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Spatial and Temporal Climate Change Vulnerability Assessment in the West Bank, Palestine

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Abstract: Climate change is widely recognized as an inevitable phenomenon, with the Mediterranean region expected to experience some of the most severe impacts. Countries in this region, including Palestine, are already observing significant effects on key sectors such as agriculture, water resources, industry, and health. Consequently, there is a need for multidimensional analyses of vulnerability. This study applied a Climate Change Vulnerability (CCV) index to assess spatial and temporal changes in vulnerability across different governorates in the West Bank, Palestine. Climate change vulnerability maps for the West Bank were developed using Geographic Information System (GIS) tools and Analytical Hierarchy Process (AHP) matrices, incorporating various indicators across categories such as Health, Socio-demographic, Agriculture, Service, Housing, and Economic components. The findings indicate that socio-demographic factors contribute significantly to the West Bank's overall vulnerability to climate change. Although the overall vulnerability has decreased over time, the developed maps reveal that 76% of the West Bank's population resides in areas classified as highly vulnerable to climate change impacts. In contrast, 10% of the population lives in areas classified as low to very low in terms of vulnerability, including the governorates of Tubas, Salfit, Qalqiliya, and Jericho and Al-Aghwar. These results are invaluable for policymakers, offering guidance on selecting appropriate mitigation and adaptation measures, particularly in highly vulnerable areas, to reduce the impacts of climate change across the region.

Keywords: vulnerability; climate change; West Bank; socio-demographic factors; analytical hierarchy process; geographic information system; indexing

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1. Introduction

In contemporary times, climate change has emerged as the foremost environmental challenge worldwide [1], representing one of the most significant events ever faced by humanity [2]. Recognized as a critical issue affecting both human societies and natural ecosystems [3], climate change is a global phenomenon [4,5] primarily resulting from human activities [6,7]. It is linked mainly to fluctuations in atmospheric greenhouse gas concentrations [8], with a significant portion of emissions originating from human development activities [9]. While greenhouse gases are distributed relatively evenly in the atmosphere on a large scale, the impacts of climate change vary significantly across regions [10]. These variations are influenced by a range of factors, including ecological and economic conditions and geographical location [10]. Over the past century, carbon dioxide concentrations in the atmosphere have risen from pre-industrial levels of 278 parts per million to 379 parts per million, leading to an average temperature increase of 0.74 °C—the most significant and rapid global warming trend observed [8].

Climate change refers to long-term alterations in expected average weather patterns on Earth or in specific regions, impacting factors such as rainfall, temperature, humidity, and wind speed [11]. According to the Intergovernmental Panel on Climate Change (IPCC), climate change is a change in the status of the climate; it can be determined by changes in the average and/or variability of climate properties (for decades or longer) [12].

While climate change is a global concern, its effects differ across sectors, communities, regions, and countries [13]. These impacts occur on various scales, from local to global [14], posing challenges to water resources, forests, human health, and agriculture [15]. It is evident that climate change threatens life on Earth [14].

The Mediterranean region, including Palestine, is classified as a climate change hotspot [16]. Over the 20th century, this region has experienced a decline in total rainfall and an increase in temperature [17]. Consequently, climate change poses significant risks to the West Bank, with projections indicating disturbances in rainfall and temperature patterns and in hydroclimatic extreme events [18]. Consequently, climate change has negatively affected natural resource availability in the West Bank, such as groundwater [19].

Vulnerability refers to the susceptibility to negative impacts [20], encompassing the potential for damage and the capacity to cope [21,22]. In climate change contexts, vulnerability assessment frameworks are diverse. According to the IPCC, vulnerability is the extent to which a system is sensitive to or unable to cope with the negative impacts of climate change, including variability and extremes [20]. Vulnerability is a multidimensional concept encompassing economic, biophysical, and socio-cultural indicators [23].

Developing nations, such as Palestine, are anticipated to be more vulnerable to climate change impacts than developed countries [24]. Within these developing nations, marginalized communities, particularly in Palestine, are disproportionately affected due to limited adaptive capacity [25]. However, the impacts of climate change vary in frequency and magnitude across areas, with certain regions more vulnerable due to different ecological and economic conditions [26]. Identifying the areas most affected by climate change is essential for developing appropriate adaptation measures [27], requiring vulnerability assessments in different regions [27].

Given the escalating risks and vulnerabilities, identifying effective tools for assessing climate change vulnerability is critical [28]. These tools are essential in developing adaptive measures by providing a realistic understanding of vulnerability in specific areas [28]. The first IPCC assessment report in 1990 highlighted the importance of vulnerability assessment in evaluating climate impacts and risks, such as changes in rainfall and temperature [29].

Vulnerability assessment involves various approaches to systematically analyze the interaction between individuals and their social and physical environments [30]. Approaches differ, with some focusing solely on physical exposure and others including social factors. Some researchers incorporate vulnerability into the broader concept of risk, considering exposure within the assessment [31,32].

Vulnerability includes pillars such as sensitivity and adaptive capacity [21]. Sensitivity refers to conditions that alter the degree of impact from climate change exposure on a system, whether human or biophysical [33,34]. Adaptive capacity is the ability to plan for or adapt to climate risks [33,35]. In this study, adaptive capacity and sensitivity are incorporated into the vulnerability assessment.

As vulnerability is a theoretical concept and not directly measurable, assessments rely on indicators [36]. The selection of appropriate definitions and metrics is crucial [37,38], with socioeconomic and environmental indicators commonly used [39]. While indices vary, they often rely on arithmetic or weighted means of indicators for simplicity and the availability of weighting methods to better address problems [28].

Researchers use various weighting approaches, such as weights derived from principal component analysis [40], expert judgment [41], the Analytical Hierarchy Process [42], and Pareto ranking [43]. This study utilizes the Analytical Hierarchy Process (AHP) approach to assess vulnerability in the West Bank.

The vulnerability index, widely used in research [44–46], plays a key role in vulnerability assessments. Hahn et al. [30] introduced an indicator-based assessment model, which has been adopted by many researchers [47–51]. These indices were used to identify vulnerable areas through mapping [52]. Vulnerability maps, a common tool for characterizing vulnerability [53], help identify highly vulnerable areas and recommend appropriate measures [39]. These maps are developed by selecting key indicators that increase a system's susceptibility to climate change [53].

Many researchers have studied climate change vulnerability [54–56]. For example, Huong et al. [57] conducted a household-level assessment in Northwest Vietnam. Lewis et al. [58] used 148 indicators to create a vulnerability index for the U.S., and Khajuria and Ravindranath [23] found that livelihood vulnerability indices are valuable tools. Pandey and Jha [59] introduced an index to identify highly vulnerable communities. In Trinidad and Tobago, Shah et al. [48] applied a livelihood vulnerability index for assessment.

This study aims to assess climate change vulnerability in the West Bank, using an AHP matrix to develop the Climate Change Vulnerability (CCV) index. Six vulnerability components will be examined: Health, Socio-demographic, Service, Housing, Agriculture, and Economic. The study will analyze the temporal and spatial evolution of CCV across different areas in the West Bank, addressing the following research questions:

(1) How can vulnerability based on multiple dimensions be assessed in a data-scarce region?
(2) Are the governorates of the West Bank highly vulnerable to climate change impacts?
(3) How has vulnerability at the West Bank and governorate levels changed over time?

This study represents an initial effort to explore the spatial and temporal dimensions of climate change vulnerability in the West Bank. Unlike previous studies, it utilizes a comprehensive set of indicators and is the first in the Middle East to apply a multi-criteria decision approach (specifically, AHP) for developing indices. Additionally, it is the only known study to assess the temporal evolution of climate vulnerability, a significant contribution given the limited data availability compared to other countries.

