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Climate Risk Analysis for Marmara Region, Türkiye

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Abstract

Assessing climate risk due to climate change for the present and future periods has been the focus of both academic and applied research in recent years, reflecting its critical importance. In this study, we evaluated climate risks for the Marmara Region in northwestern Türkiye by integrating high-resolution climate projections with socio-economic data, aiming to inform and support regional climate policies.

To achieve this, we generated climate projections at a 0.025° x 0.025° resolution using the convection-permitting COSMO-CLM model, driven by EC-Earth3-Veg from CMIP6. These projections cover both the reference period (1995–2014) and a future period (2050–2059) under the SSP3-7.0 scenario for a broader western part of Türkiye. The Marmara Region was selected as a focal area due to its vital economic significance, its diverse and densely populated urban centers, and its extensive agricultural areas. This approach allows for a comprehensive assessment of climate impacts on a region with critical socio-economic importance, providing actionable guidance to inform policy development and adaptation strategies.

We conducted a comprehensive climate risk assessment by integrating hazard data with components of sensitivity, vulnerability, and adaptive capacity components, which were derived from reliable socio-economic datasets provided by institutions such as the Turkish Statistical Institute and the Turkish State Meteorological Service. For the weighting phase, we employed multiple methodologies, including the Analytic Hierarchy Process (AHP), Principal Component Analysis (PCA), and variance-based distribution methods, to investigate their respective contributions to the final risk evaluation.

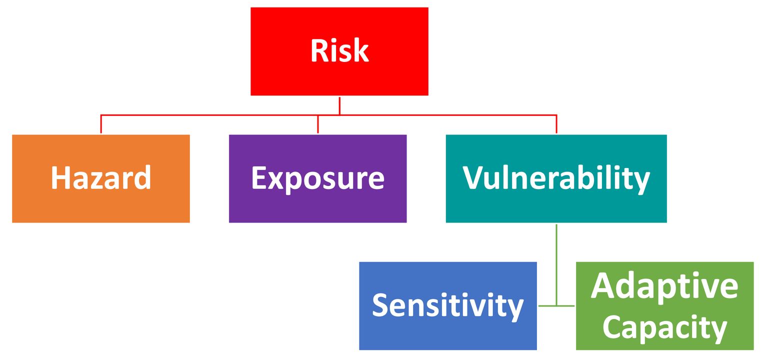
Preliminary findings reveal city-level climate risks for both the present and future periods, offering critical insights for key vulnerabilities and areas of concern. These results provide essential guidance for regional policymakers, enabling the identification of specific risk hotspots and developing targeted strategies that address the region-specific challenges. These results serve as a foundation for developing specific strategies to mitigate climate risks, strengthening resilience, and enhance adaptation capacity in the Marmara Region.

1. Background

IPCC, 2021

Risk is the possibility of events where something valuable is at risk and the outcome is uncertain. Vulnerability, exposure, and hazard combined equal risk. The possible effects of climate change on values like resources, people, ecosystems, or culture are referred to as climate risk.

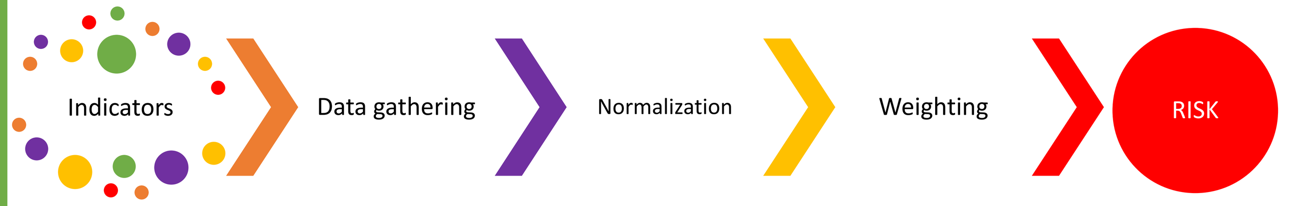
The possibility of a natural or man-made physical event, trend, or physical effect that can cause death, serious injury, health issues, property damage or loss, or impairment to infrastructure, means of subsistence, ecosystems, and natural resources is known as a **hazard**.



When people, animals, ecosystems, services, resources, buildings, or other assets related to the economy, culture, or society are present in areas where climate change may have a negative impact, it is referred to as **exposure.**

The ability to suffer negative consequences is known as **vulnerability.** Its two main parts are adaptive capacity and sensitivity. Factors that directly affect a hazard's results define **sensitivity**. It can cover a system's structural, social, cultural, and economic aspects. On the other side, **adaptive capacity** describes societies' ability to get ready for and react to the effects of the existing and upcoming environment.

