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Assessment of a Survivability Index for Drought Management in River Basins

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Abstract
The adverse effects of droughts have been a struggle for humanity from an early age and are still truly relevant problems. The efforts to understand, prevent, and mitigate the drought have motivated researchers to develop indicators, indices, and action plans for its management. The presented paper suggests a novel index entitled Survivability from Droughts Index (SDI) to evaluate quantitative and qualitative indicators that represent the WEF Nexus system as well as the pillars of sustainability: economy, social, institutional, and environmental aspects. The index consists of four main sub-indices, namely, perception, vulnerability, adaptability, and recoverability. Each of these defines the stages when engaging with drought. The SDI encapsulates the economic survivability capacity of the agricultural sector at the scale of a river basin, in the case of the Gediz River Basin (GBR), Türkiye. In GBR, the calculated SDI of a relatively wet year, 1982, is determined as 0.38. While in a relatively drier period, namely 1991–1992, the value drops to 0.31, in a recent year, 2023, the value increases to 0.48. The results of the paper both validate the historical droughts and indicate that survivability from droughts can be achieved by actions to improve the sub-indices of SDI. The overall framework of SDI demands various data and engagement with stakeholders, but the results represent a strong connection with the analyzed case study. The presented outcomes are most beneficial to the decision-makers to detect and prioritize their measurements, such as new investments, insurance policies in drought-vulnerable areas within the analyzed extent.

Keywords Drought Index · Risk Assessment · WEF nexus · Hydrologic Modelling · Water Resources Management

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1 Introduction

Throughout history, droughts have been recognized as severe disasters affecting numerous people globally (Willhite et al. 2007). Enhanced by anthropogenic activities such as climate change, population growth, and industrial development, droughts have become increasingly severe and prolonged (Mishra and Singh 2010). Research has developed various indices to assess drought, including the Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI), incorporating variables such as soil moisture and temperature (Palmer 1965, 1968; Shafer and Dezman 1982; McKee et al. 1993; Vicente-Serrano et al. 2010).

Subsequent studies introduced qualitative dimensions like vulnerability, defined as susceptibility to damage from hazards (Tsakiris 2014), and indicators measuring water stress, adaptive capacity, and socio-economic resilience (Gleick 1990; Raskin et al. 1997; Babel and Wahid 2009; Pandey et al. 2011). Hydrologists typically focus on physical water resource assessments, but drought impacts extend beyond hydrology, affecting socio-economic and environmental systems significantly. The emerging concept of social-hydrology integrates human factors into hydrological studies, underscoring how policy responses and human decisions influence resilience and vulnerability to drought (Loucks 2015, 2021).

In recent years, there has been a growing call for more integrated drought assessment frameworks that account for these complex interrelations. Studies have shown that user perceptions and local experiences significantly influence how drought indicators are interpreted and acted upon, particularly in regions with diverse climate regimes (Kchouk et al. 2022). Additionally, recent findings highlight discrepancies between meteorological indicators and their actual impacts on water and food security, calling into question the adequacy of single-dimensional metrics (Heim et al. 2023). For Mediterranean environments in particular, multidimensional assessment tools are increasingly emphasized as essential for capturing the full spectrum of drought-related vulnerabilities and responses (Tramblay et al. 2020).

Building on these insights, this study develops the Survivability from Droughts Index (SDI), combining social, economic, environmental, and water-related indicators into four comprehensive sub-indices: perception (awareness of drought), adaptability (capacity to mitigate drought impacts), vulnerability (capacity to endure drought conditions), and recoverability (ability for economic recovery post-drought). The SDI framework is distinctively stakeholder-driven, incorporating qualitative data directly from farmers via Value-Attitude-Perception (VAP) surveys, complemented by stakeholder validation workshops within the PRIMA-funded bilateral project between Xjenza Malta and The Scientific and Technological Research Council of Türkiye (TUBITAK) entitled “UNIMED” (TUBITAK Project No:122N412).

Furthermore, the SDI aligns explicitly with the WEFE Nexus (Water, Energy, Food, Ecosystem) and pillars of sustainability (economic, social, environmental, institutional), promoting proactive water security strategies (Harmancioglu et al. 2020). By applying the SDI framework to the Gediz River Basin, specifically targeting the Menemen Plain and Lake Marmara regions, this study illustrates its practical value in identifying drought-vulnerable areas, thus informing targeted drought management and effective mitigation plans for decision-makers and stakeholders.

