



Spatial modeling the climate change risk of river basins via climate classification: a scenario-based prediction approach for Türkiye

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Abstract

Climate change, triggered by the direct and indirect effects of urbanization, seriously threatens the ecosystem, earth cycles, and vitality. It is quite complex to investigate the reasons for the devastating effect of extreme events that occur with the impact of climate change. However, future projections based on probabilities are needed for governments and urban planning to develop strategies and manage the crisis on a global scale. This research aims to simulate the effects of climate change on temperature, precipitation, and climate classes, which are the basic parameters in spatio-temporal conditions. In this context, within the framework of SSPs 245 and SSPs 585 scenarios defined by The Intergovernmental Panel on Climate Change (IPCC) reports, forecast maps were produced by using De Martonne (I_{DM}), Emberger (I_E), and Lang (I_L) indexes in twenty-year periods until 2100. I_{DM} reveals that arid areas not included in the area today will constitute 41.96% of the site according to 2100 models. The I_E classification estimates that very humid areas will decrease from 58.36 to 0.23%. According to I_L , while humid regions (90.86%) occupy a prominent place, they will reduce to 0.42% in 2100 and turn into semi-humid areas (69.43%). The research presents climate risk and the devastating threat facing the world by simulating shifts in the most common climate classes according to different climate class indexes.

Keywords Climate change · Climate hazards · Basin management · Vulnerability · Precautions

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1 Introduction

Climate change causes financial (Chenet et al. 2021; Ye 2022), ecological (Manes et al. 2021), demographic risks such as food (Shahid et al. 2021; Molotoks et al. 2021), and public health (Ebi et al. 2021), and depending on some features such as location, geographical structure, precaution, and awareness level of the human living environment (Ahmad et al. 2022). In addition, current research (Cappelli et al. 2021) investigates that countries with income inequality are more affected by extreme events caused by climate change. Evaluation reports of IPCC describe analyzes and strategies that guide the world against climate risks (Kemp et al. 2022). The report highlights the duration of exposure and vulnerability to climate risks alongside climate hazards (Das et al. 2020; Viner et al. 2020; Pörtner et al. 2022). Therefore, all living things need defense strategies to minimize material and spiritual losses by being aware of the dangers (Dwivedi et al. 2022; Viktor et al. 2022). Therefore, spatial studies are needed to make modeling and produce decisions about the effects of climate change (Mansuroğlu et al. 2021; Isinkaralar 2023a). In this context, the temporal-spatial variation in climate zones provides a valuable perspective in various climatological studies. While making long-term/top-down planning, climate parameters are a basic inventory and must be taken into account in decisions to be taken for cities and regions (Knott et al. 2019; Lo et al. 2020; Ghozat et al. 2021).

Global warming, increased temperature values, and scarcity of water make the increase in aridness inevitable. Although the number of studies focusing on this issue addressing this problem is increasing day by day (Dalagnol et al. 2022; Pulido-Velazquez et al. 2022; Rahif et al. 2022), climate change is an area that needs to be progressed due to its multi-dimensional effects (Sinha et al. 2022). Some climate classifications such as De Martonne 1942; Emberger 1933 and Lang (quoted by Akman 1990) in the world allow us to understand the distribution of climatic features according to the land surface. These classifications enable us to make future predictions of multi-parameter climate zones starting from the regions and to determine the locations of the areas affected by the process by offering an analytical perspective on Earth's land surface problems (Addor et al. 2018). As a result of global warming, the geographical distribution of climate classes has started to shift with the increase in the earth's temperature. This is an alarming risk that threatens the climate-based living ecosystem.

Climate risk research is carried out at different levels, from building scale (Nyberg et al. 2022; Ringsmuth et al. 2022; Ziervogel et al. 2022) to provinces (Chung et al. 2022; Gaborit 2022; He et al. 2022; Wang et al. 2022a) from countries (Chen et al. 2022a; Raikes et al. 2022) to the global scale (Javaid et al. 2022; Huang and Lin 2022). Research carried out on an urban scale, within the borders of the country or province, has advantages such as producing local policy, identifying the sources that trigger climate change, and making appropriate decisions in terms of legislation. However, research has proven that climate risk is effective in both urban and rural areas and is related to geography regardless of urbanity (Kc et al. 2021). From this point of view, while analyzing the temporal changes of climate types spatially, the river basin's scale was considered. River basins are an ecological structure where people and all other living things continue their lives, especially the sustainable use of water resources. It is suitable to produce management plans on a macro scale and deal with social, economic, and environmental concerns together (Liu et al. 2022a; Sun and Wang 2022; Wang et al. 2022b). Within a watershed boundary, land uses such as water resources, wetlands, agriculture and forests coexist as a system and show an ecologically holistic feature (Chen et al. 2022b; da Silva Almeida et al. 2022). The European Water Framework Directive (WFD)

has recently emphasized the importance of watersheds as it defines water management and the hydrological cycle as a holistic ecological structure (Keci et al. 2022). The precipitation regime affects not only the location where the precipitation falls but all vegetation within the basin borders (Geng et al. 2022; Zhang et al. 2022). Therefore, river basins represent not only a boundary connected to water resources; they are an ecologically fragile natural threshold (Cui et al. 2022). Ecological cycles are completed within the basin, and after some emergency, the basin becomes a self-organizing complex system (Santana et al. 2022).

