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Research Article

Assessment of Climate Change Vulnerability in Iran; Historical Trend and Future Projections

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ABSTRACT

Introduction: Climate change susceptibility is linked to a number of socioeconomic variables or features, such as the economy, infrastructure, health, education, governance, women's status, demographics, and culture. The GDL Data Lab Vulnerability Index (GVI) was created to compare nations and regions across specific socioeconomic characteristics in order to evaluate the state of societies on these dimensions. The GVI is based on an additive formula that condenses the key elements of seven main socioeconomic vulnerability dimensions into a single number. The aim of this study was to assess Iran's socioeconomic vulnerability index to climate change using the GVI from 2000 to 2020, and to project it until 2100 along five socioeconomic pathways (SSP1 to SSP5).

Methods: GVI data for Iran for the period 2000 to 2020, as well as future projections of this index under five different socioeconomic development scenarios (SSP1 to SSP5) for the period 2020 to 2100, were extracted from the Global Data Lab (GDL) database and analyzed using GraphPad Prism software.

Results: The results of the study showed that the GVI index declined from 54 to 38 over the past two decades, reflecting progress in education, health, and infrastructure. Future projections also suggest that vulnerability will continue to decline, with the SSP5 scenario showing the largest decrease from 37.2 to 18.7, and the SSP3 scenario showing the smallest decline from 40.5 to 36.8 reflecting a wide range of socioeconomic outcomes.

Conclusion: The findings highlight the need for policies that support equitable and sustainable growth, particularly those aligned with the SSP1 model.

Keywords: Climate Change Vulnerability; Socio-Economic Vulnerability; Global Vulnerability Index; Climate Change; Shared Socioeconomic Pathways

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Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as long-term alterations in global weather patterns that are attributed to human activities. These changes have significant effects on the physical and mental health and well-being of populations worldwide [1]. The effects of climate change are being widely experienced around the world [2], manifesting in a range of physical and biological changes that adversely affect human health, agriculture, and the environment [3, 4].

According to the Intergovernmental Panel on Climate Change, vulnerability is defined as the "propensity or predisposition to be adversely affected" [5]. It results from a combination of factors, including economic conditions, education, health, gender equity, governance quality, demographic characteristics, and infrastructure adequacy, which together influence a system's sensitivity to climate impacts and its ability to cope and adapt [6, 7].

It is important to note that vulnerability to the effects of climate change is higher in low- and lower-middle-income countries [8]. Climate-related disasters are increasing worldwide, but their negative health impacts are unevenly distributed. Those most affected are often from vulnerable and socioeconomically disadvantaged communities, who are exposed to high-risk conditions and lack the adaptive capacity to cope with these threats [9].

In this regard, accurate and scientific assessment of socio-economic vulnerability indicators to climate change is of great importance for formulating effective policies and programs to reduce risk and increase resilience. Composite vulnerability indicators, which include various economic, social, governance, and infrastructure dimensions, are suitable tools for analyzing the vulnerability status of different countries and regions [10]. These indicators enable comparisons across various regions and time periods by condensing complex data into a single number, which aids policymakers in determining priorities more effectively. One of the most recent and authoritative indicators in this field is the Global Data Lab Vulnerability Index (GVI).

GVI, as a composite index, focuses on the human aspects of vulnerability and, using a simple aggregate formula, summarizes seven key socio-economic dimensions including economy, education, health, status of women, governance, population, and infrastructure into a single number [7]. This index is considered an efficient tool for analysis and planning in the field of climate change due to its simplicity, flexibility, and ability to predict future vulnerability trends based on socio-economic development scenarios. Validation studies have also shown that the GVI index has a high correlation with reputable global indices such as ND-GAIN, INFORM, and the Global Risk Index, and can effectively indicate the vulnerability status of countries and regions [11].

Iran has experienced significant climatic shifts in recent decades, including declining precipitation, rising temperatures, and intensifying droughts. Between 1970 and 2020, the country faced numerous climate-induced events such as floods and prolonged droughts, leading to agricultural losses, food insecurity, and economic damage particularly in rural areas [12–15]. These effects have been compounded by governance inefficiencies and mismanagement of natural resources, notably the depletion of surface and groundwater and the desiccation of major lakes and rivers [16].

Social and economic factors further exacerbate Iran's climate vulnerability. Gender inequality remains a significant barrier, with limited participation of women in the workforce and constrained access to education, healthcare, and adaptation resources—particularly in rural areas. Iran's economic dependence on fossil fuel exports, combined with inflation and poverty, has further reduced household resilience. Additionally, disparities in infrastructure, digital connectivity, and educational access between urban and rural areas have deepened regional vulnerabilities [12, 13, 16–19].