2 Materials and methods

2.1 Study Area

Gediz River Basin, located in Western Türkiye, covers an area of 17,034 km² (Fig. 1). The main river, Gediz, is approximately 350 km long and has several tributaries, many drying up in summer (Aksoy 2020). Key lakes include Marmara, Karagöl, Gölcük, and Sazlı, while major dams are Demirköprü, Avşar, and Buldan. The basin experiences a semi-arid Mediterranean climate, with annual precipitation averaging around 578.5 mm but varying between 400 mm in the lower plains to over 1000 mm in upstream mountainous areas. Rainfall predominantly occurs from November to March, whereas summers are typically hot and dry, intensifying the mismatch between water supply and agricultural demand.

The water resources infrastructure of the basin is composed of several key engineering structures. The Demirköprü Dam, constructed on the main branch of the Gediz River, plays a central role in regulating flow and supplying irrigation water. Supplementary storage is provided by the Avşar and Buldan dams, while the Gördes Dam was developed to augment supply but has not performed as intended due to substantial leakage losses. Water distribution in the basin relies on both open canal systems and groundwater abstraction.

Since the 1990 s, increased population, industrial growth, and climate change have significantly reduced water availability and quality, particularly affecting Menemen Plain. Over-reliance on groundwater has led to declining groundwater levels, seawater intrusion, and increased soil salinity. Lake Marmara, a previously vital wetland and water resource, has completely dried up due to the ineffective implementation of Gördes Dam and related conveyance infrastructure. This situation severely impacts Menemen Plain, exacerbating its vulnerability to drought and water scarcity. Consequently, Menemen Plain (high cotton production) and Lake Marmara (responsible for 80% of Türkiye's Sultanas grape exports) were selected as focal areas for this study, with local stakeholder input significantly shaping qualitative aspects of the research.

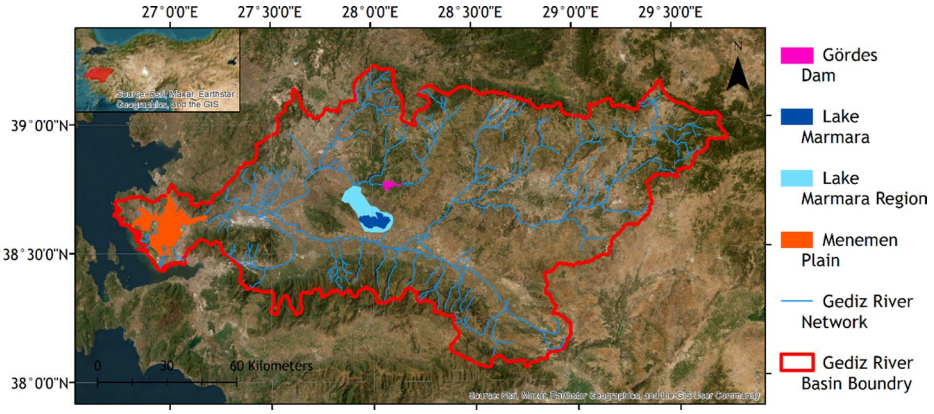

Fig. 1 Gediz River Basin

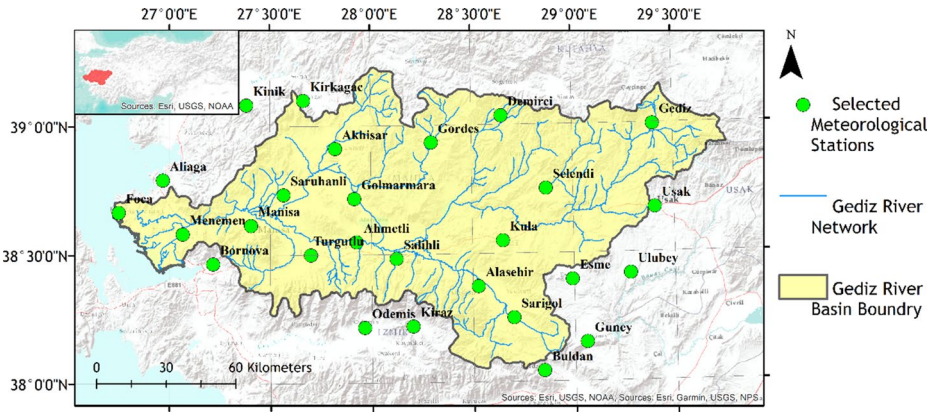

Fig. 2 Gediz River Basin and selected meteorological stations

Table 1 Comparison of long-term vs. year 2023 precipitation and temperature values at the main meteorological stations of Gediz river basin

Station	Average long-term Precipitation (mm)	Average year 2023 Precipitation (mm)	Change (%)	Average long-term Temperature (°C)	Average year 2023 Temperature (°C)	Change (°C)
Manisa	486.47	661.70	36.0	16.88	18.15	1.27
Akhisar	585.06	745.20	27.4	16.95	16.68	−0.27
Alaşehir	470.77	478.20	1.6	16.55	17.33	0.78
Güney	539.25	543.80	0.8	13.79	15.06	1.27

2.2 Meteorological Data

The study utilizes meteorological data to calculate drought indicators such as the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI). From over sixty meteorological stations in and around the Gediz River Basin, 27 stations with reliable and representative data from the Turkish State Meteorological Services (DMI) were selected (Fig. 2, Supplementary Information - Appendix 1). The data cover the period between 1929 and 2013. Missing data were imputed using the "MICE" package in R software (Van Buuren and Groothuis-Oudshoorn 2011).