The most obvious effect of global climate change on meteorological conditions is temperature and precipitation. In addition, disasters that resulted in great losses began to occur in different geographies. Local reports in Türkiye reveal that the most common environmental disasters are precipitation, flooding, and forest fires. According to the country's fire statistics in 2021 and 2022, forest fires spread over the widest areas. Widthwise, floods, and overflows with great destructive power occurred in 2021–2022, and emergency flood action plans were prepared especially in the western Black Sea region. However, probabilistic spatial simulation studies are seen as a necessity for being prepared for major natural disasters in the future, developing adaptation and prevention strategies, and effective disaster management. In this context, the research aims to make future predictions of climate parameters and climate zones between 2020 and 2100 depending on the climate scenarios in the Western Black Sea basin in the Black Sea region of Türkiye which is one of the critical basins of the country in terms of flood and disaster management.

2 Materials and methods

2.1 Materials

The Western Black Sea basin is located in the Black Sea Region, north of Türkiye, covering the TR81 and TR82 NUTS regions in Fig. 1. The Western Black Sea Basin is located between 40°34'42" and 41°27'52" northern latitudes, 30°52'33" and 35°12'12" east longitudes. It has a critical structure in disaster management as there are floods and floods resulting in loss of life in the basin.

Melen Stream, Ereğli, Filyos, Bartın, and Devreakani Gerze are the sub-basins within the basin boundaries. A large part of the basin is within the administrative borders of Düzce, Zonguldak, Bartın, and Karabük, while the remaining amount is within the borders of Bolu, Çankırı, Kastamonu, and Sinop provinces. In the basin, which is covered mainly by forest areas (54.8%), dry agricultural regions have an area of 24.9%, pasture areas 7.8%, heath areas (5.1%), hazelnut orchards (2.3%), and irrigated agricultural areas have an area of 2.2%. The land cover has a rich natural structure with the diversity it offers in terms of vegetation in Table 1.

2.2 Scenarios of climate modeling

The variety of chaotic structures, uncertainty, and possible areas determine climate risks. However, to obtain interpretations of a time series, we need assumptions. In this context, the research was based on the scenarios of SSPs 245 (4.5 W m^{-2} - an intermediate) and SSPs 585 (8.5 W m^{-2} - the most extreme) defined by the IPCC reports regarding climate. Estimations of changes in climate parameters and climate types were made in four different periods (2040, 2060, 2080, and 2100) at intervals of twenty years starting from the present land.

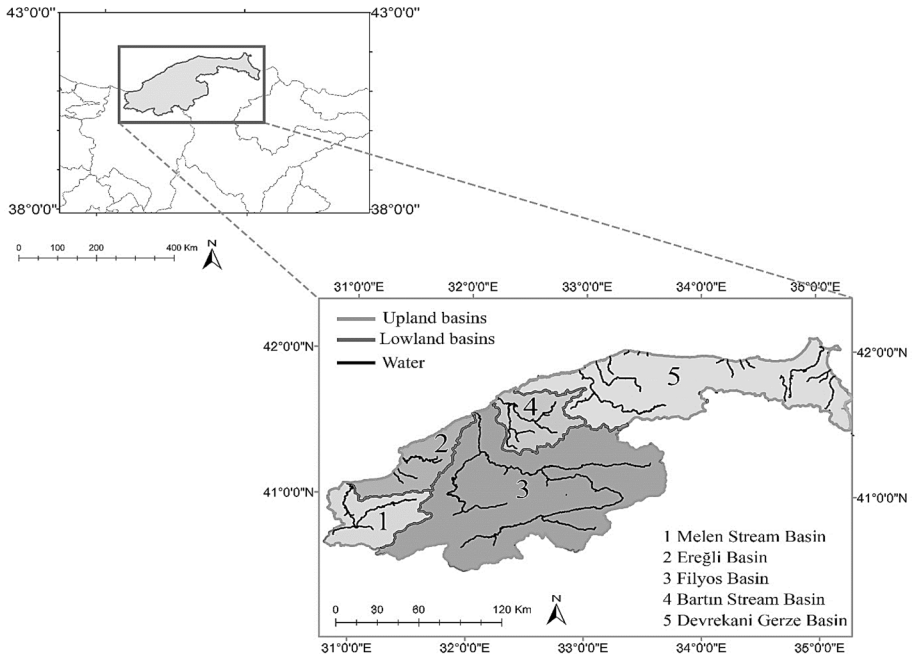


Fig. 1 The location of the west black sea basin in Türkiye

2.3 Methodology of climate index (CI)

The change of climate types was determined according to three different climate indexes as De Martonne, Emberger, and Lang climate index is based on the following formula by using temperature and precipitation data from climate parameters using Eq. 1 as follow:

Table 1 Land cover distribution of the basin

Land cover	Area (hectares)	Rate (%)
Garden	10,137	0.35
Meadow	5958	0.21
Shrubbery	147,948	5.13
Dry farming	719,031	24.94
Irrigated agriculture	63,356	2.20
Forest	1,578,795	54.76
Pasture	224,365	7.78
Bond	182	0.01
Hazelnut	65,502	2.27
Citrus	1015	0.04
Olives	56	0.00
Other	66,703	2.31
Total	2,883,048	100

