



Assessment of the Climate Change Vulnerability of the Cities in Turkey

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Abstract

Climate-related vulnerability indices are increasingly being utilized to enhance the creation of better disaster management strategies and to better understand and anticipate the effects of disasters related to climate change. This study evaluates the climate change vulnerability of the cities in Turkey by focusing on their exposure, susceptibilities, and adaptive capacities to climate change. Data from social, economic, and environmental sub-indicators were assessed and the most relevant indicators were aggregated to construct a composite Climate Change Vulnerability Index (CCVI). The CCVI includes six forms of capital leading to socio-economic and environmental sustainability i.e. social, public utility and transport, economics, land cover, meteorology, atmospheric conditions, and natural disaster capitals, and will be assessed by combining each of these forms of capital and its three dimensions (exposure, susceptibility, and adaptive capacity). Stakeholder-driven structured methodology that discovers and ranks context-relevant indicators and sets weights for aggregating indicator scores by using the Best-Worst method (BWM) and stepwise weight assessment ratio analysis (SWARA) method are utilized. The indicators are aggregated through the application of the BWM and SWARA weights using a linear aggregation method. From BWM and SWARA, the highest weights were obtained for meteorological conditions and land cover which are more than 0.36 and 0.22, respectively. The lowest weights were assigned to social characteristics and economy both of which were smaller than 0.10. The findings indicated that the cities on the northern, western, and southern coasts as well as the cities in the southeast region are the most vulnerable to climate change. The construction of CCVI can be used as part of the decision-making process to minimize hazards and exposure to the risk of climate change for the cities of Turkey.

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Keywords :

Climate change vulnerability; Composite indicators; Best-Worst method (BWM); SWARA method; Turkey

1. Introduction

Climate change is ambiguous, having significant effects on human and ecological systems throughout the globe (Pandey et al., 2015; Abid et al., 2023). The Intergovernmental Panel on Climate Change (IPCC, 2014) has released its fifth assessment report, which highlights how climate change is affecting every part of the globe—from tropical to Arctic regions, islands, and continents, as well as affluent and poor nations. Along with its effects on local agro-climatic and ecological conditions, rainfall patterns, and other aspects of human well-being, climate change may also have significant consequences for livelihoods, health, and other facets of human welfare (Connolly-Boutin & Smith,

2016; Pagnani et al., 2021; Sithole et al., 2023). Particularly vulnerable to climate change is the country Turkey through its geographic, climatic and socio-economic conditions, which make Turkey extremely susceptible to the effects of climate change and other environmental threats, making resilience and adaptation becoming key priorities (Bayram & Ozturk, 2021; Gumus et al., 2023). The degree to which a system is impacted by climate stressors connected to the environment, either negatively or positively, is known as its susceptibility. All aspects of climate change, such as mean climate characteristics, variability in the climate, and the frequency and intensity of extremes, are considered climate-related stressors. The term ‘adaptation’ describes changes made to ecological, social, or economic systems in reaction to real or predicted climate stressors and their consequences (UN, 2024). To mitigate potential harm or take advantage of opportunities brought about by climate change, it refers to modifications in procedures, customs, and organizational structures (UN, 2024). In addition to having a more fragile transportation system than other nations, Turkey is dealing with problems related to food security, rising water stress, and unprecedented natural disasters like the post-2020 forest fire outbreaks and the massive earthquake that struck the south-eastern region of Turkey in February 2023 (World Bank, 2022; Ozkula et al., 2023). Climate conditions, population exposure (such as the percentage of the population affected by floods, forest fires, and destructive effects of the earthquake), and socioeconomic factors (such as the percentage of the economy that is based on agriculture, human and economic losses in the region that was affected by the earthquake) all contribute to this susceptibility (World Bank, 2022). The unprecedented earthquakes that occurred in February 2023 caused damage to residential buildings, manufacturing facilities, bridges, transit systems, earth structures, harbors, and lifelines in densely populated areas. According to the World Bank (2023), initial estimates of the direct infrastructure loss exceeded \$34 billion and over 15 million of the population (about 17% of Turkey’s population) was severely affected by the earthquake. Planning adaptation measures and providing a justification for their adoption would be made possible by understanding the expected climate-related risks in specific regions and their interactions with current and future populations and varieties of assets (Castells-Quintana et al., 2018; Singh & Chudasama, 2021). Understanding the geography of climate change susceptibility has several benefits, including improved disaster risk reduction, a decreased exposure of ecological and human resources, and the identification of people who are more susceptible to climate change. Consequently, strategies for mitigating susceptibility and adapting to climate change have gained widespread attention from the public. However, Turkey’s changing environment is not well monitored, and it is still unclear exactly what the future repercussions will be and where they will occur. Furthermore, information about the degree and distribution of human susceptibility to climate change and its effects in the area is scarce.