To contextualize 2023 hydrologically, an analysis was performed using four stations (Manisa, Akhisar, Alaşehir, and Güney) with over 50 years of continuous data (Table 1). Results indicated that 2023 experienced above-average precipitation at all stations, notably higher by 36% and 27% at Manisa and Akhisar, respectively. Thus, 2023 can be classified as relatively wet meteorologically. However, despite favorable precipitation, moderate SDI values highlighted the significant influence of non-meteorological factors such as irrigation inefficiencies, groundwater reliance, and infrastructural limitations.

Temperature anomalies (+1.27 °C in Manisa and Güney, +0.78 °C in Alaşehir) increased evapotranspiration, offsetting precipitation gains. These findings support the SDI approach, which integrates meteorological and socio-economic indicators to better capture drought vulnerability variations across the basin.

2.3 Survey Data

Within the context of the UNIMED project, 3 surveys have been conducted. The first and the third surveys were aimed at the farmers of Lake Marmara and Menemen Plain in order to collect data for the SDI indicators and feedback for the VAP questionnaire (Supplementary Information - Appendix 2 and 3). These surveys did not focus on any specific farmer group or community, and the invitations to the survey events have been distributed by the local chamber of agriculture offices. The second survey was aimed at the Community of Practice (CoP) members to collect their expert opinions on the weighting process of indicators and sub-indices of SDI (Supplementary Information - Appendix 4). The CoP members consisted of officials of the Lake Marmara Chamber of Agriculture, researchers, and members of university staff. Again, this survey did not focus on any specific group or community; the invitations were distributed to the local researchers and officials of the Gediz River Basin.

2.4 Method

The severe conditions of Lake Marmara and its sustainability under different demand management scenarios were previously assessed by Gunacti et al. (2022), highlighting the critical role of drought risk. In this study, drought risk is explicitly defined using an innovative adaptation of the Kaplan-Meier Estimator method (Cetinkaya and Gunacti 2024).

Development of the SDI began with a literature review to identify indicators representing the WEFE Nexus and survivability sub-indices. Stakeholder workshops in Türkiye and Malta refined these indicators (Supplementary Information - Appendix 5).

As SDI includes qualitative data, Value-Attitude-Perception (VAP) surveys were conducted among local farmers to understand their attitudes toward drought under climate change. These surveys are rooted in psychology, sociology, and marketing research, focusing on perceptions and attitudes regarding climate change impacts (Supplementary Information - Appendix 3). Two additional expert surveys determined indicator weights and quantitative data, conducted during the UNIMED project's workshops (Supplementary Information - Appendix 2 and 4).

2.4.1 SPI/SPEI Calculations

Drought indicators such as SPI and SPEI are directly included in the SDI framework, as they represent the drought conditions based on historical data. SPI calculates standardized precipitation by fitting cumulative precipitation over selected periods to a parametric statistical distribution and converting these probabilities to the standard normal distribution.

$$SPI = \frac{P_i - P_m}{\sigma_x} \tag{1}$$

where P_m is the mean precipitation, σ_x is the standard deviation, and P_i is the precipitation for the month i.

Similarly, SPEI considers the cumulative climatic water balance (difference between precipitation and potential evapotranspiration (PET)):

$$SPEI = \frac{D_i - D_m}{\sigma_d} \tag{2}$$

where D_i is the difference between monthly precipitation (P_i) and PET_i:

$$D_i = P_i - PET_i \tag{3}$$

These D values are accumulated over selected time scales:

$$D_n^k = \sum_{i-0}^{k-1} P_{n-1} - (PET)_{n-1} \tag{4}$$

The Log-logistic distribution recommended by Vincente-Serrano et al. (2010) and confirmed by Stagge et al. (2015) was applied to the accumulated D values, and SPEI was standardized using Abramowitz et al.'s (1965) approach:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{5}$$

$$W = \sqrt{-2 \ln (P)} \quad for\ P \leq 0.5 \tag{6}$$

P=1-f(x) represents the probability of exceeding a predetermined D_i value, and the constants are:

$$C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328,$$

$$d_1 = 1.432788,\ d_2 = 0.189269\ , d_3 = 0.001308$$

SPI and SPEI values were calculated using the "SPEI package" in R for 3-, 6-, and 12-month accumulation periods. Shorter periods reflect soil moisture and local streamflow conditions, while longer periods indicate streamflow and reservoir storage states, making these indicators versatile tools for drought analysis.