Table 2 De Martonne climate index classification

No.	I_{DM} values	Climate classification
1	0–10	Arid
2	10.1–20	Semiarid
3	20.1–24	Mediterranean
4	24.1–28	Semihumid
5	28.1–35	Humid
6	35.1–55	Very Humid
7	> 55	Overhumid

$$I_{DM} = \frac{P}{(T + 10)} \tag{1}$$

where P is the annual rainfall (in mm), and T is the annual mean temperature (°C). The De Martonne Climate Index consists of 7 classifications from arid to extremely humid in Table 2.

Based on temperature and precipitation values of an area, the Emberger (1933) climate classification is Eq. (2). as follows:

$$I_E = \frac{100 \times P}{(M^2 - m^2)} \tag{2}$$

where M is the average temperature of the hottest month (°C), m is the average temperature of the coldest month (°C), and P is the annual mean temperature (mm). It consists of 4 classifications, increasing from arid to humid in Table 3.

Lang (1990) includes the desert class in addition to the climate classification Emberger in Eq. 3. I_L is based on the formula:

$$I_L = \frac{P}{T_a} \tag{3}$$

where P is the annual average total precipitation (in mm), and T_a is the annual average temperature (°C). It consists of five classifications, increasing from desert to humid in Table 4. Using the climate classification of De Martonne, Emberger, and Lang indexes, climate models of the Western Black Sea basin were produced via spatial analysis toolbar in ArcGIS 10.5 software.

Table 3 Emberger climate index classification

No.	I_E values	Climate classification
1	< 30	Arid
2	30–50	Semiarid
3	50–90	Semihumid
4	> 90	Humid

Table 4 Lang Climate Index Classification

No.	I_L values	Climate classification
1	0–20	Desert
2	20.1–40	Arid
3	40.1–60	Semiarid
4	60.1–100	Semihumid
5	100.1–160	Humid

3 Results

3.1 The risks related to climate parameters

The first parameter that commonly comes to mind is the warming of the world and the increase in average temperature values within the scope of the climate risk, which is the result of the eternal nature of carbon emissions. The governments cannot control due to their complex structure on a global scale. The average temperature values between 8 and 10 °C constitute the largest share of the area, 31.26% at present. The highest average temperature values are between 14 and 16 °C in Table 5.

The temperature range, which has the highest share with a rate of 28.35% in 2060, rises to 10–12 within the scope of the SSPs 245 scenario. For the SSPs 585 scenario, the most common temperature range in the area reaches 14–16 °C. The highest temperature range seen in the area was estimated in the range of 16–18 °C according to SSPs 245 in 2100, while the range of 20–22 °C was determined in SSPs 585 simulations in Fig. 2.

One of the most basic indicators reflecting the future weather and climate hazards of drought waves is the amount of precipitation falling on the area. Anomalies, which express the measurement of rainfall in a unit area, either extremely intensely or exceptionally rare, are one of the riskiest dimensions of climate change. This value makes

Table 5 Risk prediction based on temperature rise

Temperature (°C)	Present (%)	SSPs 245				SSPs 585			
		2040	2060	2080	2100	2040	2060	2080	2100
2–4	0.13	NA	NA	NA	NA	NA	NA	NA	NA
4–6	2.42	0.28	0.08	0.02	NA	0.19	0.07	NA	NA
6–8	22.45	5.49	1.87	0.70	0.29	3.61	0.83	0.05	NA
8–10	31.26	28.78	20.68	12.53	6.14	25.51	14.01	1.62	0.04
10–12	23.84	28.35	32.24	33.33	29.83	30.06	33.26	20.14	1.46
12–14	19.39	24.03	24.52	25.33	28.27	24.11	25.18	32.66	19.80
14–16	0.50	13.08	19.95	22.99	24.76	16.52	22.35	25.23	32.90
16–18	NA	NA	0.65	5.11	10.71	0.00	4.31	19.76	25.94
18–20	NA	NA	NA	NA	NA	NA	NA	0.54	19.43
20–22	NA	NA	NA	NA	NA	NA	NA	NA	0.42

