REPUBLIC OF TÜRKİYE
MINISTRY OF ENVIRONMENT,
URBANIZATION AND CLIMATE CHANGE
DIRECTORATE GENERAL OF COMBATING
DESERTIFICATION AND EROSION

TÜRKİYE DESERTIFICATION MODEL

SENSITIVITY AND HAZARD MAPS

TECHNICAL SUMMARY

Bibliography Information: Türkiye Desertıfıcatıon Model Sensıtıvıty and Hazard Maps Technıcal Summary, Directorate General of Combating Desertification and Erosion Publications, Ankara, 2025.

Design/Print: Asma Köprü Medya Ltd. Şti.
Zübeyde Hanım Mh. Devrez Sk. No:1/1 Altındağ/Ankara
Phone: 0312 384 78 98
Printing Press Certificate Number: 71674

Photos: DG ÇEM Archive

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FOREWORD

Desertification is not merely an environmental issue today; it is a multidimensional process that directly affects our country's sustainable development through its economic, social, and ecological dimensions. Due to its geographical location, topographical structure, and climatic characteristics, Türkiye is among the countries sensitive to desertification and land degradation. The extent of arid and semi-arid areas, overgrazing, intensive agricultural activities, deforestation, improper land use, and the increasing effects of climate change are accelerating this process. Therefore, it is of great importance to analyze desertification sensitivity and hazard using scientific methods in order to protect our natural resources, maintain agricultural production capacity, and ensure the continuity of ecosystem services.

The study entitled "Türkiye Desertification Model: Sensitivity and Hazard Maps," conducted within this scope, offers a scientifically grounded and innovative approach that will guide our country's efforts to combat desertification. In this study developed a fully data-driven, objective, and reproducible model using 11 criteria derived from climate, soil, vegetation cover, and land use characteristics. Conducting the analyses at a spatial resolution of 30 meters across the country has enabled more detailed assessments at the local level. Furthermore, the use of climate projections produced for the first time at a resolution of 3 kilometers by the Climate Change Directorate has ushered in a new era in desertification hazard analysis for the future.

This study goes beyond being an analysis that merely reveals the current situation; it provides a strategic vision for Türkiye's efforts to combat desertification. The findings provide a strong scientific basis for our goals of protecting our natural resources, establishing sustainable land management, and increasing climate resilience in the face of the increasingly apparent effects of climate change. I believe that this model, supported by high-resolution spatial data, will serve as a guiding reference for decision-makers, researchers, and implementing institutions.

This study once again reinforces our determination to strengthen Türkiye's fight against desertification, increase climate resilience, and leave a more livable environment for future generations. I would like to thank all the institutions, experts, and researchers who contributed to this comprehensive study; I hope that these scientific outcomes achieved will provide guidance for our country's sustainable land management policies.

Prof. Dr. Kasım YENİGÜN
General Director

ABBREVIATIONS

AHP	Analytic Hierarchy Process
EU	European Union
ALOS PALSAR	Advanced Land Observing Satellite Phased Array Type L-band Synthetic Aperture Radar
FAHP	Fuzzy Analytic Hierarchy Process
GIS	Geographic Information System Desertification Sensitivity Index
DSI	Desertification Sensitivity Index
CI	Climate Index
CMIP 6	Coupled Model Intercomparison Project Phase 6
DHI	Desertification Hazard Index
EC-Earth3-Veg (ECV)	EC-Earth3-Veg Climate Model (Vegetation-Interactive EC-Earth3 Version)
MEDALUS	Mediterranean Desertification and Land Use
MODIS	Moderate Resolution Imaging Spectroradiometer
MPI-ESM1-2-HR (MPI)	Max Planck Institute Earth System Model, High Resolution
MRI-ESM2-0 (MRI)	Meteorological Research Institute Earth System Model, Version 2.0
NDVI	Normalized Difference Vegetation Index
PET	Potential Evapotranspiration
SI	Soil Index
SSP	Shared Socioeconomic Pathways
DEM	Digital Elevation Model
TI	Terrain Index
SOC	Soil Organic Carbon
UASİS	National Land Cover Classification and Monitoring System
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
VI	Vegetation Index
WRF	Weather Research and Forecasting Model

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EXECUTIVE SUMMARY

This technical summary presents the methodological framework and key findings of the Türkiye Desertification Model Sensitivity and Hazard Maps, developed to assess desertification sensitivity and future desertification hazard in Türkiye. Compared to previous models, this study offers three key scientific and technological innovations in analyzing desertification sensitivity:

- The Euclidean distance approach, a fully data-driven and reproducible method, was used. Analyses were conducted based on a total of 11 criteria reflecting climate, soil, vegetation cover, and land characteristics.
- The analyses were performed at a resolution of 30 meters for the entire country of Türkiye. This high level of detail has enabled desertification sensitivity to be identified in much greater detail at the local and regional scales.
- This study does not merely present a static snapshot of the current situation; it also utilizes climate projection data produced at a 3 km resolution for the first time in Türkiye. Data from the MRI-ESM2-0 (MRI), EC-Earth3-Veg (ECV), and MPI-ESM1-2-HR (MPI) global climate models have been dynamically downscaled to 3 km resolution using the WRF model. These data were produced as part of a project conducted by UNDP Türkiye, benefiting the Climate Change Directorate, and were used directly in this study.

Two main outputs were produced in this study:

- **Türkiye Desertification Sensitivity Map:** Approximately 16.92% of Türkiye's land area is classified as highly vulnerable.
- **Future Projections (Hazard):** Desertification hazard was assessed for three periods (2025–2050: near future, 2050–2075: medium future, and 2075–2100: distant future) in line with climate scenarios; and projections with a spatial resolution of 30 m have been produced for the year 2100 under both optimistic (SSP 2-4.5) and pessimistic (SSP 5-8.5) scenarios.

The most striking and original finding of the study is that the main driving force behind the future threat of desertification in Türkiye is not so much rainfall deficiency as steady and severe temperature increases. Rising temperatures trigger evaporation and soil moisture loss, subjecting our country to systematic aridification pressure.

Future projections quantitatively demonstrate how critical this effect is:

- According to the optimistic scenario (SSP 2-4.5), the proportion of areas vulnerable to desertification is projected to rise to 51.5% by the end of the century. This indicates that the current high level of sensitivity will be maintained with a slight increase.
- According to the pessimistic scenario (SSP 5-8.5), the proportion of areas sensitive to desertification is expected to exceed 60%, reaching a critical threshold. The most striking finding is that the share of areas in the "very high" hazard category, currently at 17%, will rise to 24.5% by the end of the century.

The integrated analysis of the two main outputs, Türkiye's Desertification Sensitivity and Future Projections (Hazard), clearly reveals the scale and dynamics of the threat facing the country. The findings present a critical picture that requires urgent and multi-layered action.

1

PURPOSE AND SCOPE OF THE STUDY

The primary objective of the study conducted under the project **“Preparation of Sensitivity and Hazard Maps for the Türkiye Desertification Model”** implemented by the General Directorate of Combating Desertification and Erosion under the Ministry of Environment, Urbanization, and Climate Change is to assess Türkiye’s current desertification sensitivity and the desertification hazard it may face in the future, using up-to-date scientific methods and high-resolution environmental data sets.

Türkiye is among the countries sensitive to desertification due to its geographical location, topographical structure, and climatic characteristics. The extensive coverage of arid and semi-arid areas, intensive use of agricultural and pasture lands, land use pressures, and the intensifying effects of climate change necessitate monitoring desertification sensitivity at different spatial scales. In this context, the Türkiye Desertification Model enables the objective, data-driven analysis of desertification processes across the country at a high spatial resolution. Within this scope, desertification processes, assessment models, monitoring methods, and indicators found in national and international literature have been analyzed. The findings aim to establish a conceptual and methodological basis for modeling studies to be implemented at the Türkiye scale.

2

TÜRKİYE DESERTIFICATION MODEL

According to the UNCCD, desertification is defined as process characterized by declining land productivity in arid, semi-arid, and dry sub-humid regions, driven by both anthropogenic activities (e.g., overgrazing, unsustainable agricultural practices, and deforestation) and the effects of climate change (drought, rising temperatures). This process results in multiple forms of land degradation, including soil degradation, erosion, salinization, biodiversity loss, and water resource depletion. Desertification represents a multidimensional and dynamic phenomenon shaped by complex interactions among climatic variability, land-use practices, hydrological processes, and socioeconomic drivers (Zhao et al., 2023). Therefore, a scientifically grounded and systematic analysis of the components of this process is essential for the establishment of robust national-scale monitoring and assessment frameworks, as well as for the formulation of effective and targeted intervention strategies. In this regard, desertification sensitivity maps constitute a key analytical instrument for delineating areas vulnerable to land degradation, identifying spatial and temporal patterns of desertification, and supporting evidence-based sustainable land management planning.

In this study, rather than employing the Analytical Hierarchy Process (AHP) and MEDALUS approaches used in previous models, which primarily relied on expert judgment, an objective and data-driven framework based on a Euclidean distance multi-criteria evaluation model was implemented.

This method determines an area's sensitivity to desertification by numerically quantifying the extent to which fundamental factors, such as climate, soil, vegetation, and terrain deviate from their "ideal" conditions.

The prominent advantages of the method are as follows: it relies entirely on the statistical distribution of the data itself, without requiring expert opinion or subjective weighting. Obtaining consistent results when the same datasets are used enhances the scientific reliability and transparency of the method. The contribution of each criterion to desertification sensitivity is calculated mathematically based on the degree of deviation from ideal conditions. This makes the method more balanced, objective, and defensible. Due to its scientific, transparent, and universal structure, the Euclidean distance method has been adopted as the most appropriate methodological framework for achieving the objectives of this study.

