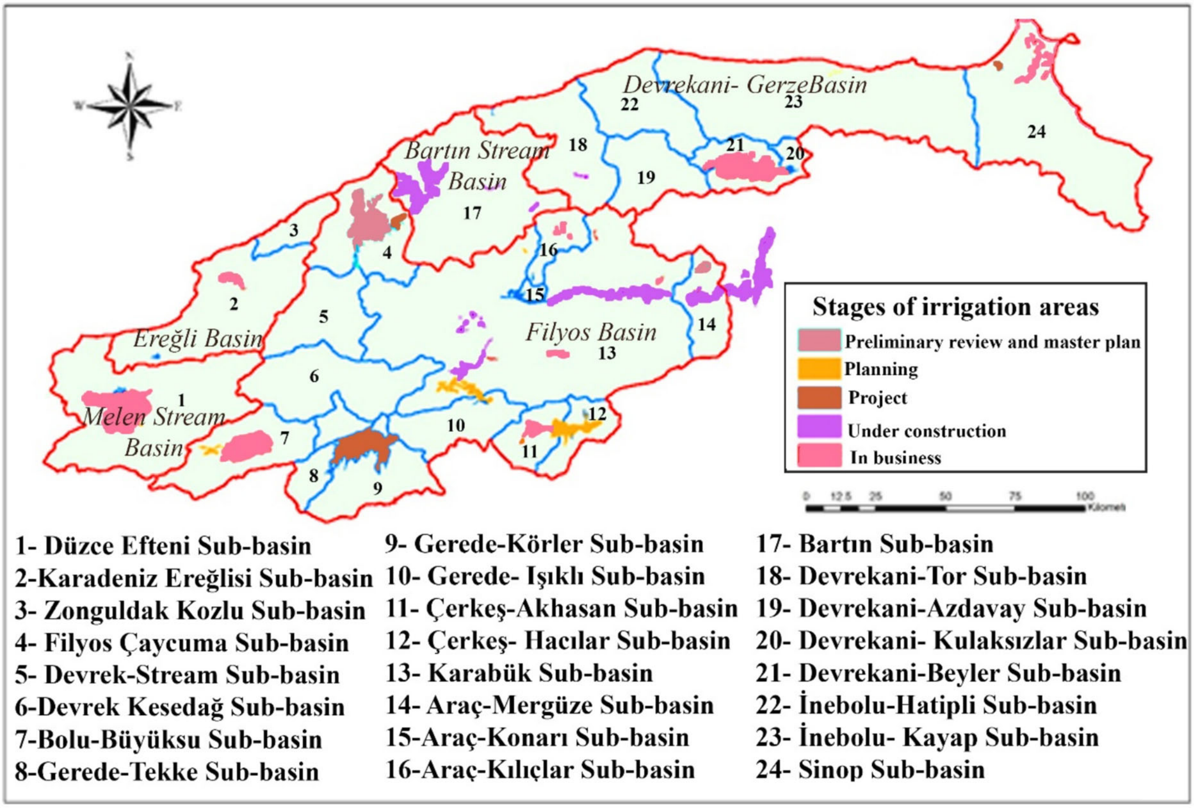

Fig. 3
Watershed location map and sub-watershed details of the Western Black Sea Basin

For the example of Devrekani-Beyler and Devrekani-Kulaksızlar Sub-Basins, information about the size of the irrigation areas, the plant pattern of the irrigation area, the maximum and minimum yield values for dry and irrigated agriculture, and the floor and ceiling unit prices of the products for 2020 are given. Using the information given, average values were used, and assuming that irrigation areas were used at full capacity, the product amounts to be obtained in irrigated and dry farming were calculated, and monetary equivalents were determined based on average product prices. The effects of changes in the amount of water on product amounts and income were evaluated. Similar information has been given for other sub-basins, and a basis has been prepared for similar studies. In this context, the sub-basins for which detailed studies are carried out are subject to evaluation as i) Devrekani-Beyler and Devrekani-Kulaksızlar, ii) Düzce-Efteni, iii) Bartın, iv) Karabük, v) Çerkeş-Akhasan and Çerkeş-Hacılar and vi) Sinop.

The map of Beyler Irrigation and Kulaksızlar Irrigation, which are within the borders of Kastamonu province and include important agricultural areas of the Western Black Sea Basin, can be seen in Fig. 5. Although a part of Kastamonu province remains within the Western Black Sea Basin borders, other parts are included within the borders of the Kızılırmak Basin. According to the trend analysis results, no trend has been observed in the Devrekani-Azdavay Sub-Basin, a sub-basin close to the Beyler and Kulaksızlar Irrigations. However, considering their contribution to the regional economy, according to the results of the studies carried out by the GDSHW. It is helpful to evaluate the drought risk in detail.

An increasing trend is observed in the region of the Düzce-Efteni Sub-Basin, where the average