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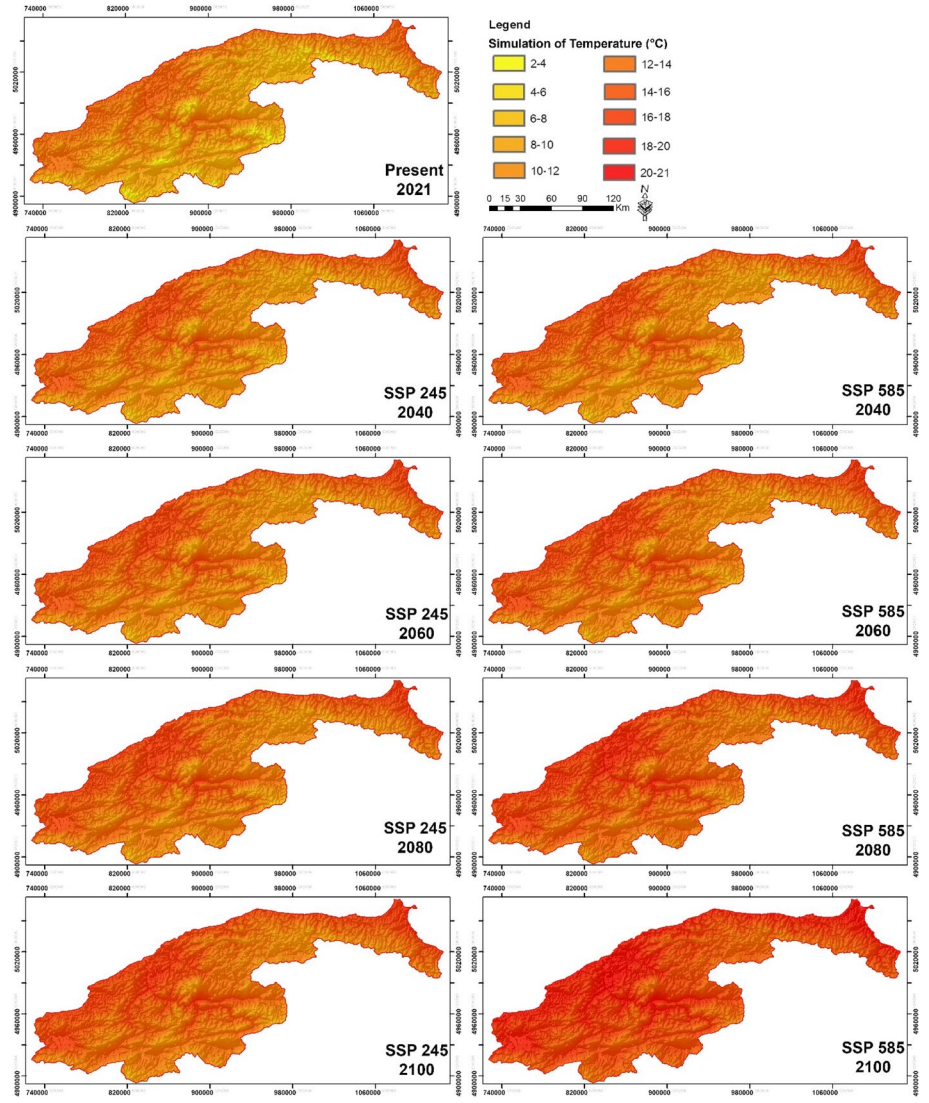


Fig. 2 Simulation of temperature rise risk

forecasting and measures difficult. Precipitation values that make up 23.32% of the area today are 650–700 mm in Table 6.

According to SSPs 245, the share of areas in this range will decrease by 1.09% in 2100. In addition, it has been determined that regions in the 1150–1200 mm field will not be found as of 2080, according to SSPs 245, and from 2040 according to SSPs 585. On the other hand, while there is no area with precipitation in the range of 450–500 mm, representing the lowest density of the estimation scale, these values will emerge since the precipitation concentration will decrease from 2060, according to SSPs 585 in Fig. 3.

Table 6 Risk prediction based on precipitation decrease

Precipitation (mm)	Present (%)	SSPs 245				SSPs 585			
		2040	2060	2080	2100	2040	2060	2080	2100
450–500	NA	NA	0.04	0.14	0.08	0.00	0.38	0.68	1.88
500–550	2.01	2.86	4.98	5.77	5.02	3.42	7.07	7.94	11.29
550–600	10.50	11.09	15.32	16.47	15.13	11.71	17.89	19.35	20.20
600–650	21.53	22.41	20.09	20.91	20.79	23.38	21.83	23.98	22.92
650–700	23.32	23.04	21.83	21.85	22.23	23.22	21.52	20.54	19.01
700–750	17.44	16.96	16.23	14.94	15.75	24.39	13.14	11.12	10.68
750–800	9.58	9.28	8.48	8.17	8.80	5.60	7.48	6.68	5.81
800–850	5.78	5.61	5.15	4.72	4.96	3.30	4.38	4.01	3.52
850–900	3.90	3.46	3.14	2.96	3.10	2.42	2.82	2.62	2.52
900–950	2.52	2.45	2.39	2.20	2.23	1.41	1.92	1.73	1.17
950–1000	1.88	1.58	1.26	1.03	1.02	0.64	0.90	0.76	0.68
1000–1050	0.79	0.71	0.66	0.54	0.60	0.33	0.45	0.42	0.21
1050–1100	0.48	0.36	0.26	0.19	0.19	0.15	0.15	0.16	0.11
1100–1150	0.17	0.13	0.15	0.12	0.11	0.02	0.08	0.03	NA
1150–1200	0.11	0.06	0.02	NA	NA	NA	NA	NA	NA

NA this value is not available

3.2 Simulation of CI Risks

I_{DM} reveals that arid areas that do not exist today will be formed by 2040 and constitute 41.96% of the site, according to 2100 estimates in Table 7. According to SSPs 245, the areas in the humid class will decrease to 0.07% in 2060 and will not be included in the area as of 2080. Having a pessimistic approach, SSPs 585 reveals the threat to the climate by showing that in 2100, 57.84% of the site will be covered by semiarid and 41.96% by arid areas in Fig. 4. In the I_E classification, semi-arid regions will begin forming in 2100 according to SSPs 245 and 2080 according to SSPs 585 in Fig. 5.