2.4.2 Adaptation of Kaplan-Meier Estimator for Drought Risk Assessment

Wet and dry conditions are categorized based on the determined SPI and SPEI values (Table 2). Drought occurrence or the change from a wet to a dry condition are indicators of the "events" that Kaplan-Meier (1958) outlined. The data upon which the study is based

Table 2 SPI/SPEI classification scale

SPI/SPEI values	Description of state
SPI/SPEI < −2	Extreme drought
−2 < SPI/SPEI < −1.5	Severe drought
−1.5 < SPI/SPEI < −1	Moderate drought
−1 < SPI/SPEI < 1	Near normal
1 < SPI/SPEI < 1.5	Moderately wet
1.5 < SPI/SPEI < 2	Severely wet
SPI/SPEI > 2	Extremely wet

refers to the drought incidences as "events." The product limit or survival probability of the wet periods (in this example, months) would thus be produced by applying the Kaplan-Meier or "Product-Limit" estimator.

$$\widehat{S}(t) = \prod_{i:\, t_i \le t} \left(1 - \frac{d_i}{n_i}\right) \tag{7}$$

where, n_i is the total number of wet states at time t_i, d_i is the number of dry states that happened at time t_i, and t_i is the moment at which a dry state occurs.

The result $S(t_i)$ shows the probability of a wet period extending longer than t_i or the "event" not taking place at the time t_i. From the standpoint of drought risk, 1-S(t) would characterize the likelihood of the "event" occurring or the risk of drought occurrence, DR(t), as outlined by Cetinkaya and Gunacti (2024).

$$DR(t) = 1 - \widehat{S}(t) = 1 - \left(\prod_{i:\, t_i \le t} \left(1 - \frac{d_i}{n_i}\right)\right) \tag{8}$$

As a higher value of drought risk would indicate a more fragile system, "inverse" drought risk values (1-DR) have been used to align with the same concept as SDI, where the higher sub-index values of SDI indicate higher survivability, as their value increases near 1.

2.4.3 Selection of the Indicators

The Survivability from Drought Index (SDI) relies on carefully selected indicators that reflect the complexity of drought through the WEFE Nexus. While many indicators exist in the literature, the final list (Fig. 3) was shaped by expert input, stakeholder engagement, and data availability (Supplementary Information - Appendix 6). Each indicator corresponds to one of the four sub-indices: perception reflects farmers' awareness; vulnerability captures water and labor dependency along with biodiversity and economic efficiency; adaptability measures the farmers' flexibility to cope through alternative seeds, water sources, or markets; and recoverability assesses post-drought resilience via income diversity and soil fertility. Importantly, as the definition of the "Vulnerability" term, one assumes that a higher value would mean a more vulnerable, fragile system. Yet in the methodology of SDI, as all 4 sub-index values increase near 1, they identify a more "survivable", a more resilient system. Hence, a higher Vulnerability sub-index value indicates a higher capacity to endure the incoming droughts.

2.4.4 Normalization and Weighting of the Indicators

A portion of the defined indicators that make up the SDI are the quantitative and qualitative data that have been collected from the farmers such as their perception of drought, their benefit/cost ratio, etc. In order to normalize the data, min-max normalization (range transformation) has been applied according to the equation below,