2. Materials and Methods

2.1. Study Area

The study area for this research is the West Bank, Palestine. There are several factors that point to this country as a case of special interest for assessing its vulnerability to climate change. One critical factor is its demographic trends. According to the Palestinian Central Bureau of Statistics, the West Bank had a population of nearly 2.9 million people in 2017 [60]. This population is distributed across 11 governorates: Salfit, Jenin, Tubas, Nablus, Jericho and Al-Aghwar, Hebron, Tulkarm, Qalqiliya, Jerusalem, Bethlehem, and Ramallah and Al-Bireh (see Figure 1). Between 2007 and 2017, the population in the West Bank increased by 23% [60,61]. This growth also led to an increase in population density, from 441 to 537 people per square kilometer. Daily domestic water consumption per capita rose as well, from 73 L in 2010 [62] to 86.4 L in 2022 [63].

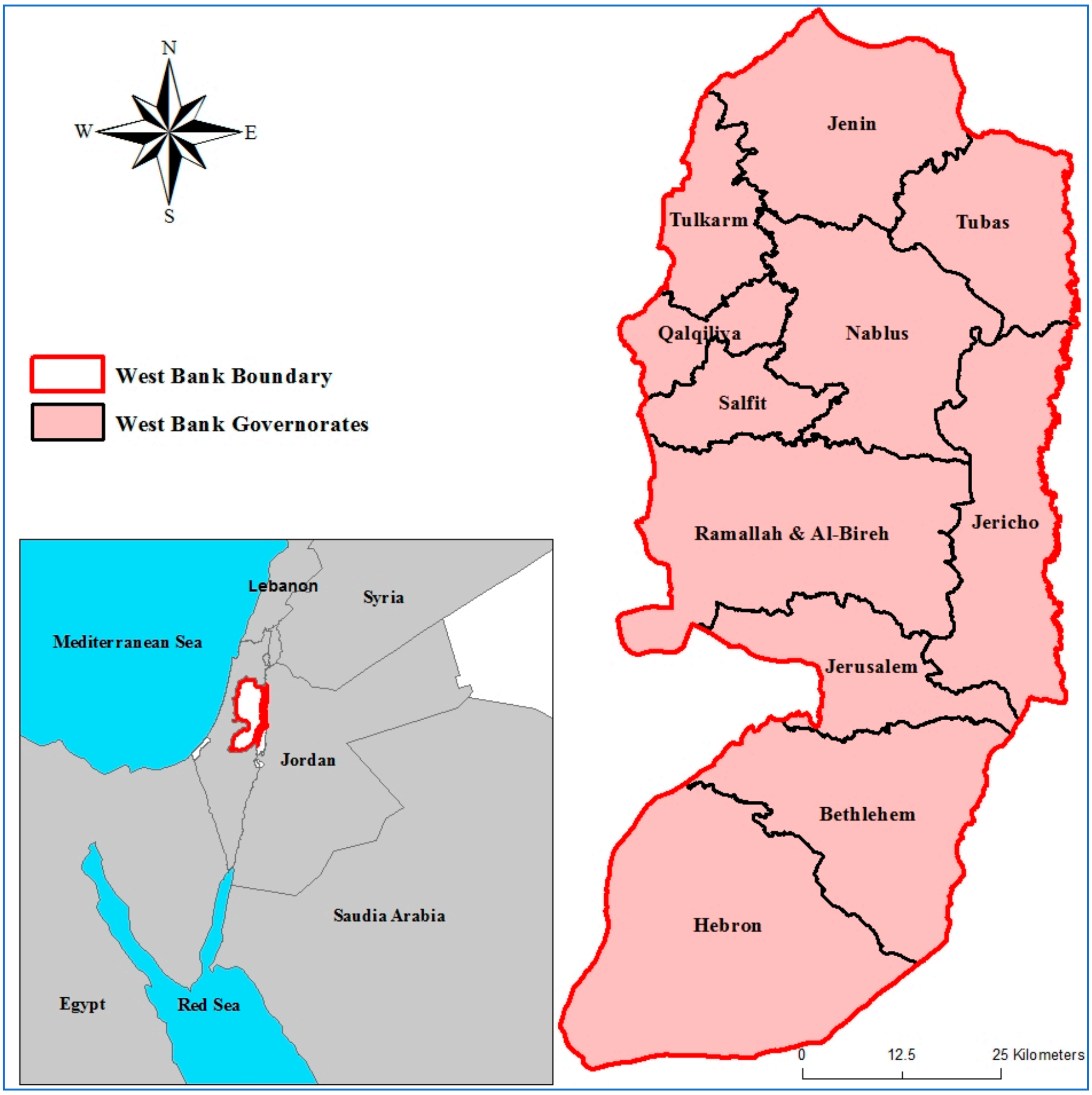

Figure 1. Map locating the study area.

The climate of the West Bank is classified as eastern Mediterranean, characterized by mild, rainy winters and dry summers [64]. Average summer temperatures peak at 27.4 °C, while the coldest months (January and February) have an average temperature of 12.4 °C [65]. Additionally, the average monthly temperature ranges between 20.8 °C and 30 °C in summer and between 8.7 °C and 14 °C in winter [66]. The rainy season lasts from October to May [67], with a long-term annual average rainfall of approximately 420 mm [68]. Land use in the West Bank is divided into three main categories: rough grazing (62%), agricultural areas (32%), and built-up areas (5%), with Israeli settlements comprising an additional 1% [69].

2.2. Climate Change Vulnerability Analysis

2.2.1. Spatial Vulnerability Analysis in the West Bank

In this study, the CCV index was used to assess vulnerability across the various governorates of the West Bank. A CCV map of the West Bank was then developed to classify these governorates into categories based on their vulnerability levels: very low, low, moderate, high, and very high. This allowed for a spatial analysis of vulnerability differences among the governorates. Figure 2 illustrates the overall methodological approach used in this assessment.