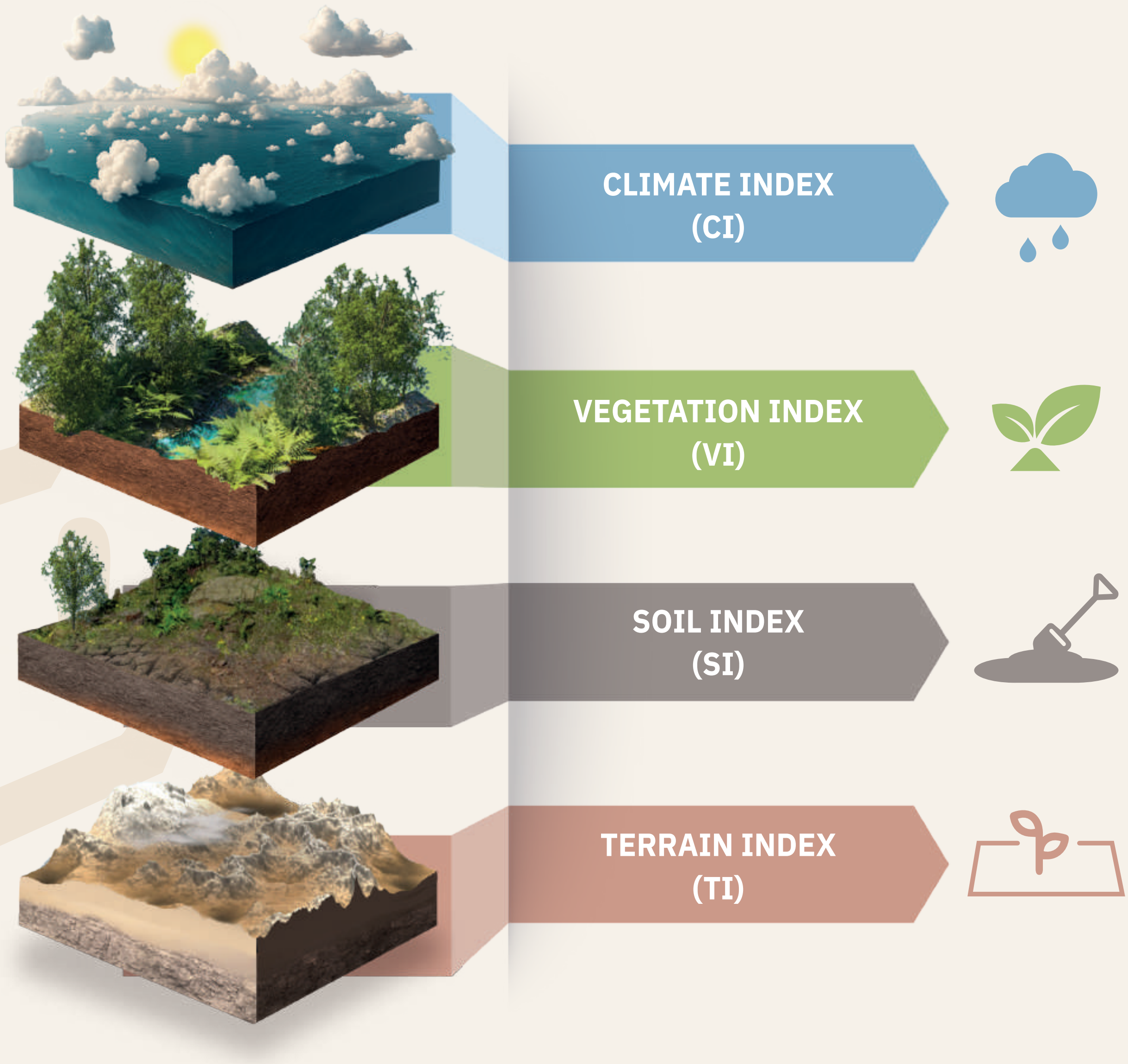
The workflow diagram illustrating the methodology adopted for the desertification sensitivity study is presented in Figure 1.

Figure 1 Workflow Diagram

The fundamental components of the model consist of four main indices:

- **Climate Index (CI):** Includes temperature, precipitation, aridity, and wind speed parameters.
- **Soil Index (SI):** Includes soil organic carbon content, sand–clay balance, and soil moisture parameters.
- **Terrain Index (TI):** Consists of slope and aspect variables (i.e., solar exposure direction).

These four indices are combined into a comprehensive structure to form the Desertification Sensitivity/Hazard Index (DSI/DHI). In the hazard analysis, data obtained from CMIP6 global climate projections were integrated into the model. At this stage, the SSP2-4.5 (optimistic) and SSP5-8.5 (pessimistic) scenarios were used to assess the potential desertification hazard under two different future climate conditions.



2.1. Theoretical Framework of the Model

The desertification sensitivity and hazard model employed in this study is based on the Euclidean distance principle, which is widely used in mathematics, statistics, and various scientific disciplines to measure differences or distances between multidimensional datasets (Zhao et al., 2023). The fundamental approach of the model is to determine an area's sensitivity to desertification by calculating the extent to which soil, vegetation cover, climate, and terrain (topographic) indices deviate from a reference condition considered least sensitive to desertification (i.e., the ideal or low-sensitivity level). Accordingly, sensitivity is evaluated based on the combined effect of all relevant indicators (soil, climate, vegetation, and terrain conditions), rather than on a single factor.

In the calculations, the data were first normalized to eliminate scale differences arising from variations in measurement units and value ranges across the indicators. During this process, the direction of each indicator's relationship with desertification sensitivity (positive or negative) was considered. Indicators whose values decrease as sensitivity increases (e.g., soil moisture, NDVI, precipitation, soil organic carbon, clay content, and aridity index) were classified as negatively related. In contrast, indicators whose values increase as sensitivity increases (e.g., sand content, slope, temperature, and wind speed) were classified as positively related. Appropriate standardization formulas were then applied to each group (Zhao et al., 2023). Thus, all indicators were rendered comparable within the 0–1 range.

$$\text{Equations 1. } X_i' = \frac{X_i - min\{X_i\}}{max\{X_i\} - min\{X_i\}} \quad (1)$$

$$\text{Equations 2. } X_i' = \frac{max\{X_i\} - X_i}{max\{X_i\} - min\{X_i\}} \quad (2)$$

For indicators containing time series data (e.g., NDVI), minimum and maximum values were determined at the national scale using all cell grid values for the period 2003–2022, and normalization procedures were performed based on this common range.

For climate variables, both historical (observational) and projection periods (2003–2100) were evaluated together; historical model data, observations, and future scenarios were integrated to create a comprehensive time series. This approach enabled the development of a consistent and comparable hazard scale extending from the past into the future.

After standardization, degree of deviation from the ideal condition was determined for each indicator, and separate sub-sensitivity indices were calculated for four main indicator groups: Soil (SI), Vegetation (VI), Climate (CI), and Terrain (TI). As the index value increases, the corresponding factor group is assumed to deviate further from the ideal state, indicating a higher level of sensitivity. In the final stage, these four sub-indices (SI, VI, CI, TI) were combined using the Euclidean distance approach to generate the Final Desertification Sensitivity Index (DSI) or Desertification Hazard Index (DHI) (Zhao et al., 2023; Cheng et al., 2004).

$$SI = \sqrt{(SOC - SOC_{low})^2 + (Sand - Sand_{low})^2 + (Clay - Clay_{low})^2 + ("Soil\ Moisture\ - "Soil\ Moisture_{low})^2}\ (3)$$

$$VI = \sqrt{(NDVI - NDVI_{low})^2}\ (4)$$

$$CI = \sqrt{(Precipitation - Precipitation_{low})^2 + ("Temperature - Temperature\ _{low})^2 + (Aridity - Aridity_{low})^2 + (Wind\ Speed\ - Wind\ Speed_{low})^2}$$

(5)

$$TI = \sqrt{(\ Slope\ -\ Slope\ _{low}\ )^2 + (Aspect\ -\ Aspect\ _{low}\ )^2}\ (6)$$

$$\text{Ç}HI\ /\text{Ç}TI = \sqrt{(SI - SI_{low}\ )^2 + (VI - VI_{low}\ )^2 + (CI - CI_{low}\ )^2 + (TI - TI_{low}\ )^2}\ (7)$$

Since the lowest values, denoted as “low” in the equations, are set to 0 through the standardization process, the term “low” in Equations 3–7 represents the degree of deviation of the relevant indicator from the most suitable (optimal) condition with respect to desertification.

$$SI = \sqrt{SOC + \text{Soil}^{\ 2} + \text{Clay}^{\ 2} + \text{Soil Moisture}^{\ 2}}(8)$$

$$VI = \sqrt{\text{NDVI}^2}(9)$$

$$TI = \sqrt{\text{Slope}^{\ 2} + \text{Aspect}^{\ 2}}(10)$$

$$\text{CI} = \sqrt{Precipitation^{\ 2} + \text{Temperature}^{\ 2} + \text{Aridity}^{\ 2} + \text{Wind Speed}^{\ 2}}(11)$$

$$\text{DSI} = \sqrt{SI^2 + VI^2 + CI^2 + TI^2}(12)$$

2.2. Literature Review and Justification for Method Selection

In desertification sensitivity assessments, in addition to commonly used methods such as MEDALUS, AHP, and BAHP, Machine Learning and Geodetector-based approaches have also been applied in recent years. The advantages, limitations, and data requirements of these methods were evaluated, and a comprehensive analysis for method selection was conducted in consultation with the project advisors.