Vulnerability indicators offer a potentially valuable way to track vulnerability over time and space, pinpoint the processes that lead to vulnerability, rank the strategies that reduce vulnerability, and assess how well these strategies work in various ecological and social contexts (Adger et al., 2009). They make it possible to compare the systems under evaluation and make information about what has to be changed in an easy-to-understand manner more visually appealing. Numerous authors have used this technique in different ways, either locally or nationally. Birkmann et al. (2022), Edmonds et al. (2020), Formetta and Feyen (2019), and Abid et al. (2023) developed a set of critical indicators using a quantitative method to evaluate the vulnerabilities and adaptive capabilities of nations worldwide. On a regional level, Busby et al. (2014) showed how climate change indicators can be used to identify communities that are most vulnerable to climate impacts in Africa; Fawcett et al. (2017) indicated how two longitudinal methodologies—cohort and trend studies—are employed in the evaluation of climate change susceptibility through an analysis of case studies from the Arctic region; Malik et al. (2012) assessed Pakistan’s climate change vulnerability by combining evaluations of climatic risk, environmental and population sensitivity, and adaptive capacity; and Gupta et al. (2020) developed a spatial social vulnerability index for evaluating the socio-environmental vulnerability in four altitude zones in the Indian Himalayas. Buchir and Detzel (2023) considered the governance factor besides exposure, sensitivity, and adaptive capacity which constitute the vulnerability index to assess the climate vulnerability in Mozambique. At the local level, Notenbaert et al. (2013) examined how Mozambican agro-pastoralists manage their sensitivity to climatic pressures and their coping mechanisms, as well as the reliability of several widely used indicators of vulnerability. Mainali and Pricope (2017) created maps of Nepal’s climate change vulnerability by combining evaluations of climatic risk, and geo-physical and socio-economic factors sensitivity, and analysed how these different variables interact to shape climate vulnerability in Nepal. Kumar et al. (2016) is another local study that applied a method for assessing the susceptibility of cities to climate change by evaluating different indicators,

demonstrating the vulnerability assessment approach, and presenting a spatial assessment of climate change sensitivity patterns. Omerkhal et al. (2020) conducted questionnaires to assess vulnerability and adaptation strategies for smallholder farmers in the hills of Yangi Qala District in Takhar province, Afghanistan. A final example is Phuong et al. (2023) which applied a livelihood vulnerability index to examine the vulnerability of minority communities in upland regions of Thua Thien Hue province, central Vietnam. The literature on climate change in Turkey is multi-variate including climate change policy applied in Turkey between 1992-2015 (Turhan et al., 2016); renewable energy used for climate change mitigation (Keles & Bilgen, 2012); impacts of climate change on precipitation climatology and variability (Turkes et al., 2020), evaluation of climate change simulations over climate zones of Turkey (Onol & Unal, 2014), climate change and its consequences in Turkey (Bayram & Ozturk, 2021), and impacts of climate change on agricultural yield (Chandio et al., 2020). Despite there is increasing literature on climate change, particularly in recent periods (Kelse & Bilgen, 2012; Onoş & Unal, 2014; Turhan et al., 2016; Turkes et al., 2020; Chandio et al., 2020; Bayram & Ozturk, 2021), to the knowledge of the authors, no study in Turkey focuses on developing composite climate change vulnerability indices representing the climate vulnerability of the cities in Turkey.

This article represents the first attempt to rate Turkey's cities based on how vulnerable they are to climate change. This is accomplished by creating an index of climate change sensitivity that accounts for the natural exposure of these cities to climate change, in addition to their socioeconomic fragility and occupants' ability to adapt. Sectors generally identified with socio-economic and environmental sustainability i.e. social, public utility and transport, economics, land cover, meteorology, and atmospheric conditions, and natural disasters experience differences in vulnerability. Data from the official sources obtained for Turkey contain vulnerability indices across these six sectors over 81 regions (cities) were used to construct a composite climate change vulnerability index (CCVI) for each region. The CCVI was constructed through the application of weights that were developed from expert-based systems including the BWM (Gomez-Limon et al., 2020) and the SWARA method (Hashemkhani Zolfani et al., 2018). The former is a multi-criteria decision-making process in which pairwise comparisons are conducted when the best and the worst options are selected from a list of options. The latter method, on the other hand, was introduced in 2010 as a different paradigm in the multiple attributes decision-making field (Hashemkhani Zolfani et al., 2018). It was designed to be used in decision-making procedures where policy-making is given greater weight than in traditional decision-making processes (Haghnazar Kouchaksaraei et al., 2015). The SWARA is a newly proposed method; however, it has been used for solving many problems such as selection of green suppliers (Yazdani et al., 2016), selection of hotel projects based on environmental sustainability (Zolfani et al., 2018), evaluation of sustainable design of the household furnishing materials (Zolfani and Chatterjee, 2019), evaluation of investment alternatives of microgeneration energy technologies (Dinçer et al., 2022), and assessment of medical waste treatment techniques (Patel et al., 2023). SWARA's advantage is that it evaluates the accuracy of experts and weighs each criterion by taking into account the opinions of several experts. The most significant rank criterion is the first one, and the least significant rank criterion is the last one. The final rankings are decided by a panel of experts using the mean of their ratings. Other weight assessment methods need extensive computations with low accuracy rates; in contrast, SWARA is intuitive and time-efficient. The multiple weighs of pairwise comparisons resulting from a high number of criteria or alternatives would make addressing Multi-Criteria Decision Making (MCDM) problems more complex and would also cause pairwise comparisons to become less consistent. Rezaei (2015) who introduced the BWM noted that the unstructured method of performing pairwise comparisons is the cause of the constraint, and that the many workloads and expert complexity are not required. Rezaei came up with a novel method—the BWM—to close this gap by conducting pairwise comparisons in an organized manner. Since the BWM's appearance, it has drawn the interest of numerous academics, and numerous studies on the BWM have been published. Some examples include: Ahmadi et al. (2017), Salimi and Rezaei (2018), Kheybari et al. (2019), Wankhede and Vinodh (2021), Uyan and Ertunç (2023), Amjad et al. (2024).

