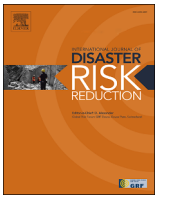
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# Multidimensional assessment of agricultural drought vulnerability based on socioeconomic and biophysical indicators

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ABSTRACT

Agricultural drought threatens Türkiye's food security and economy, revealing a lack of multidimensional provincial vulnerability studies. Therefore, the primary objective of this study is to evaluate Türkiye's vulnerability to drought utilizing a multidimensional strategy incorporating biophysical and socio-economic indicators. In this context, an initial step involved the development of a conceptual framework for drought vulnerability, drawing upon the Intergovernmental Panel on Climate Change recommended elements of exposure, sensitivity, and adaptive capacity. Subsequently, this conceptual framework was applied at the provincial level, encompassing parameters such as temperature, precipitation, soil characteristics, water resources, agricultural earnings, demographic traits, educational levels, innovation, insurance coverage, and road density.

The Aridity Index was used as an indicator for drought exposure, representing the physical dimension of drought. Under the sensitivity component, a total of 14 variables were defined under the indicators of *"soil", "water and land resources", "economy",* and *"population"*, while under the adaptive capacity component, a total of five variables were identified. The weights of these indicators and variables were determined based on expert opinions using the Analytic Hierarchy Process method. As a result, five different indices were obtained by combining the indicators: Exposure Index, Sensitivity Index, Adaptation Capacity Index, Potential Drought Impact Index, and Agricultural Drought Vulnerability Index. In addition, spatial distribution models of these indices were also generated. Research results showed that the climatic regions most exposed to drought are also the most vulnerable. The Central, Southeastern, and Eastern Anatolian regions constitute the regions where the most vulnerable provinces are concentrated spatially.

## 1. Introduction

Recently, drought caused by factors such as climate change, population growth, depletion of water resources, and increased human activity has been a growing problem [1]. report indicates that there is an increase in temperatures, a decrease in precipitation amounts and soil moisture levels at regional levels as global temperatures continue to rise [2]. findings illustrate that the frequency of drought events is projected to increase by 30 % by 2030 if the current trends continue. Additionally, with the increase in population

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growth, industry, energy production, and expansion of agricultural areas, the water demand by sectors is likely to exacerbate the risk of drought in many regions of the world day by day.

Drought -an insidious natural hazard that is difficult to predict its onset and end and occurs in almost all climate types-is a challenging phenomenon [3]. On the other hand, when compared to other natural hazards, drought is generally not considered a significant hazard by the public, as its effects are not immediately observable or tangible, primarily due to the gradual nature of the event. Contrary to that, drought can have significant adverse effects on the environment, society, and economy, not only in the regions where it occurs but also in more distant areas [4,5]. [6] asserts that the effects of drought emerge hierarchically, whereby the consequences, starting from income loss, bankruptcy, and migration at the local level, can escalate into famine, scarcity, and conflicts at the international level. At the local level, to say that the agricultural sector is the sector most affected by drought, particularly, would be a valid statement. Because, especially in agricultural regions nourished by rainfall, the soil moisture component of the hydrological system will be the first to be affected. Moreover, the absence of timely and effective precipitation during the growing season can substantially reduce the productivity of crops and fodder [7]. In addition [5], underline that the impacts of drought are largely dependent on the vulnerability of the community in the region where the drought takes place.

[8] emphasizes the need for collaboration among policymakers, civil society organizations, and other stakeholders to combat drought and mitigate its negative effects on different sectors. This collaboration involves developing strategies and plans to reduce drought risks and provide a more resilient future for people, ecosystems, and economies. A proper vulnerability assessment is necessary to develop tangible plans for mitigating drought hazards since vulnerability assessment provides information to make appropriate decisions for reducing potential damage before it occurs [9]. Therefore, the main purpose of vulnerability assessment is generally to assist policymakers in minimizing harm by adapting to ongoing or expected changes [10]. However, data availability generally makes it difficult for drought assessment in drought-prone areas.