These elements increase preexisting vulnerabilities, especially in socioeconomically deprived areas; therefore, determining Iran's vulnerability is essential for developing focused adaptation and mitigation plans. Accordingly, the purpose of this study was to assess Iran's socio-economic vulnerability to climate change using the GVI, analyzing historical trends from 2000 to 2020 and projecting future vulnerability under the Shared Socioeconomic Pathways (SSP1 to SSP5) through 2100.

Methods

Data collection

In this study, the Global Vulnerability Index (GVI) was used as the main measure to assess Iran's vulnerability to climate change. The GVI focuses on the human and social aspects of vulnerability in communities, countries, or other geographical areas. The index integrates seven main dimensions: economy, education, gender, health, infrastructure, governance, and demography. Each dimension is measured by a set of sub-indicators, such as GDP per capita, poverty rate, average years of schooling, gender development index, life expectancy, access to water and electricity, quality of governance, and population dependency ratio [20] (Tables 1 and 2).

The GVI provides a standardized 0–100 vulnerability score, where low values indicate low vulnerability to climate change, and high values indicate considerable vulnerability. GVI data for Iran for the period 2000 to 2020, as well as future projections of this index under five different socio-economic development scenarios

Table 1: Dimensions and Indicators Comprising GVI

Dimension	Measurement Indicators
Economic	GDP per capita based on purchasing power parity (constant 2017 international dollars) Proportion of population below $3.20/day poverty line
Educational	Mean years of schooling of the population aged 25 and above
Gender	Gender Development Index
Health	Life expectancy at birth
Infrastructure	Access to safe drinking water, electricity and (mobile) phone
Governance	Worldwide Governance Indicator
Demographic	Urbanization rate

Table 2: Dimensions and Indicators Comprising GVI

Shared Socioeconomic Pathway (SSP)	Descriptive Title	Climate Change Characteristics	Key Socio-Economic Features
SSP1	Green road	Low challenges for mitigation and adaptation; includes Paris Agreement-compatible scenarios	Increased investment in education and health; reduced intra- and inter-country inequalities
SSP2	Middle of the road	Moderate challenges for mitigation and adaptation; includes current climate commitments pathways	Uneven and stagnant economic growth; continued vulnerability challenges
SSP3	Rocky road	High challenges for mitigation and adaptation	Decreased investment in education and technology; continued or worsened inequalities overtime
SSP4	Inequality pathway	Low challenges for mitigation; high challenges for adaptation	Significant gaps within and between countries; some regions advance while others remain impoverished; focus on structural inequalities
SSP5	Fossil-fueled development pathway	Low challenges for adaptation; high challenges for mitigation	Rapid growth based on fossil fuels; widespread environmental degradation; high-energy technology development; significant economic inequalities

(SSP1 to SSP5) for the period 2020 to 2100, were extracted from the Global Data Lab (GDL) database and analyzed [7, 21, 22].

The Shared Socioeconomic Pathways (SSPs) provide a framework for projecting possible futures based on demographic, economic, social, and technological changes that explore the interplay with climate change. The pathways include five main scenarios, each with distinct characteristics and challenges in terms of climate change mitigation and adaptation [22].

Statistical Analysis

Descriptive statistics and linear regression were used to analyze historical and projected GVI trends. Statistical measures included mean, minimum/maximum, standard deviation, regression slope, intercept, coefficient of determination (R^2), and p-values. All analyses were conducted using GraphPad Prism software, version 9.0.2.

Results

Trend Analysis of GVI in Iran in the period 2000-2020

The assessment of GVI over the period 2000 to 2020 showed a decreasing trend in socio-economic vulnerability (Fig. 1). The average value of this index was 43.62, with a standard deviation of 5.482, indicating moderate variability in annual values. The minimum and maximum GVI values were 37 and 54, respectively. The standard error of the mean was calculated to be 1.196, indicating acceptable accuracy in estimating the mean (Table 3). Linear regression demonstrated a significant decreasing trend in GVI over time (slope = –0.8584, y-intercept = 53.06, $R^2 = 0.9442$, $p < 0.0001$), indicating a relative improvement in Iran's socio-economic vulnerability over the past two decades (Table 4).

Trend Analysis of GVI in Iran in the period 2020-2100

For the projected period 2020–2100, the GVI was analyzed under five different SSP scenarios (SSP1 to SSP5), each representing a distinct trajectory for future development and climate change adaptation. The minimum index in the SSP5 scenario was 18.7, and in the SSP3 scenario it was 36.8 (Table 5). These results indicate that different socio-economic development scenarios have varying impacts on the level of vulnerability.