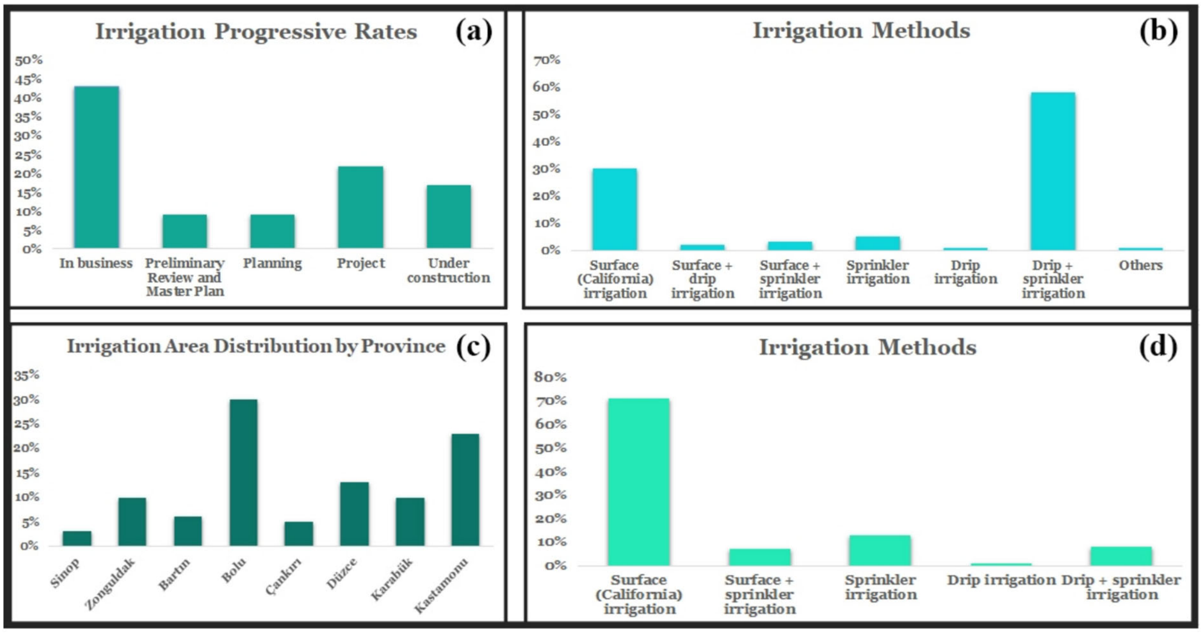

Fig. 4
Characteristics of irrigation areas

altitude is. A decreasing trend is observed in the upper basin of Düzce Plain Irrigation, which is located in Fig. 6. Düzce Plain is an important region in terms of the basin's agricultural potential. When heavy rainfall and floods are typical, October, November, December, January, February, March, and April are considered the beginning of the irrigation season.

Suppose the occupancy rate of Hasanlı Dam, which irrigates the plain, is at a maximum level with sufficient rainfall. In that case, the net irrigable agricultural area is 11,000 ha, and the amount of water that can be used for the irrigation line is 7000 lt/sec. In Düzce Plain Irrigation, classical/canal network type is used, and irrigation is done using the flood (California) method. According to the policies to be implemented, if the dam has a 100% occupancy rate, the vegetation pattern of Düzce Plain agricultural areas.

Bartın sub-basin includes Kozcağız Dam Irrigation and Kirazlıköprü Dam Irrigation areas, which are important for the region in Fig. 7. Kozcağız Dam Irrigation is at the project stage with a closed pipe irrigation network type and drip + sprinkler irrigation method. When completed, the project will be able to provide irrigation water to an area of 2148 ha. A decreasing trend was detected in the connected stream branch. Planning reports may need to be reviewed in the future. Kirazlıköprü Dam is an important regional facility providing energy production benefits and irrigation. The pattern expected to be planted with irrigation is given below.

There are important irrigation projects for the region within the Karabük Sub-Basin. Aldeğirmen Dam, Filyos Vehicle Dam Irrigation, Düzçam Pond Irrigation, Hatipoğlu Pond Irrigation, Hanköy Regulator Irrigation, Yazıboyu Pond Irrigation, Adiller Pond Irrigation, Bulduk Irrigation, Deresemail Irrigation, Tuzaklı Pond Irrigation, Gökgöz Pond Irrigation, Safranbolu Acısu Pond Irrigation are the central essential irrigation systems.

It is seen that the water potential in the Akhasan Dam Irrigation, Hacılar Dam Irrigation, Saçak Pond Irrigation, Dikenli Pond Irrigation, Atkaracalar Pond Irrigation regions located in Çerkeş Akhasan and Hacılar Sub-Basins has not changed much compared to previous years and has followed a stable course. Of the facilities, only Akhasan Dam Irrigation is in the