While there is no highly humid climate in any period in the area, it is estimated that very humid areas will decrease from 58.36 to 0.23%. I_L presents a more moderate classification approach, simulating that arid regions will begin to form in 2100 at rates of 0.03%, which is considerably lower according to SSPs 585 principles. According to these estimates, humid areas, which have a share of 90.86% today, will transform into semi-arid and semi-humid regions to a large extent. While there are humid areas in the current situation, according to SSPs 585, places in the semi-humid class will dominate in 2100 in Fig. 6.

4 Discussion

Models for future investigations that the changes to be experienced due to climate risk are not long-term, and significant differences will occur in the next century (Lawrence et al. 2014; Trenberth et al. 2014). Concrete reflections of climate change on living things have begun to be observed (Kumar et al. 2021; Talanow et al. 2021). The most obvious of these effects is the melting of snow and glaciers (Huss et al. 2021). One of the negative

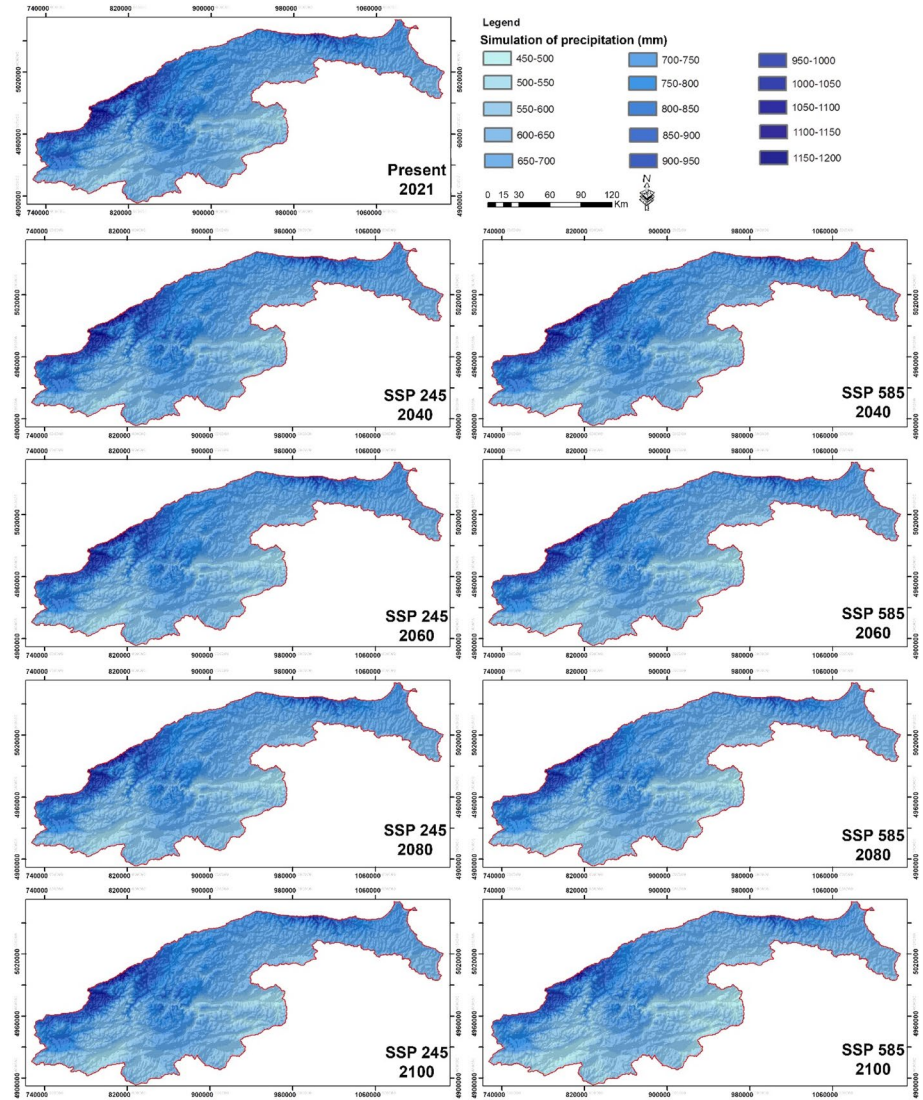


Fig. 3 Simulation of precipitation rise risk

consequences of the processes experienced is the extinction of living species that cannot survive in changing climatic conditions. For example, some insects are among the most sensitive creatures to climate change, and it has been proven that they disappear rapidly because they cannot meet their ecological needs (Oliver et al. 2015; Halsch et al. 2021). Similarly, patterns related to climate effects are modeled using butterflies and moths (Hill et al. 2021). It has been proven that plant species will struggle to survive. Concrete findings on the displacement of plants, which are among the most disadvantaged living species in terms of mobility, are quite interesting. Tekin et al. (2022) state that *Abies cilicica* species will shift to different climatic conditions. These changes in the distribution areas of plant