Using this framework, we assess the findings from the composite indicators estimated in the study by contrasting two different weighting techniques that allow us to estimate weights external to the data. Our composite indicator of CCVI is different from other studies as we considered these two novel methods of multi-criteria decision analysis in the construction of the composite indicators. Also it represents the local conditions of the regions in Turkey which makes it different from the other indices that included different sub-criteria in the construction of the climate vulnerability index. Specifically, we want to examine the composite indicator values that come from different weighting strategies

that are calculated at the regional level for Turkey. We selected a wide variety of indicators that are relevant to describe relative socio-economic and environmental vulnerability to construct a CCVI informing vulnerability to climate change. However, different input construction methods exist to generate composite climate change vulnerability indices, resulting in different outcomes. Literature providing guidance on the assessment of the methods used and composite indicator outcomes are still scarce. Therefore, our study aims to quantify the differences between climate change vulnerability outputs from the two different approaches (BWM and SWARA methods). Through constructing CCVI from these approaches, the developed composite indicators could assist in climate practitioners in evaluating and policy making regarding the climate change vulnerability in Turkey.

2. Study Area, Data and Methods

2.1. Study Area

Turkey is the 36th largest country in the world with a considerable land area of 783,356 square kilometres. Turkey is located at the crossroads of Europe and Asia, occupying a strategic position that has been historically referred to as the “bridge between East and West” (Figure 1). The country benefits from a varied landscape, encompassing coastal plains, rugged mountains, and fertile valleys. Around 44% of the country’s land is used for agriculture, with forests covering approximately 15% of the territory and only 1.8% of the land is occupied by urbanized areas (OECD, 2017; EUCC, 2024). The diverse landscape in Turkey not only enhances its natural aesthetics but also sustains a rich range of ecosystems and biodiversity. Despite its natural beauty and cultural significance, Turkey has faced escalating challenges in recent years due to climate change and natural disasters (UNDP, 2007). According to the Turkish Ministry of Environment, Urbanization and Climate Change (EUCC), Turkey has experienced a significant increase in its average temperature over the last century, surpassing the global average temperature rise of approximately 1.3°C. (EUCC, 2021). Turkey is particularly susceptible to a variety of natural disasters, such as earthquakes, floods, landslides, droughts, and wildfires, due to its geographical positioning. Because of the existence of multiple active fault lines, such as the North Anatolian Fault and the East Anatolian Fault, the country is highly vulnerable to seismic activity (UNDP, 2007).



Figure 1: The study area

Note: NUTS: Nomenclature of Territorial Units for Statistics

2.2. Data

The assessment of vulnerability to climate change includes utilizing many indicators and criteria based on exposure, sensitivity, and adaptive capacity components to estimate the potential impacts and consequences of climate change (Žurovec et al., 2017). To assess the climate change vulnerability of the cities in Turkey, a comprehensive dataset consisting of 55 indicators across 6 themes such as economy, land cover change, meteorological conditions, natural

disasters, public utility, and transport and social characteristics were utilized, as outlined in Table 1. The selection of indicators is based on a literature review (Pandey and Jha, 2012; El-Zein and Tonmoy, 2015; Zanetti et al., 2016; Balaganesh et al., 2020; Edmonds et al., 2020; Birkmann et al., 2022) and the availability of data in the Turkish case was also influential.

Table 1: Indicators and data sources used for the vulnerability analysis.