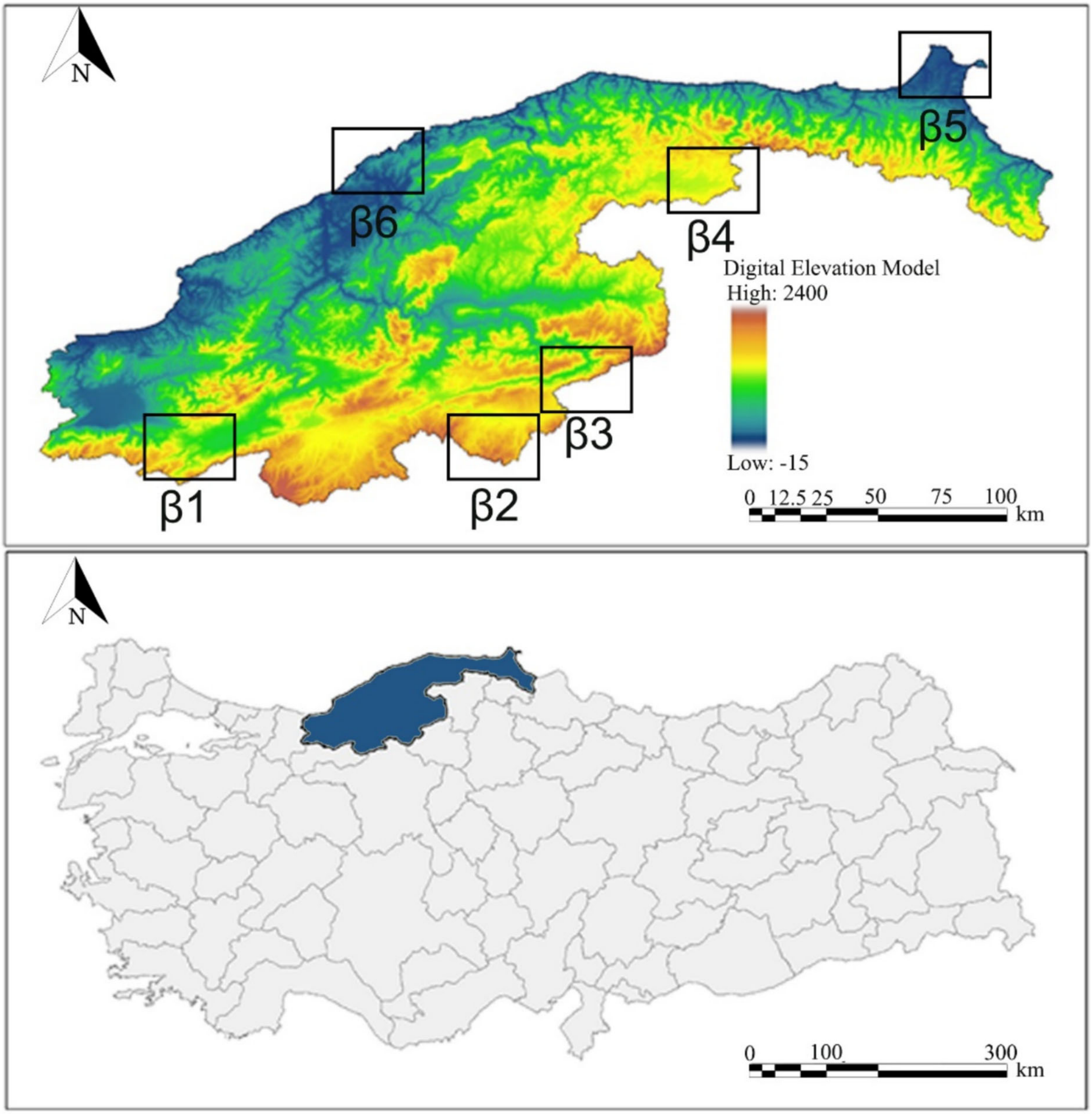

Fig. 5
Location of the sub-basins

operational phase. Considering that Saçak Pond Irrigation is in the project phase and Hacılar Dam Irrigation, Dikenli Pond Irrigation, and Atkaracalar Pond Irrigation are in the planning stages, the potential of the sub-basin can be seen. Economically and socioculturally, the region is open to development.

Balıfakı Pond and Irrigation, which is in the project phase within the borders of Sinop Sub-Basin, Karasu Plain Irrigation, and Tasmanlı Pond Irrigation, which are in the operational phase, are important agricultural areas for Sinop province. Balıfakı Pond and Irrigation will be operated by drip + sprinkler irrigation method. Karasu Plain Irrigation is irrigated

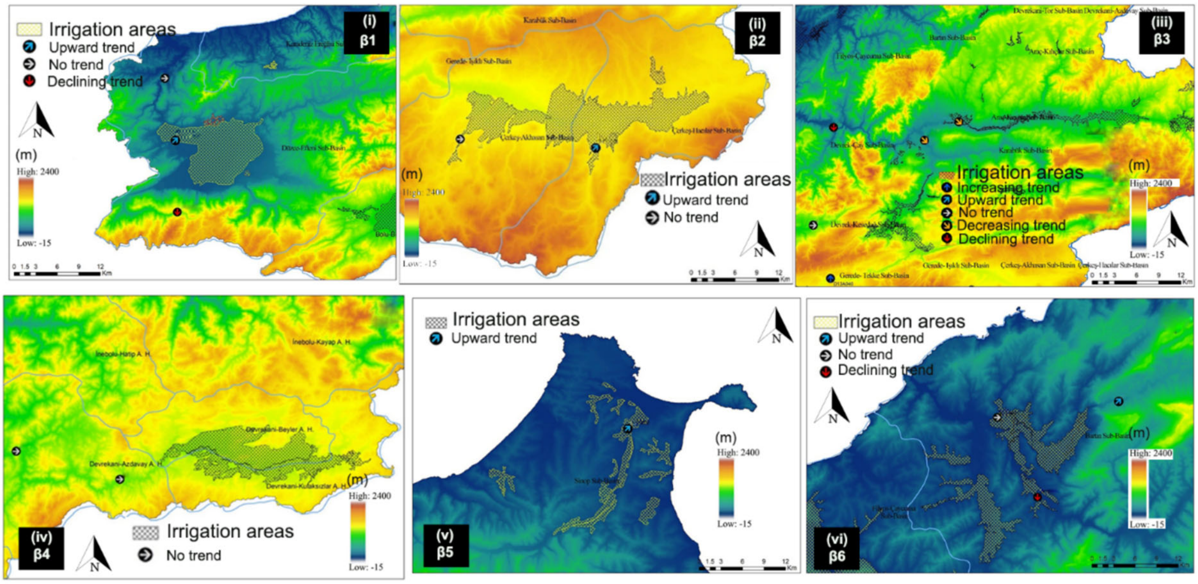

Fig. 6
Trends of sub-basins (i) β1: Düzce Efteni, (ii) β2: Çerkeş-Akhasan, (iii) β3: Karabük, (iv) β4: Devrekani-Beyler (v) β5: Sinop and (vi) β6: Bartın sub-basins (Aydin et al., 2025)

by the flood + sprinkler method. Taşmanlı Pond is operated by the release (California) method. According to the results of the analysis, an increasing trend in minimum flows was detected. In the future, rice, which has higher economic returns and is suitable for the region's climate, will be produced. It is beneficial to focus on these products.

3.3. *Characterization of Irrigation Plant Pattern*

The income loss analysis for irrigated and dry farming situations for the Devrekani Sub-Basin sample, which is within the borders of the Western Black Sea Basin, has been roughly carried out below. Beyler Dam Irrigation, one of the irrigation areas, has a net irrigation area of 5178 ha. Although the network type of Beyler Dam Irrigation is a classical (trapezoidal) type, irrigation is carried out by the release (California) method. Below are the plant pattern rates showing the agricultural activity in the Beyler Irrigation Area. The irrigation area of Kulaksızlar Dam covers an area of 5128 ha. In Kulaksızlar Dam Irrigation, a piped network type is used, and irrigation is done with a closed system sprinkler method. The irrigation area is 2755 ha and was designed according to the closed irrigation network type and drip + sprinkler irrigation method. The dam has been put into operation, and irrigation facility construction continues in Table 3.