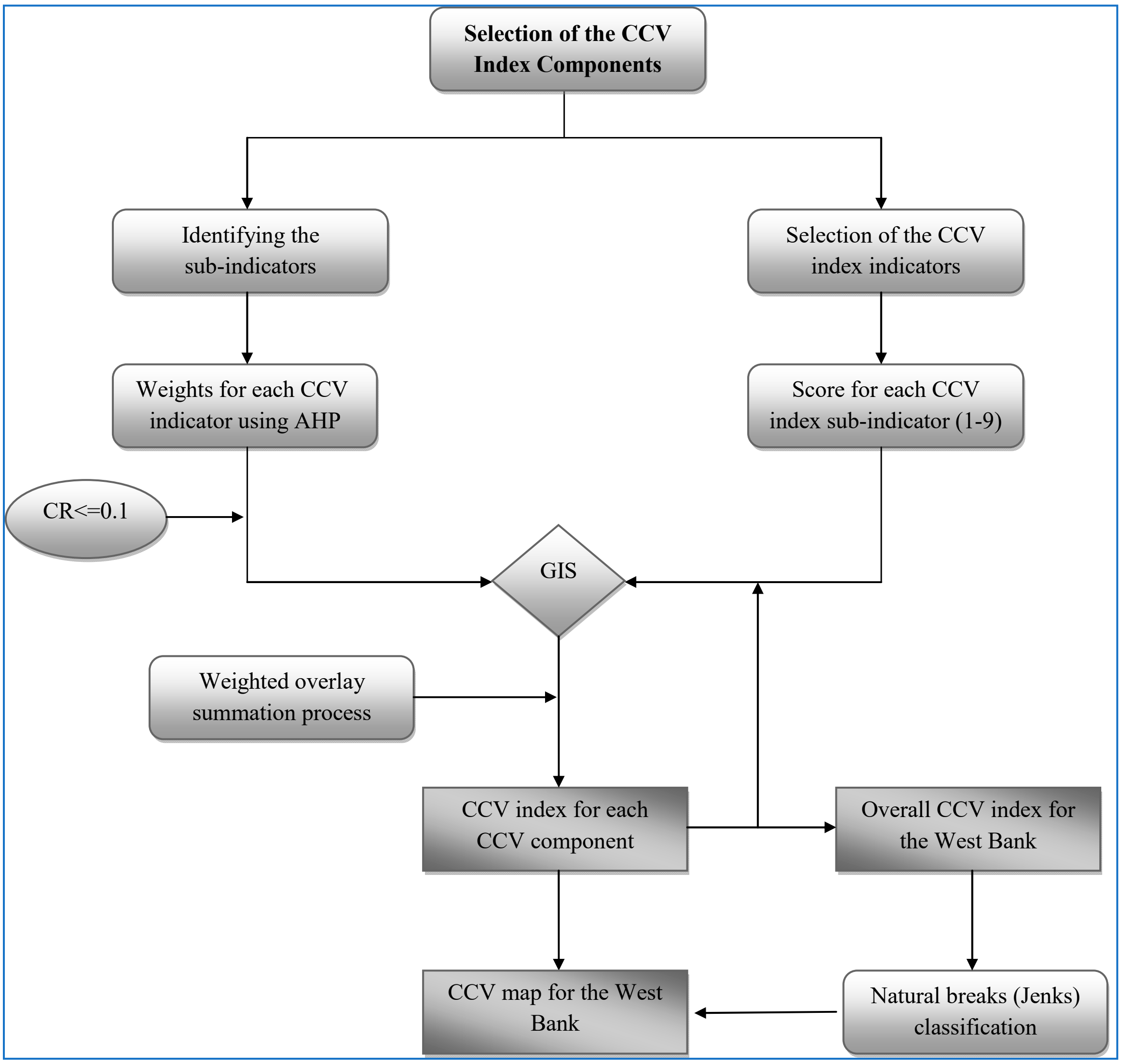

Figure 2. Spatial climate change vulnerability analysis methodological approach.

As previously noted, indices are valuable tools for assessing vulnerability [70]. This assessment method uses a set of indicators, each subdivided into various sub-indicators with assigned weights for detailed vulnerability analysis [71]. The main challenge lies in selecting appropriate indicators, as these choices strongly influence the final index values [72].

In this study, indicators for assessing vulnerability in the West Bank were selected following an extensive review of prior research on vulnerability assessment. Indicators were screened and chosen based on data availability at the governorate level in the West Bank. The selected indicators were organized into six main components: Health, Housing, Socio-demographic, Agriculture, Service, and Economic. Each component includes multiple indicators, which are further divided into sub-indicators. Table 1 presents the indicators used to construct the CCV index for the West Bank, along with references to relevant literature. The data were obtained from different sources such as Ministry of Health [73–76], the Palestinian Central Bureau of Statistics [60–64,75–101], and Palestinian Water Authority [63,102]. These institutions provide this open data through online platforms and in published reports.

Table 1. Climate change vulnerability indictors, data sources, year of data, and references to studies that have used similar indicators to assess climate change vulnerability.

Vulnerability Components	Vulnerability Indicators	Abbreviations	Year and Source of Data (Present)	Year and Source of Data (Past)	Description	References
Health	Infant Mortality Rate	IM	2022 [73]	2009 [76]	Infant mortality rate (per 1000 life birth)	[32,59]
	Daily Necessities	DN	2022 [73]	2009 [76]	Percentage of children underweight (12 months)	[23]
	Recent Death	RD	2022 [73]	2009 [76]	Deaths rate (per 1000 population)	[59]
	Health Centre	HC	2022 [73]	2009 [76]	Population per primary health care center	[103,104]
	Health Care Visit	HV	2022 [73]	2009 [76]	Rate of visits for physician per person in year (PHC)	[105]
	Nursing and Midwife	NM	2022 [73]	2009 [76]	Nursing and midwife (per 10,000 population)	[103]
	Diabetes	Di	2022 [73]	2009 [76]	Rate of diabetes (per 100,000 of population)	[58]
	Cancer	Ca	2022 [73]	2009 [76]	Incidence rate (per 100,000 population)	[58]
	Hospital Beds	HB	2022 [73]	2009 [76]	Number of hospital beds (per 10,000 population)	[58]
	Chronic Diseases	CD	2017 [74]		Number of populations diagnosed with chronic diseases (per 10,000 population)	[23,106]
	Health Insurance	HI	2017 [75]		Number of health insured persons (per 10,000 population)	[107]
	Under-Five Mortality Rate	UM	2022 [73]		Under-five mortality rate (per 1000 life birth)	[108]
	Health Vulnerability	Vu	2021 [77]		Covid vulnerability index	[109]

Table 1. *Cont.*

Vulnerability Components	Vulnerability Indicators	Abbreviations	Year and Source of Data (Present)	Year and Source of Data (Past)	Description	References
Socio-demographic	Adult Literacy	AL	2022 [78]	2007 [61]	Percentage of population (15 years and above) can read and write (exclude the population with the educational attainment elementary, preparatory, secondary, associate diploma, bachelor and above)	[110]
	Older Persons	OP	2017 [79]	2007 [61]	Number of population more than 65 years old (per 10,000 population)	[111–113]
	Education	Ed	2022 [77]	2007 [61]	Percentage of population (15 years and above) who have elementary educational attainment	[113,114]
	Female	Fe	2017 [79]	2007 [61]	Number of female (per 10,000 population)	[115]
	Young Person	YP	2017 [79]	2007 [61]	Persons 0–17 years old (per 10,000 population)	[116]
	Disabled People	DP	2017 [79]	2009 [61]	Number of disabled people (per 10,000 population)	[117]
	Suicide Rates	SR	2022 [73]		Suicide attempt incident rate	[58]
	Homicide Crime	HC	2022 [80]	2013 [93]	Number of victims in homicide crime (per 10,000 population)	[58]

Table 1. *Cont.*

Vulnerability Components	Vulnerability Indicators	Abbreviations	Year and Source of Data (Present)	Year and Source of Data (Past)	Description	References
Economic	Financial Services	FS	2022 [81]	2010 [94]	Capita per bank branch	[23]
	Population in the Workforce	PW	2020 [82]	2007 [95]	Labor force participation rate of persons aged 15 years and above	[113,117]
	Dependency Ratio	DR	2020 [83]	2007 [96]	Unemployment rate of population aged 15 years and above	[118,119]
	Household Received Assistance	HA	2018 [84]		Percentage of household that received assistance	[23]
	Loans	Lo	2018 [84]		Percentage of households that obtained loans/advanced payments/debts (during the past 12 months)	[103,108]
	Industrial Development	ID	2019 [85]		Number of operating industrial enterprises in Palestine (5 employed persons and more)	[116]
Agriculture	Plant Area	PA	2021 [86]	2010 [97]	Percentage of cultivated area of field crops, vegetables, and tree horticulture from total governorate area	[120]
	Main Income from Agriculture	MI	2021 [86]	2010 [97]	Percentage of agricultural holders worked in agriculture as their main job from the total number of agricultural holders	[23,103]
	Irrigated Land	IL	2021 [86]	2010 [97]	Percentage of irrigated field crops area	[121]
	Bovine	Bo	2021 [86]	2010 [97]	Number of cattle	[122]

Table 1. *Cont.*

Vulnerability Components	Vulnerability Indicators	Abbreviations	Year and Source of Data (Present)	Year and Source of Data (Past)	Description	References
Agriculture	Chemical Fertilizer	CF	2021 [86]	2010 [97]	Percentage of agricultural holdings that use chemical fertilizer from total area of agricultural holdings	[110]
	Land Suitability	LS	2017 [69]		Percentage of high agricultural land value from total governorate area	[103]
	Agriculture Water Poverty Index	WP	2020 [87]		Agriculture water poverty index	[103]
	Farm Organization	FO	2021 [88]		Percentage of agricultural holders by receiving an agricultural training/education from total agricultural holders	[39]
	Aquaculture Area	AA	2021 [88]		Percentage of area used for aquaculture from total area of agriculture holding	[116]
Housing	Household Sizes	HS	2017 [60]	2008 [123]	Average household size	[105]
	Built Up Area	BA	2021 [89]	2011 [96]	Percentage of residential built up land from total governorate area	[116]
	Water Consumption	WC	2021 [63]	2009 [102]	Daily consumption rate per capita per day	[116]
	Housing Density	HD	2017 [89]	2007 [98]	Average housing density (person per room)	[23]
	Renter Population	RP	2017 [60]	2007 [98]	Percentage of rented household (furnished and unfurnished) from total household	[122]
	Population Density	PD	2017 [69]	2007 [99]	Capita per km^2	[124]