The concept of vulnerability, which refers to the likelihood of experiencing harm or loss, is a crucial element in hazard research and plays a central role in the formulation of hazard reduction strategies at the international, national, and local levels [11]. According to the [12]; understanding how vulnerability is generated, increased and formed is important to effectively manage drought risk. Therefore, drought vulnerability is a complex concept that encompasses both biophysical and socio-economic driving factors of the drought impact, determining the ability to cope with and recover from drought conditions [13]. On the other hand, understanding a region's vulnerability to drought is not an easy task due to the multidimensional, complex, and dynamic nature of vulnerability to drought. However, it is necessary for designing drought preparedness, mitigation, and relief policies and programs [14]. For this purpose, many studies, among others, in the literature attempt to assess vulnerability to drought hazards in arid and semi-arid regions of the world, particularly in the Mediterranean region. For example [5], studied agricultural drought vulnerability in the United States state of Nebraska and presented one of the early studies in this area. Then [15], addressed the national-scale agricultural drought vulnerability in Ghana. While [16] examined the general drought vulnerability at the national level in South Korea [17], addressed the issue on the scale of India [13]. examined the overall drought vulnerability at the pan-African scale, addressing the wide-ranging impacts on the continent [18]. study examined the drought vulnerability of small farmers in the semi-arid subregion of Brazil [19]. analyzed the spatial characteristics of agricultural drought vulnerability in a sub-region of India, while [20] evaluated the overall drought vulnerability at the global level [21]. examined the drought vulnerability of different sectors on a pan-European scale and presented examples in Europe. The study of [22–24] examining drought vulnerability, resilience and impacts of farmers in southern Iran highlights regional characteristics.

The concept of vulnerability is a useful concept that is often applied to many other natural disasters in addition to the danger of drought. For example [25,26], examined socio-economic vulnerability to climate change, while [27] evaluated regional vulnerability to climate change and globalization with an integrated approach [28]. evaluated the vulnerability of global change on a pan-European scale [29]. examined the relationship between proximity to cities and flood vulnerability using predominantly socio-economic indicators [30]. used the concept of vulnerability to examine the effects of the heat wave on human health. Moreover [31], evaluated the earthquake vulnerability of a city center with a holistic approach. Typical climate types preponderant over the territories may cause drought events to diversify and have different characters and may entail new approaches in drought vulnerability assessment studies.

Various climate types are seen in Türkiye, which has a wide geography. The main factors that shape these climate types are determined by the atmospheric circulation that is effective in Türkiye's latitudes where it is located and its physical geography features such as geomorphological characteristics, continentality, and vegetation. Especially in the Anatolian Peninsula, the physiographic features that vary in short distances cause very different climate types to emerge. However, the climate type that is effective in a significant part of the country is the Mediterranean climate, which is characterized by rainy winters, hot-arid summers, and lack of soil moisture. This climate feature, which is characterized by low precipitation, especially in summer months, puts pressure on water resources. Additionally, the Mediterranean basin is one of the world's leading regions in terms of observed increases in agricultural and ecological drought due to global climate change [1]. Accordingly, it can be said that Türkiye is currently facing a terrifying increase in the risk of agricultural drought, which threatens its food security and economic stability. There are many studies examining the historical drought characteristics of Türkiye from a physical point of view [32–35]. In this context, the results of a recent study by Ref. [36] clearly showed that Türkiye has historically been exposed to frequent severe droughts (especially in 1973, 1977, 1990, 1991, 1999 and 2000 years). The author states that these severe droughts have significant effects on agriculture, water resources and energy production.

Although the share of the agricultural sector in GDP is low in Türkiye, agriculture is still an important source of income for some regions. The beginning of these regions are the southeastern, eastern, and inner regions of the country. Moreover, in most of these regions, agricultural activities are carried out in a low-capital and labor-intensive manner. Therefore, agriculture plays a major role in

terms of employment and income generation, especially in rural areas. For this reason, the agricultural sector is important not only for its share in GDP but also for social and regional development. Due to some inherited characteristics of Turkish agriculture, the agricultural sector in Türkiye is like crazy sensitive and fragile to drought episodes.