Themes	Definition of the Indicators	Sub-indicators	Data Source
Economy	This theme includes economic indicators such as the GDP values in agriculture, industrial, services sectors, purchasing power per capita, as well as the changes in GDP per capita (2004-2021).	Agricultural GDP ^S (₺) (+), industrial GDP ^R (₺) (-), services sector GDP ^R (₺) (-), change of GDP per capita ^R (₺) (-), purchasing power per capita ^R (₺) (-), average household size ^E (person) (+)	Turkish Statistical Institute (TUIK), ESRI Business Analyst
Land Cover Change	This theme includes indicators representing the changes in agricultural land, artificial surfaces, forest and water bodies over the years (2000-2018).	Change of: agricultural land ^S (+), artificial surface ^S (+), forest ^R (-), water body ^S (-), wetland ^S (-) (% km ²)	CORINE Land Cover
Meteorological Conditions	This theme includes indicators for meteorological & atmospheric conditions like wind speed, temperature, vapour pressure, rainfall, precipitation, solar radiation (1970-2000), heating & cooling day-degree change (2010-2022).	Average values of wind speed ^S (m s ⁻¹) (+), precipitation ^S (mm) (+), water vapor pressure ^S (kPa) (+), solar radiation ^S (kJ m ⁻² day ⁻¹) (+), min. temperature ^S (°C) (+), max. temperature ^S (°C) (+), average temperature ^S (°C) (+), heating day degree ^S (+), cooling day degree ^S (+) (degree day)	Turkish Meteorological Service, National Air Quality Monitoring, WorldClim
Natural Disasters	This theme includes indicators such as the air pollution, number of floods, avalanches and landslides in the past years (1950-2019), areas affected by forest fires (2020) and the number of earthquakes.	Change of: PM2.5 ^S (+), PM10 ^S (+), NO2 ^S (+), O3 ^S (+), NOx ^S (+) (% change). Number of: landslides ^S (+) floods ^S (+), avalanches ^S (+), forest fires ^S (+), water erosions ^S (+), earthquakes ^S (+) (number)	Disaster & Emergency Management Authority (AFAD)
Public Utility and Transport	This theme includes transport-related indicators such as total length of primary and secondary roads and railways, number of vehicles, energy-related indicators such as energy use and renewable energy potential, and waste-related indicators such as total amount of solid and liquid waste.	Length of: rail network ^R (-), primary road ^R (-), secondary road ^R (-) (km); change in number of road vehicles ^S (%) (+), electric vehicle charging stations ^R (number) (-), change of electricity consumption per capita ^E (%) (+), Number of : geo-thermal energy plants ^R (-), hydrothermal energy plants ^R (-), wind turbines ^R (-), biogas and solar energy plants ^R (-) (number); change of municipal waste per capita ^R (%) (+)	ESRI Business Analyst and ArcGIS Hub, TUIK, OpenStreetMap
Social Characteristics	This theme has socio-cultural related indicators such as total population and migration changes (2007-2022), changes in educational attainment (2008-2022), socio-economic development index, number of hospital beds & doctors.	Change in: Population ^E (-), population density ^E (-), immigration ^E (+), outmigration ^E (-), people having high degree education ^R (-), illiterate people ^R (%) (+); socio-economic development index ^R (-) (index score), number of hospital beds/doctors (number) ^R (-)	ESRI Business Analyst and ArcGIS Hub, TUIK

Note: ^S Susceptibility; ^R Resilience; ^E Exposure; (+): positive relation with vulnerability; (-): negative relation with vulnerability

2.3. Normalisation of variables

The large and narrow range in the variance between the variables in multivariate statistical analysis necessitates normalizing the variables. Thus, before they are aggregated, indicators must be converted into dimensionless numbers. The variables listed in Table 1 were normalized using the min-max approach, which rescales the data

linearly by placing a value of 0 at the worst and a value of 1 at the best. Eq. (1) was utilized to represent a positive indicator, and Eq. (2) was utilized to represent a negative indicator.

$$z_{ij} = \frac{(x_{ij} - \min(x_i))}{(\max(x_i) - \min(x_i))} \tag{1}$$

$$z_{ij} = 1 - \frac{(x_{ij} - \min(x_i))}{(\max(x_i) - \min(x_i))} \tag{2}$$

2.4. The weighting of indicators with MCDM methods

Assessing climate change vulnerability in cities is a complex and crucial task that necessitates the application of comprehensive and robust approaches. Multi-criteria decision Analysis (MCDA) approaches play a key role in this assessment since they allow for the creation of composite indicators and index computations (El-Zein & Tonmoy, 2015; Žurovec et al., 2017; Truong et al., 2023). The BWM and SWARA are two powerful MCDA methods that offer a structured and quantitative way to calculate the weights of different indicators and combine information to create composite indicators and indexes.

Rezaei (2015) introduced the BWM, which offers a methodical way to assess the significance of different criteria by comparing them pairwise and pinpointing the most and the least crucial factors to establish reliable weightings. The method is praised for its simplicity, efficiency, and capacity to generate dependable weights with little cognitive load on respondents (Bovkir et al., 2023). SWARA complements BWM by providing a detailed method for adjusting initial weights based on expert judgment. Keršulienė et al. (2010) introduced the SWARA method, which enables experts to iteratively adjust weights by hierarchically evaluating criteria and considering differences in importance among successive indicators. This method is an MCDA method and does not involve complex and time-consuming calculation processes.

The BWM methodology involves multiple steps (Rezaei, 2015):

- An expert panel was assembled to provide a wide range of insights and perspectives. Experts identified the most (the best; *Bi*) and the least (the worst; *Wi*) important indicators for each vulnerability dimension based on their potential impact on urban climate change vulnerability.
- Experts conducted pairwise comparisons between *Bi* and all other indicators, as well as *Wi* against all others, using a numerical scale (Table 2) to indicate relative importance or unimportance.
- Weights were calculated by solving a linear programming problem aimed at minimizing the inconsistency of expert comparisons to ensure the reliability of the derived weights implementation.

Table 2: 1 to 9 scale for pairwise comparisons (Source: Saaty, 1980)

<i>Intensity of importance</i>	<i>Definition</i>
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values

The outstanding characteristic of the SWARA method is that it can estimate the opinions of experts or interest groups regarding the importance of variables in the weight-determination process (Mardani et al., 2017). In our study, six professionals in the fields of public policy, environmental science, geomatics engineering, and urban development and planning made up the panel of experts. They were asked to rank the importance of particular criteria based on the weights given in Table 2. Because each pair of criteria was represented as a single number in the pairwise comparison matrix, they assigned relative weights to the subject criteria based on their level of expertise. The resulting outcomes were then averaged to obtain a single value for each pair of criteria. The application methodology of the SWARA method is generally described in six steps (Alrasheedi et al., 2023; Jalilian et al., 2022).