Table 1. *Cont.*

Vulnerability Components	Vulnerability Indicators	Abbreviations	Year and Source of Data (Present)	Year and Source of Data (Past)	Description	References
Services	Electricity	El	2017 [60]	2007 [61]	Percentage of occupied housing units which connected to electricity public network from total household	[108]
	Toilet Facility	TF	2017 [60]	2007 [61]	Percentage of population use improved sanitation	[105]
	Internet Access	IA	2017 [90]	2007 [100]	Percentage of households that connected to the internet	[113]
	Landfills	La	2017 [69]	2008 [101]	Number of landfills	[58]
	Road Length	RL	2022 [91]	2007 [125]	Road network length	[126,127]
	Access to Water	AW	2017 [60]	2007 [61]	Percentage of population using safely managed drinking water services	[128]
	Forest-based Energy	FE	2017 [60]		Percentage of household used wood for cooking from total household	[23]
	Number of Vehicle	NV	2022 [92]		Number of licensed road vehicles (per 10,000 population)	[116]

The next step involves calculating the weight for each indicator. For this purpose, the Analytic Hierarchy Process (AHP), introduced by Saaty [129], was applied. The Saaty rating scale was used to determine indicator weights through pairwise comparisons. To ensure the reliability of the evaluated weights, the consistency ratio (*CR*) was calculated, with a threshold of $CR \leq 0.1$ to confirm acceptable consistency [130,131]. The following equations were used to test the consistency ratio for the different CCV indicators [130].

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda - n}{n - 1} \tag{2}$$

where *CI* is the consistency index, *RI* is a random consistency index that depends on the number of indicators as calculated by Saaty [129], λ is the maximum eigenvector of the matrix, and *n* is the number of indicators. Annex 1 in the Supplementary Materials presents the AHP matrix for the different CCV components.

Two scenarios were tested to evaluate the overall CCV index. In the first scenario, equal weights were assigned to the six vulnerability components. In the second scenario, weights were varied based on each component's impact on the CCV. The calculated index for each component was then used to determine the overall CCV index. If a governorate has a high index for a specific component, and that component is given a high weight due to its significant influence on the CCV, the governorate's overall vulnerability will increase. Thus, the level of vulnerability largely depends on the weights assigned to each component.

Each vulnerability component was developed based on a different number of available indicators, which may lead to varying levels of accuracy among them. After analyzing the results of both scenarios, this study provides a detailed examination of the first scenario, in which equal weights were assigned to each component. This approach offers a balanced estimation where each component contributes equally to the overall vulnerability index. However, results for the CCV assessment under scenario 2, where components have varying weights, are included in the Supplementary Materials (Annex 2) for comprehensive review.

The use of GIS, particularly through the Analytical Hierarchy Process (AHP) matrix, is a widely adopted approach in vulnerability assessments [132]. In this study, the GIS environment (ArcMap) was utilized to estimate vulnerability index categories. Each indicator was classified into seven sub-indicators, each scored based on its effect on vulnerability (from 1 to 9), as shown in Table 2 for the Health component. Scores for other components are provided in the Supplementary Materials (Annex 3). To calculate the index for each vulnerability component and the overall vulnerability index for the West Bank, the weighted overlay summation technique in ArcMap was applied. Each indicator's weight was multiplied by its scored raster, and the summation of these results represents the final value for each vulnerability component, based on the following equation [133]:

$$CCV\ index\ for\ each\ vulnerability\ components = \sum_{i=1}^{n} Wi \times Sij \tag{3}$$

where *CCV* index is the climate change vulnerability index for each component, *Wi* is a normalized weight for each indicator ($\Sigma Wi = 1$), *Sij* is the score of the ith cell for the *j*th raster, and *n* is the number of cells in each *j*th layer. Afterwards, the results of the index for each vulnerability components were used in the estimation of the overall index. In the overall index, the weight is the weight for each component (all components have the same weight) and *Sij* is the score value for each developed component in the different layers.

Table 2. Example of the scores for the climate change vulnerability index for the Health sub-indicators.

Indicator #	Indicator	Sub-Indicator	Score
1	HB	<6	9
		6–8.4	8
		8.4–10.1	7
		10.1–10.4	6
		10.4–10.5	5
		10.5–18.799999	3
		≥18.799999	2
2	Ca	<84.800003	2
		84.800003–98	3
		98–109.900002	5
		109.00002–117.900002	6
		117.90002–130.600006	7
		130.600006–138.800003	8
		≥138.800003	9
3	Di	<55.900002	2
		55.900002–148	3
		148–168.100006	4
		168.100006–189.699997	5
		189.699997–218.100006	6
		218.100006–298.100006	8
		≥298.100006	9
4	NM	<20.894823	9
		20.894823–29.93848	8
		29.93848–40.317467	7
		40.317467–43.667606	6
		43.667606–43.921768	5
		43.921768–60.634556	3
		≥60.634556	2
5	HC	<3016	9
		3016–3454	8
		3454–3818	7
		3818–4209	6
		4209–4941	4
		4941–5255	3
		≥5255	2

Table 2. *Cont.*

Indicator #	Indicator	Sub-Indicator	Score
6	RD	<2.2	2
		2.2–2.4	3
		2.4–3.1	4
		3.1–3.2	6
		3.2–3.4	7
		3.4–3.6	8
		≥3.6	9
7	IM	<6.7	2
		6.7–7.6	3
		7.6–8.3	4
		8.3–9.3	5
		9.3–10.4	6
		10.4–11.9	8
		≥11.9	9
8	DN	<4	2
		4–6	3
		6–13	4
		13–21	5
		21–30	6
		30–42	8
		≥42	9
9	HV	<0.6	2
		0.6–0.7	3
		0.7–0.8	4
		0.8–0.9	5
		0.9–1.1	7
		≥1.1	9
10	Vu	<3.84	2
		3.84–4.37	3
		4.37–4.79	4
		4.79–5.23	5
		5.23–5.63	6
		5.63–6.24	8
		≥6.24	9

Table 2. *Cont.*

Indicator #	Indicator	Sub-Indicator	Score
11	UM	<7.7	2
		7.7–8.7	3
		8.7–9.4	4
		9.4–10.1	5
		10.1–11	6
		11–13.4	8
		≥13.4	9
12	HI	<2039.549927	9
		2039.549927–5824.502441	7
		5824.502441–6141.465332	6
		6141.465332–6596.859863	5
		6596.859863–7029.911133	4
		7029.911133–7500.355957	3
		≥7500.355957	2
13	CD	<63.200943	2
		63.200943–182.326279	3
		182.326279–242.479797	4
		242.479797–279.251373	5
		279.251373–421.975098	7
		421.975098–464.553436	8
		≥464.553436	9

HB = Hospital Bed, Ca = Cancer, Di = Diabetes, NM = Nursing and Midwife, HC = Homicide Crime, RD = Dependency Ratio, IM = Infant Mortality Rate, DN = Daily Necessities, HV = Health Care Visit, Vu = Vulnerability, UM = Under-Five Mortality Rate, HI = Health Insurance, CD = Chronic Diseases.

Finally, the developed index was used to classify the West Bank governorates into five categories (very low, low, moderate, high, and very high) based on their vulnerability to climate change. The natural breaks (Jenks) in Arcmap were used in this classification and developed the CCV maps for the West Bank.