As a result of these evaluations, it was deemed appropriate to employ a Euclidean distance-based multi-criteria decision-making approach to determine desertification sensitivity. The preference for this method was influenced by its ability to integrate criteria into the model and the hazard that subjectively weighted methods, such as AHP, may produce inconsistent results in large-scale, high-resolution studies. Analyzing approximately 1.5 billion grid cells at a spatial resolution of 30 meters across Türkiye makes it challenging to reliably determine weights that vary across both space and time.

Furthermore, the use of different weight sets for the same indicators across various studies in the literature suggests the absence of an objective weight standard. Therefore, within the scope of this study, equal analytical importance was assigned to all criteria, and the indicators were statistically normalized based on their established relationship with desertification trends. The fundamental criteria used in the model consist of a total of 11 indicators: NDVI, precipitation, temperature, wind speed, aridity, soil moisture, sand and clay content, soil organic carbon, aspect, and slope.

Normalized values for dynamic indicators (NDVI, soil moisture, aridity, precipitation, wind speed, and temperature) were calculated annually based ontheir respective observational data range; thus, interannual comparability and consistency in assessment results were ensured. The normalization process was performed using Equation 1 and Equation 2 (Zhao et al., 2023) according to each indicator's established relationship with desertification sensitivity (i.e., positive or negative correlation). Summary information on the normalization process of the indicators is provided in Table 1.

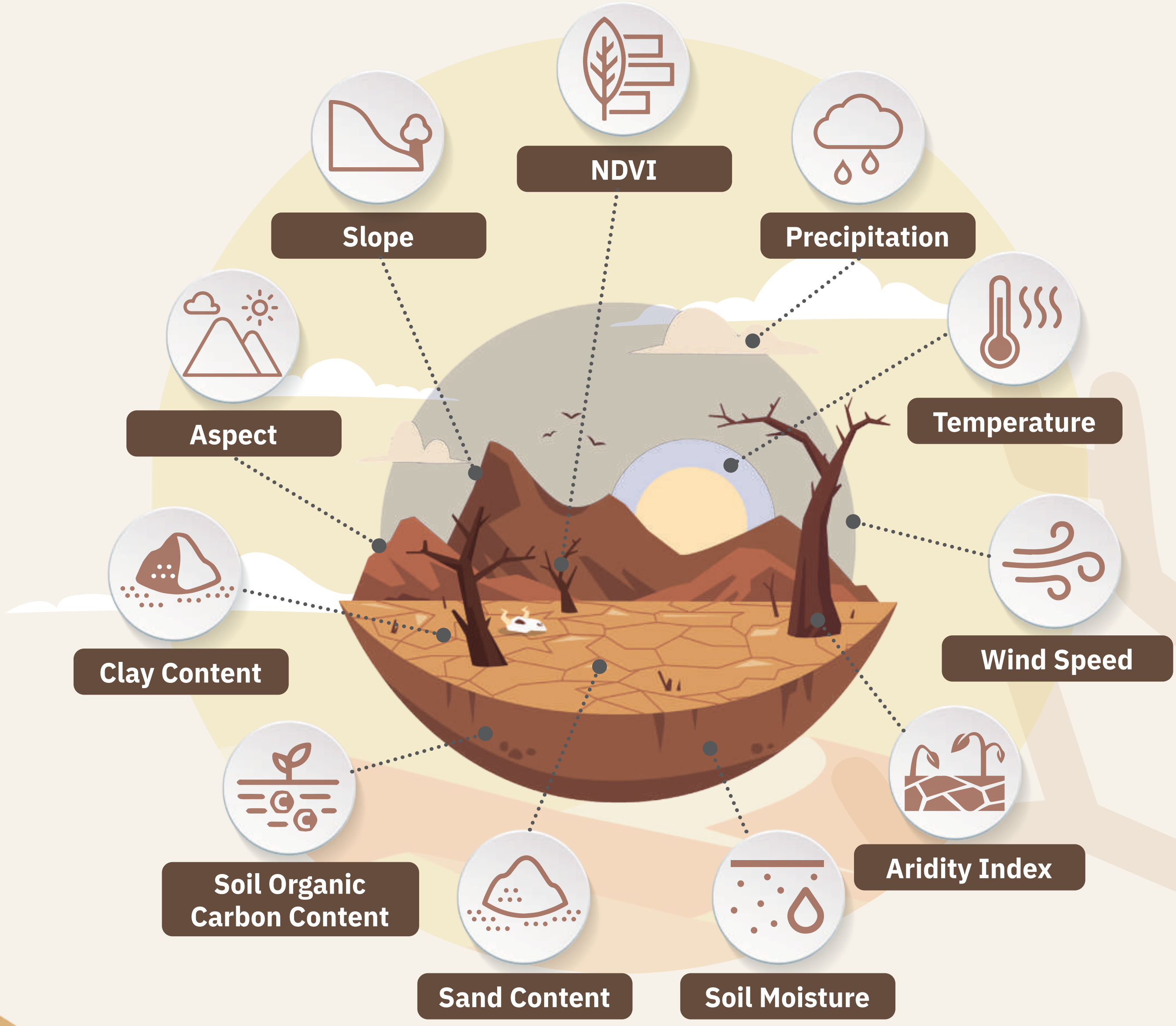


Table 1. Normalization Rules Applied to Indicators

Indicator	Normalization Type	Normalization Equation	Description
Aridity	-	Equation 1	Sensitivity increases as the aridity value decreases.
Precipitation	-	Equation 1	Sensitivity increases when precipitation decreases.
Temperature	+	Equation 2	Sensitivity increases as the temperature value increases.
Wind Speed	+	Equation 2	Sensitivity increases as wind speed increases.
Soil Organic Carbon Content	-	Equation 1	Sensitivity increases as the soil organic carbon content value decreases.
Sand Content	+	Equation 2	Sensitivity increases as the sand content value increases.
Clay Content	-	Equation 1	Sensitivity increases as the clay content value decreases.
Soil Moisture	-	Equation 1	Sensitivity increases as soil moisture decreases.
NDVI	-	Equation 1	Sensitivity increases as the NDVI value decreases.
Aspect			South and south-facing slopes have a value of 1, other areas have a value of 0.
Slope	-	Equation 1	Sensitivity increases as the slope value decreases.

2.3. Data Collection

In desertification modeling, various environmental datasets reflecting the current biophysical characteristics of the land, its recent dynamics, and future climate projections are of critical importance. Table 2 presents the datasets and their sources used in this study.

Table 2. Datasets Used in the Modeling Process

Data Set	Original Resolution	Data Source	Temporal Interval
SOC	250 m	Directorate General of Combating Desertification and Erosion, Türkiye	Static
Soil Content	1 km	Directorate General of Combating Desertification and Erosion, Türkiye	Static
Clay Content	1 km	Directorate General of Combating Desertification and Erosion, Türkiye	Static
NDVI	250 m	MODIS–Aqua	2018-2022
Aridity	~3 km	This data was collected from a study conducted under the EU Partnership Project implemented by UNDP Türkiye, with the Climate Change Directorate as the beneficiary institution.	2003-2100
Temperature	~3 km	This data was collected from a study conducted under the EU Partnership Project implemented by UNDP Türkiye, with the Climate Change Directorate as the beneficiary institution.	2003-2100
Precipitation	~3 km	This data was collected from a study conducted under the EU Partnership Project implemented by UNDP Türkiye, with the Climate Change Directorate as the beneficiary institution.	2003-2100
Wind Speed	~3 km	This data was collected from a study conducted under the EU Partnership Project implemented by UNDP Türkiye, with the Climate Change Directorate as the beneficiary institution.	2003-2100
Soil Moisture	~3 km	This data was collected from a study conducted under the EU Partnership Project implemented by UNDP Türkiye, with the Climate Change Directorate as the beneficiary institution.	2003-2100
Slope	30 m	ALOS	2003-2100
Aspect	30 m	ALOS	Statik

Climate Index:

The Aridity Index, which reflects climatic conditions, was calculated using temperature and precipitation data derived from the same dataset and was used as a key indicator for assessing the region’s drought trends and climatic water balance. Low Aridity Index values represent high aridity conditions, indicating an increased desertification sensitivity, while high index values reflect humid climatic conditions, indicating a reduced sensitivity (Zhang et al., 2021). Additionally, wind speed data obtained from the same dataset has been integrated into the model as a critical dynamic factor affecting evaporation rates and wind erosion potential.

Vegetation Cover Index:

The Normalized Difference Vegetation Index (NDVI), which reflects the density and ecological health of vegetation cover, was calculated using 250 m resolution MODIS-Aqua satellite data for the period 2018–2022. NDVI, as an indicator of photosynthetic activity, is an important parameter for assessing land cover productivity and vegetation continuity. High NDVI values represent dense and healthy vegetation cover, indicating low desertification sensitivity; low NDVI values reflect sparse and stressed vegetation cover, indicating increased desertification sensitivity (Zhao et al., 2023).

Soil Index:

Soil organic carbon (SOC), a critical determinant of soil structural stability, water retention capacity, and the sustainability of the nutrient cycle, is one of the fundamental indicators of soil health and ecosystem resilience. High SOC levels increase resistance to desertification processes by preserving the physical integrity of the soil, while low SOC levels increase the tendency for degradation (Zhao et al., 2023). However, the sand and clay ratios of the soil also play an important role in determining the textural structure and susceptibility to erosion. A high sand content reduces water retention capacity and intensifies wind erosion, while a high clay content increases water and nutrient retention, supporting soil resilience (Zhao et al., 2023; Reichert et al., 2016).

Terrain (Topography) Index:

Static variables representing topographic features such as slope and aspect were obtained using a 30 m resolution Digital Elevation Model (DEM) derived from ALOS PALSAR data. These variables provide important inputs for assessing the spatial distribution of desertification processes and land sensitivity by determining the effects of surface shape on water accumulation, flow direction, and soil moisture.