3.4. *Spatial Structure of Agricultural Areas*

Land use and land cover changes are dynamic processes that significantly impact the Earth's surface, and understanding these changes is essential for effective environmental monitoring and sustainable land management (Isinkaralar & Isinkaralar, 2025; Viana & Rocha, 2020). Remote sensing and GIS techniques were employed to identify land use and land cover classes and their spatial distribution, determine the trend, nature, location, and magnitude of forest cover change, and prepare maps of forest-cover change in different periods (Sajjad et al., 2015). The supervised image classification technique was applied to Landsat satellite images, enabling the identification of key classes such as agriculture, forest, barren land, snow, and water. These techniques are used to analyze land cover and landscape changes (Isinkaralar et al., 2024; Sari & Pamungkas, 2019). Land cover types relevant to specific regions

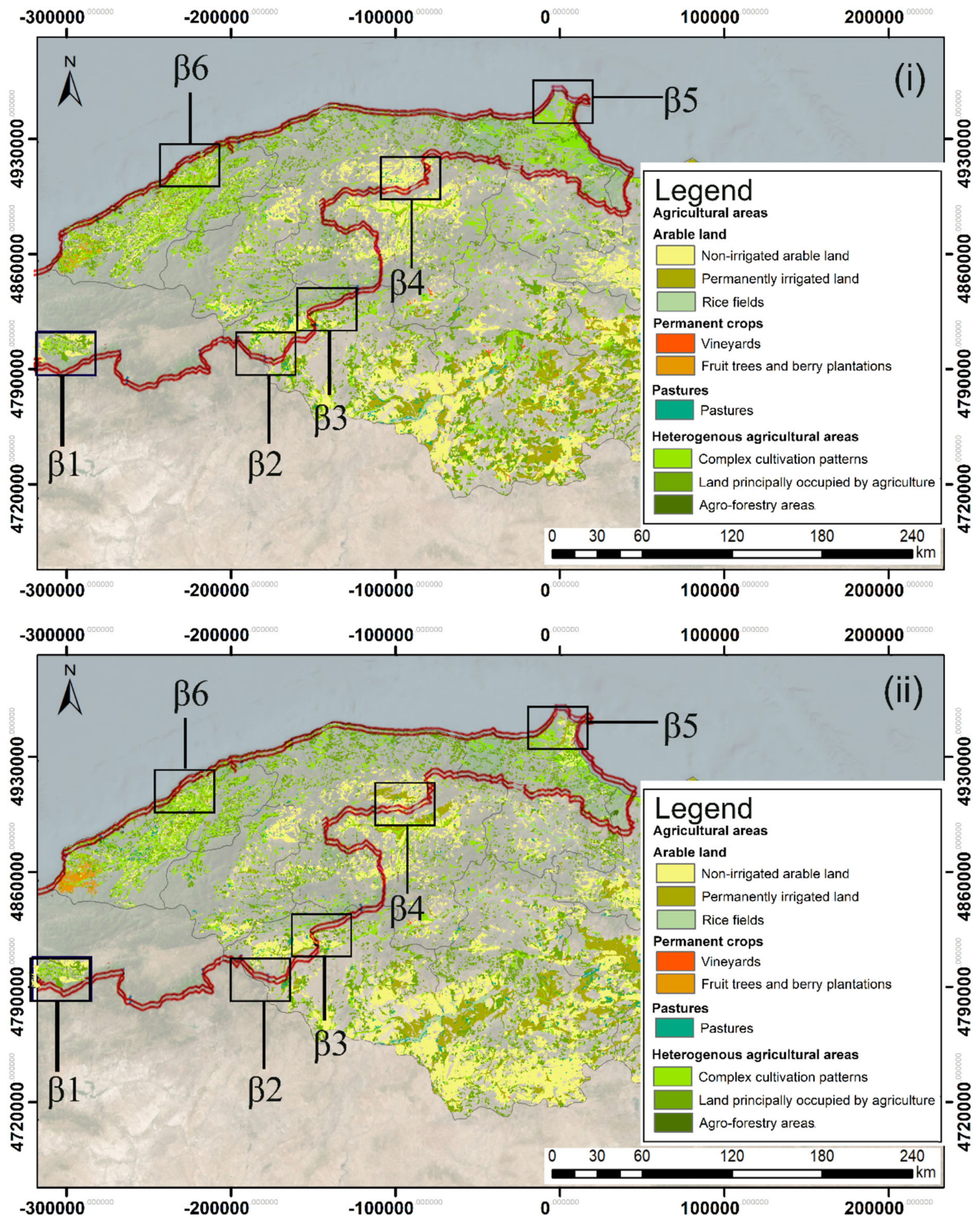

Fig. 7
Spatial structure of selected agricultural areas via CORINE database (i) 1990 and (ii): 2008

are often reclassified into broader categories to facilitate analysis and interpretation. These include grouping them into broadleaf forests, needleleaf forests, mixed forests, shrublands, meadows, farmlands, deserts, and water bodies.

The study utilized the CORINE land cover datasets to examine the changes and dynamics of grassland ecosystems in the West Black Sea basin, considering land cover changes and transitions between different grassland and other land cover types from 1990 to 2018 via the ArcGIS 10.4.1 program. The CORINE land cover classification system comprises nine distinct land cover classes for agricultural areas at the third hierarchical level of the comprehensive nomenclature in Fig. 7. The land principally occupied by agriculture areas increased by 26.54% between 1990–2008 in the basin. On the other hand, Non-irrigated arable land decreased by 10.47%, Permanently irrigated land decreased by 4.80%, and Complex cultivation patterns decreased by 12.55%. It can be said that irrigated and non-irrigated lands turned into agricultural-oriented structures at the basin scale. While it showed a complex cultivation pattern feature in 1990, in 2008, non-irrigated arable land increase in β3 and β5 is critical for agricultural irrigation. In β6, it is observed that permanently irrigated areas have turned into complex cultivation patterns. In the β2 sub-basin, losses in pastures are seen. It is observed that non-irrigated arable areas are converted into permanently irrigated areas in the β4 sub-basin.