2.2.2. Temporal Evolution of CCV in the West Bank

The temporal evolution of the CCV in the West Bank was assessed by comparing present and past indices, based on data from the 2020s and the late 2000s, respectively, as presented in Table 1. The results for both periods are compared to evaluate vulnerability trends over time in the West Bank.

Data for both the past and present indices were sourced from consistent references, although data availability varied between the two periods. The present index was developed using 50 indicators, while the past index relied on 35 indicators due to data limitations. To address this difference, an uncertainty analysis was conducted to confirm that missing indicators from the past did not significantly impact the temporal trend results.

This uncertainty analysis involved comparing a modified present CCV index—constructed using only the 35 indicators available for the past index—with the present CCV index derived from the full set of 50 indicators (see Figure 3). Spider diagrams show minimal differences in index values by governorate and component, indicating that the past index is sufficiently reliable for temporal trend analysis. The uncertainty analysis results are included in the Supplementary Materials (Annex 4).

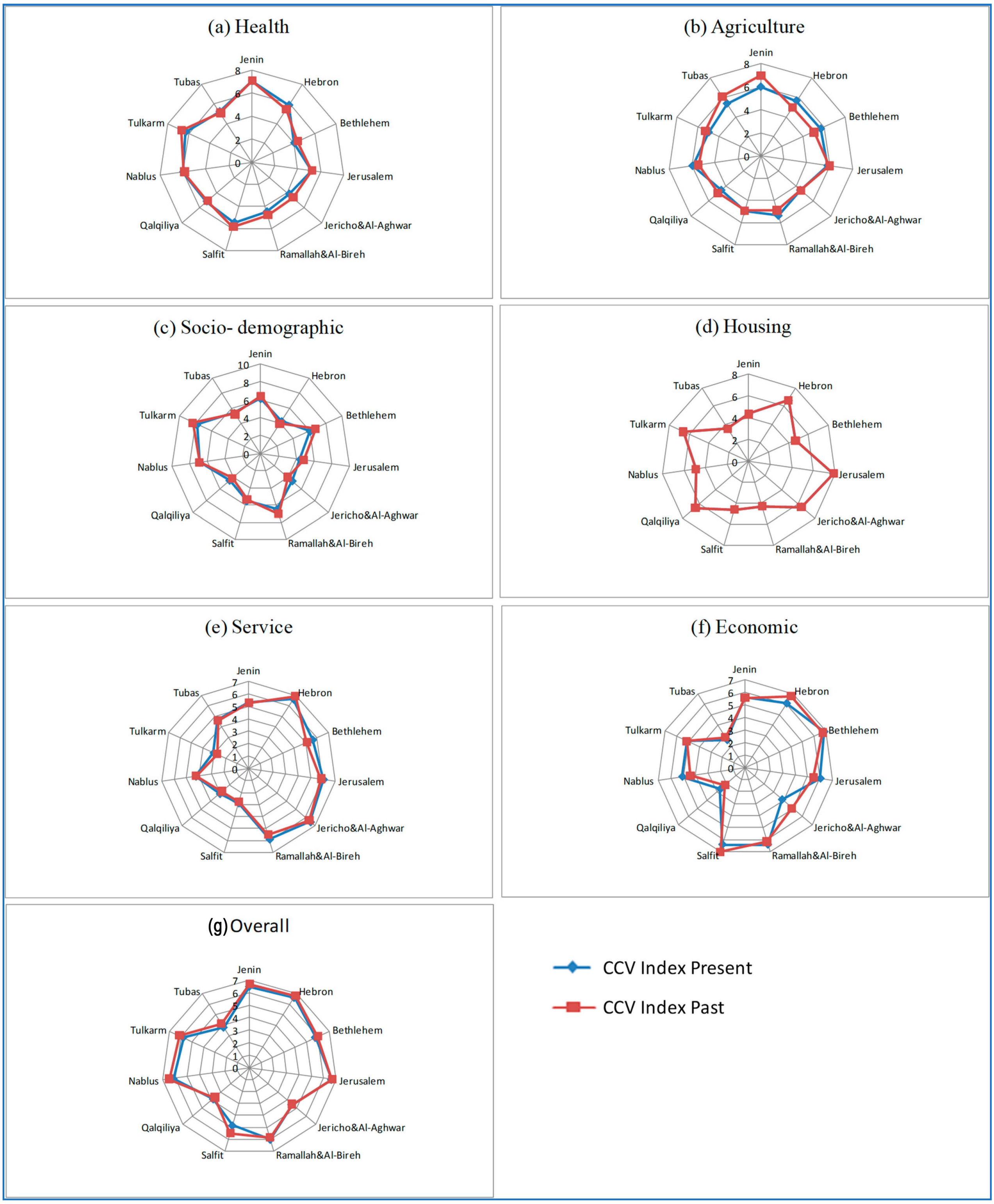

Figure 3. Uncertainty analysis of the temporal evolution analysis of the climate change vulnerability indices ((**a**) Health, (**b**) Agriculture, (**c**) Socio-demographic, (**d**) Housing, (**e**) Services, (**f**) Economic, (**g**) Overall).

3. Results and Discussion

3.1. CCV in the West Bank

In this study, the CCV index was employed to assess vulnerability to climate change in the West Bank. According to the results, the average value of this index for the West Bank is approximately 5.4, ranging between 4.9 and 5.65 across different CCV index components (Table 3). The CCV component having the most negative impact on overall vulnerability is Socio-demographic. Conversely, the Service component contributes the most to reducing vulnerability.

Table 3. Average climate change vulnerability index for the different climate change vulnerability components.

CCV Components	Average Value of CCV Index
Health	5.374
Agriculture	5.323
Socio-demographic	5.659
Housing	5.492
Service	4.908
Economic	5.492

Regarding spatial differences in the CCV index across West Bank governorates, values range from 3.8 to 6.6. As shown in Figure 4, Jenin and Hebron governorates exhibit the highest vulnerability (the highest index values), while Qalqiliya and Tubas are the least vulnerable. The study by Shadeed and Alawna [18] indicated that the rainfall in Jenin will be vulnerable to the impact of climate change. Analysis of the CCV index components across different governorates reveals that the Health and Agriculture components contribute to the high vulnerability in Jenin, while the Housing and Service components account for the high vulnerability in Hebron (Figure 5). In contrast, the lower CCV index values in Tubas are primarily due to low values in the Service and Economic components. Similarly, the low index value in Qalqiliya is explained by low vulnerability in the Agriculture, Socio-demographic, and Economic components.

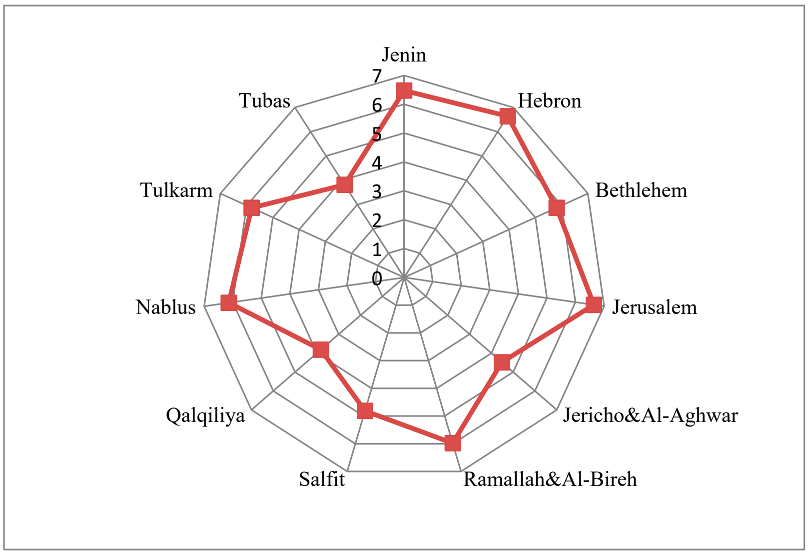

Figure 4. Spider diagram for the climate change vulnerability index for the different West Bank governorates.