3

TÜRKİYE DESERTIFICATION SENSITIVITY MAP

Türkiye Desertification Sensitivity Map (Figure 2), produced as a result of the model developed in this study, reveals that sensitivity to the desertification process shows distinct regional differences across the country. The map clearly shows that desertification sensitivity varies in terms of intensity and spread across different regions of Turkey due to the influence of different climatic, topographic, and soil characteristics.

According to the findings, on average, 16.92% of Türkiye's land area is classified as "very high," 32.19% as "high," 29.31% as "medium," 16.76% as "low," and 4.83% as "very low" sensitivity. This distribution shows that approximately half of the country's land is at a high or very high sensitivity level.

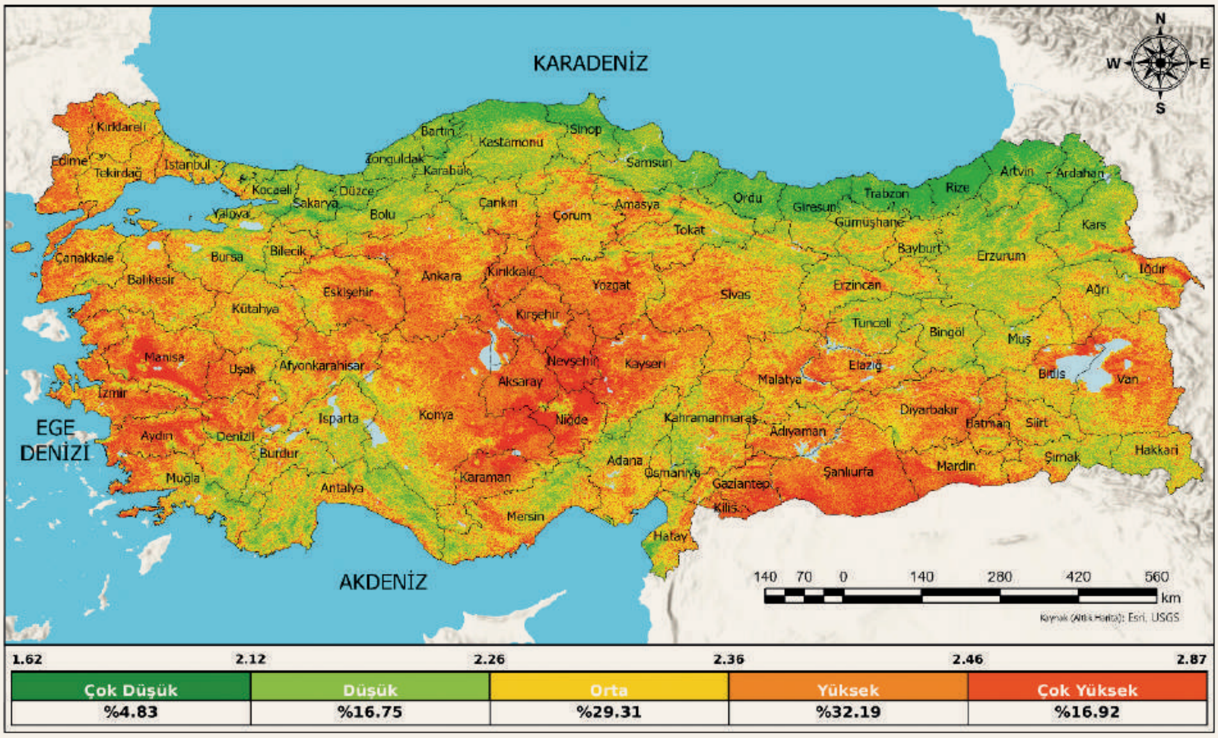


Figure 2 Türkiye Desertification Sensitivity Map

3.1. Spatial Distribution of Sensitivity Classes

The final Türkiye Desertification Sensitivity Map (Figure 2) reveals the general pattern across the country However, it is also crucial to understand the distribution of sensitivity at different management and planning scales. Therefore, this section analyzes the spatial distribution of sensitivity classes in more detail based on Basin, Geographical Region, Province, and Main Land Types, respectively.

3.1.1. Basin-Based Distribution Analyses

The Desertification Sensitivity Map has been overlaid with 25 main watershed boundaries, and the spatial percentages of sensitivity classes have been calculated for each watershed (Table 3).

Table 3 Percentage Distribution of Desertification Sensitivity Classes by Basin

Basin	Very Low Sensitivity (%)	Low Sensitivity (%)	Moderate Sensitivity (%)	High Sensitivity (%)	Very High Sensitivity (%)
Gediz	0.06	2.64	18.88	38.79	39.64
Konya	0.27	5.3	14.63	42.24	37.56
Small Menderes	0.02	1.82	19.38	44.47	34.31
Northern Aegean	0.04	2.38	23.88	47.4	26.3
Great Menderes	0.13	7.28	26.01	40.31	26.27
Lake Van	0.02	3.91	25.14	44.7	26.23
Kızılırmak	1.28	11.15	21.53	39.87	26.18
Meric-Ergene	0	0.27	32.83	46.4	20.51
Akarçay	0.14	9.24	29.48	40.74	20.41
Euphrates and Tigris	0.41	13.41	33.66	34.9	17.62
Sakarya	1.4	11.6	29.95	40.2	16.85
Seyhan	1.2	15.69	32.24	34.73	16.15
Asi	2.54	15.79	35.28	32.5	13.89
Susurluk	0.48	8.62	42.5	36.2	12.2
Burdur	0.08	12.55	40.77	34.42	12.18
Ceyhan	0.94	16.39	40.56	30.48	11.64
Eastern Mediterranean	1.91	20.33	37.65	29.7	10.41
Marmara	2.35	20.64	38.41	29.05	9.54
Western Mediterranean	3.41	27.38	35.77	24.38	9.07
Yeşilırmak	5.06	25.91	36.82	24.4	7.81
Antalya	3.14	28.6	39.51	22.96	5.79
Aras	11.05	38.89	29.61	15.74	4.7
Çoruh	24.77	41.24	24.54	8.46	0.98
Western Black Sea	25.26	48.64	20.82	5.08	0.19
Eastern Black Sea	57.32	30.61	9.27	2.66	0.15

Gediz (39.64), Konya (37.56), Small Menderes (34.31), Northern Aegean (26.3), Great Menderes (26.27), Van Lake (26.23), and Kızılırmak (26.18) basins are highly sensitive. These basins are generally subject to arid and semi-arid climatic conditions and intense human activity, making them the regions with the highest sensitivity to desertification. It is essential to prioritize the development of desertification control and sustainable land management practices in these areas.

3.1.2. Regional Distribution Analyses

In addition to basin-based analyses, understanding how desertification sensitivity is distributed across Türkiye's seven geographical regions is important for regional development plans and climate change strategies. To this end, the final sensitivity map was overlaid with geographical region boundaries, and the spatial percentages of the five sensitivity classes (very low, low, moderate, high, very high) were calculated for each region (Table 4).

Table 4 Percentage Distribution of Desertification Sensitivity Classes by Region

Basin	Very Low Sensitivity (%)	Low Sensitivity (%)	Moderate Sensitivity (%)	High Sensitivity (%)	Very High Sensitivity (%)
Southeastern Anatolia	0.11	4.89	24.16	41.72	29.12
Central Anatolia	0.17	5.89	22.02	43.56	28.36
Aegean	0.43	7.83	27.56	39	25.19
Marmara	2.02	13.98	36.58	34.33	13.09
Eastern Anatolia	3.8	24.8	35.7	26.51	9.2
Mediterranean	2.33	23.35	39.45	26.43	8.44
Black Sea	23.03	34.7	25.52	13.35	3.4

Southeastern Anatolia, Central Anatolia, and the Aegean regions exhibit the highest sensitivity, whereas the Black Sea Region shows the lowest sensitivity, primarily due to its high precipitation and extensive forest cover. In contrast, the Marmara, Mediterranean, and Eastern Anatolia regions display more complex spatial patterns, with "medium" and "high" sensitivity levels predominating (Table 4).

3.1.3. Distribution Analyses by Province

The examination of desertification sensitivity based on provincial administrative boundaries is important in terms of providing a basis for the planning and intervention efforts of local governments and relevant institutions. In this context, the spatial percentages of desertification sensitivity classes (very low, low, medium, high, very high) have been calculated for all 81 provinces in Turkey. The detailed percentage distribution for all provinces is presented in Table 5.