$$X_i' = \frac{X_i - X_{min}}{X_{max} - X_{min}} \tag{9}$$

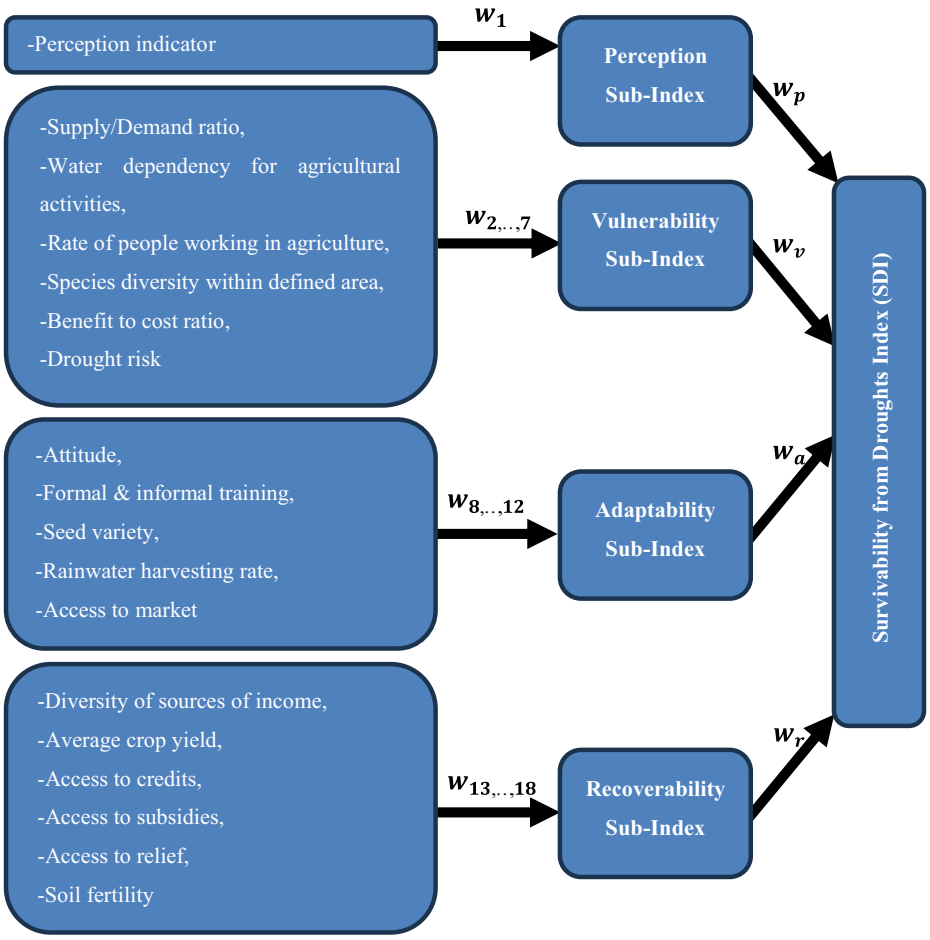

Fig. 3 Flowchart of indicators and sub-indices of SDI

Where X_i represents the *i*-th value of the respective time series, X_{min} is the minimum value of the timeseries, X_{max} is the maximum value of the timeseries, and the X_i' is the normalized value of X_i.

Also, the defined indicators must be weighted in order to calculate the SDI. A survey among the CoP members has been conducted to collect their expert opinions.

The budget point allocation method has been used as the weighting method. The process of budget point allocation, also known as fixed point allocation, demands that the decision-maker assign relative weights to various criteria by weighing their relative relevance (Gendreau et al. 2019).

In the case of the weighting survey that was conducted in the second CoP meeting, the total points to allocate have been altered in order to: (i) force the survey attendees to avoid allocating equal weights to each indicator/sub-index, (ii) simplify the total points allocated. Usually, the survey attendees tend to give equal weight to the concepts. Each survey section has been designed to have 2 times the number of concepts plus two points to overcome an

equal-weighted result. Hence, the sub-index weighting section, which has 4 sub-indices, has 10 points to allocate, while the sections where indicators of adaptability, vulnerability, and recoverability have 12, 14, and 14 points respectively (Supplementary Information - Appendix 4). Since the perception sub-index has only one indicator, no weight assignment was required.

3 Results

In the SDI assessment for 2023, indicator values for the Gediz River Basin were calculated using surveys, stakeholder input, and official data sources (Table 3). For the Vulnerability sub-index, the supply/demand ratio was determined at 45.00%, based on data from Water Associations Unions (WUA). Water dependency was calculated at 66.67% and inverted to 33.33% since higher dependency negatively impacts survivability. The percentage of people working in agriculture was recorded as 14.80% (TUIK), species diversity was 86.45% based on bird species data from Izmir Natural Life Park, the benefit-cost ratio was 51.37%, and the inverted annual drought risk (SPI-12) was 34.06%, calculated using the Kaplan-Meier method.

For the Adaptability sub-index, the attitude indicator, based on stakeholder VAP survey responses, yielded 55.97%. Formal and informal training events organized by local institutions resulted in a value of 16.67%. Seed variety and market access were both recorded as 100%, while rainwater harvesting was not practiced (0.00%).

The Recoverability sub-index included six indicators. Diversity of income sources was 34.29%, average crop yield (grapes) was 51.39%, and access to credits and subsidies was high at 82.86% and 85.71%, respectively. Access to relief was 0.00%, and soil fertility, represented by Soil Organic Carbon (SOC), was calculated at 0.0157% from Soilgrids data (Poggio et al. 2021).

The perception indicator has been calculated according to the feedback on the questions of the "perception" section. The questions were graded between 1 and 5, and the average of the total feedback was then normalized within this range and yielded 52.68%.

