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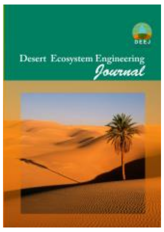

Comparative Analysis of A1FI-MI and B1TME Climate Change Scenarios on Iranian Saffron Cultivation

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Extended Abstract

Introduction: Saffron (*Crocus sativus* L.), the dried stigmas of the *Crocus sativus* flower, is the world's most valuable spice by weight. Its exceptional economic value is underpinned by a precise dependence on specific climatic conditions, making it acutely vulnerable to global climate change. As the dominant global producer, contributing approximately 90% of world output, Iran's agricultural sector, rural economies, and export revenues are intrinsically linked to the sustainable cultivation of this "red gold." The crop's phenology, especially its critical flowering stage, is highly sensitive to subtle variations in temperature and precipitation regimes, underscoring the necessity for long-term strategic planning.

This study conducts a rigorous comparative analysis of the potential impacts of two divergent climate change scenarios on the spatial and qualitative suitability for saffron cultivation across Iran. These scenarios represent contrasting futures for global development and energy policy. The first, the A1FI-MI scenario from the IPCC's Special Report on Emissions Scenarios (SRES), projects a future of rapid economic growth driven by intensive fossil fuel consumption. The second, the B1TME scenario, envisions a globally convergent pathway prioritizing sustainability, characterized by a transition to a service and information economy and the widespread adoption of clean, resource-efficient technologies.

The primary objective of this research is to project 21st-century changes in key climatic variables—specifically temperature and precipitation—and to quantitatively evaluate their effects on the geographic distribution and quality of land deemed climatically optimal for saffron production in Iran. By employing advanced geospatial modeling, this work addresses a critical knowledge gap. It provides a detailed, scenario-based assessment essential for policymakers, agricultural planners, and farmers to formulate robust, long-term adaptation and resource management strategies to protect this cornerstone of Iranian agriculture.

Materials and Methods: This study employed an integrated geospatial modeling approach, primarily utilizing the TerrSet Geospatial Monitoring and Modeling System. The core climatic analysis was performed using the system's Climate Change Adaptation Modeler (CCAM) component. The methodology comprised four sequential steps.

First, the two representative emission scenarios, A1FI-MI (fossil-fuel intensive) and B1TME (sustainable transition), were selected to encompass a range of plausible future climates.

Second, the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) model was employed to generate global-scale temperature change projections. Key MAGICC parameters were configured following IPCC guidelines, including a climate sensitivity of 3.0°C for a doubling of atmospheric CO_2 concentration. The baseline year was set to 1990, with projections extended to 2100.

Third, the SCENGEN (SCENario GENerator) model was used to statistically downscale the global climate projections from MAGICC. SCENGEN translated broad-scale temperature changes into high-resolution (approximately 50 km) spatial datasets of projected changes in temperature and precipitation. To enhance the reliability of the projections and account for inter-model variability, an ensemble average of 18 different Ocean-Atmosphere General Circulation Models (OAGCMs) was computed for each scenario for the target years of 2070 and 2100.

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The fourth step involved assessing the impact of these projected climatic changes on saffron cultivation suitability, using the Crop Climate Suitability Modeling (CCSM) module within TerrSet. The CCSM model evaluates suitability based on a crop's specific biophysical requirements, defined by optimal and absolute threshold parameters for temperature (e.g., TMIN, TOPMIN, TOPMAX, TMAX, KTMP) and precipitation (e.g., RMIN, ROPMIN, ROPMAX, RMAX). The parameterization for saffron was calibrated using established ecological requirements from the scientific literature. To ensure practical applicability, the initial climatic suitability outputs were refined by applying a series of constraining "mask" layers. These masks systematically excluded areas unsuitable or unavailable for agriculture, including urban zones, water bodies, dense forests, protected areas, and lands with slopes exceeding 8 degrees, based on data from MODIS land cover classification. The final outputs were detailed raster maps classifying Iran's land area into six suitability categories for saffron cultivation: "Unsuitable," "Very Low," "Low," "Medium," "High," and "Very High."

Results

The modeling results reveal starkly divergent futures for Iranian saffron cultivation, fundamentally dependent on the global emission pathway followed.