Table 5 Percentage Distribution of Desertification Sensitivity Classes by Province

Basin	Very Low Sensitivity (%)	Low Sensitivity (%)	Moderate Sensitivity (%)	High Sensitivity (%)	Very High Sensitivity (%)
Nevşehir	0	0	0.45	33.38	66.17
Aksaray	0	0.2	1.64	46.4	51.75
Niğde	0.34	4.36	13.13	30.6	51.56
Şanlıurfa	0	0.38	8.44	44.68	46.5
Kilis	0	0.69	10.33	43.7	45.28
Aydın	0.02	2.01	14.14	40.92	42.92
Manisa	0.05	2.14	17.97	37.57	42.27
Kırşehir	0	0.05	6.82	51.97	41.16
Gaziantep	0.02	2.36	17.13	42.6	37.9
Kayseri	0.46	3.79	16.33	45.37	34.06
Kırıkkale	0	0.58	12.45	54.14	32.83
Mardin	0	1.21	25.91	40.73	32.15
İzmir	0	1.55	21.11	45.55	31.78
Karaman	0.25	5.92	20.53	43.18	30.12
Yozgat	0.02	2.5	18.45	49.05	29.98
Edirne	0	0.07	18.19	54.43	27.32
Konya	0.28	7.2	22.52	43.68	26.32
Uşak	0.03	5.22	24.99	43.64	26.12
Ankara	0.2	4.73	22.52	47.69	24.85
Eskişehir	0	3.46	26.32	47.15	23.07
Diyarbakır	0.11	3.52	29.14	44.67	22.56
Adıyaman	0.01	5.21	30.32	43.2	21.26
Çanakkale	0	2.95	32.26	43.98	20.8
Elâzığ	0.07	6.71	32.05	40.46	20.71
Van	0.05	6.37	31.38	42.28	19.93
Batman	0.03	3.99	31.16	45.24	19.58
Afyonkarahisar	0.05	6.45	29.85	44.13	19.52
Bitlis	0.01	8.19	36.64	36.07	19.1
Malatya	0.01	5.73	34.65	41.74	17.88
Denizli	0.88	13.88	30.64	36.84	17.77
Balıkesir	0.03	4.17	37.29	41.57	16.95
Iğdır	0.49	16.08	31.62	35.32	16.49
Kırklareli	0.08	6.05	37.19	40.5	16.18
Muğla	2.14	19.68	33.19	30.49	14.5
Sivas	0.2	10.37	36.61	38.38	14.44
Çorum	0.15	10.57	38.07	36.97	14.24
Amasya	3.31	15.9	35.14	32.53	13.12
Tekirdağ	0	1.28	49.28	36.7	12.74

Basin	Very Low Sensitivity (%)	Low Sensitivity (%)	Moderate Sensitivity (%)	High Sensitivity (%)	Very High Sensitivity (%)
Kahramanmaraş	0.92	17.85	36.4	32.22	12.62
Siirt	0.05	9.71	40.88	36.81	12.55
Kütahya	0.08	9.68	43.69	35.24	11.31
Mersin	1.97	19.24	37.6	30.31	10.87
Hatay	3.55	19.58	38.83	28.38	9.66
Çankırı	0.58	22.35	38.04	30.08	8.96
Adana	1.08	19.86	44.42	26.03	8.61
Şırnak	0.77	23.99	39.34	27.83	8.08
Ağrı	0.25	17.06	45.45	29.23	8
Erzincan	1.04	23.1	40.07	27.97	7.82
Tokat	2.43	24.28	40.9	25.09	7.3
Burdur	1.2	23.38	42.16	26.2	7.06
Bursa	2.25	21.79	42.91	26.24	6.81
İstanbul	1.23	25.11	40.89	26.33	6.45
Osmaniye	2.17	24.28	44.15	22.95	6.44
Bilecik	0.24	20.06	46.64	26.71	6.34
Tunceli	3.02	32.28	36.32	22.38	5.99
Isparta	0.78	25.22	43.24	25.29	5.46
Antalya	4.72	31.81	37.34	20.82	5.31
Muş	0.42	21.29	48.89	24.59	4.82
Hakkâri	0.97	29.55	42.6	23.18	3.7
Bingöl	0.95	31.2	41.48	23.02	3.34
Bayburt	1.46	30.17	44.74	20.78	2.85
Kars	8.54	49.17	28.11	11.42	2.75
Bolu	4.75	43.58	34.44	14.82	2.4
Gümüşhane	6.21	38.37	35.6	17.51	2.31
Sakarya	14.35	44.54	28.97	10.71	1.43
Erzurum	7.22	44.27	34.38	12.88	1.25
Kocaeli	12.19	50.42	27.18	9.15	1.06
Kastamonu	21.45	43	25.63	8.96	0.96
Sinop	34.91	37.13	19.94	7.15	0.87
Yalova	3.77	46.75	37.29	11.47	0.72
Giresun	42.22	32.36	17.17	7.62	0.63
Samsun	22.62	52.94	19.66	4.61	0.17
Karabük	9.86	53.15	28.27	8.56	0.16
Artvin	53.89	33.44	10.3	2.21	0.16
Düzce	23.23	55.36	18.28	3.1	0.02
Ordu	46.05	41.93	10.38	1.62	0.02
Zonguldak	16.57	59.29	21.47	2.66	0.01
Bartın	29.15	52.87	16.44	1.54	0
Ardahan	41.92	46.92	10.93	0.23	0
Rize	83.38	14.24	2.19	0.18	0
Trabzon	73.13	23.88	2.8	0.18	0

Nevşehir (66.17%) and Aksaray (51.75%) are the provinces with the highest sensitivity. These are followed by provinces such as Niğde (51.56%), Şanlıurfa (46.5%), Kilis (45.28%), Aydın (42.92%), Manisa (42.27%), and Kırşehir (41.16%), which are mostly located in the Central Anatolia, Southeastern Anatolia, and Aegean regions. These provinces are severely affected by factors such as arid/semi-arid climate, water stress, intensive agriculture, and land degradation.

3.1.4. Distribution Analyses by Land Cover

Understanding the distribution of desertification sensitivity across different land use/cover types is critical for identifying sector-specific sensitivity and developing appropriate management strategies. To this end, the Desertification Sensitivity Map was overlaid with the main land cover types obtained from Turkey’s National Land Cover Classification and Monitoring System (UASİS) data, and the spatial percentages of sensitivity classes were calculated for each land type. The analysis results are summarized in Table 6.

Table 6 Percentage Distribution of Desertification Sensitivity Classes by Main Land Type

Land Cover	Very Low (%)	Low (%)	Moderate (%)	High (%)	Very High (%)
Agricultural Land	2.64	6.33	22.81	41.56	26.67
Wetlands	12.19	7.22	17.21	37.73	25.65
Urban Areas	2.26	9.1	27.75	38.15	22.73
Forests and Semi-Natural Areas	6.28	22.5	32.7	26.98	11.54
Waterways and Water Bodies	71.15	1.81	7.56	11.93	7.55

Analysis using UASIS data reveals that desertification sensitivity varies according to land type:

1. Agricultural Lands :

Agricultural lands stand out as the most vulnerable land use type in terms of desertification sensitivity. The sum of the “high” (41.56%) and “very high” (26.67%) sensitivity classes indicates that 68.23% of agricultural lands in Türkiye are directly threatened by desertification.

2. Wetlands:

Wetlands in the “high” (37.73%) and “very high” (25.65%) sensitivity classes constitute the second highest sensitivity group.

3. Urban Areas:

Urban areas and their surroundings are under “high” (38.15%) and “very high” (22.73%) sensitivity.

4. Forests and Semi-Natural Areas:

Bu alanlar, diğerlerine kıyasla daha dirençli bir yapı sergilese de “yüksek” (%26,98) ve “çok yüksek” (%11,54) hassasiyet oranları dikkat çekmektedir.

5. Waterways and Water Bodies:

71.15% of these areas fall under the “very low” sensitivity category. The presence of water itself acts as a natural buffer against desertification.

3.2. Validation

In this study, an alternative method was applied to validate the model due to insufficient field data. Badlands, which are naturally highly prone to desertification, were used as the reference dataset. It was expected that these areas would largely fall into the "high" and "very high" classes on the desertification sensitivity map; therefore, statistical analyses were performed on pixels covering badlands areas across Turkey. Desertification values were calculated for a total of 1,366 badlands areas and classified according to the determined threshold values. In the accuracy assessment a 50% threshold value was used; accordingly, for an area to be considered "correctly classified," at least half of it had to be in the "high" or "very high" sensitivity classes.

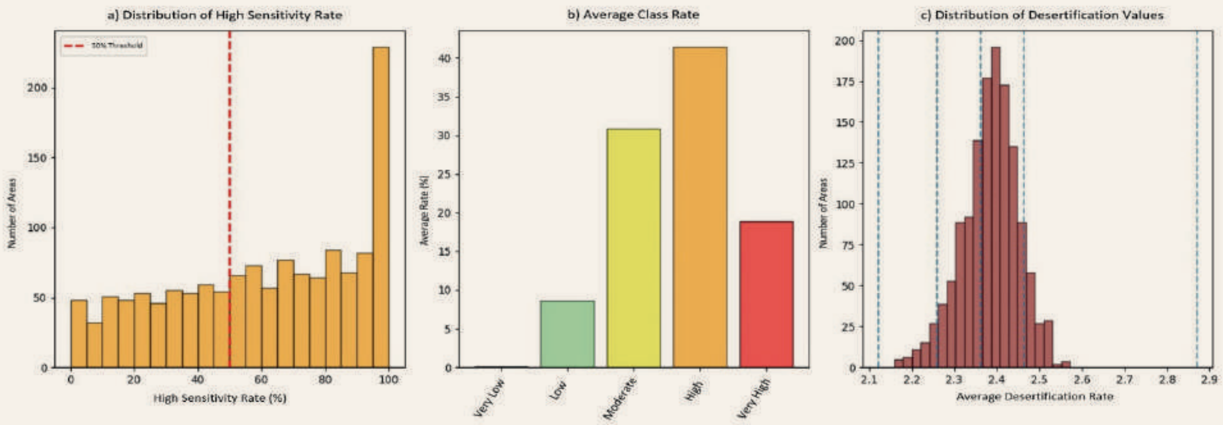


Figure 3 Accuracy Analysis Results of the Desertification Map of Badlands

The analysis results (Figure 3) show that the desertification sensitivity map largely correctly identifies the badlands as high-sensitivity regions.

a) *A significant concentration (63.5%) was observed to the right of the 50% threshold in the distribution of high-risk ratios, with a peak in the 80–100% range, indicating that most of the badlands have high sensitivity rates.*

b) *When the average class ratios were examined, 41.4% of the badlands were classified as "high" and 18.9% as "very high," revealing that a total of 60.3% of these areas were correctly accurately classified in the high sensitivity category.*

c) *The concentration of desertification values in the 2.3–2.5 range and their clustering around the value of 2.4 confirms that arid areas are generally at the "high" class threshold.*

These findings demonstrate that the desertification map has a high level of accuracy in identifying areas prone to desertification.