According to the weight survey, the weights of each indicator and sub-index were determined and normalized to the maximum votes available for each weighting exercise, such as 10 votes for the 4 sub-indices, 12 for adaptability, 14 for vulnerability, and recoverability. Since perception consists of just one indicator, no such weighting was necessary. The SDI has been calculated as 48.34% according to the calculated data and defined weights, representing a fairly low-moderate percentage considering the max value of 100% (Table 3).

To compare 2023 with a severely dry (1991–1992) and a relatively wet (1982) period, key indicators such as supply/demand ratio, water dependency, benefit-cost ratio, and drought risk were calculated using historical data. Due to limited data availability for other indicators, expert judgment was used: training and seed variety were set to 0.00%, income diversity and subsidies to 10.00%, credits to 50.00%, and perception to 30.00% (Table 4). The resulting SDI values were 30.86% for 1991–1992 and 37.61% for 1982—both notably lower than the 2023 value of 48.34%. This highlights that while drought risk is important, broader socio-economic and institutional factors also play a crucial role in survivability.

Furthermore, the weighted values of indicators and sub-indices according to the current period and simulated periods have been presented as radar charts showcasing the influence

Table 3 Calculated values of indicators, sub-indices, and the SDI for the year 2023

	Indicator Name	Definition	Value	Indicator Weights	Weighted Values of Indicators	Sub-index Weights	Weighted Values of Sub-indices	SDI
Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	0.527	1.000	0.527	0.255	0.134	0.483
Vulnerability	**Supply/Demand Ratio**	Annual total supply allocated to agriculture over total demand of agricultural sector.	0.450	0.185	0.083	0.232	0.100	
	Water dependency for agricultural activities	Total amount of water allocated to food production over long-term average of water available for agricultural irrigation (resulting value inverted for the purpose of the study)	0.333	0.232	0.077			
	Rate of people working in Agriculture	Number of people working in agriculture over total population	0.148	0.118	0.017			
	Species diversity within defined area	Shannon Diversity Index of the pilot study area to measure the diversity of species (Shannon 1948)	0.865	0.131	0.114			
	Benefit to cost ratio	Average agricultural land benefit to cost ratio of the case study farmers	0.514	0.141	0.073			

Table 3 (continued)

	Drought Risk	Average 12-month drought risk of the study area according to SPI12 calculated by adapted Kaplan-Meier method (resulting value inverted for the purpose of the study)	0.341	0.192	0.065			
	Indicator Name	Definition	Value	Indicator Weights	Weighted Values of Indicators	Sub-index Weights	Weighted Values of Sub-indices	SDI
Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	0.560	0.249	0.140	0.277	0.149	0.483
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	0.167	0.207	0.035			
	Seed variety	Total number of seed variety cultivated (Cultivating various seeds promotes the biodiversity and ecosystem resilience)	1.000	0.216	0.216			

Table 3 (continued)

	Rainwater harvesting rate	Rate of irrigation water sourced by rainwater harvesting to total amount of water allocated to irrigation	0.000	0.181	0.000		
	Access to market	Rate of farmers conducting business in local/national/international markets	1.000	0.146	0.146		
Recoverability	**Diversity of source of income**	Number of income sources independent of agricultural activity	0.343	0.164	0.056	0.236	0.101
	Average crop yield	Total yield divided by the surface area dedicated to crop production, normalized to long-term observed min-max values	0.514	0.140	0.072		
	Access to credits	Percentage of agricultural community benefiting from credits	0.829	0.133	0.110		
	Access to subsidies	Percentage of agricultural community benefiting from subsidies	0.857	0.216	0.185		
	Access to relief	Percentage of agricultural community benefiting from relief funds after a drought	0.000	0.150	0.000		

Table 3 (continued)

Soil fertility	The average of Soil Organic Carbon rate in the first 2 meters of soil in the case study extent	0.016	0.196	0.003

Table 4 Indicator values revised for previous periods

Indicator Name	1982	1991–1992	2023
Supply/Demand ratio	**0.96**	**0.49**	0.45
Inverted Water dependency for agricultural activities	**0.00**	**0.00**	0.33
Rate of people working in Agriculture	0.15	0.15	0.15
Species diversity within defined area	0.86	0.86	0.86
Benefit to cost ratio	**1.83**	**0.97**	0.51
Inverted Drought Risk	**0.82**	**0.61**	0.34
Attitude	0.55	0.55	0.55
Formal & informal training	*0.00*	*0.00*	0.17
Seed variety	*0.00*	*0.00*	1.00
Rainwater harvesting rate	0.00	0.00	0.00
Access to market	1.00	1.00	1.00
Diversity of source of income	*0.10*	*0.10*	0.34
Average crop yield	0.51	0.51	0.51
Access to credits	*0.50*	*0.50*	0.83
Access to subsidies	*0.10*	*0.10*	0.86
Access to relief	*0.00*	*0.00*	0.00
Soil fertility	0.01	0.01	0.01
Perception	*0.30*	*0.30*	0.52
SDI	37.61%	30.86%	48.34%

Bold: revised by calculation, *Italic: revised by expert opinion*

of each element that determines the final SDI value (Fig. 4). In the case of the vulnerability sub-index, the water dependency for agricultural activities is observed to be the least sensitive indicator, as it doesn't change much throughout the periods, as the water dependency exceeds the available water amount in most cases.