2. General Methodology



The risk assessment consists of the five main steps outlined above. Climate indices used for indicators for hazard component in Box.3, selected and collected indicators for socio-economic data are given in Box.4, model configuration used for Hazard component is given in Box.5, normalization is done by the equation given below and weighting methods are given in Box.6.

$$x_{i,0\,to\,1} = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$

3. Hazard Indices

The climate indices used for the hazard component are listed on the table. After being computed using the 0.025° resolution model output, these indices were calculated for each city using a city-level shapefile, and the averages of the resulting data were used.

Indices	
CDD	Consecutive Dry Days
CWD	Consecutive Wet Days
FD	Frost Days
ID	Ice Days
R10mm	Heavy Precipitation Days (≥10 mm)
R20mm	Very Heavy Precipitation Days (≥20 mm)
SDII	Simple Daily Intensity Index
SPEI	Standardized Precipitation-Evapotranspiration
SU	Summer Days
TN10	Cold Nights
TN90	Warm Nights
TR	Tropical Nights
TX10	Cool Days
TX90	Hot Days

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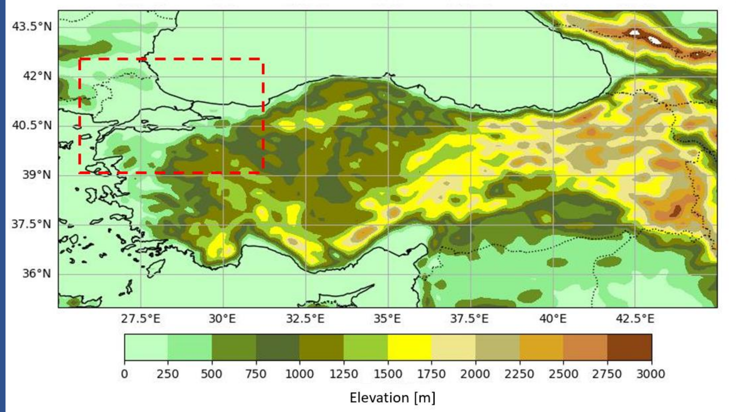
4. Socio-Economic Indicators

The steps followed for the risk assessment include the identification of indicators, data collection, normalization, weighting, and risk calculation. While determining the indicators, the accessibility, temporal, and spatial coverage of each selected indicator intended for use in the study should be checked, and the process of obtaining the data should begin. Statistical data such as population can be obtained from the Turkish Statistical Institute, while data on forested/urban areas can be sourced from CORINE data. Data needs to go through a validation process after being collected from multiple sources and organizations.

Code	EXPOSURE	Data Source	Data Period
E01	Population	Turkish Statistical Institute	2011
E02	Building Density	CORINE	2012
E03	Urban Areas	CORINE	2012
E04	Industrial Areas	CORINE	2012
E05	Forest Areas	CORINE	2012
E06	Agricultural Areas	CORINE	2012
Code	**SENSITIVITY**	**Data Source**	**Data Period**
S01	Population without a degree	Turkish Statistical Institute	2011
S02	Gross Domestic Product (GDP)	Turkish Statistical Institute	2005-2014
S03	Unemployed Population	Turkish Statistical Institute	2013
S04	Single-Person Households	Turkish Statistical Institute	2014
S05	Internal Migration Rate	Turkish Statistical Institute	2008-2014
S06	Population Growth Rate	Turkish Statistical Institute	2008-2014
S07	Wetlands	CORINE	2012
Code	**ADAPTIVE CAPACITY**	**Data Source**	**Data Period**
A01	Education Level	Turkish Statistical Institute	2011-2014
A02	Literacy Rate	Turkish Statistical Institute	2008-2014
A03	Working Population	Turkish Statistical Institute	2013
A04	Socio-Economic Development	Presidency of Strategy and Budget	2011
A05	Access to roads	General Directorate of Highways	2025
A06	Access to Health Services	Turkish Statistical Institute	2005-2014
A07	Number of usable vehicles	Turkish Statistical Institute	2007-2014
A08	Natural areas	CORINE	2012

5. Domain & Model Configuration



In the study, the EC-Earth3-Veg CMIP6 data was first downscaled to a 0.11° resolution, and then further refined to a convection-permitting 0.025° resolution. The model configuration used in this process is provided in this table down below, and for this study, the Marmara region was extracted from the 0.025° resolution domain.