4. Discussion

Drought is a multidimensional issue that impacts numerous aspects of society and the natural world. Its definition can vary based on different perspectives, including meteorological, agricultural, hydrological, or socioeconomic, each with distinct features and criteria. (O'Farrell et al., 2010) Meteorological drought is identified by an extended period of reduced rainfall, which can result in the exhaustion of surface and underground water supplies, a situation referred to as hydrological drought (Bae et al., 2019). Agricultural drought relates to reducing soil water content and its effects on crop yields, while socioeconomic drought encompasses the broader economic and social implications of water shortages (Liu et al., 2016). Drought's effects extend beyond a single area, encompassing various sectors such as regional growth, disaster risk mitigation, and climate change adaptation plans (Marengo et al., 2022). Droughts can disrupt agricultural output, affecting food availability and economic well-being in impacted areas. Water resources may also be strained, resulting in disputes and difficulties for nearby populations. Additionally, droughts can intensify natural calamities like wildfires and dust storms, posing considerable risks to public welfare and the ecosystem (Zubieta et al., 2021). A holistic, multi-sector strategy is necessary to enhance resilience and adjust to shifting climate patterns to tackle the diverse consequences of drought.

Drought can severely affect regional development in regions with limited water resources, particularly arid and semi-arid areas where agriculture plays a crucial economic role. The consequences of drought include decreased farm output, reduced employment opportunities, and heightened poverty levels, which impede economic progress and regional growth. (Haghighi et al., 2020) Furthermore, water scarcity resulting from drought can intensify existing social disparities, as underprivileged communities often lack the resources to manage its adverse effects effectively. In the face of climate change challenges, resilience plays a vital role in agricultural systems. This concept refers to a system's capacity to adapt and sustain its essential functions and output when confronted with disruptions, such as drought (Wable et al., 2019). For semi-arid agricultural watersheds, where water scarcity is a significant issue, it is essential to identify the elements that enhance resilience to ensure sustainable food production. These elements may encompass on-site water management techniques, crop variety, and the implementation of drought-tolerant plant varieties, among other factors (Bharambe et al., 2023). By assessing the resilience of these systems, scientists and decision-makers can formulate approaches to bolster agricultural communities' ability to endure and bounce back from drought occurrences, fostering long-term food security in a changing climate landscape. This study investigates the drought resilience of a semi-arid agricultural watershed, emphasizing the impact of climate risk and regional adaptation tactics. The research examines the factors contributing to the watershed's capacity to adjust and maintain productivity when faced with drought, a significant challenge in this water-scarce area. The study aims to guide strategies for sustainable food production and climate change adaptation in comparable semi-arid agricultural regions by identifying the key drivers of resilience. The Western Black Sea Basin, a semi-arid area, faces considerable agricultural challenges due to the rising frequency and intensity of drought conditions caused by climate change (Din et al., 2022; Minh et al., 2024). Anticipated changes, including milder and wetter winters alongside hotter and drier summers, are expected to modify the frequency and severity of water-related risks, posing substantial threats to primary food production in the region (Uwimbabazi et al., 2022). Exploring and implementing various strategies to improve the resilience and adaptive capacity of the region's agricultural systems to these growing climate risks is crucial to safeguard food security and promote sustainable agricultural development. This research paper offers a thorough analysis of the current understanding of climate change impacts on the Western Black Sea Basin's semi-arid agricultural watershed. It explores a range of potential adaptation strategies to build resilience in response to these critical challenges to ensure food security and sustainable agricultural development in the region.

5. *Conclusion*

In this study conducted to evaluate the impact of drought in the Western Black Sea Basin, it was observed that the risk of drought is increasing in the middle parts of the Karabük Lower Basin, in the parts of the Düzce Plain close to the upper basin and a part of Kirazlıköprü irrigation. Measures deemed appropriate to reduce the risk of drought in these regions are given below.

- Developing and supporting correct agricultural practices will enable savings in irrigation water, which has a significant share in water use. Policies should be produced, and support packages should be created to switch to more effective and cost-saving irrigation methods. It is necessary to provide training and practical training to people, institutions, and organizations that do irrigation.
- In agricultural activities, each plant has different water requirements. The optimum amount of water for plants should be determined in the light of scientific data, and the ideal amount of water should be given to the agricultural areas, considering the difference in the amount of water the agricultural areas receive naturally. Necessary training activities should be organized to use sufficient and correct water, and farmers should be given practical training.
- Par31Considering that irrigation water evaporates during daytime irrigation and its practical effect decreases, the issue of switching to night irrigation for suitable plant species should be examined. In order to encourage this situation, it would be beneficial to make pricing more advantageous for water use at night.

5.1. *Final remarks*

The results obtained from the analyses made for all flow observation stations in the Western Black Sea Basin that were deemed appropriate overlapped with irrigation areas to evaluate the drought effect. The following determinations were made for cases where the irrigation areas and the flow observation stations are located in the exact location:

- No significant trend was observed in annual minimum flows in the region where the Devrekani-Beyler Sub-Basin and Devrekani-Kulaksızlar Sub-Basin are located, which are the sub-basins of the Devrekani-Gerze Basin. It cannot be said that the drought effect is increasing or decreasing for the Beyler and Kulaksızlar irrigation areas located in the sub-basins.
- In the Düzce-Efteni Sub-Basin, a sub-basin of the Melen Stream Basin, a decreasing trend was detected in the upper basin region where the altitude is high, and an increasing trend was detected in the coastal areas. An increase in the drought risk of agricultural areas close to the

Düzce Plain's upper basin has been detected. It has been observed that the drought risk is decreasing in the lower parts of the basin.

- Various results were obtained at flow observation stations located in different tributaries in the Bartın Sub-Basin. In the regions of Kirazlıköprü irrigation, there is an increasing trend, and the risk of drought is decreasing.
- In the middle parts of the Karabük Sub-Basin, a sub-basin of the Filyos Basin, a decreasing trend was detected, and the risk of drought is increasing for the central parts of the sub-basin.
- In the regions where Çerkeş-Akhasan and Çerkeş-Hacılar Sub-Basins are located in the upper parts of the Filyos Basin, no significant trend was observed in annual minimum flows in the Çerkeş-Akhasan Sub-Basin. It cannot be said that the drought effect is increasing or decreasing for the irrigation areas in the sub-basin. In the Çerkeş-Hacılar Sub-Basin, an increasing trend in minimum flows was detected. It has been observed that the risk of drought in the sub-basin is decreasing.
- An increasing trend in annual minimum flows has been observed for the region where the Sinop Basin, a sub-basin of the Devrekani-Gerze Basin, is located. It has been determined that the drought risk has decreased for the Balıfakı Irrigation, Karasu Plain Irrigation, and Tasmanlı Irrigation areas located in the basin.