Determination of the decision criteria (j) on the relevant problem.

Decision-makers rank the criteria from the best to the worst based on their own knowledge and experience.

Considering the created ranking, the criteria are scored comparatively, starting from the second-ranked criterion, between 0-1, consistent with multiples of 5%. In this way, s_j values are calculated.

The k_j coefficient expressed in Eq. (3) is calculated for each criterion.

$$k_j = \{1, \text{if } j = 1 \quad s_j + 1, \text{if } j > 1 \quad (3)$$

The weight coefficient q_j expressed in Eq. (4) is calculated for each criterion.

$$q_j = \{1, \text{if } j = 1 \quad \frac{q_{j-1}}{k_j}, \text{if } j > 1 \quad (4)$$

The relative weights (w_j) of the criteria are obtained using Eq. 5.

$$w_j = \frac{q_j}{\sum_{k=1}^n q_k} \quad (5)$$

2.5. Development of climate change vulnerability index

The composite vulnerability index was computed based on the 6 main indicators and their sub-indicators as summarised in Table 1. The climate change vulnerability index (CCVI) was computed through a weighted linear summation of the indicators as shown in Eq. (6)

$$CCVI = \sum_{j=1}^n W_j I_j \quad (6)$$

Where CCVI is the climate change vulnerability index; n is the number of factors influencing climate change that are considered in the analysis; W_j is the weight of criterion j which was calculated using the BWM and SWARA methods; I_j is the j th indicator that was normalized based on Eq.s (1) and (2). The value of the vulnerability score, CCVI, ranges between 0 and 1 where a value close to 0 represents lower climate change vulnerability while 1 indicates a higher vulnerability. The overall methodology in the development of CCVI is presented in Figure 2.

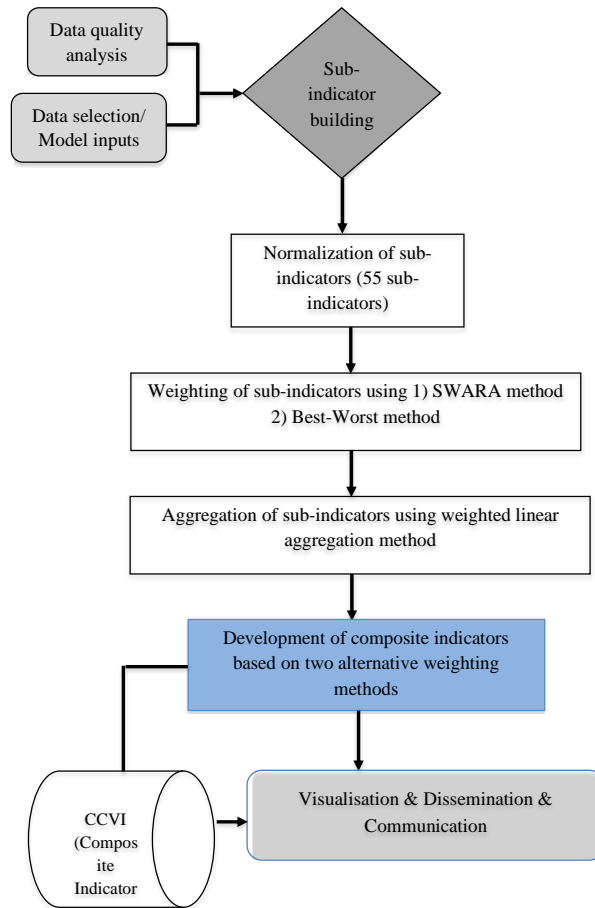


Figure 2: Different stages of the construction of the composite indicator (CCVI) in our study