	Domain	
Resolution	0.11°	0.025°
Grid	i=198, j=128	i=401, j=310
Vertical Levels	40 Levels	50 Levels
Dataset	EC-Earth3-Veg	FNEST
Microphysics Scheme	2-Category Ice Scheme	3-Category Ice Scheme
Convection Scheme	Tiedke, 1989	Shallow Tiedtke
Radiation Scheme	Ritter and Geleyn, 1992	Ritter and Geleyn, 1992
Land Surface Scheme	TERRA_ML	TERRA_ML
Land Use Data	GLOBECOVER	GLOBECOVER
Soil Data	FAO-DSMW	FAO-DSMW
Periods	RF: 1995-2014, SSP3: 2015-2099	RF: 2005-2014, SSP3: 2050-2059, 2090-2099

6. Weighting Methods

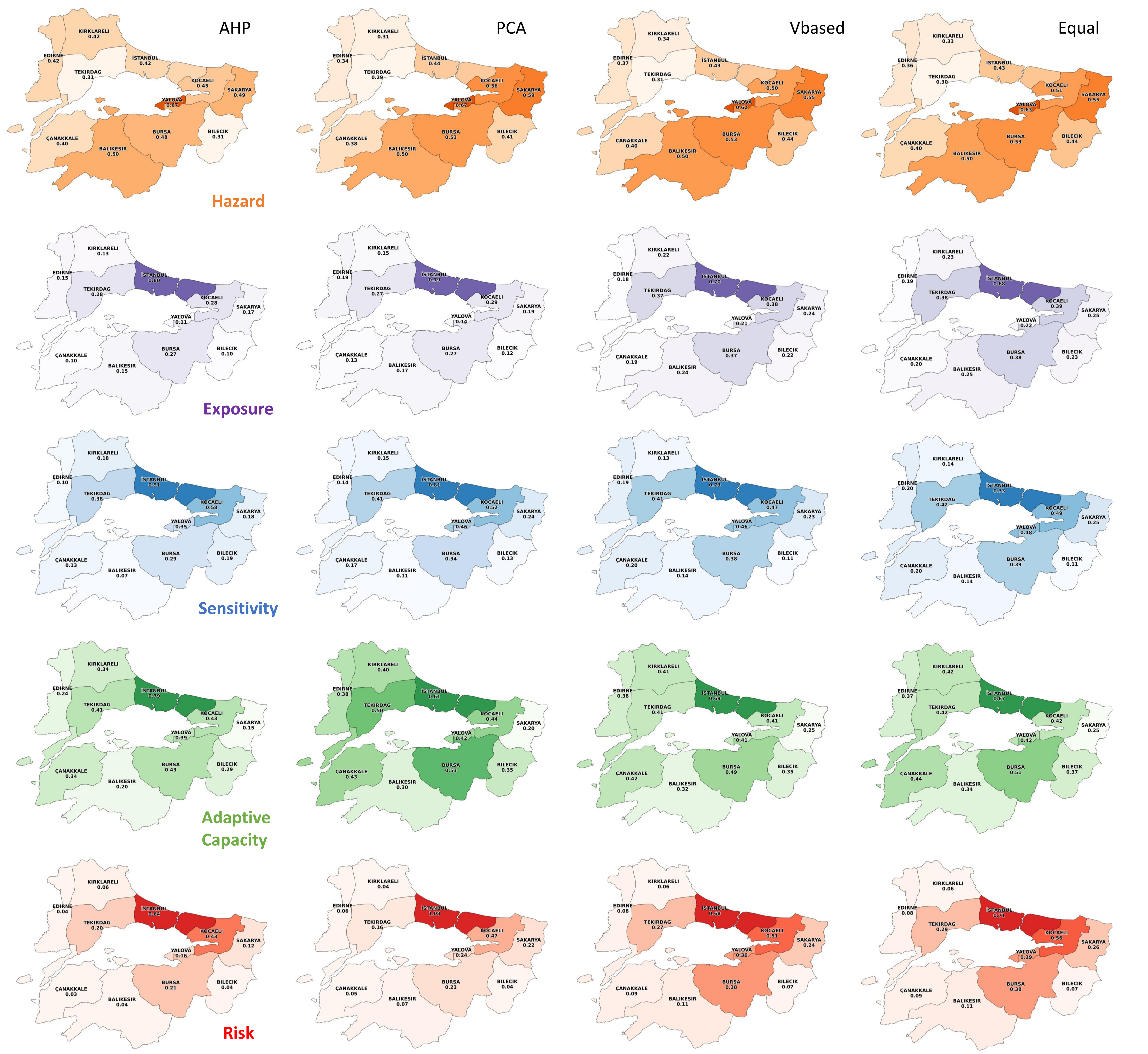
Three different methods were used for the weighting step to understand the extent to which the choice of method influences the results and to determine which of these methods provides the most suitable outcome for the study area.