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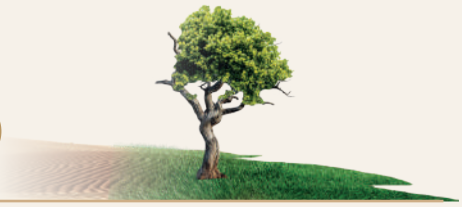
* Badland is a type of arid terrain where softer sedimentary rocks and clay-rich soils have been largely eroded by wind and water.

4

TÜRKİYE DESERTIFICATION MODEL AND HAZARD MAP



This study reveals that the primary determinant of desertification hazard in Turkey throughout the 21st century is the temperature increase consistently projected across all scenarios. The continuous warming trend exponentially increases potential evapotranspiration (PET), leading to significant and irreversible decreases in aridity index and soil moisture, particularly under the SSP 5-8.5 scenario.

Desertification risk was assessed for the near (2025–2050), medium (2050–2075), and distant (2075–2100) future periods using ECV, MRI, and MPI climate models, under SSP 2-4.5 (optimistic) and SSP 5-8.5 (pessimistic) scenarios. It was found that the proportion of areas with “very high desertification sensitivity,” which was 16.92% in the reference period (2003–2022), shows an increasing trend in all models in the future.

In the optimistic scenario (SSP 2-4.5), by the end of the century (2075–2100), this ratio remains close to current levels at 16.99% in the MPI model, while rising to 19.81% in the ECV model. In the pessimistic scenario (SSP 5-8.5), the proportion of areas at risk reaches 22.27% in the MPI model and 27.26% in the ECV model.

Table 7 Model-Based Desertification Hazard Results (SSP 2-4.5 Optimistic Scenario)

Category	ECV			MRI			MPI		
	2025-2050	2050-2075	2075-2100	2025-2050	2050-2075	2075-2100	2025-2050	2050-2075	2075-2100
Very Low (%)	4.104	3.847	3.407	4.563	4.273	4.236	4.261	4.052	4.304
Low (%)	16.822	15.702	14.568	17.932	16.591	15.941	17.141	16.315	16.569
Moderate (%)	29.792	28.682	27.654	31.447	29.879	29.251	30.606	29.825	29.462
High (%)	32.697	33.694	34.557	31.282	32.637	33.167	32.283	32.971	32.678
Very High (%)	16.584	18.075	19.814	14.776	16.620	17.405	15.709	16.836	16.987

Table 8 Model-Based Desertification Hazard Results (SSP 5-8.5 Pessimistic Scenario)

Category	ECV			MRI			MPI		
	2025-2050	2050-2075	2075-2100	2025-2050	2050-2075	2075-2100	2025-2050	2050-2075	2075-2100
Very Low (%)	4.193	3.536	2.329	5.004	3.672	3.263	5.057	3.714	3.549
Low (%)	17.445	14.363	11.029	19.226	15.652	12.381	18.238	15.408	13.777
Moderate (%)	30.359	26.757	23.093	31.619	28.322	24.127	31.260	28.147	25.532
High (%)	32.160	34.687	36.291	30.304	33.710	35.776	30.942	33.893	34.871
Very High (%)	15.844	20.658	27.259	13.846	18.644	24.453	14.503	18.839	22.271

4.1. Desertification Hazard Maps
(Near Future 2025-2050)

Near-future projections do not predict a significant increase in desertification hazard compared to the 2003-2022 reference period, but show minor differences between scenarios.

- ***SSP 2-4.5 (Optimistic Scenario):*** According to this scenario, the proportion of areas in the very high hazard class is 15.64%. This rate indicates a limited decrease compared to the reference period (16.92%). The proportion of areas in the medium hazard class has increased from 29.31% to 30.65% (Figure 4).
- ***SSP 5-8.5 (Pessimistic Scenario):*** In the pessimistic scenario, areas in the very high hazard category It has been calculated as 14.68%. In this scenario, a slight decrease is observed compared to the reference period. The proportion of areas in the low hazard class has increased from 16.75% to 18.29% (Figure 5).

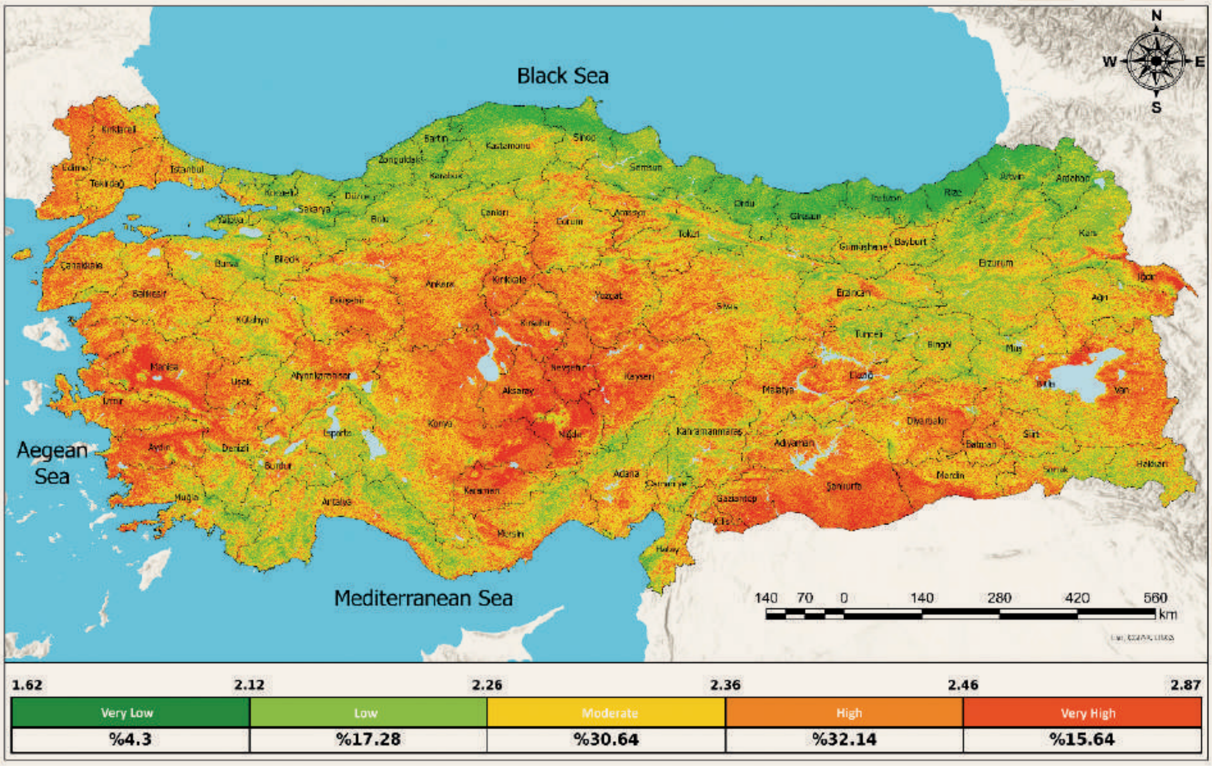


Figure 4 Türkiye Desertification Hazard Map (SSP 2-4.5 2025-2050)