Linear regression was also performed for the GVI

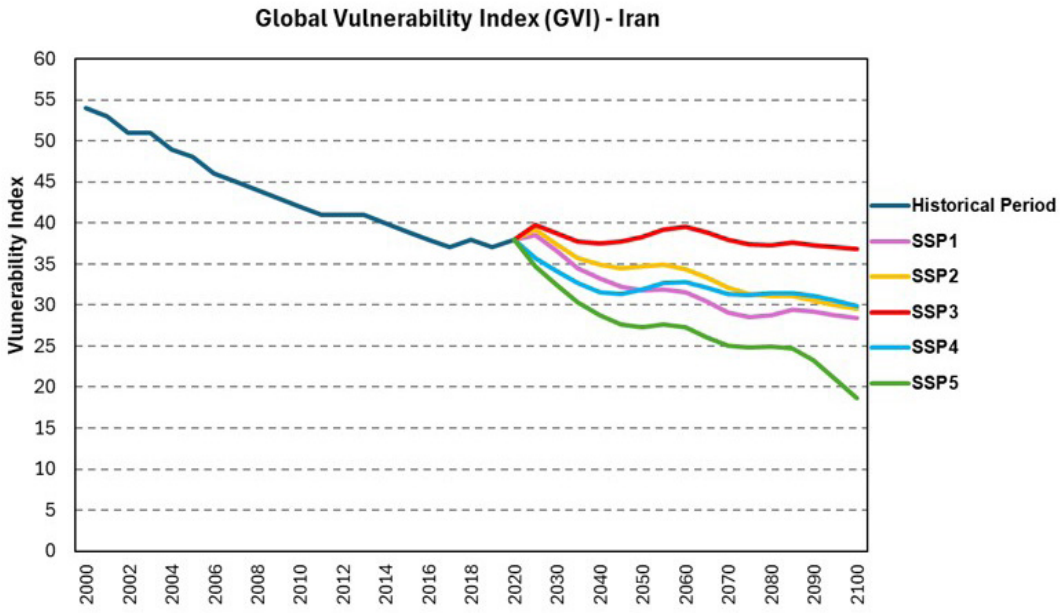

Figure 1: Global Vulnerability Index (GVI) for Iran, for historical period (2000–2020) and projected trends under SSP1–SSP5 (2020–2100).

Table3: Descriptive statistics of GVI (2000-2020)

Statistic	GVI
Minimum	37
Median	42
Maximum	54
Mean	43.62
Std. Deviation	5.482
Std. Error of Mean	1.196

Table 4: Linear Regression Parameters for GVI 2000-2020

Regression Parameter	GVI
Slope	-0.8584
Y-intercept	53.06
R squared	0.9442
P value	<0.0001

Table 5: Descriptive statistics of GVI under different SSP scenarios 2020-2100

Parameters	GVI-ssp1	GVI-ssp2	GVI-ssp3	GVI-ssp4	GVI-ssp5
Minimum	28.4	29.5	36.8	29.9	18.7
Median	31.5	34.4	37.7	31.6	27.3
Maximum	40.5	40.5	40.5	37.2	37.2
Mean	31.95	33.84	38.18	32.29	27.15
Std. Deviation	3.676	3.179	1.051	1.854	4.64
Std. Error of Mean	0.8916	0.7711	0.2548	0.4496	1.12

in each of the SSP scenarios, showing a declining GVI trend across all pathways, though with varied slopes and statistical strengths (Table 6). The highest negative slope was observed in the SSP5 scenario (–0.8730), indicating the fastest improvement, while the lowest slope was observed in SSP3 (–0.1456). R^2 values indicate that the regression models fit well for SSP1, SSP2, SSP4, and SSP5 (all above 0.65), but the fit was weaker in SSP3 (R^2 = 0.4896), signifying greater uncertainty in vulnerability projections for this scenario. All regression trends

Table 6: Linear regression parameters for GVI under five SSP scenarios

Parameters	GVI- ssp1	GVI- ssp2	GVI- ssp3	GVI- ssp4	GVI- ssp5
Slope	-0.6650	-0.6071	-0.1456	-0.2978	-0.8730
Y-intercept	37.93	39.31	39.49	34.97	35.01
R squared	0.8344	0.9299	0.4896	0.658	0.9022
P value	<0.0001	<0.0001	0.0018	<0.0001	<0.0001

were statistically significant ($p < 0.05$). These results, confirmed by Figure 1, show that Iran's vulnerability to climate change can decline at different speeds depending on the socio-economic development path, with SSP5 showing the most rapid reduction and SSP3 the least.