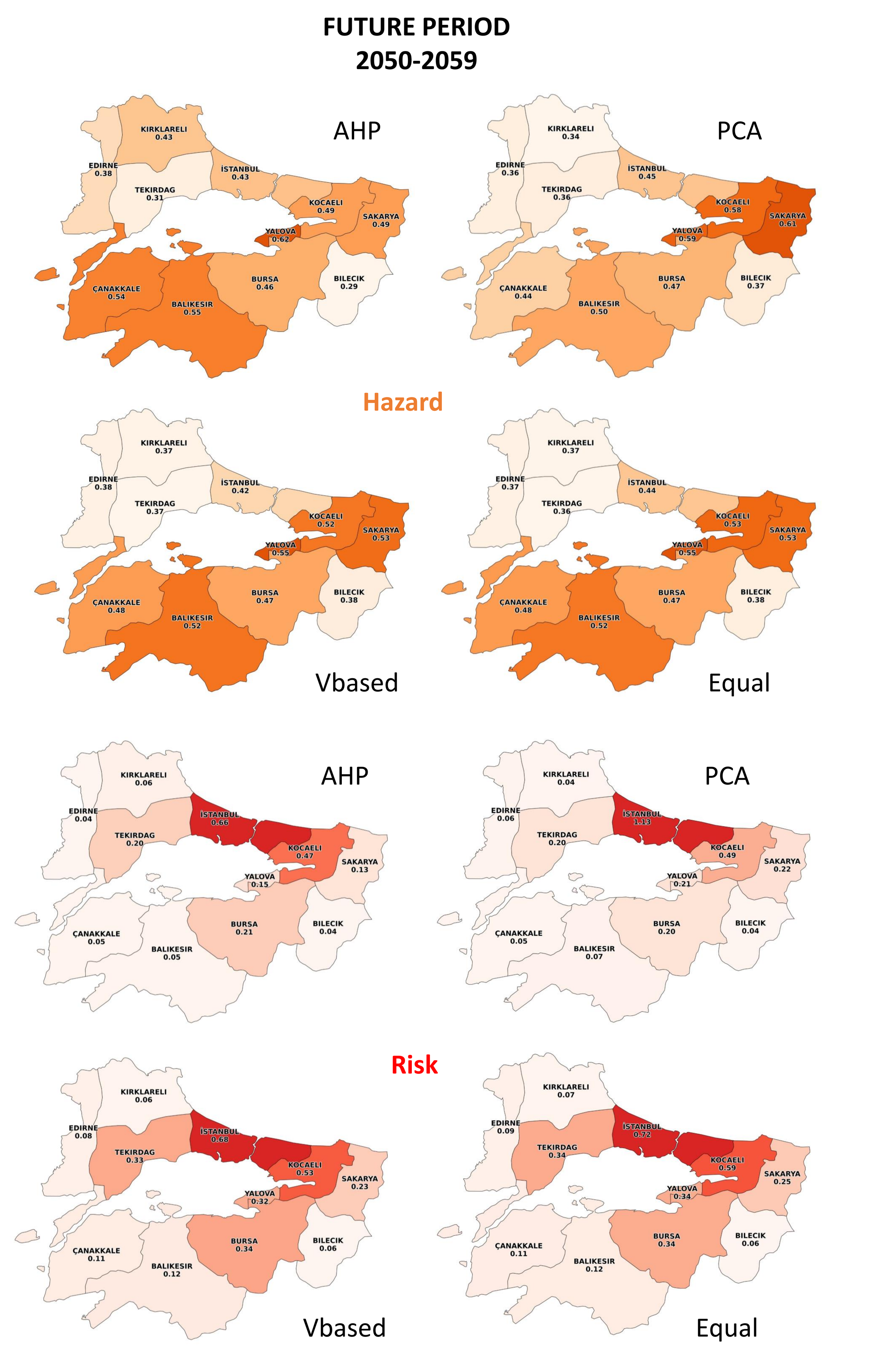
The **Analytic Hierarchy Process (AHP)**, developed in the 1970s, is a technique that applies mathematical methods to decision-making (Saaty, 2008). According to this method, making sound decisions involves four main steps. First, the problem is defined, and the type of information needed is determined. Second, a hierarchy is established from the highest to the lowest level to reach the goal. Third, a pairwise comparison matrix is created. Finally, based on the matrix structure, the weights for each element are determined. During the comparisons, a scale is used to express how much more significant or important one element is compared to another.