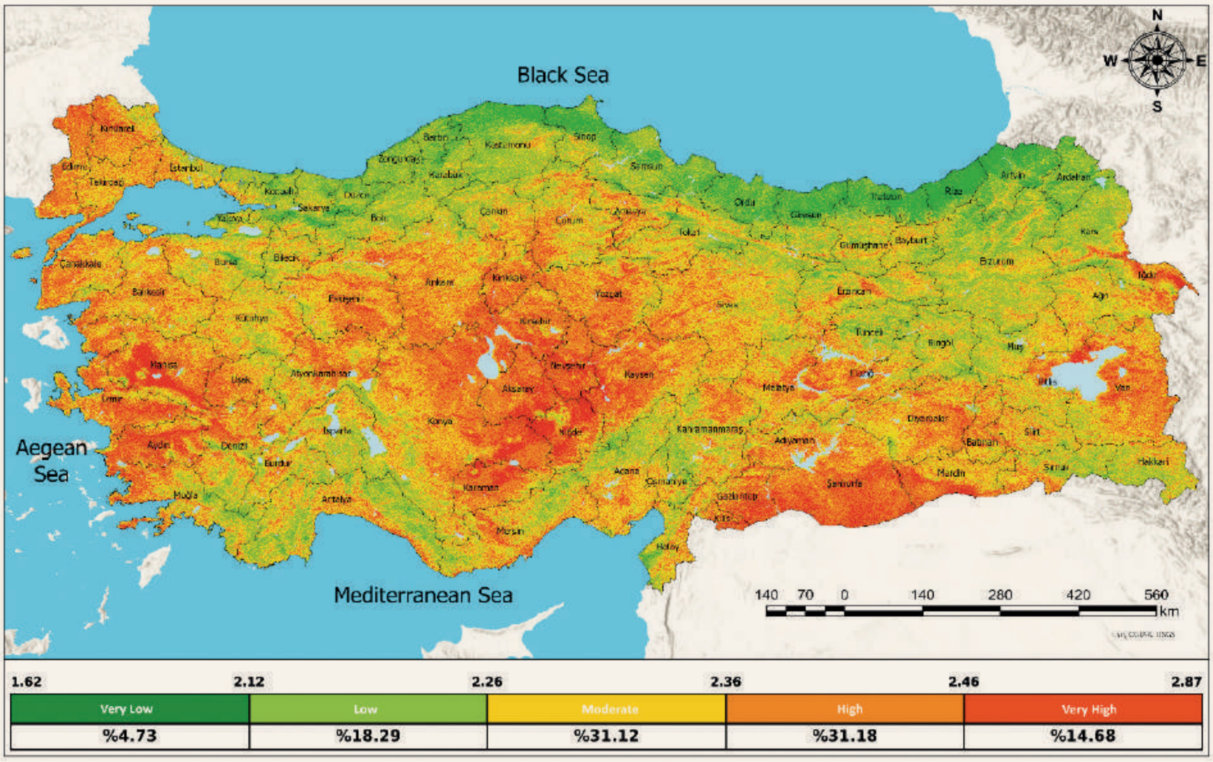


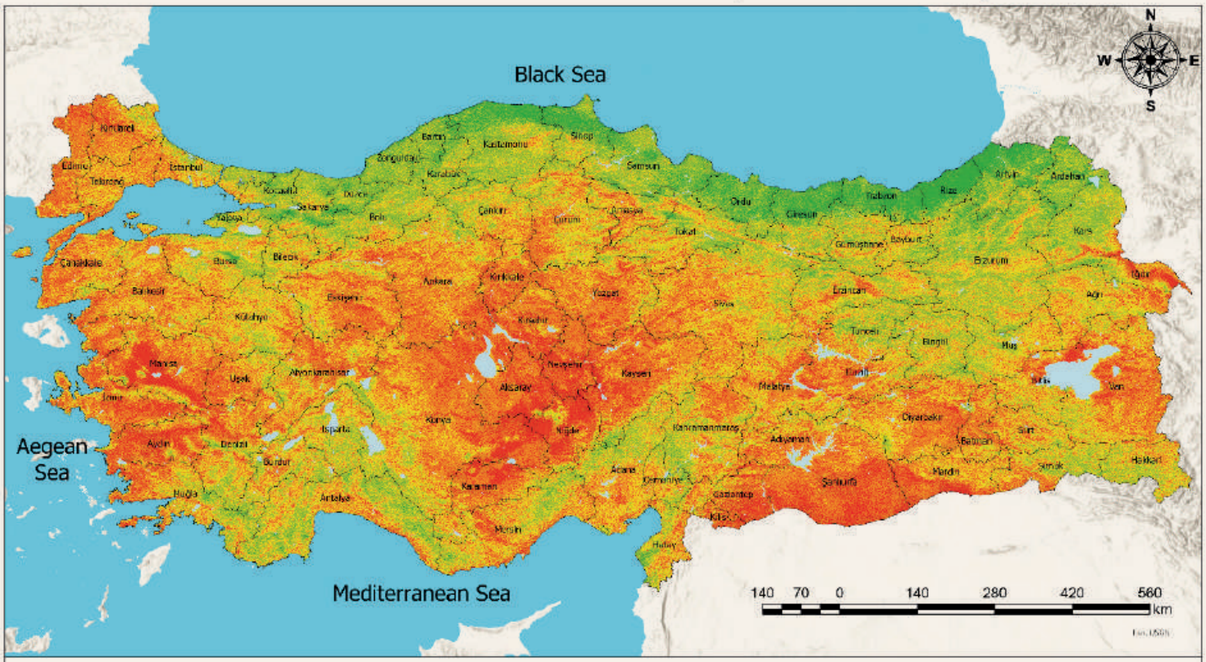
Figure 5 Türkiye Desertification Hazard Map (SSP 5-8.5 2025-2050)

4.2. Desertification Hazard Maps
(Mid-to-late 21st Century 2050-2075)

The mid-to-late 21st century future represents a period in which the desertification threat begins to become apparent and the differences between scenarios widen.

- ***SSP 2-4.5 (Optimistic Scenario):*** In this scenario, the proportion of areas under “very high hazard” has risen to 17.14%, representing a significant increase compared to the reference period. The fact that areas in the very high hazard category have exceeded the reference period level again indicates that the hazard trend is continuing (Figure 6).
- ***SSP 5-8.5 (Pessimistic Scenario):*** Under the pessimistic scenario, desertification hazard is seen to reach a more serious level. The proportion of areas in the “very high hazard” class rises to 19.34%, while the total proportion of the “very low” and “low” hazard classes declines from 21.59% in the reference period to 18.76% (Figure 7).

During this period, especially under pessimistic scenario conditions, it is observed that areas with high sensitivity have geographically expanded in Central Anatolia and Southeastern Anatolia, while areas with a “moderate” hazard level in the interior of the Mediterranean and Aegean regions have shifted towards the “high” hazard category.



1.62 | 2.12 | 2.26 | 2.36 | 2.46 | 2.87

Very Low	Low	Moderate	High	Very High
%4.04	%16.19	%29.48	%33.15	%17.14

Figure 6 Türkiye Desertification Hazard Map (SSP 2-4.5 2050-2075)

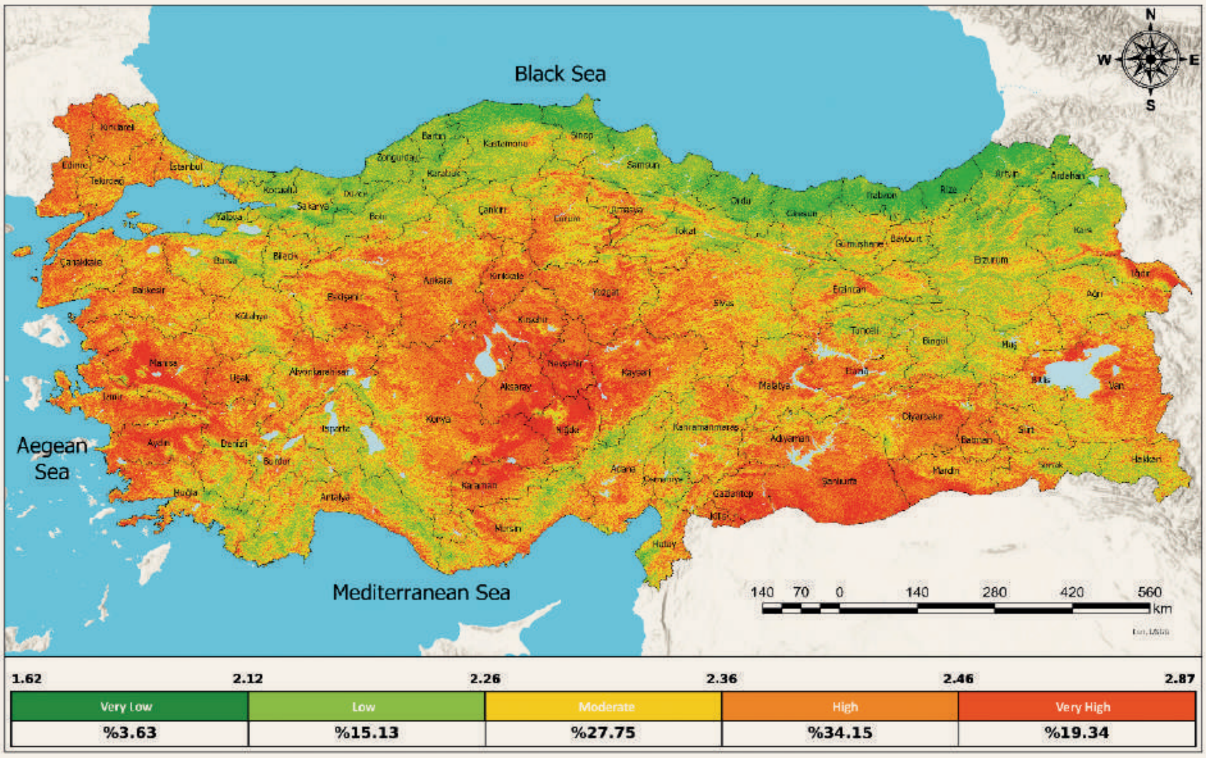


Figure 7 Türkiye Desertification Hazard Map (SSP 5-8.5 2075-2100)

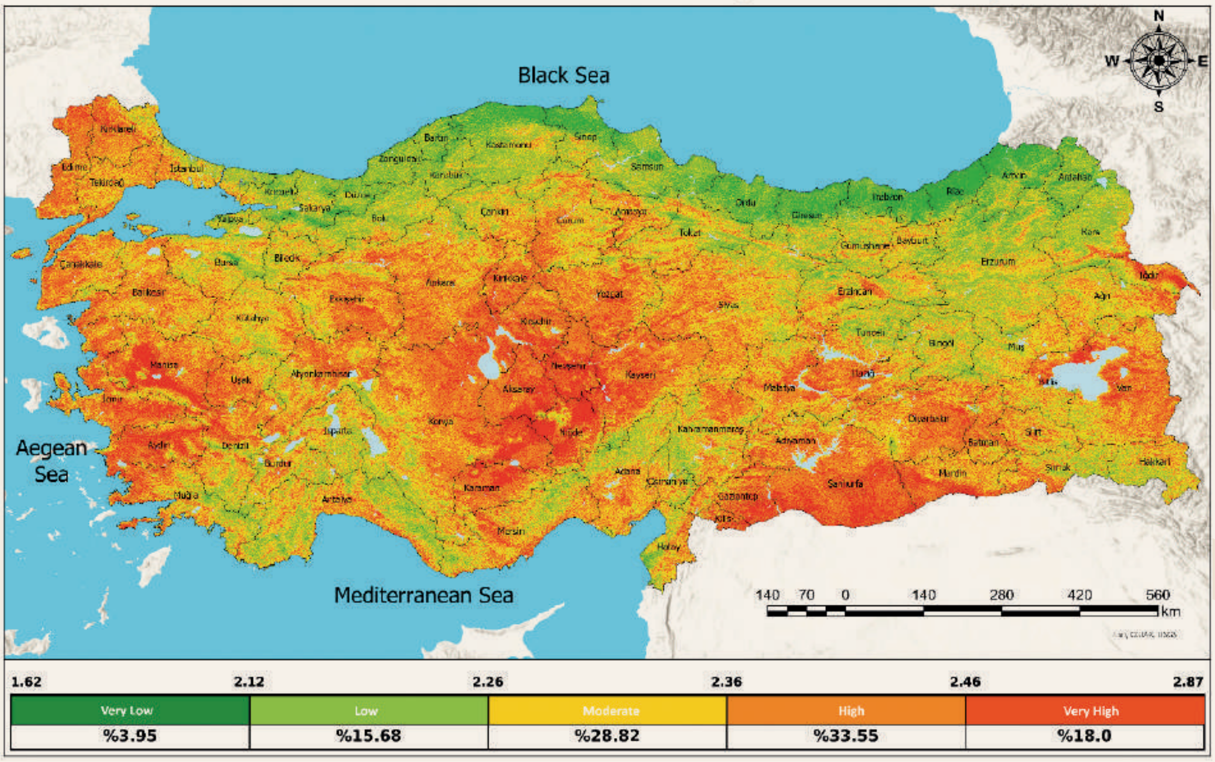
4.3. Desertification Hazard Maps
(Distant Future 2075-2100)

The last quarter of the century stands out as the period when the effects of climate scenarios on Türkiye will be felt most clearly and dramatically. During this process, the difference between the two scenarios becomes apparent.