Previous studies of drought analysis in Türkiye have focused more on the physical characteristics of drought, such as temporal and spatial, intensity and frequency [32–35,37]. Previous studies on drought vulnerability assessment have focused both on general drought vulnerability and used a limited number of variables. Therefore, most studies have failed to capture the complexity and diversity of agricultural drought vulnerability across different provinces. For example [38], evaluated Türkiye's drought vulnerability with a limited set of variables consisting of irrigation, total agricultural area, population density and water demand. Although this assessment is the first of its kind, it is controversial that the limited data set used adequately reflects Türkiye's drought vulnerability. In addition, the weight of each variable was assumed to be equal in his study. Furthermore [39], underline that vulnerability emerges in a multidimensional structure. Moreover, as noted by Ref. [40]; the equal weight assumption can be criticized when considering real-world conditions. These discussions suggest that there is a general lack of multidimensional research on drought sensitivity and vulnerability in the Mediterranean basin, in which Türkiye is located. The novelty of this research can be attributed to the lack of studies in this area, specific indicators chosen by the data availability and the adopted methodology consisted of a multidimensional integrated approach. Therefore, the aim of this study is to evaluate Türkiye's agricultural drought vulnerability with a multidimensional integrated approach based on climate characteristics, soil characteristics, water resources, economy, population, education, and infrastructure indicators.

The vulnerability assessment presented in our proposed paper is grounded on 20 biophysical and socio-economic variables that are thought to have a strong association with Türkiye's agricultural drought vulnerability. For this purpose, the three-component vulnerability conceptual framework of exposure, sensitivity, and adaptive capacity as proposed by the [41] was utilized. As [42] pointed out, there is no commonly agreed approach or method to operationalize this conceptual framework. Nevertheless, the most commonly used method to operationalize a vulnerability framework is the approach of aggregating a set of indicators or variables into a scalar variable or index [27,39,40,43]. Correspondingly, the conceptual framework of this study has been operationalized based on temperature, precipitation, soil properties and water resources, agricultural income, population characteristics, education, innovation, insurance, and road density features related to Türkiye's agricultural drought vulnerability. Consequently, this study has utilized a multidimensional approach to assess the agricultural sector's vulnerability to drought in Türkiye, which is under a significant threat of drought.

The study follows a structured framework outlined below: The second section, called "Materials and Methods", begins by providing an overview of the study area with a description of the data sources. Then, in the same section, explanations about the selection of relevant indicators and variables, data processing procedures, rigorous weight calculations and derivation of indices are given accordingly. Moving on to the third section titled "Results", the meticulously calculated weight values are presented concisely, supported by explanations of the spatial distribution maps of the indices. The fourth and concluding section, aptly called "Conclusions and Discussion," provides for a comprehensive discourse covering the findings of the study, a thorough discussion of its internal limitations, and the judicious formulation of appropriate recommendations.

## 2. Materials and methods

### 2.1. Study area

Türkiye is a country situated between Europe and Asia, with the Black Sea to the north, the Aegean Sea to the west, the Mediterranean Sea to the south, and the Eastern Anatolian Mountains to the east (Fig. 1). Its strategic location has made it a crossroads of civilizations throughout history. Türkiye has various features of physical geography. The narrow coastal plains along the Aegean and southwestern Mediterranean coasts are present, and there are wider coastal plains on the Black Sea coast. Inland, there are high mountain ranges, vast plateaus, valleys, and basins. The Eastern Anatolia region is covered with high mountains, including Mount Ararat -Türkiye's highest peak. Türkiye has a large geography (783,562 $km^2$) and is covered with various climatic types. For instance, the northern Black Sea region has a rainy climate, while the Southeastern Anatolia region has a hot and dry climate. From a human geography perspective, Türkiye, with a population of approximately 86 million, is a multicultural country where different cultures, languages, and religions coexist. Türkiye has undergone significant modernization in recent years, particularly in its urban centers where the majority of the population lives. Istanbul is the largest city in Türkiye and serves as the country's economic, cultural, and historical center. Despite its modernization, Türkiye still faces some social and economic challenges, such as income inequality and regional disparities.

### 2.2. Data sources

To calculate the Aridity Index, data on monthly average temperature (in degrees Celsius) and monthly total precipitation (in mm) were necessary, and these data were acquired from The Turkish State Meteorological Service. The Aridity Index can be utilized to evaluate the degree of aridity or dryness in a particular area, and it is an essential tool for understanding the lingering effects of climate change and the suitability of land for various uses, including agriculture and human habitation. The meteorological stations across Türkiye for which the Aridity Index is calculated are shown in Fig. 1.

Furthermore, Fig. 1 provides detailed information on the borders of regions and provinces, the spatial distribution of water bodies, and the spatial distribution of highlands. Furthermore, the slope and depth data were obtained from the National Soil Database (NSD), water holding capacity data from NASA's Oak Ridge National Laboratory (ORNL), soil organic matter content data from the Food and Agriculture Organization (FAO), irrigated and non-irrigated area data from the Coordination of Information on the Environ-