5.2. Research limitation and future studies

This research has been prepared within the scope of some sub-basins selected within a basin and does not cover the entire basin area. The characteristic features of the selected basins, trend indicators, and sectoral effectiveness of the basins have been evaluated through agricultural land changes depending on the years. However, land cover information up to 2008 could be reached from the CORINE database, which provides data in agricultural detail. This research can be interpreted in more detail by basing it on current data and real field studies. However, future studies can be expanded on agricultural yield and profitability apart from agricultural land changes. It can be addressed in many different dimensions, especially from energy production to tourism potential, as mentioned in the Introduction section. In summary, it cannot be limited to the agricultural sector.

Acknowledgements

This study is produced from the MSc thesis titled as " The evaluation of the drought effect in the Western Black Sea basin by using the trend analysis techniques" conducted at Kastamonu University, Kastamonu, Türkiye Graduate School of Natural and Applied Sciences, Civil Engineering MSc Programme.

Authors' Contributions Hakan Aydin: Processing analysis, data interpretation, writing original draft, and data curation. Kasım Yenigün: Supervision, Processing analysis, data interpretation, writing original draft, and data curation. Oznur Isinkaralar: Data interpretation, writing editing, data curation, processing analysis and interpretation. Kaan Isinkaralar: Data interpretation, writing editing.

Funding

There is no financial support and commercial support.

Data Availability

No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics Approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

References

Alemu, Z. A., & Dioha, M. O. (2020). Climate change and trend analysis of temperature: The case of Addis Ababa, Ethiopia. *Environmental Systems Research, 9*, 1–15. https://doi.org/10.1186/s40068-020-00190-5

Aydin, H., Yenigun, K., Isinkaralar, O., & Isinkaralar, K. (2025). Hydrological low flow and overlapped trend analysis for drought assessment in Western Black Sea Basin. *Natural Hazards, 121*(2), 1833–1863. https://doi.org/10.1007/s11069-024-06880-y

Bae, H., Ji, H., Lim, Y. J., Ryu, Y., Kim, M. H., & Kim, B. J. (2019). Characteristics of drought propagation in South Korea: Relationship between meteorological, agricultural, and hydrological droughts. *Natural Hazards, 99*(1), 1–16. https://doi.org/10.1007/s11069-019-03676-3

Baudoin, M. A., Vogel, C., Nortje, K., & Naik, M. (2017). Living with drought in South Africa: Lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction, 23*, 128–137. https://doi.org/10.1016/j.ijdrr.2017.05.005

Bharambe, K. P., Shimizu, Y., Kantoush, S. A., Sumi, T., & Saber, M. (2023). Impacts of climate change on drought and its consequences on the agricultural crop under worst-case scenario over the Godavari River Basin. *India. Climate Services, 32*, Article 100415. https://doi.org/10.1016/j.cliser.2023.100415

Bonaccorso, B., Bordi, I., Cancelliere, A., Rossi, G., & Sutera, A. (2003). Spatial variability of drought: An analysis of the SPI in Sicily. *Water Resources Management, 17*, 273–296. https://doi.org/10.1023/A:1024716530289

Carrão, H., Naumann, G., & Barbosa, P. (2018). Global projections of drought hazard in a warming climate: A prime for disaster risk management. *Climate Dynamics, 50*(5), 2137–2155. https://doi.org/10.1007/s00382-017-3740-8

Cunha, A. P. M., Zeri, M., Deusdará Leal, K., Costa, L., Cuartas, L. A., Marengo, J. A., et al. (2019). Extreme drought events over Brazil from 2011 to 2019. *Atmosphere, 10*(11), 642. https://doi.org/10.3390/atmos10110642

Din, M. S. U., Mubeen, M., Hussain, S., Ahmad, A., Hussain, N., Ali, M. A., et al. (2022). World nations priorities on climate change and food security. Building climate resilience in agriculture: theory, practice and future perspective, 365–384. https://doi.org/10.1007/978-3-030-79408-8_22

Gasmi, H., Burte, J., Martins, E. S. P. R., Younsi, S., Morardet, S., & Kuper, M. (2024). A participatory approach for characterizing the resilience of rural water supply systems in semi-arid areas. *Regional Environmental Change, 24*(1), 12. https://doi.org/10.1007/s10113-023-02161-9

González Tánago, I., Urquijo, J., Blauhut, V., Villarroya, F., & De Stefano, L. (2016). Learning from experience: A systematic review of assessments of vulnerability to drought. *Natural Hazards, 80*, 951–973. https://doi.org/10.1007/s11069-015-2006-1

Han, J., & Singh, V. P. (2023). A review of widely used drought indices and the challenges of drought assessment under climate change. *Environmental Monitoring and Assessment, 195*(12), 1438. https://doi.org/10.1007/s10661-023-12062-3

Hayes, M. (2006). *Drought Indices.* Van Nostrand's Scientific Encyclopedia.

Hayes, M. J., Svoboda, M. D., Wiihite, D. A., & Vanyarkho, O. V. (1999). Monitoring the 1996 drought using the standardized precipitation index. *Bulletin of the American Meteorological Society, 80*(3), 429–438. https://doi.org/10.1175/1520-0477(1999)080%3c0429:MTDUTS%3e2.0.CO;2

Isinkaralar, O., & Isinkaralar, K. (2025). Sustainable urban growth boundaries for ecological protection via 2046 models of İzmir. *Spatial Information Research, 33*(1), 1–13. https://doi.org/10.1007/s41324-024-00601-0

Isinkaralar, O., Sharifi, A., & Isinkaralar, K. (2024). Assessing spatial thermal comfort and adaptation measures for the Antalya basin under climate change scenarios. *Climatic Change, 177*(8), 118. https://doi.org/10.1007/s10584-024-03781-8