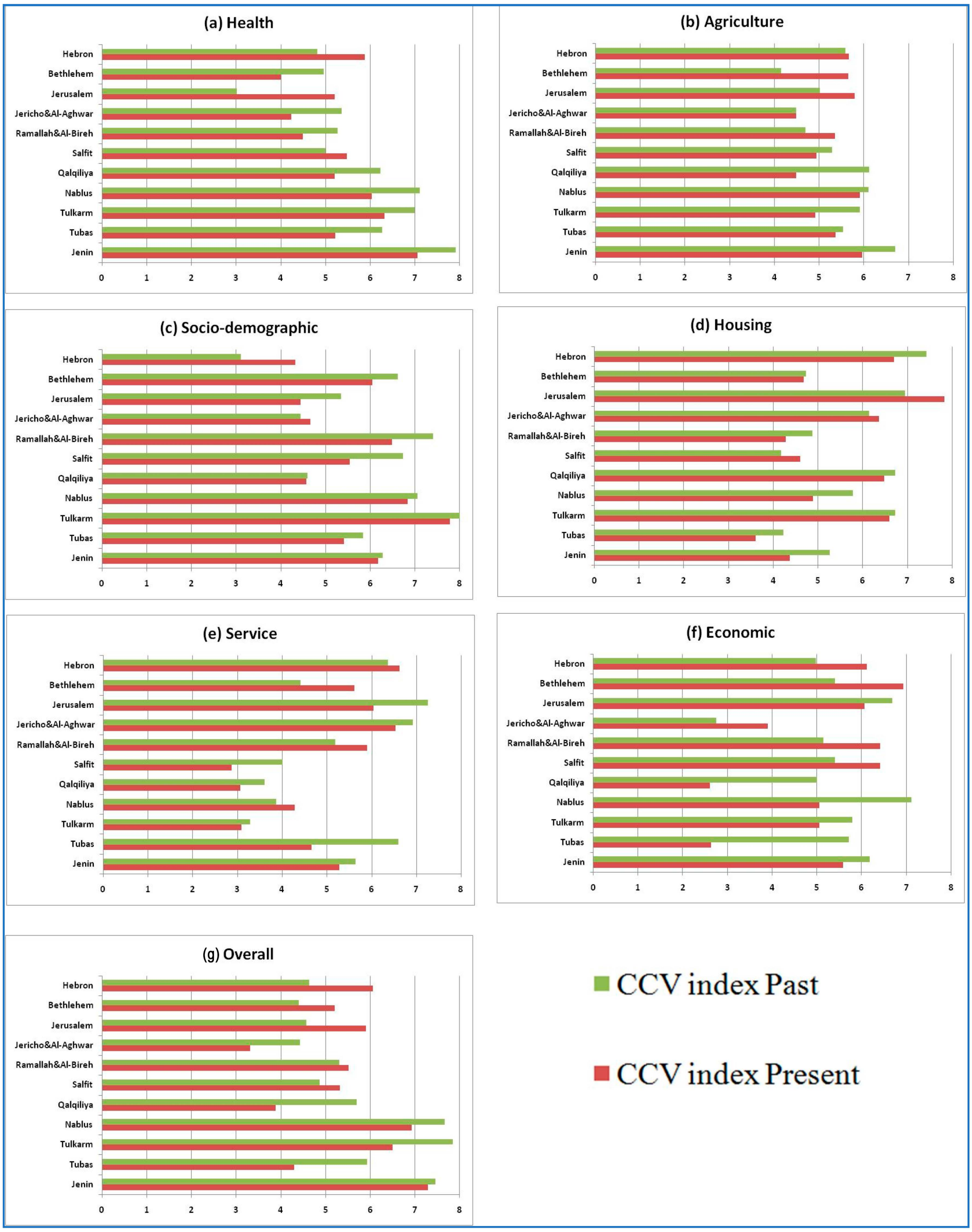

Figure 5. Temporal change in the average climate change vulnerability index for the different climate change vulnerability components ((**a**) Health, (**b**) Agriculture, (**c**) Socio-demographic, (**d**) Housing, (**e**) Services, (**f**) Economic, (**g**) Overall).

In the Health component, Jenin exhibits the highest CCV index, which is attributed to its highest values for three indicators (IM, RD, UM), collectively contributing nearly 0.42 to the total weight. Similarly, in the Agriculture component, Jenin demonstrates the highest vulnerability index. Tulkarem and Jerusalem are highly vulnerable to Socio-demographic and Housing factors, respectively. Furthermore, Jericho and Al-Aghwar and Bethlehem face the most significant challenges in the Service and Economic components (Figure 5).

The resulting indices were used to develop the CCV maps for the West Bank. Based on these maps, the different governorates of the West Bank were classified into five categories based on their vulnerability to climate change: very high, high, moderate, low, and very low, as presented in Figure 6.

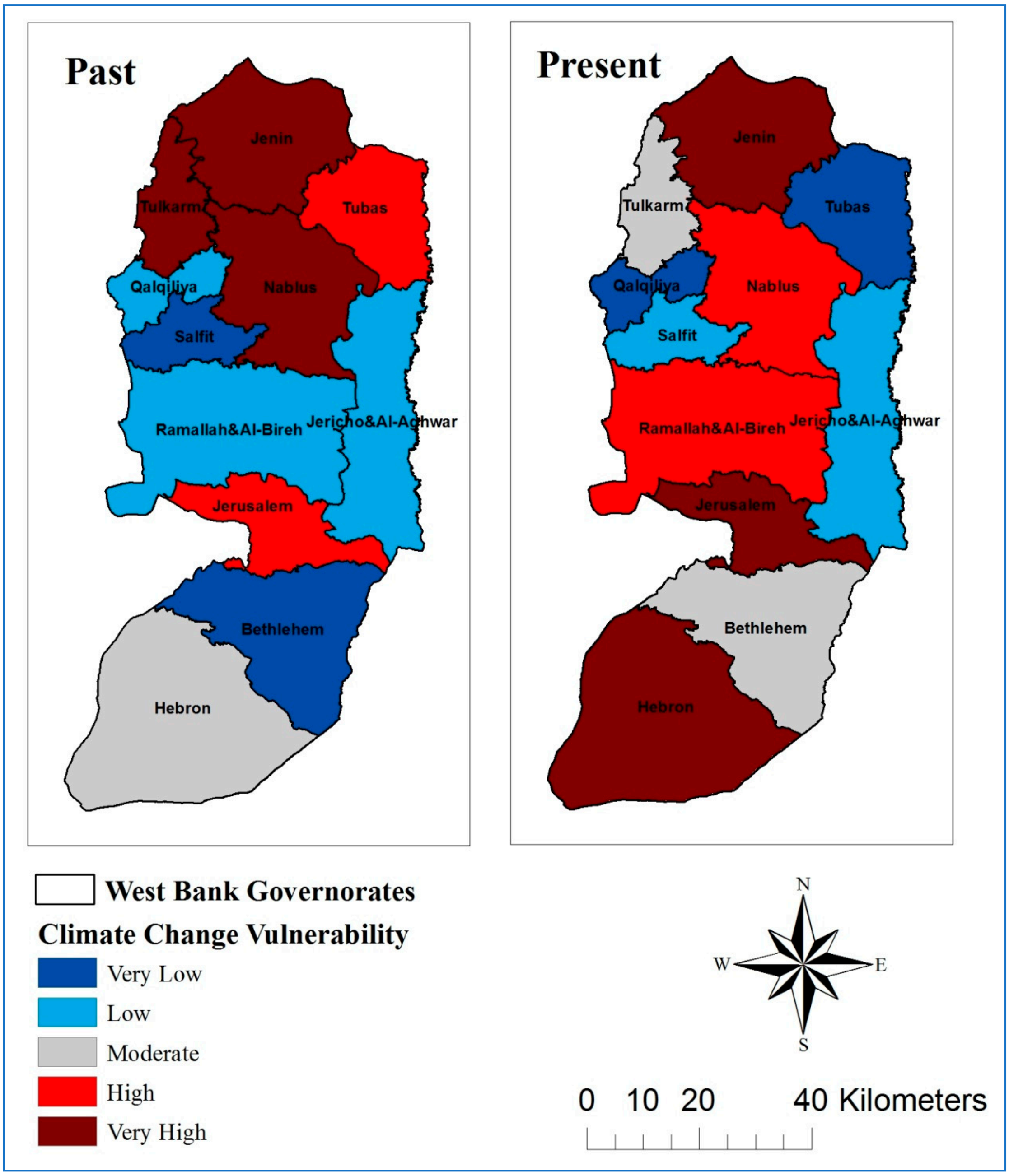

Figure 6. Temporal and spatial evolution of climate change vulnerability maps (**left**: past, **right**: present).