Discussion

In this study, we used the Global Vulnerability Index (GVI) to assess Iran's socio-economic vulnerability to climate change from 2000 to 2020 and to project it to 2100 along five Shared Socioeconomic Pathways (SSP1 to SSP5) (22). The results show a significant decline in the GVI from 54 in 2000 to 38 in 2020 over the past two decades (slope = -0.8584), which is attributed to improvements in education, health, and infrastructure [7]. At the same time, challenges such as poverty, gender inequality, and limited access to resources in rural areas still exist and require special attention. This downward trend for the vulnerability index is confirmed by the historical data presented in Figure 1 and indicates a relative increase in Iran's capacity to adapt to climate change, although these improvements have not been evenly distributed across the country.

Also, regarding the GVI for the projected period 2020–2100, the results show that the GVI has decreased in all SSP scenarios, but each scenario will decrease at different rates and patterns. The largest decrease in the index was for the SSP5 scenario (fossil fuel-based development), with a slope of -0.8730 and a decrease from 37.2 in 2020 to 18.7 in 2100, indicating a rapid improvement in vulnerability, although this path is associated with widespread environmental degradation consequences [22]. While under SSP3 (rocky road), vulnerability has the smallest decrease, with a slope of -0.1456, decreasing from 40.5 to 36.8, and is expected to remain almost stagnant. This result indicates a continuation of high vulnerability due to reduced investment in education and technology and worsening inequalities [10].

Also, the SSP1 (green road) and SSP2 (middle of the road) scenarios show milder reductions by 2100 to 28.4 and 29.5, respectively. The reason for this mild reduction in the SSP1 scenario is related to its sustainable development approach and environmental improvement, which is accompanied by increased use of renewable energy, reduced land use, and reduced greenhouse gas emissions from human activities in 2100 [23]. This path results in a decrease in inequality both within and between nations, a rise in investments in health and education, and a change in emphasis from economic growth to human well-being [22].

The route SSP2 is regarded as a "middle of the road" approach in terms of the difficulties associated with adaptation and mitigation, and it is essentially a continuation of past trends in social, economic, and technical development. This approach results in uneven and stagnant economic growth and development, as well as sluggish progress towards the UN Sustainable Development Goals [24].

The SSP4 (Inequality Path) scenario also shows an intermediate pattern, decreasing from 37.2 to 29.9. Based on current values of GVI, countries around the world are divided into three categories of low, medium, and high vulnerability. Low-vulnerability countries have an average of 25, medium-vulnerability countries around 40, and high-vulnerability countries around 70 [22].

According to the current values of GVI, Iran is situated within the medium vulnerability range [25–40] for SSP1, SSP2, and SSP3 scenarios. Figure 1 visually illustrates these differences and confirms that the choice of socio-economic development path plays a decisive role in reducing future vulnerability. Iran's dry climate, with an average annual rainfall of 240 mm and a projected temperature increase of 4.5°C by 2100, exacerbates climate pressures, especially in rural areas and for vulnerable groups [16, 25]. In addition to these challenges, the scarcity of water resources and the occurrence of extreme weather events increase socio-economic vulnerability and highlight the need for local adaptation strategies. Therefore, future policies in the country should prioritize sustainable and equitable development, in particular by adopting the SSP1 scenario, which encourages investment in healthcare, education, and reducing inequality. This strategy can prevent the worsening of vulnerability in deprived areas and increase Iran's ability to adapt to climate change. On the other hand, adopting the SSP5 scenario, due to its dependence on fossil fuels, is not a suitable solution, even if it leads to a rapid reduction in vulnerability.

Conclusion

The GVI is a straightforward additive formula that summarizes the seven main aspects of human vulnerability to climate change, including infrastructure,

governance, gender, health, education, economy, and demography. We used this index to assess Iran's socio-economic vulnerability to climate change. The findings show a significant decline in the GVI for the historic period (2000–2020), which is attributed to improvements in education, health, and infrastructure. Also, regarding the GVI for the projected period 2020–2100, the results show that the GVI has decreased in all SSP scenarios, but each scenario will decrease at different rates and patterns. Thus, sustainable and equitable development should be given top priority in the nation's future policies, especially by implementing the SSP1 scenario, which promotes investment in healthcare, education, and inequality reduction.

Authors' Contributions

Masoumeh Rahmatinia: Conceptualization, Data Collection, Data Analysis, writing –Original Draft, Writing – Review & Editing, Supervision, Funding Acquisition. **Mostafa Hadei**: Conceptualization, Data Collection, Data Analysis, writing –Original Draft, Writing – Review & Editing, Supervision, Funding Acquisition. **Parnia Hatami Moghadam:** Conceptualization, Data Collection, Data Analysis, writing –Original Draft, Writing – Review & Editing, Supervision, Funding Acquisition.

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Ethical Considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy) have been completely observed by the authors.

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