Ji, Y., Zhou, G., Wang, S., & Wang, L. (2015). Increase in flood and drought disasters during 1500–2000 in Southwest China. *Natural Hazards, 77*, 1853–1861. https://doi.org/10.1007/s11069-015-1679-9

Lana, X., Serra, C., & Burgueño, A. (2001). Patterns of monthly rainfall shortage and excess in terms of the standardized precipitation index for Catalonia (NE Spain). *International Journal of Climatology: A Journal of the Royal Meteorological Society, 21*(13), 1669–1691. https://doi.org/10.1002/joc.697

Lankford, B., Pringle, C., McCosh, J., Shabalala, M., Hess, T., & Knox, J. W. (2023). Irrigation area, efficiency and water storage mediate the drought resilience of irrigated agriculture in a semi-arid catchment. *Science of the Total Environment, 859*, Article 160263. https://doi.org/10.1016/j.scitotenv.2022.160263

Liu, X., Zhu, X., Pan, Y., Li, S., Liu, Y., & Ma, Y. (2016). Agricultural drought monitoring: Progress, challenges, and prospects. *Journal of Geographical Sciences, 26*, 750–767. https://doi.org/10.1007/s11442-016-1297-9

Lloyd-Hughes, B., & Saunders, M. A. (2002). A drought climatology for Europe. *International Journal of Climatology, 22*(13), 1571–1592. https://doi.org/10.1002/joc.846

Mahmoud, S. H., Gan, T. Y., & Zhu, D. Z. (2023). Impacts of climate change and climate variability on water resources and drought in an arid region and possible resiliency and adaptation measures against climate warming. *Climate Dynamics, 61*(9), 4079–4105. https://doi.org/10.1007/s00382-023-06795-7

Marengo, J. A., Galdos, M. V., Challinor, A., Cunha, A. P., Marin, F. R., Vianna, M. D. S., et al. (2022). Drought in Northeast Brazil: A review of agricultural and policy adaptation options for food security. *Climate Resilience and Sustainability, 1*(1), 17. https://doi.org/10.1002/cli2.17

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th conference on applied climatology (Vol. 17, No. 22, pp. 179–183).

Mehta, P. (2024). The Impact of Climate Change on the Environment, Water Resources, and Agriculture: A Comprehensive

Review. *Climate, Environment and Agricultural Development A Sustainable Approach towards Society*. https://doi.org/10.1007/978-981-97-8363-2_12

Meresa, H. K. (2020). River flow characteristics and changes under the influence of varying climate conditions. *Natural Resource Modeling, 33*(1), Article e12242. https://doi.org/10.1111/nrm.12242

Min, S. K., Kwon, W. T., Park, E. H., & Choi, Y. (2003). Spatial and temporal comparisons of droughts over Korea with East Asia. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 23*(2), 223–233. https://doi.org/10.1002/joc.872

Minh, H. V. T., Kumar, P., Van Toan, N., Nguyen, P. C., Van Ty, T., Lavane, K., et al. (2024). Deciphering the relationship between meteorological and hydrological drought in Ben Tre province. *Vietnam. Natural Hazards, 120*(6), 5869–5894. https://doi.org/10.1007/s11069-024-06437-z

Muzammal, H., Zaman, M., Safdar, M., Adnan Shahid, M., Sabir, M. K., Khil, A., et al. (2024). Climate Change Impacts on Water Resources and Implications for Agricultural Management. In Transforming Agricultural Management for a Sustainable Future: Climate Change and Machine Learning Perspectives (pp. 21–45). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-63430-7_2

O'Farrell, P. J., Reyers, B., Le Maitre, D. C., Milton, S. J., Egoh, B., Maherry, A., et al. (2010). Multi-functional landscapes in semi arid environments: implications for biodiversity and ecosystem services. *Landscape Ecology, 25*, 1231–1246. https://doi.org/10.1007/s10980-010-9495-9

Orimoloye, I. R., Belle, J. A., Olusola, A. O., Busayo, E. T., & Ololade, O. O. (2021). Spatial assessment of drought disasters, vulnerability, severity and water shortages: A potential drought disaster mitigation strategy. *Natural Hazards, 105*, 2735–2754. https://doi.org/10.1007/s11069-020-04421-x

Orimoloye, I. R., Olusola, A. O., Belle, J. A., Pande, C. B., & Ololade, O. O. (2022). Drought disaster monitoring and land use dynamics: Identification of drought drivers using regression-based algorithms. *Natural Hazards, 112*(2), 1085–1106. https://doi.org/10.1007/s11069-022-05219-9

Ourarhi, S., Barkaoui, A. E., & Zarhloule, Y. (2022). Assessment of the agricultural intensification impact on groundwater quality: A case study of the Triffa Plain. *Water, Air, & Soil Pollution, 233*(8), 342. https://doi.org/10.1007/s11270-022-05810-7

Ourarhi, S., Barkaoui, A. E., & Zarhloule, Y. (2024a). Mapping groundwater's susceptibility to pollution in the Triffa Plain (Eastern Morocco) using a modified method based on the DRASTIC, RIVA, and AHP models. *Environment, Development and Sustainability, 26*(6), 15535–15555. https://doi.org/10.1007/s10668-023-03262-5

Ourarhi, S., Barkaoui, A. E., & Zarhloule, Y. (2024b). Enhanced methods for evaluating aquifer susceptibility: Incorporating static and dynamic vulnerability assessments. *Water Resources Management, 38*(8), 2791–2810. https://doi.org/10.1007/s11269-024-03792-1

Ourarhi, S., Barkaoui, A. E., Zarhloule, Y., Kadiri, M., & Bouiss, H. (2024c). Groundwater vulnerability assessment in the Triffa Plain based on GIS combined with DRASTIC, SINTACS, and GOD models. *Modeling Earth Systems and Environment, 10*(1), 619–629. https://doi.org/10.1007/s40808-023-01801-7

Ourarhi, S., Kadiri, M., Barkaoui, A. E., Bouiss, H., Amar, I., & Zarhloule, Y. (2024d). Assessment of risk intensity in the triffa plain aquifer: Integration of hazard quantification, land use analysis, dynamic vulnerability GCITF, and DRASTIC method. *Groundwater for Sustainable Development, 26*, Article 101291. https://doi.org/10.1016/j.gsd.2024.101291

Palmer, W. C. (1965). Meteorological drought (Vol. 30). US Department of Commerce, Weather Bureau.