While rainwater harvest rate, formal & informal training, and access to the market are measured to be the least sensitive indicators of the Adaptability sub-index, it is the access to relief and soil fertility in the case of Recoverability. An overall observation of SDI sub-indices reveals that perception is the least sensitive sub-index among the rest as the relative change in perception is lesser.

The generated SDI map of the most recent period, 2023, reveals the distribution of the SDI in the Gediz River Basin (Fig. 5). While the SDI values around Lake Marmara indicate relatively moderate magnitudes, the values around Menemen Plain are moderate to slightly higher, possibly with the influence of coastal humidity. The map also highlights other hotspots of higher and lower SDI regions for the decision-makers to investigate and

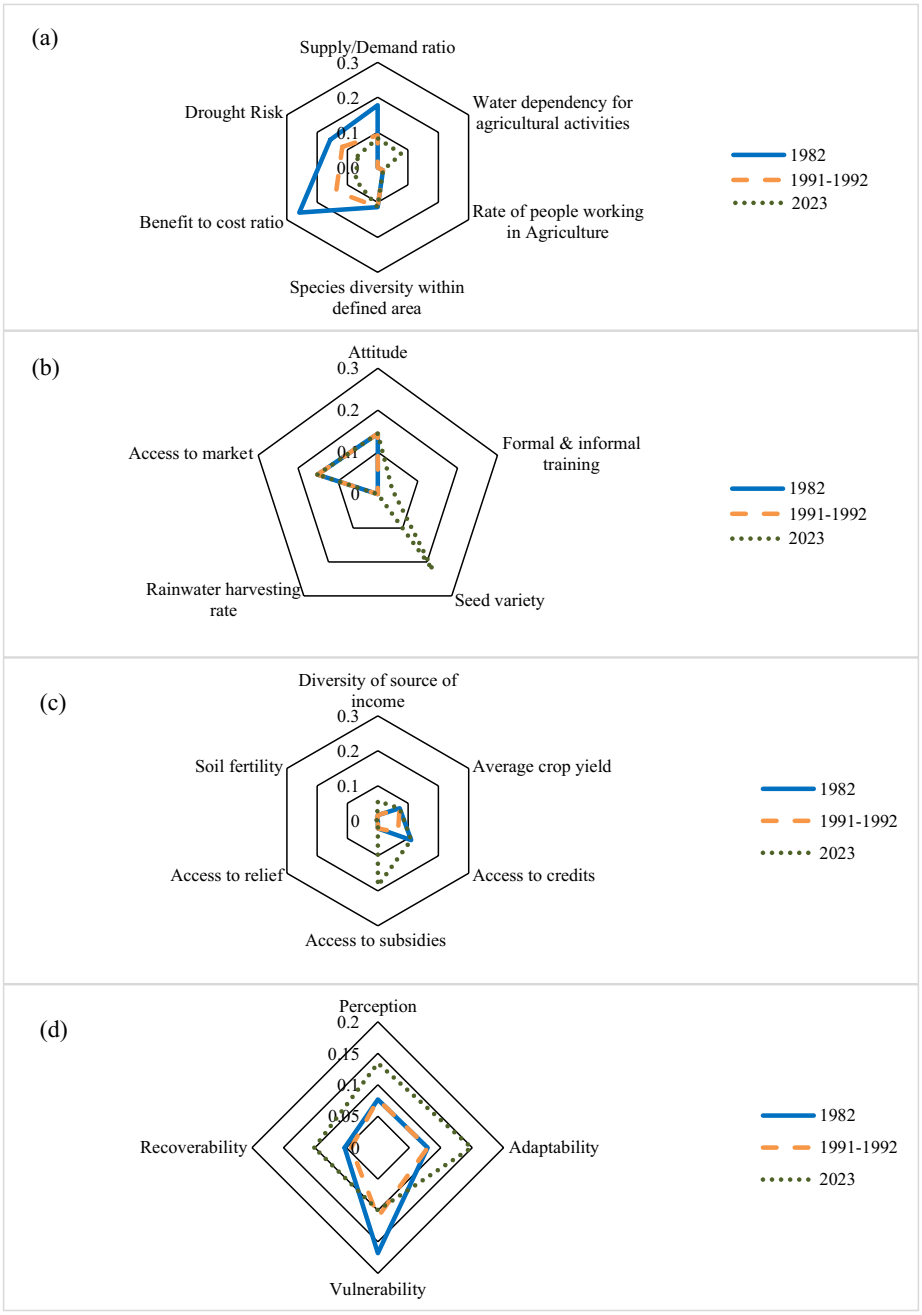

Fig. 4 Calculated weighted values of (**a**) Vulnerability sub-index, (**b**) Adaptability, (**c**) Recoverability indicators, and (**d**) SDI sub-indices for the periods of 1991-1992, 1982, and 2023