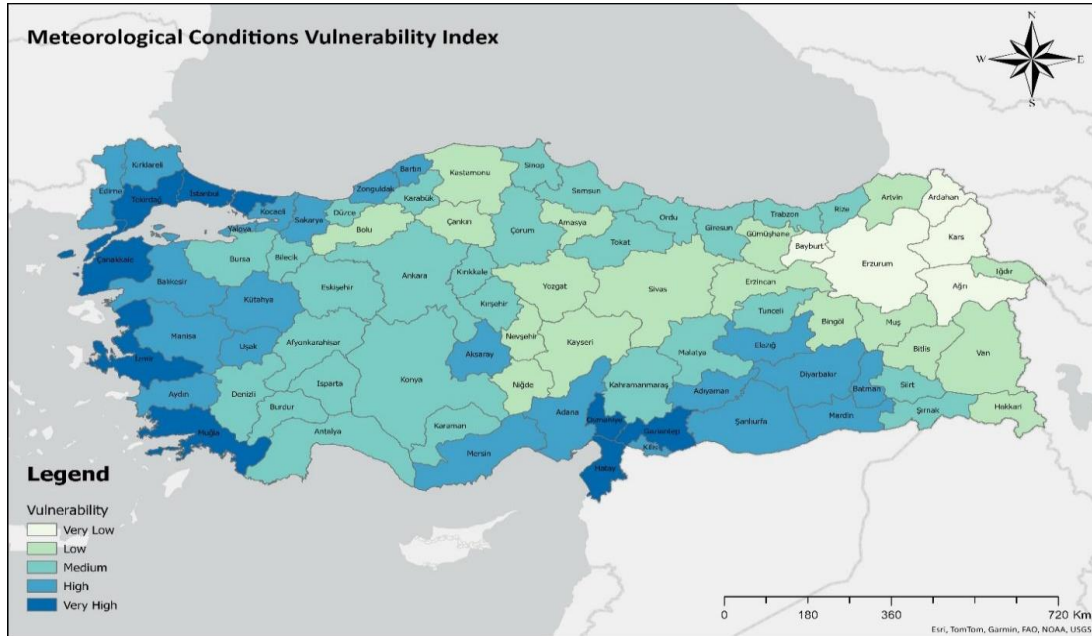
3. Results

3.1. Determining Indicators Weights

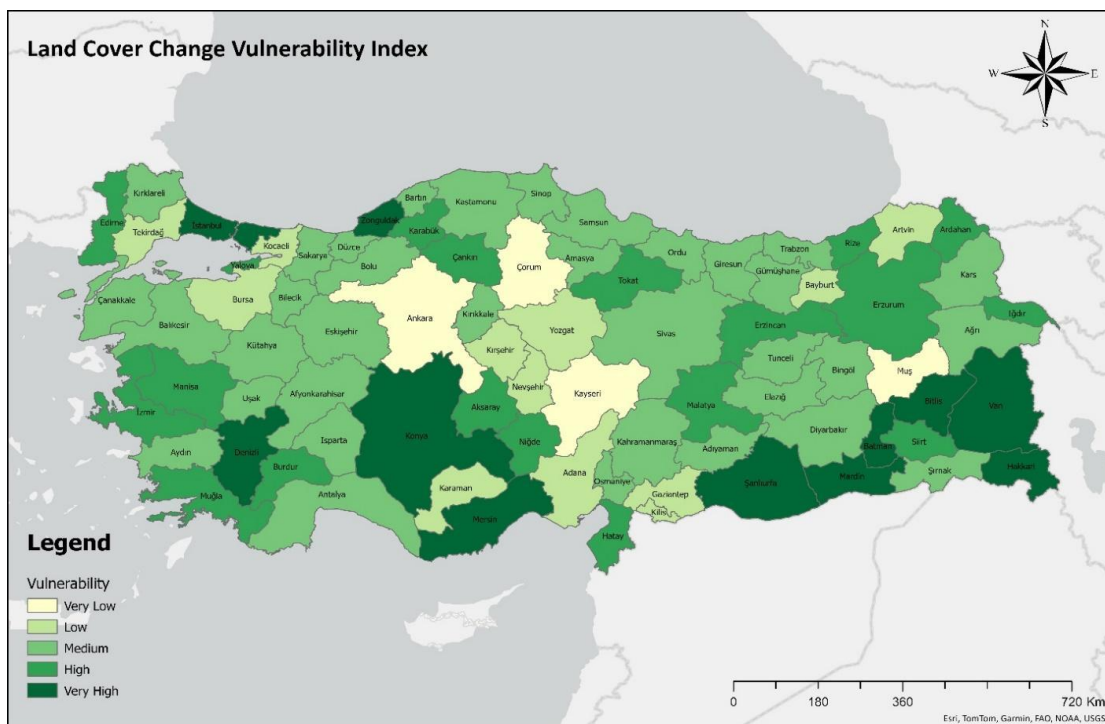
The weights of the main criteria obtained from the BWM and SWARA methods are presented in Table 3. From the Table, it can be noted that meteorological conditions and land cover change are associated with the highest weights while social characteristics and economy are assigned the lowest weights. It is also important to mention that the BWM and SWARA were applied to the main criteria and all the sub-criteria were assigned with equal weights. Therefore, we only present the results for the main criteria and skipped the presentation of the sub-criteria. As an example, the vulnerability indices calculated for meteorological conditions and land cover change are presented in Figure 3. The vulnerability maps based on other criteria can be obtained from the authors. From Figure 3, it can be seen that western, north-western, and southern cities are the most vulnerable to the changes in meteorological conditions whereas eastern and mid-cities are the least vulnerable ones. To the land cover change vulnerability, cities in the northwest and south are the most vulnerable ones and the cities in the mid-region are the least vulnerable ones. These highly vulnerable cities to land cover change are those that are accompanied by high population and urban land use growth. And the cities vulnerable to meteorological conditions are mainly the coastal cities which may be influenced by rising sea levels, extreme storms, and floods.

Table 3: The indicators weights calculated from BWM and SWARA techniques.

Main Theme	BWM Weights	SWARA Weights
Social Characteristics	0.076	0.084
Public Utility and Transport	0.114	0.117
Economy	0.045	0.052
Land Cover Change	0.228	0.229
Natural Disasters	0.152	0.152
Meteorological Conditions	0.385	0.366



(A) Note: Very Low: 0.21-0.27, Low: 0.28-0.41, Medium:0.42-0.50, High:0.51-0.58, Very High: 0.59-0.72.



(B) Note: Very Low: 0.25-0.33, Low: 0.34-0.45, Medium:0.46-0.49, High:0.50-0.53, Very High: 0.54-0.69.