- Under ***SSP 2-4.5 (Optimistic Scenario)***, the upward trend in desertification hazard continues. The proportion of areas classified as “very high hazard” has reached 18%, indicating that desertification sensitivity will continue to increase even if moderate success is achieved in combating climate change (Figure 8).

- ***SSP 5-8.5 (Pessimistic Scenario):*** The pessimistic scenario paints an extremely worrying picture for Türkiye. The total proportion of areas at very high hazard rises to 24.56%. The most striking change is that the proportion of areas in the very high hazard class has increased significantly to 24.56% compared to the reference period (16.92%). In contrast, the total of safe areas in the very low and low hazard classes has declined to 15.39% (Figure 9).

According to long-term projections, under the pessimistic scenario (SSP 5-8.5), desertification hazard is expected to reach its highest levels in already sensitive regions such as the Konya Basin, Southeastern Anatolia, and Iğdır. Furthermore, a clear trend of expansion towards the inland areas of the Aegean, Mediterranean, and Marmara regions has been identified. During this period, it is noteworthy that green areas outside the Black Sea coastal strip also decreased significantly.



1.62 – 2.12	2.12 – 2.26	2.26 – 2.36	2.36 – 2.46	2.46 – 2.87
Very Low	Low	Moderate	High	Very High
%3.95	%15.68	%28.82	%33.55	%18.0

Figure 8 Türkiye Desertification Hazard Map (SSP 2-4.5 2075-2100)

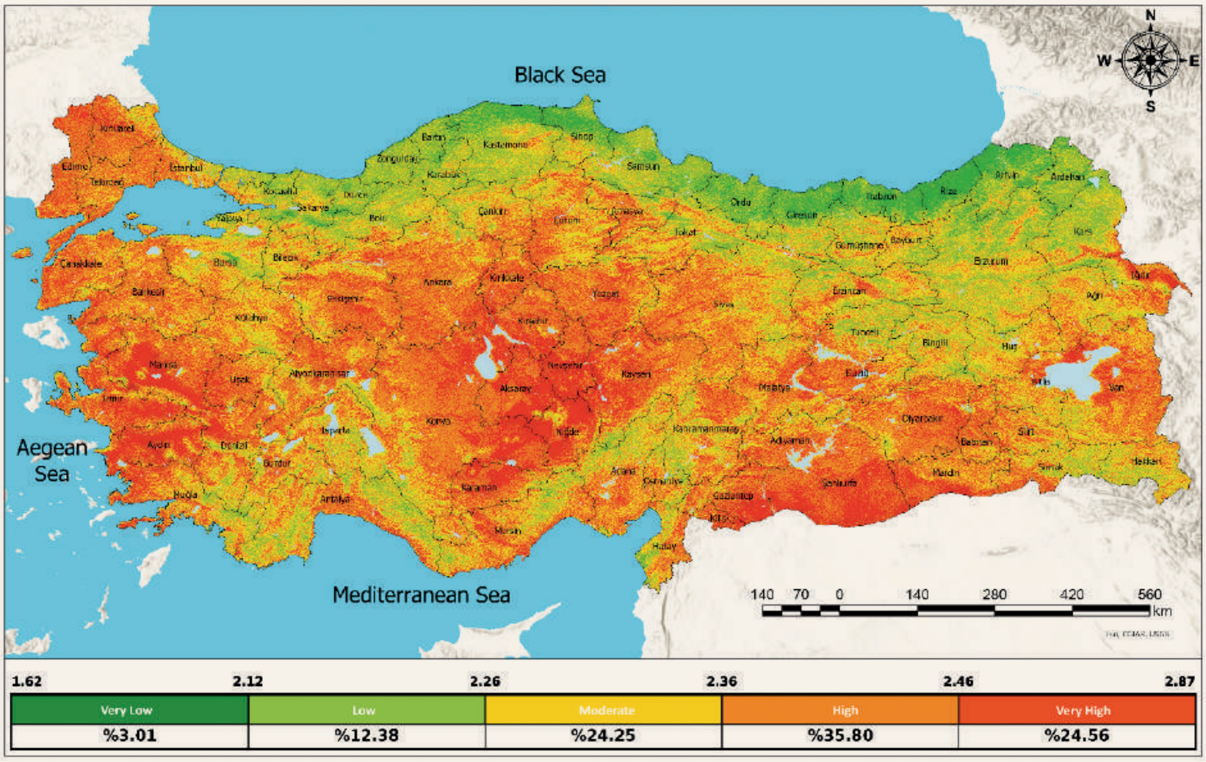


Figure 9 Türkiye Desertification Hazard Map (SSP 5-8.5 2075-2100)

The desertification hazard is expanding significantly beyond the Konya Closed Basin and Southeastern Anatolia into the inland areas of the Aegean, Mediterranean, and Marmara regions, starting in the second half of the century. This situation shows that desertification sensitivity in Türkiye is not limited to existing arid areas, but also has the potential to affect ecologically and socioeconomically more intensive regions. Although precipitation and wind projections do not reveal a clear trend, their high variability increases the vulnerability of arid lands to sudden and severe erosion events.

The findings show that hazard maps are a strategic tool that reveals not only the current situation but also future dynamic risk areas. The maps produced will enable spatial prioritization in desertification control, land use planning, and climate change adaptation policies, contributing to the implementation of a science-based, forward-looking, and sustainable approach to resource management and land use planning at the national level.

5

CONCLUSION

Within the scope of this study, Türkiye's sensitivity to desertification was mapped at a high spatial resolution of 30 meters and analyzed in detail using data from the 2003-2022 period and a multi-criteria model based on euclidean distance. The results show that, on average, 16.92% of Türkiye's land area falls into the "very high" sensitivity class and 32.19% into the "high" sensitivity class.

As expected, the highest sensitivity was concentrated in the Southeastern Anatolia and Central Anatolia regions, where arid and semi-arid climatic conditions prevail. In contrast, the Black Sea region, with its abundant rainfall and dense forest cover, was confirmed to be the most resistant area to desertification. It has been determined that climate (especially aridity and precipitation) and the resulting vegetation cover (NDVI) are the primary factors affecting the overall spatial distribution of sensitivity, while soil properties (texture, organic carbon content, soil moisture) and topographic factors play an important role in regional and local scale differences.

Annual sensitivity analyses revealed that desertification sensitivity is not a static condition and that the proportion of areas with "high" and "very high" sensitivity can increase significantly, especially in dry years when climatic stress increased nationwide, such as 2008, 2013, 2020, 2021, and 2022. In light of these findings and assessments, the sensitivity map and analyses produced should be considered a strategic tool that helps identify and prioritize risk areas by showing the spatial distribution of desertification.

This study also clearly demonstrates that the main driving force behind the desertification threat in Türkiye in the 21st century is the temperature increase, which is consistently predicted under all scenarios and could reach 4-6°C by the end of the century, based on high-resolution projections obtained by dynamic downscaling of CMIP 6 global climate models with WRF. This continuous warming exponentially increases potential evapotranspiration (PET), leading to a systematic and irreversible downward trend in the aridity index and soil moisture, especially under the SSP 5-8.5 scenario.

The quantitative results of this situation are extremely striking: The total ratio of “high” and “very high” hazard classes, which was 49.1% in the reference period (2003-2022), rises to 51.55% at the end of the century (2075-2100) under the optimistic scenario (SSP 2-4.5); under the pessimistic scenario (SSP 5-8.5) assuming current policies continue, it reaches 60.36%, crossing a critical threshold. The most alarming change is the increase in the share of the “very high” hazard category from 16.92% in the reference period to 24.56% in the pessimistic scenario. Trend analyses show that this situation occurs with a statistically significant annual increase of +0.455 points in the most negative projections, such as ECV-SSP 5-8.5, indicating that the risk profile is polarizing towards dangerous extremes.

The spatial distribution of the hazard is not limited to traditional regions such as the Konya Closed Basin and Southeastern Anatolia; since the second half of the century, it has shown a clear trend of expansion towards the inland areas of the Aegean, Mediterranean, and Marmara regions. On the other hand, the fact that precipitation and wind projections do not show a clear trend but maintain high variability creates a secondary but critical risk by leaving soils weakened by aridification more vulnerable to sudden erosion events.

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REPUBLIC OF TÜRKİYE
MINISTRY OF ENVIRONMENT, URBANIZATION
AND CLIMATE CHANGE
DIRECTORATE GENERAL OF COMBATING
DESERTIFICATION AND EROSION

Technical Summary of the Türkiye
Desertification Model