Table 7 The risks in the context of CI

Index type	CI class	Present (%)	SSPs 245				SSPs 585			
			2040	2060	2080	2100	2040	2060	2080	2100
I_{DM}	Arid	NA	0.56	1.35	3.17	4.87	0.76	3.31	12.45	41.96
	Semiarid	15.44	39.95	54.59	68.65	76.53	46.29	69.04	82.15	57.84
	Semihumid	77.78	58.65	43.84	28.11	18.58	52.45	27.59	5.40	0.20
	Humid	6.78	0.84	0.22	0.06	0.02	0.50	0.07	NA	NA
I_E	Semiarid	NA	NA	NA	NA	0.02	NA	NA	0.85	6.14
	Mediterranean	0.11	1.10	3.36	5.40	6.42	1.72	5.84	11.64	29.05
	Semihumid	4.43	10.06	15.00	21.30	24.47	12.42	22.32	40.58	48.89
	Humid	37.10	60.63	65.28	63.35	61.40	64.19	62.68	44.26	15.69
	Very humid	58.36	28.22	16.36	9.94	7.69	21.67	9.15	2.67	0.23
I_L	Extremely Humid	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Arid	NA	NA	NA	NA	NA	NA	NA	NA	0.03
	Semiarid	NA	0.17	0.70	2.24	3.85	0.19	2.73	9.64	30.13
	Semihumid	9.14	37.72	57.41	72.28	80.43	40.85	74.60	85.76	69.43
	Humid	90.86	62.11	41.89	25.48	15.72	58.95	22.66	4.60	0.42

NA this value is not available

species were determined and their future positions were modeled in some studies (Varol et al. 2022).

Outdoor temperature tolerance is a threat to all species within the ecosystem, and optimal conditions are basic needs of humanity, especially for the health (Alavipanah et al. 2021; Rahman et al. 2022; Isinkaralar 2023b; Istanbulu et al. 2023). Even in living things that can adapt to drought, irreversible effects occur with the impact of stress caused by deficiency. The increase in death cases in forest stands is primarily due to increased temperatures due to climatic characteristics. Global warming is blamed for the rise in the frequency and severity of forest fires. Developing appropriate control and strategic systems for forest management, such as a fire risk map (Yavuz et al. 2018; Sivrikaya and Küçük 2022), can reduce forest fires caused by global warming (Mansoor et al. 2022). Therefore, protected forest areas, which can store approximately 45% of the worldwide carbon (Field and Raupach 2004), will also help reduce the impact of climate change. In addition to the natural environment, the urban land in the area is also at risk from disasters that will occur due to extremes and irregularities due to climate change (Cacciotti et al. 2021). Another visible result is the loss of life and property after disasters that result in death. Flood disasters are at the forefront of these, and as the climate changes, flood frequency and intensity appear as a significant challenge in national and local planning (Ridha et al. 2022).

The spatial consequences of climate change also reduce people's quality of life (Bayulken et al. 2021; Brand et al. 2021). Access to clean and quality drinking water is one of the risks of climate change and one of the primary public health conditions (Leveque et al. 2021; Scheelbeek et al. 2021). The detected increase in drought will change many land covers in exposure areas, from agricultural crop production to forest ecosystems. The climate risk is also reflected in crop production within the food security framework and has devastating consequences for agricultural activities (Dryden et al. 2021; Abbas et al. 2022). Food insecurity affects human life, the urban economy and quality of wellness, and even