Sajjad, A., Hussain, A., Wahab, U., Adnan, S., Ali, S., Ahmad, Z., & Ali, A. (2015). Application of Remote Sensing and GIS in Forest Cover Change in Tehsil Barawal, District Dir. *Pakistan. American Journal of Plant Sciences, 6*(9), 1501. https://doi.org/10.4236/ajps.2015.69149

Salimi, H., Asadi, E., & Darbandi, S. (2021). Meteorological and hydrological drought monitoring using several drought indices. *Applied Water Science, 11*, 1–10. https://doi.org/10.1007/s13201-020-01345-6

Sari, S. P., & Pamungkas, A. (2019). Monitoring of land cover changes in mine environment. https://doi.org/10.2991/icoma-18.2019.50

Savari, M., Damaneh, H. E., & Damaneh, H. E. (2022). Drought vulnerability assessment: Solution for risk alleviation and drought management among Iranian farmers. *International Journal of Disaster Risk Reduction, 67*, Article 102654. https://doi.org/10.1016/j.ijdrr.2021.102654

Shah, D., Mishra Lloyd-Hughes, B., & Saunders, M. A. (2002). A drought climatology for Europe. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 22*(13), 1571–1592. https://doi.org/10.1002/joc.846

Shah, D., & Mishra, V. (2020). Integrated Drought Index (IDI) for drought monitoring and assessment in India. *Water Resources Research, 56*(2), e2019WR026284. https://doi.org/10.1029/2019WR026284

Sharma, A., Sharma, D., & Panda, S. K. (2022). Assessment of spatiotemporal trend of precipitation indices and meteorological drought characteristics in the Mahi River basin. *India. Journal of Hydrology, 605*, Article 127314. https://doi.org/10.1016/j.jhydrol.2021.127314

Spinoni, J., Barbosa, P., De Jager, A., McCormick, N., Naumann, G., Vogt, J. V., et al. (2019). A new global database of meteorological drought events from 1951 to 2016. *Journal of Hydrology: Regional Studies, 22*, 100593. https://doi.org/10.1016/j.ejrh.2019.100593

Svoboda, P., Janska, A., Spiwok, V., Prášil, I. T., Kosova, K., Vitamvas, P., & Ovesna, J. (2016). Global scale transcriptional profiling of two contrasting barley genotypes exposed to moderate drought conditions: Contribution of leaves and crowns to water shortage coping strategies. *Frontiers in Plant Science, 7*, 1958. https://doi.org/10.3389/fpls.2016.01958

Tirivarombo, S. O. D. E., Osupile, D., & Eliasson, P. (2018). Drought monitoring and analysis: Standardised precipitation evapotranspiration index (SPEI) and standardised precipitation index (SPI). *Physics and Chemistry of the Earth, Parts a/b/c, 106*, 1–10. https://doi.org/10.1016/j.pce.2018.07.001

TURKSTAT, (Turkish Statistical Institute) (2020). https://www.tuik.gov.tr/Home/Index. Access date: May 14, 2020.

Uwimbabazi, J., Jing, Y., Iyakaremye, V., Ullah, I., & Ayugi, B. (2022). Observed changes in meteorological drought events during 1981–2020 over Rwanda, East Africa. *Sustainability, 14*(3), 1519. https://doi.org/10.3390/su14031519

Viana, C. M., & Rocha, J. (2020). Evaluating dominant land use/land cover changes and predicting future scenario in a rural region using a memoryless stochastic method. *Sustainability, 12*(10), 4332. https://doi.org/10.3390/su12104332

Wable, P. S., Jha, M. K., & Shekhar, A. (2019). Comparison of drought indices in a semi-arid river basin of India. *Water Resources Management, 33*, 75–102. https://doi.org/10.1007/s11269-018-2089-z

Wambua, R. M., Mutua, B. M., & Raude, J. M. (2015). Spatio-temporal drought characterization for the Upper Tana River Basin, Kenya using the Standardized Precipitation Index (SPI). *World Journal of Environmental Engineering, 3*(4), 111–120. https://doi.org/10.12691/wjee-3-4-2

Wang, Q., Liu, Y. Y., Zhang, Y. Z., Tong, L. J., Li, X., Li, J. L., & Sun, Z. (2019). Assessment of spatial agglomeration of agricultural drought disaster in China from 1978 to 2016. *Scientific Reports, 9*(1), 14393. https://doi.org/10.1038/s41598-019-51042-x

Wang, Z. L., Wang, J., & Wang, J. S. (2015). Risk assessment of agricultural drought disaster in southern China. *Discrete Dynamics in Nature and Society, 2015*, 1–8. https://doi.org/10.1155/2015/172919

Wilhite, D. A., & Easterling, W. G. (2019). Drought policy: Toward a plan of action. In Planning For Drought (pp. 573–583). Routledge.

Willeke, G., Hosking, J. R. M., Wallis, J. R., & Guttman, N. B. (1994). The national drought atlas. Institute for water resources report, 94.

WMO (World Meteorological Organization), (2012) Standardized precipitation index user guide (M Svoboda, M Hayes and D Wood), Geneva.

Zhang, X., Hao, Z., Singh, V. P., Zhang, Y., Feng, S., Xu, Y., & Hao, F. (2022). Drought propagation under global warming: Characteristics, approaches, processes, and controlling factors. *Science of the Total Environment, 838*, Article 156021. https://doi.org/10.1016/j.scitotenv.2022.156021

Zubieta, R., Molina-Carpio, J., Laqui, W., Sulca, J., & Ilbay, M. (2021). Comparative analysis of climate change impacts on meteorological, hydrological, and agricultural droughts in the lake Titicaca basin. *Water, 13*(2), 175. https://doi.org/10.3390/w13020175

(Received August 9, 2024, revised April 17, 2025, accepted July 18, 2025, Published online August 6, 2025)