The developed CCV index and maps clearly indicate that the West Bank is highly vulnerable to climate change. The study found that 60% of the West Bank area is classified as highly to very highly vulnerable to climate change impacts, with nearly 76% of the population being susceptible. These populations are concentrated in Jenin, Nablus, Jerusalem, Hebron, and Ramallah and Al-Bireh governorates. Conversely, Tubas, Qalqiliya, Salfit, and Jericho and Al-Aghwar, which make up 24% of the West Bank area and 10% of the population, are under low to very low vulnerability conditions. It is thus essential to prioritize mitigation measures in these areas to reduce vulnerability. The Socio-demographic component, which includes various sensitivity indicators, is the principal contributor to the overall CCV in the West Bank, as observed in other studies (e.g., [108]). This highlights the need to enhance adaptive capacity indicators, particularly those related to literacy and education.

However, local specificities emerged through the spatial analysis [58]. Certain areas, such as Jenin, Hebron, and Jerusalem, require focused mitigation measures to strengthen adaptive capacity in key sectors like health, housing, and agriculture. The health system—encompassing health insurance, health centers, hospital beds, and nursing staff—needs substantial improvements to reduce vulnerability in Jenin and Hebron. Similarly, housing conditions in these areas require upgrades. Enhancing the agriculture sector is also vital for increasing adaptive capacity and mitigating climate impacts in highly vulnerable areas such as Jerusalem and Jenin. Research on climate vulnerability in India similarly emphasizes that supporting agriculture is key to reducing vulnerability [134].

3.2. Temporal Evolution of CCV in the West Bank

The previous assessment also included a study of the late 2000s period to evaluate temporal changes in the West Bank by comparing it with the results presented earlier (detailed information on past CCV estimation is provided in the Supplementary Materials, Annex 4).

The analysis results indicate that, in general, the West Bank has experienced a decrease in vulnerability to climate change impacts in recent years. Specifically, the average value of the West Bank CCV index has decreased from 5.61 to 5.49. The results demonstrate a general decline in the average CCV for all components over time, as shown in Figure 5. This trend can be attributed to the region's low sensitivity and high adaptive capacity to climate change. Given the current situation in Palestine, adjusting sensitivity is challenging. Therefore, efforts could be focused on enhancing adaptive capacity, which would lead to a reduction in overall vulnerability [135].

Figure 5 presents the change in the average vulnerability index for the different West Bank governorates. As seen, the CCV index has decreased in most governorates. Some exceptions include Hebron, Bethlehem, Jerusalem, Salfit, and Ramallah and Al-Bireh.

For the Health component, the average indices decreased over time for all governorates except Hebron, Salfit, and Jerusalem (refer to Figure 5). In these governorates, sensitivity to climate change increased (e.g., Di, Ca, and HV). Additionally, certain indicators related to adaptive capacity, such as HB and HC in Jerusalem, decreased. Hebron and Jericho and Al-Aghwar became more vulnerable to Socio-demographic factors as the number of OP increased over time.

Regarding the Agriculture component, adaptive capacity improved in various West Bank governorates. However, sensitivity increased in Bethlehem, Jerusalem, Ramallah and Al-Bireh, and Hebron governorates, leading to an increase in the CCV index. Furthermore, the CCV index increased in Jerusalem, Salfit, and Jericho and Al-Aghwar governorates for the Housing component, as certain indicators (e.g., RP, PD) increased.

In Hebron, Bethlehem, Ramallah and Al-Bireh, and Nablus governorates, the CCV for the Service component increased as certain adaptive capacity-related indicators decreased. Conditions worsened in five governorates (Hebron, Jericho and Al-Aghwar, Bethlehem, Salfit, and Ramallah and Al-Bireh) for the Economic component due to low adaptive capacity in these areas.

The temporal evolution of vulnerability in the West Bank was also assessed by mapping changes in vulnerability categories across different governorates (Figure 6). It was observed that the vulnerability classes shifted to less vulnerable categories in four governorates, while they transitioned to more vulnerable categories in five others. The populations in Tulkarm, Tubas, Nablus, and Qalqiliya governorates experienced low-vulnerability conditions. In contrast, Salfit, Jerusalem, Bethlehem, Ramallah and Al-Bireh, and Hebron governorates became more vulnerable to climate change impacts. Meanwhile, the vulnerability status in Jenin and Jericho and Al-Aghwar governorates remained unchanged.

Figure 7 illustrates changes in vulnerability for different components. The northern governorates of the West Bank showed increased resilience to climate change, with vulnerability either remaining unchanged or shifting to less vulnerable categories for most components. However, Nablus, Qalqiliya, and Salfit experienced changes in the Services and Socio-demographic vulnerability, transitioning from very low to low classes in Nablus and Qalqiliya, respectively. Furthermore, Salfit saw increased vulnerability in the Health, Housing, and Economic components. In most of the southern governorates of the West Bank, vulnerability increased for most components, except for the Socio-demographic component. In the central governorates of the West Bank, vulnerability decreased for the Health, Socio-demographic, and Services components in two governorates, while it increased in one. However, there was no change in the Housing component. Additionally, the vulnerability for the Economic and Agriculture components increased in two governorates.