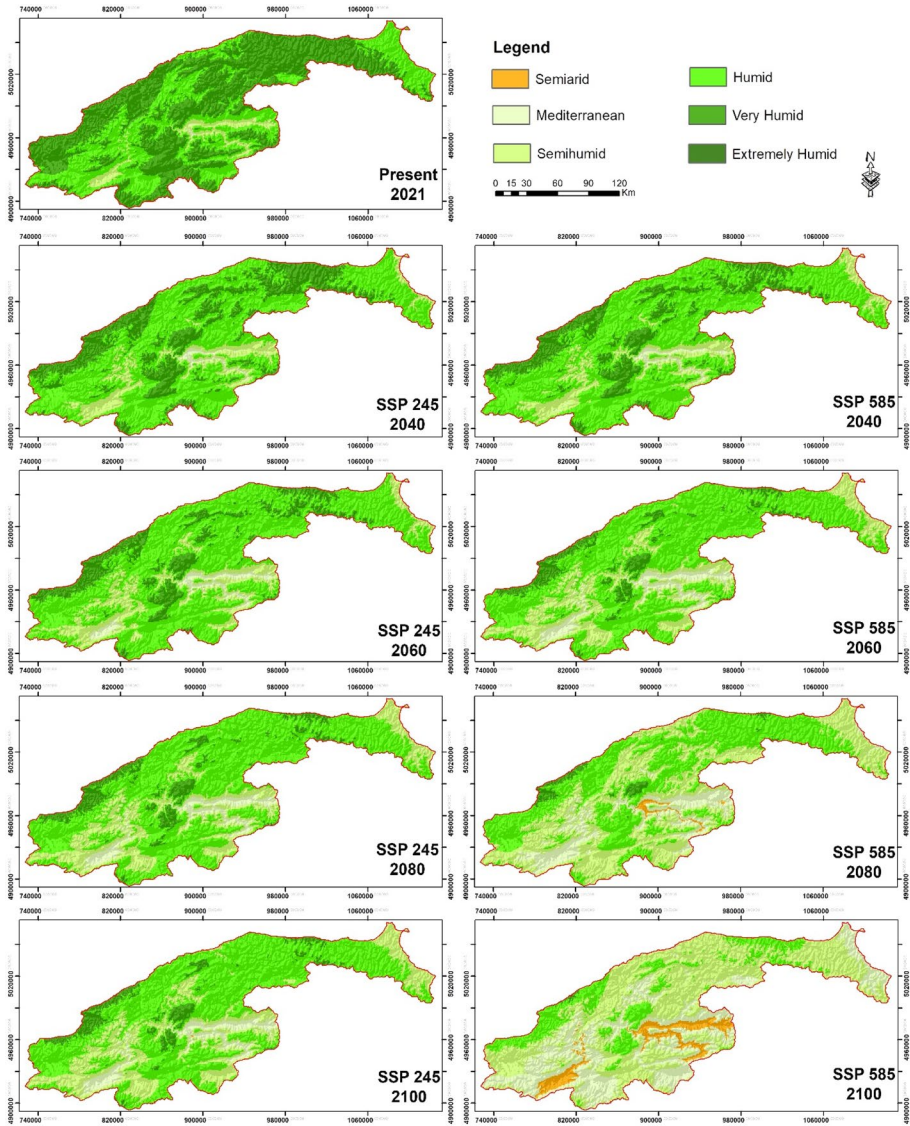


Fig. 4 Simulation of climate risk of I_{DM}

survival. Thus, emerging climate risk responses need planning interventions as they organize themselves.

In the study, the processes affected by climate change are handled on a basin basis as a sub-ecosystem boundary. Malede et al. (2022) presented the signals of climate change and variability in the Upper Blue Nile Basin within the framework of hydrological anomalies. Liu et al. (2022b) investigated the carrying capacity of irrigation areas in the Tarim basin, one of the cotton production fields, in the context of climate change. Another study at the basin scale (Pulido-Velazquez et al. 2022) produced monthly numerical forecasts for

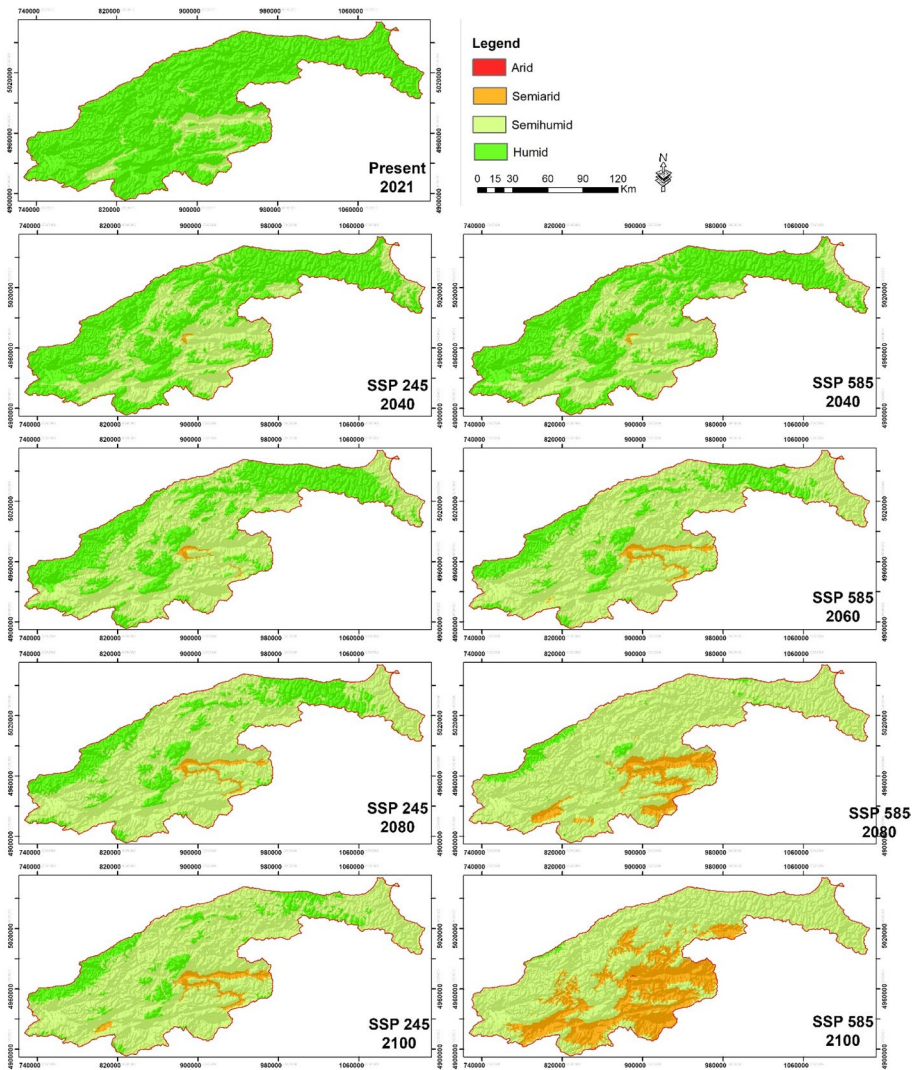


Fig. 5 Simulation of climate risk of I_E

2071–2100 with three climate scenarios. Accordingly, the results in the Segura Basin indicate that future drought characteristics have deteriorated significantly. Although there are studies in the context of climate change at the basin scale, there is a need to develop comprehensive models.