Figure 3: Vulnerability indices calculated for (a) meteorological conditions (b) land cover change

3.2. Producing Climate Change Vulnerability Indexes

Because the weights we obtained from BWM and SWARA were close to each other (Table 3), the calculated composite vulnerability indicators were also similar. Therefore, we jointly presented the results as given in Figure 4. The dark colors in the Figure present the cities that are the most vulnerable to climate change in terms of exposure, susceptibility, and adaptive capacity. These cities are mainly located in the northern, western, and southern coasts of Turkey as well as the cities in the southeast region. This suggests two important observations that need to be highlighted: First, coastal areas and climate risk are interlinked, and the closest cities to the coast are also the most vulnerable to climate change. Second, the highest temperature extremes are related to impacts of the climate change. The highest seasonal temperatures particularly in summer are observed in south-eastern cities which were found to be most vulnerable to climate change. Forecasts of poor rainfall and extreme temperatures in the southeastern region suggest that a high percentage of population and livelihoods could be at risk. Based on the continuation of this trend, food security could be affected due to a lower amount of arable land, draught, and low yields of agricultural production. These regions are also prone to wildfires, among which Şanlıurfa and Mardin are the most vulnerable cities with annual share of burned land averaging 6.6 and 5.4 percent, respectively between 2011 and 2021 (World Bank, 2022). These cities are among those with large shares of poor population in Turkey implying that the poor population had to cope with the devastating impacts of wildfire in the past 10 years.

The coastal cities are vulnerable to climate change due to heavy rainfalls resulting in rising sea levels, floods, and windstorms. The estimations by Kerblat et al. (2021) indicated that a 200-year flood along the Mediterranean coast could push 100,000 people into poverty. There were 935 extreme events in 2019 with heavy rain/floods (36%), windstorms (27%), and hail (18%) that pose risks to people's lives and infrastructure (World Bank, 2022). It was estimated by the World Bank (2022: 33) that a 100-year flood would affect more than 3 percent of GDP (or \$20 billion) and 3 million people. And it was shown that both rich and poor people are affected by floods, particularly in the coastal areas.

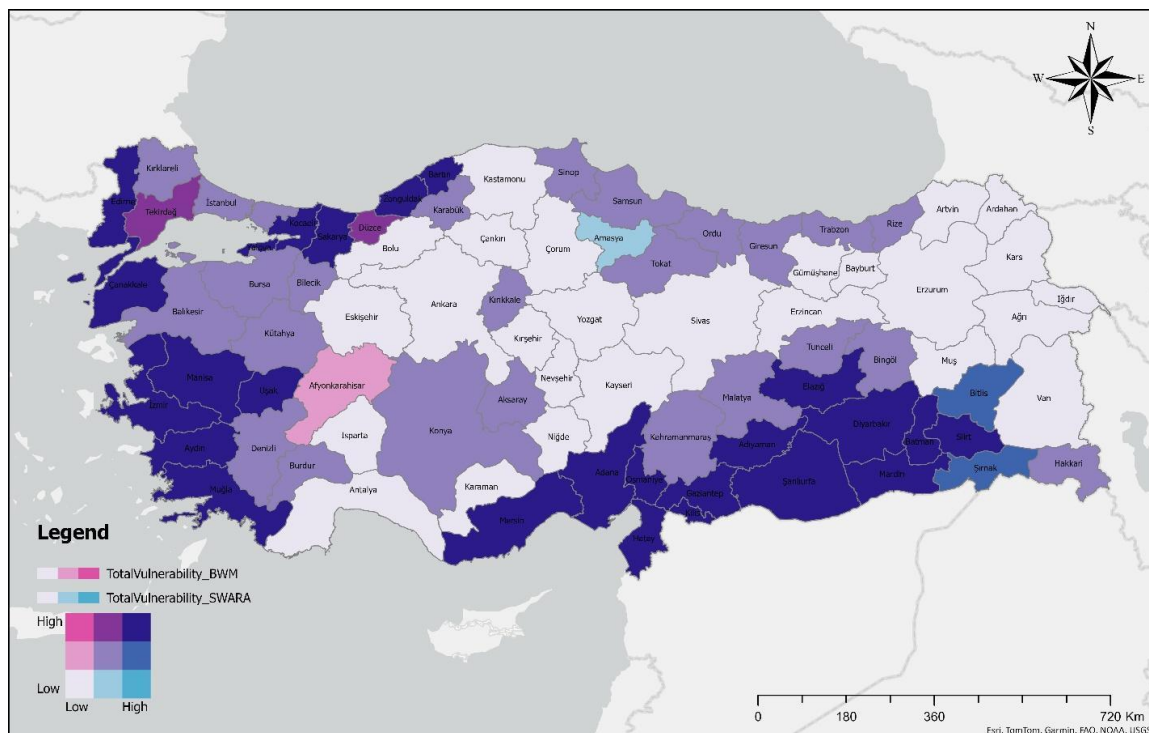


Figure 4: Climate Change Vulnerability Indices obtained from BWM and SWARA techniques.