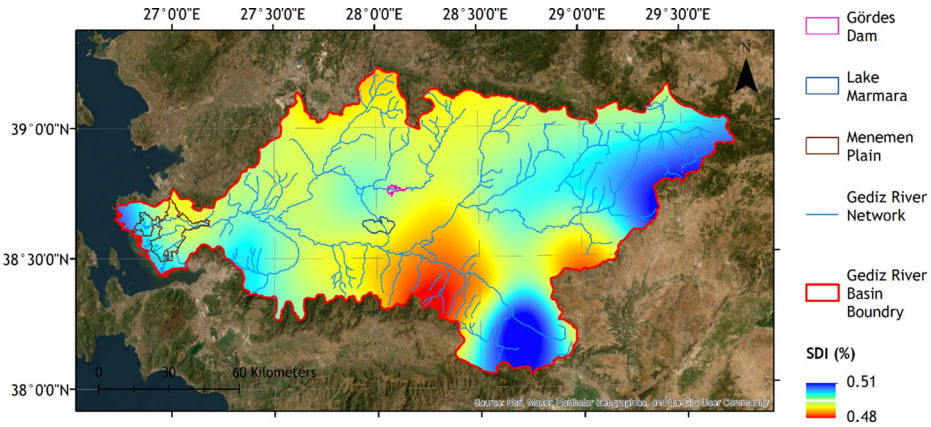

Fig. 5 Generated Gediz River Basin SDI map of 2023

prioritize while developing action plans. Additionally, the map generation and visualization of the results provide a better understanding of the SDI for the stakeholders.

The value range depicted in Fig. 5 shows that the current situation of the Gediz River Basin is almost homogeneous throughout the Basin. Either a basin-wide improvement in the related indicators can be made, or since the spatial resolution of the qualitative data (i.e., VAP Survey has been conducted by the participation of farmers from Lake Marmara and Menemen) is coarse, further studies can be conducted for a SDI map with higher resolution, and maybe data range. This also points out a common limitation, not only specific to SDI but also to all data-driven studies, data availability.

4 Conclusions

The proposed Survivability from Droughts Index assesses drought perception, vulnerability, adaptability, and recovery capacity by integrating meteorological, socio-economic, institutional, and perceptual indicators. Applied to the Gediz River Basin, Türkiye, the SDI framework highlighted spatial and temporal disparities in drought survivability, even in relatively wet years like 2023. This emphasizes the importance of considering multi-dimensional indicators beyond precipitation and temperature for drought resilience.

The final list of indicators and their weighting was guided by stakeholder input through workshops, revealing that factors such as farmer attitudes were highly valued, while others, including water dependency and soil fertility, showed lower sensitivity. The SDI_{2023} value (48.34%) significantly surpassed values from severe drought (1991–1992: 30.86%) and relatively wet periods (1982: 37.61%), validating its effectiveness in capturing both climatic and socio-economic factors influencing survivability, as stated by the farmers and the expert opinions.

Despite that, the 2023 period is characterized as wet or near-normal; the lower "inverse" drought risk values indicate that this period's drought risk was the highest among other periods. This actually can be interpreted as rainfall and temperatures rise relative to long-term values in the year 2023, so does the drought risk, implying that climate extremes (higher

precipitation amounts could lead to higher flood risks), such as floods and droughts, are observed more often, which also agrees with the impacts of climate change and actual flood and drought events in the region.

The novelty of this study lies in operationalizing the SDI, uniquely integrating meteorological, socio-economic, institutional, and perceptual indicators. Unlike conventional indices, the SDI provides a comprehensive and spatially explicit drought survivability assessment. This study represents the first application of the SDI in the Gediz Basin and contributes to integrating stakeholder perceptions into drought resilience analyses. Consequently, the SDI offers stakeholders and decision-makers an integrated tool to prioritize interventions and enhance drought resilience through participatory governance.

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Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by MC Gunacti and CP Cetinkaya. The first draft and previous versions of the manuscript were written by MC Gunacti and CP Cetinkaya. All authors read and approved the final manuscript.

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Data Availability All data used in the study is presented in Supplementary Information document.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication All authors agree to publish.

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