Principal Component Analysis (PCA) is a method commonly used with large datasets and is often considered challenging to interpret. By applying PCA, the dimensionality of such datasets can be reduced with minimal information loss, thereby enhancing interpretability. This is achieved by generating new components that capture the highest possible variance within the data. These new components are referred to as "principal components." They are derived by calculating the eigenvectors and eigenvalues of the dataset. Since these values must be recalculated for each dataset, PCA becomes a highly adaptable and unique data analysis method for different studies (Jolliffe & Cadima, 2016).

The **variance-based weighting method** was developed to overcome the limitations of the PCA approach and to offer a more straightforward alternative. It is particularly useful in risk analyses, especially when comparing regions or cities, as it allows for the weighting of indicators in a more accessible and interpretable manner (Iyengar & Sudarshan, 1982; Sekhri, Kumar, Fürst, & Pandey, 2020).

7. Risk Analysis





The years 2005–2014 were used as the reference period, while the years 2050–2059 were studied as the future periods. While keeping the exposure, sensitivity, and adaptive capacity values constant for the year future period (2050-2059), an increase in the risk scores of the cities is observed due to changes in hazard and overall risk levels. However, when comparing the risk rankings calculated using different weighting methods for both study periods, it is seen that each city generally maintains a similar position in the rankings for both reference and future periods.

8. Risk Rankings

REF	AHP	AHP Rank	PCA	PCA Rank	Vbased	Vbased Rank	Equal	Equal Rank
BALIKESIR	4,41	9	6,94	7	11,31	7	11,36	7
BILECIK	4,00	10	3,93	11	6,51	10	7,19	10
BURSA	21,42	3	22,77	4	37,88	3	38,27	4
CANAKKALE	3,45	11	4,59	9	8,98	8	9,20	8
EDIRNE	4,47	8	5,52	8	7,72	9	8,48	9
ISTANBUL	63,70	1	107,95	1	68,17	1	71,12	1
KIRKARELI	6,22	7	4,15	10	5,80	11	6,46	11
KOCAELI	42,74	2	46,89	2	50,99	2	56,15	2
SAKARYA	12,46	6	21,63	5	23,67	6	26,34	6
TEKIRDAG	19,54	4	16,20	6	27,41	5	28,66	5
YALOVA	15,68	5	24,29	3	35,77	4	39,09	3
2050-2059	**AHP**	**AHP Rank**	**PCA**	**PCA Rank**	**Vbased**	**Vbased Rank**	**Equal**	**Equal Rank**
BALIKESIR	4,85	8	6,89	7	11,68	7	11,73	7
BILECIK	3,77	11	3,58	11	5,69	11	6,16	11
BURSA	20,67	3	20,30	5	33,97	3	34,17	5
CANAKKALE	4,72	9	5,30	9	10,81	8	11,17	8
EDIRNE	4,05	10	5,85	8	7,96	9	8,80	9
ISTANBUL	66,07	1	112,72	1	67,68	1	72,16	1
KIRKARELI	6,33	7	4,50	10	6,42	10	7,10	10
KOCAELI	46,65	2	49,10	2	53,10	2	58,66	2
SAKARYA	12,61	6	22,42	3	22,63	6	25,03	6
TEKIRDAG	19,85	4	20,25	6	32,86	4	34,47	3
YALOVA	14,52	5	21,50	4	31,72	5	34,20	4

9. Results

- The increased frequency of climate indices associated with hazards in the future period contributes to a rise in both the hazard component and the overall risk that includes the hazard.
- Although the calculated risk values vary depending on the weighting method used, the overall ranking of the cities remains generally consistent within themselves.
- In this study, the exposure, sensitivity, and adaptive capacity components were kept constant for the future period. However, this assumption does not fully reflect reality. Future studies should incorporate socio-economic data that better represent expectations for the future, such as population projections.
- Finally, in future studies, the hazard and socio-economic components (exposure, sensitivity, and adaptive capacity) should not be assessed at the city level for a precise representation. Instead, the hazard component should be evaluated at the resolution of the climate model, while socio-economic data should be used at the most detailed available scale (such as district or neighborhood level) to calculate the risk values more accurately.

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AuthorCV

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