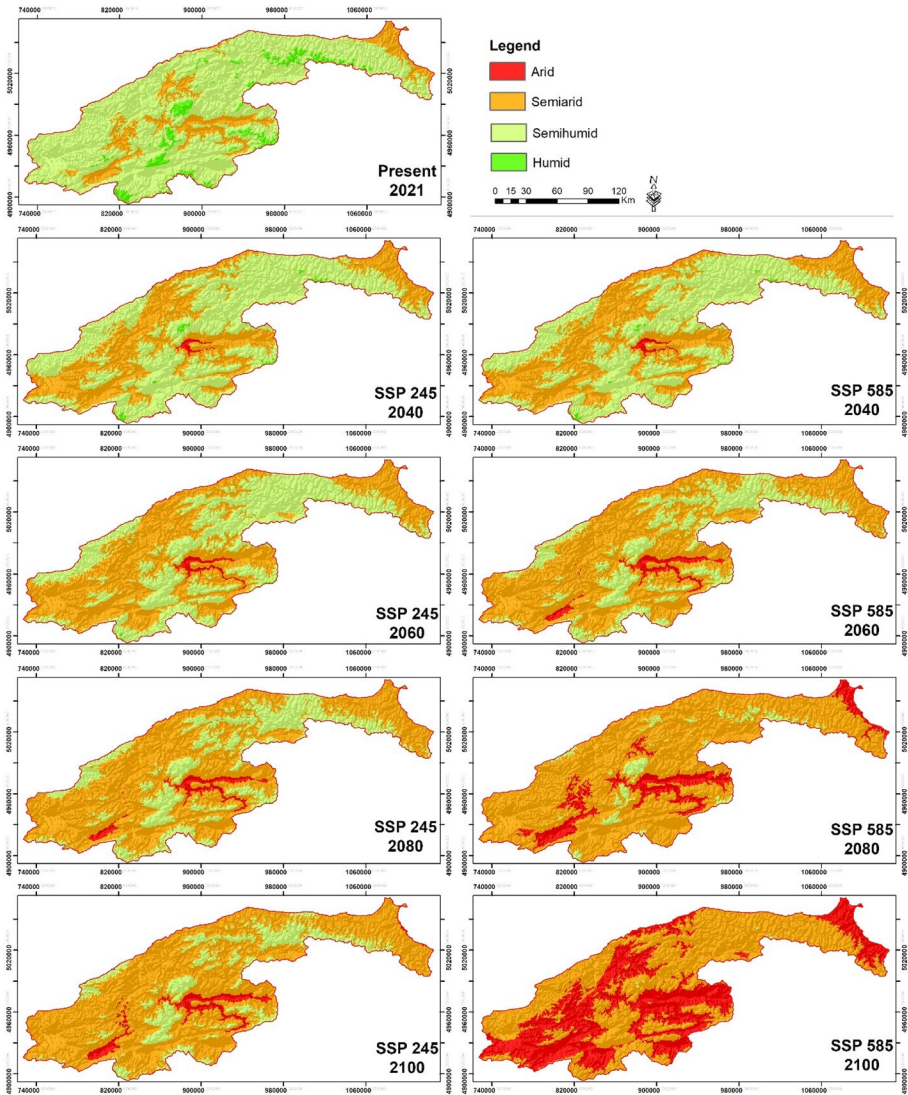


Fig. 6 Simulation of climate risk of I_L

5 Conclusion

Developed countries have measures such as models, action plans, and early warning systems against climate change risk. However, developing and underdeveloped countries are more vulnerable to climate risk and have high risks in managing extraordinary processes in the long run. This study reveals striking results in determining the areas facing climate risk. Although the uncertain aspect of climate change seems to be an obstacle to effective climate risk management, research based on scenarios in which the possibility areas are diversified is very useful regarding the clues they offer. Creating

policies to reduce the effects of climate change on river basins is an issue that governments should consider globally. However, managing the global process is quite complex due to cross-border variables. Even if international efforts are practical, adaptation actions are required to complement mitigation efforts, as climate change is inevitable. In this context, the research results guide against adverse effects such as agriculture, forestry, energy production, tourism, and infrastructure, especially for the river basins vulnerable to climate risk.

Author contributions OI: Processing analysis, data interpretation, writing original draft, data curation, processing analysis and interpretation. KI: Processing analysis, data interpretation, writing original draft, and data curation. HS: Conceptualization, software and editing. ÖK: Formal research, data interpretation and review.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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Humans or animal rights This article does not contain any studies involving animals or humans performed by any authors.

Consent to participate Not applicable.

Consent for publication Not applicable.

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