4. Discussion

The vulnerability index can be utilized to evaluate the possible effects of a program, initiative, or policy by changing the value that is anticipated to change and adjusting the index through recalculation (Nguyen et al., 2016). The new predicted proportion might be entered into the formula to determine the new vulnerability score, for instance, if the

goal of the policy is to increase access to social security benefits. Any policy intervention's true direct and indirect consequences, however, are hard to quantify and require an additional assessment procedure (Pandey et al., 2017). As an alternative, the index can be applied to determine which components are most important in causing vulnerability when guiding policy. Our results from weight calculation analysis indicated that the most significant factors contributing to climate change vulnerability are meteorological conditions and land cover change. Therefore, policy applications should address these issues to increase the resilience and adaptability of societies and reduce their vulnerability. Meteorological factors and land cover were also highlighted in the research by Yoo et al. (2011) which focused on the development of climate vulnerability indices in the selected coastal city in Korea; Pandey and Jha (2012) constructed a climate vulnerability index by considering multiple criteria to assess the vulnerability of communities in rural Himalaya, India; Krishnamurthy et al. (2014) which provided a methodological framework to evaluate the impacts of climate risk on food security at the national level in the globe; and Balaganesh et al. (2020) which developed composite climate index to assess climate change-induced drought in India. Other factors were also mentioned in the literature such as ecosystem services, food, human habitat, health, governance, electricity and waste, infrastructure, and water (Edmonds et al., 2020; Kling et al., 2021; Al Mamun et al., 2023; Buchir & Detzel, 2023; Phuong et al., 2023).

Meteorological conditions and land cover change make the Country highly vulnerable to the impacts of climate change and other environmental hazards and bring adaptation strategies and resilience to the forefront. Compared to similar nations, Turkey's transportation infrastructure is more susceptible, and the Country is dealing with problems related to food security, rising water stress, and unprecedented natural disasters like the 2021 forest fire season and earthquakes in February 2023 in the southeastern region. Climate conditions, population exposure (such as the percentage of the population exposed to floods and forest fires), and socioeconomic factors (such as the percentage of agriculture in the economy) all contribute to this susceptibility. Another important factor contributing to climate susceptibility is the energy sector- which includes power and different land use sectors (transport, industry, residential uses, etc.)-is the country's largest contributor to greenhouse gas emissions. Therefore, land use changes observed in the Country such as conversion of agricultural land to urban uses or conversion of forests to agricultural uses all contribute to increasing energy use resulting in higher greenhouse gas emissions. The air pollutants such as methane and carbon contribute to climate change and are associated with serious health problems. For the decarbonization of the power sector, some strategies can be introduced such as promoting energy efficiency and electrification for zero carbon transport and buildings, industrial energy efficiency and technological innovation to mitigate emissions, emission reduction in waste and agricultural sectors, and optimizing the carbon sequestration potential of forests and agricultural landscapes. Additionally, there are chances for more focused adaptation measures to control long-term climate change and natural risks. These steps can lessen the damage caused by natural disasters, but they can also delay the effects of climate change on agriculture, water availability, and human habitation.

The index developed in this study can be adopted to different contexts and spatial scales by following the same methodology that is introduced in the paper. At the more detailed spatial levels, there can be different indicators representing more spatial details that can be included in the analysis to compute the CCVI. If the study is repeated in a different national context, indicators that are relevant for a specific nation may provide vulnerability indices that are different from the ones shown here. Weights that are assigned to indicators and sub-indicators can be different at the national context as these will be specified by experts to highlight the importance of country specific factors. The index can be calculated at different time periods based on the availability of the indicator data to monitor the impact of government policies that aim to alleviate the impacts of climate change. This can be useful to compare vulnerability of cities at the benchmark year with the year when the policy is applied. The change in climate according to different climate scenarios have an influence on the CCVI in that the value of the index can be modified and the new vulnerability score can be re-computed. Within this framework, climate models can serve as a valuable input for the construction of the vulnerability index. Through the prediction of expected climate-related occurrences, together with the corresponding financial consequences and mortality under various scenarios, an understanding of how climate affects vulnerability can be gained. Another important step in the development of a composite indicator is the sensitivity analysis. The main goal with sensitivity analysis is to measure the impact of input elements on the model result. Sensitivity analysis methods allow the whole range of values for each input variable to be explored without

assuming anything about the structure of the model (e.g., additivity or linearity). Sensitivity analysis can be specified to be performed as a future research focus.

5. Conclusion

The findings offered here provide a novel assessment of the Turkish population's susceptibility to the physical, social, and environmental effects of climate change. The creation of a set of indicators specific to the Turkish context and the mapping of the state of Turkish cities' vulnerabilities from a climatic standpoint are the study's two main accomplishments. The findings indicate that since socio-economic status, infrastructure transportation, and meteorological conditions were among the variables influencing the communities' existing susceptibility, particularly in the coastal cities and the cities in the south-eastern region of Turkey, improving people's quality of life, health, and infrastructure and alleviating the impacts of meteorological conditions would be a key policy toward preparing the Turkish population to deal with the effects of climate change. Investing in urban infrastructure, such as health, physical infrastructure, communication networks, and disaster preparedness, is another crucial step towards enhancing adaptive capacity, since drought, forest fires, and flood events may become more regular in the regions that are associated with high vulnerability. An increase in the severity of climate events suggests a threat to the food security of the area, while there is also an increased risk of death for the local population which may be influenced by severe floods, windstorms, and forest fires. The employed methodology was designed to be straightforward to understand and apply for policy making, allowing decision-makers at the local and provincial levels to adopt it. The development of CCVI at the province level made it possible to target resources and policies based on geographical differences and assess vulnerability comprehensively. Based on the availability of data, this approach can be used in the future in more local areas with the use of local indicators that show different socio-spatial features.

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The authors declare that there is no competing interest.

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