Under the high-emission A1FI-MI scenario, a pronounced and sustained increase in global mean temperature was projected, driving severe alterations in Iran's local climatic patterns. The analysis indicates a dramatic contraction in land area with high suitability for saffron. Specifically, the area classified as "Very High" suitability plummeted from 4.05% (66,182 km²) of the country's total area in 2070 to a mere 0.62% (10,196 km²) by 2100—representing a decline of approximately 85%. Concurrently, the total area deemed "Unsuitable" for cultivation expanded significantly, rising from 79.55% to over 80.13% by the century's end. Geographically, this trend manifested as a severe degradation of suitability in the traditional saffron heartlands of the eastern provinces (South Khorasan, Razavi Khorasan, and North Khorasan), driven primarily by extreme heat stress and adverse shifts in precipitation regimes. Notably, the model projected a distinct spatial shift, with some areas in western and northwestern provinces (e.g., Kermanshah, Hamedan, and Kurdistan) emerging as newly suitable or retaining suitability due to more moderated future climate conditions.

In direct contrast, the sustainable B1TME scenario projected a far more attenuated rise in global temperatures. The consequent climatic changes across Iran were less severe, resulting in a significantly more favorable outlook. While the area of "Very High" suitability also decreased (from 3.95% to 0.93% by 2100), the overall landscape of suitability underwent a transformative change. The most critical finding was the substantial contraction of "Unsuitable" land, which fell from 78.72% in 2070 to 55.02% in 2100. This reduction corresponded with a marked expansion in land area classified as having "Low" suitability (increasing from 5.07% to 14.59%) and "Very Low" suitability (increasing from 3.05% to 12.14%). This indicates that while optimal "Very High" suitability zones diminish under both scenarios, the B1TME pathway preserves an extensive strategic reserve of land with marginal to moderate climatic suitability. This provides critical adaptive capacity and long-term resilience, allowing cultivation to persist—though potentially requiring adjusted agronomic practices—across significantly larger portions of the country, particularly in central and western regions.

Discussion and Conclusion

The findings of this study underscore the profound threat that unmitigated climate change poses to Iranian saffron production, while simultaneously highlighting how global policy decisions critically determine the severity of these impacts. The drastic reduction in climatically suitable land under the A1FI-MI scenario quantifies the significant yield declines previously projected for eastern Iran under high-emission pathways, driven primarily by increased extreme heat and altered precipitation.

The identification of a potential north-western shift in suitability under the A1FI-MI scenario offers a crucial, novel insight, though it necessitates detailed investigation into non-climatic factors such as soil quality, water resource availability, and socio-economic readiness for adopting a new cash crop in these regions.

The most salient conclusion is the clear quantitative evidence for the benefits of mitigation. The comparative success of the B1TME scenario in preserving a vast area of cultivable land validates the imperative to integrate sustainable development and clean energy policies into strategic planning. This research moves beyond identifying vulnerabilities; it provides a compelling, evidence-based argument that a sustainable global pathway is not merely an environmental goal but a direct economic necessity for safeguarding Iran's flagship agricultural product and the livelihoods it supports.

In conclusion, to ensure the resilience of Iran's saffron industry, the following strategic actions are recommended:

1. **Prioritize Immediate Adaptation in Vulnerable Regions:** Develop and deploy climate-smart agricultural practices in the eastern heartlands. This requires investment in efficient irrigation technologies, the development of drought and heat-tolerant cultivars, and the implementation of soil moisture conservation techniques.
2. **Champion Sustainable Development Policies:** The results unequivocally demonstrate that a B1TME-like pathway offers a far more secure future. National policy should actively promote reduced fossil fuel dependency, renewable energy adoption, and the integration of environmental sustainability into all economic and agricultural planning.

3. **Initiate Feasibility Studies in Emerging Regions:** Conduct detailed agro-ecological and socio-economic feasibility studies in the identified potential new suitable areas in western and northwestern Iran. This preparatory work is essential to inform a managed, equitable, and beneficial geographic transition, should it become necessary.
4. **Enhance Integrated Research and Monitoring:** Invest in long-term, high-resolution regional climate modeling and establish robust environmental monitoring networks. Future research must integrate climatic projections with hydrological data, detailed soil mapping, and socio-economic analysis to provide a holistic foundation for adaptive decision-making.

Keywords: Adaptation, Suitability Assessment, Global Warming, MAGICC-SCENGEN.