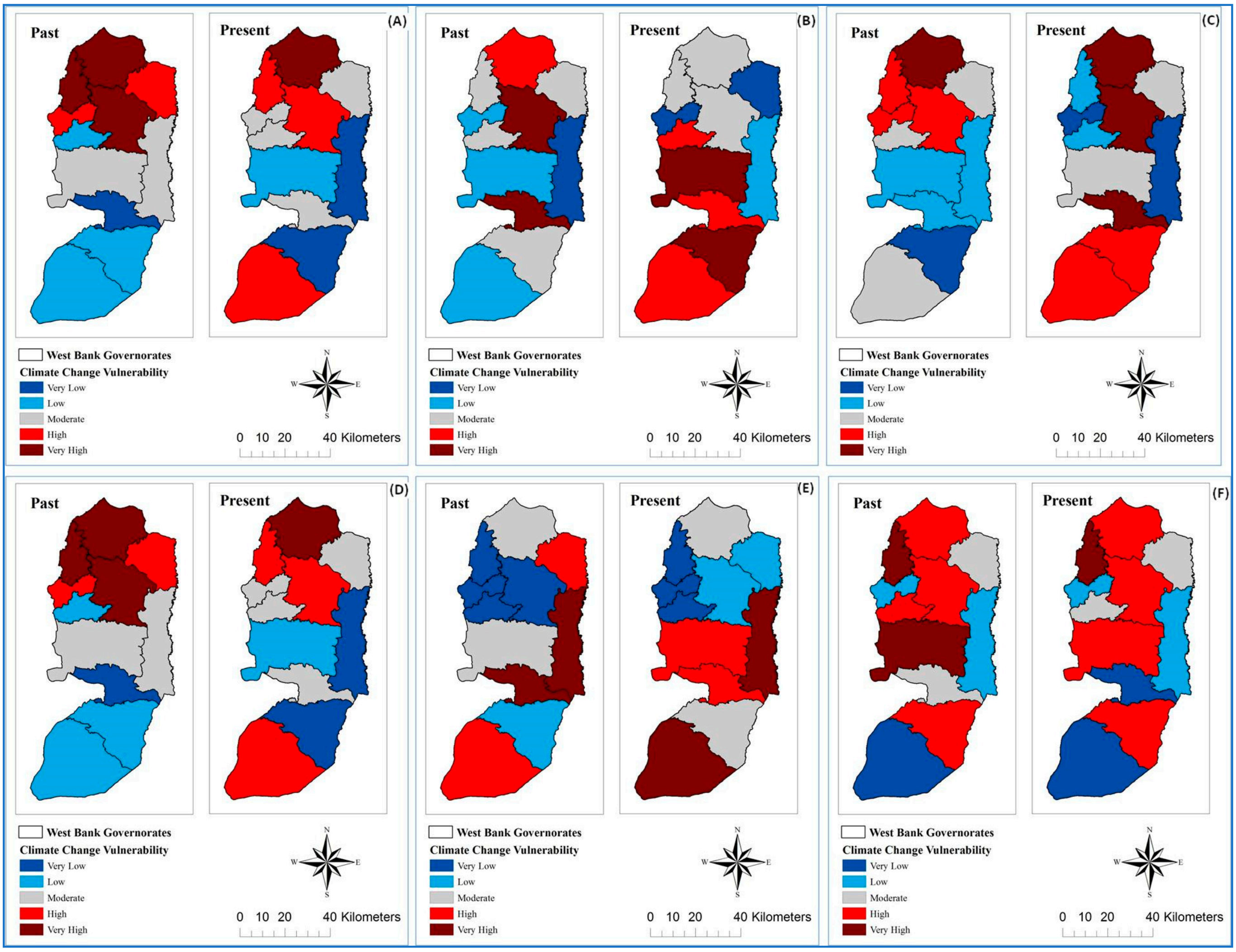

Figure 7. Temporal evolution of climate change vulnerability mapping for Health (**A**), Economic (**B**), Agriculture (**C**), Housing (**D**), Services (**E**), and Socio-demographic (**F**) components.

Overall, the temporal changes in the vulnerability maps (vulnerability classes) are primarily influenced by changes in different components, with some governorates experiencing decreases and others showing increases.

Regional and global climate models indicate that the Mediterranean region is especially vulnerable to future climate change impacts [136]. Historical data also show considerable climate shifts in this region [137]. According to the IPCC, the Mediterranean has been designated as a "climate change hotspot" due to its heightened exposure to climate hazards [138]. Despite increasing exposure to climate change impacts in the region, our findings suggest that the West Bank has become less vulnerable overall in recent years. Yet, analysis of spatial differences shows that certain areas have experienced an opposite trend. Governorates such as Salfit, Jerusalem, Bethlehem, Ramallah and Al-Bireh, and Hebron have shown increasing vulnerability over time due to shifts in various indicators. This indicates that, while some progress has been made in reducing overall vulnerability, targeted interventions are still needed in these specific areas to address emerging challenges.

3.3. Climate Change Management Implications

Suitable adaptation and mitigation measures become a dire need in potentially vulnerable areas [139], such as in some parts of the Mediterranean region, which suffer from complex and unstable socio-economic conditions [15,140]. Therefore, a comprehensive vulnerability assessment should be the first step in building a successful strategy [141]. The developed approach offers a valuable tool for decision-makers to identify high-vulnerability areas and select effective mitigation strategies [142]. The national adaptation plan to climate change for Palestine [143] addresses high-vulnerability issues by sector, including agriculture, water, and health. However, this sector-based approach overlooks the most vulnerable populations. The obtained vulnerability index and maps can help policymakers refine this plan by highlighting the main vulnerable areas and ensuring that adaptation measures specifically target these regions based on identified vulnerability issues [144].

The approach emphasizes the importance of focusing on highly vulnerable areas to reduce climate change vulnerability by enhancing adaptive capacity. This includes strengthening health systems, housing, and the agricultural sector in key governorates. Additionally, addressing economic factors such as access to financial services, unemployment rates, and household loans—particularly in Salfit, Bethlehem, and Ramallah and Al-Bireh—can substantially improve resilience. The services and housing components are crucial in bolstering population resilience to climate change. Expanding access to water, electricity, and internet services can reduce vulnerability, while factors like built-up area expansion, landfill distribution, and the number of renter households should also be considered in vulnerability-reduction efforts. According to Lee [145], the social pillar of vulnerability is more important than the physical one.

3.4. Study Limitations and Future Research

A key limitation of this study is data availability, particularly for the temporal analysis, due to various constraints, including political factors. An uncertainty analysis was conducted to assess the impact of these data gaps on accuracy. Data availability challenges are common in Palestine, where political constraints, among other factors, often hinder data collection. The sensitivity and adaptive capacity pillars were incorporated into the vulnerability assessment. The resulting maps are valuable, as they were developed based on a range of indicators across crucial sectors in the West Bank. However, exposure to climate change was not included in the overall CCV estimation, as it could be more appropriately addressed in a comprehensive risk assessment [146]. Integrating exposure with vulnerability is essential to assess the overall disaster risk [147], underscoring the need for comprehensive assessments that include exposure to climate change [148].

Further climate research is recommended to enhance the understanding of climate risk and vulnerability within the Palestinian context. Integrating exposure with vulnerability is essential for a comprehensive assessment of climate change and other disaster risks. Although the proposed approach has limitations, it can significantly inform the development of effective climate adaptation and mitigation strategies. Future research should focus on addressing data gaps and deepening the understanding of climate risk and vulnerability in the West Bank to support more informed decision-making and policy formulation.

4. Conclusions

Assessing the CCV index is crucial for understanding climate change impacts within the Palestinian context. This study used the climate change vulnerability index to evaluate the vulnerability of West Bank governorates over time, utilizing GIS and the AHP matrix. The assessment considered six components—Health, Socio-demographic, Agriculture, Service, Housing, and Economic—incorporating a total of 50 indicators to develop the climate change vulnerability map. The findings of this study indicate that the West Bank governorates are particularly vulnerable in socio-demographic aspects and less vulnerable in service-related areas. Specifically, Jenin, Nablus, Jerusalem, Hebron, and Ramallah and Al-Bireh are classified as high to very high in vulnerability, while Tubas, Qalqiliya, Salfit, and Jericho and Al-Aghwar are classified as low to very low in vulnerability. The study found that 60% of the West Bank area is classified as highly to very highly vulnerable to climate change impacts, with nearly 76% of the population being susceptible, whereas 24% of the West Bank area and 10% of the population are under low to very low vulnerability. These results offer critical insights for policymakers, emphasizing the need to develop targeted national adaptation and mitigation plans to alleviate climate change impacts, especially in high-vulnerability areas, as special attention should be provided to the populations within these areas. The main limitation of this research is mainly focused on the data gap, as data is the main challenge in a data-scarce country (Palestine). The developed climate change vulnerability maps represent a theoretical advancement in assessing climate change in the West Bank. Additionally, political constraints, such as those imposed by the war in Gaza, pose a significant challenge to the environmental situation in Palestine, directly affecting climate exposure, vulnerability, and the capacity for adaptation. Finally, further research is recommended to deepen the understanding of climate risk and its sector-specific impacts on water, agriculture, and health, advancing sustainability goals in Palestine.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments12020069/s1, Annex 1: Analytical Hierarchy Process matrix for the different climate change vulnerability components; Annex 2: Scenario 2 climate change vulnerability assessment; Annex 3: Scores for the climate change vulnerability index indicators; Annex 4: Past climate change vulnerability estimation.

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