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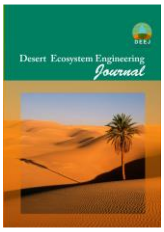

Evaluation of Climate Change Scenarios' Effects on Vegetation Cover in Arid and Semi-Arid Rangelands

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Extended Abstract

Introduction : Dry and semi-arid rangelands are vital ecosystems, encompassing approximately 40–50% of the Earth's terrestrial surface. These regions provide essential ecological services, such as forage production, soil conservation, carbon sequestration, and biodiversity maintenance. However, climate change poses a significant threat to these fragile environments through altered temperature regimes, modified precipitation patterns, and an increased frequency of extreme weather events. In Iran—particularly in the provinces of Chaharmahal and Bakhtiari and Isfahan—these challenges are further exacerbated by prevailing overgrazing and unsustainable land management practices. This study aims to quantitatively evaluate the impacts of different climate change scenarios on vegetation dynamics within these critical rangeland ecosystems.

Materials and Methods: This study was conducted across three key regions—Marjan, Qomishlu, and Sangsefid—selected to represent a gradient of ecological conditions based on precipitation and temperature. Field sampling was carried out during the peak vegetation growth period (mid-May to late June). In each region, seven study sites were established. Within each site, three 30 m × 30 m plots were delineated, and four 2 m × 2 m quadrats were randomly placed inside each plot for detailed assessment. Vegetation cover percentage was estimated visually, and annual plant biomass was harvested, cut 1 cm above the soil surface, and weighed.

Future climate projections were obtained from the MRI-ESM2-0 model within the CMIP6 database, considering four Shared Socioeconomic Pathway scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) for the period 2021–2100. From an initial set of 19 bioclimatic variables, mean annual temperature (Bio1) and annual precipitation (Bio12) were selected for modeling after applying Variance Inflation Factor (VIF) analysis to mitigate multicollinearity. Four distinct modeling techniques were evaluated: Generalized Linear Model (GLM), Generalized Additive Model (GAM), Support Vector Machine (SVM), and Random Forest (RF). Model performance was quantified using the coefficient of determination (R^2) and the Root Mean Square Error (RMSE).

Results and Discussion: The Random Forest (RF) algorithm demonstrated superior performance in simulating vegetation parameters compared to other modeling approaches. Spatiotemporal analysis of vegetation dynamics across the three study regions revealed distinct responses to the projected climate scenarios over four future periods (2021–2040, 2041–2060, 2061–2080, 2081–2100).

Marjan Region (Resilient Profile): This region exhibited significant resilience and adaptive capacity. The current vegetation cover (36.18%) showed consistent increases under most scenarios, particularly under the high-emission SSP5-8.5 scenario in the 2081–2100 period, reaching 39.04%. This positive trend suggests the Marjan ecosystem currently operates below its temperature optimum, where moderate warming may enhance physiological processes and extend the growing season. The region likely benefits from "biodiversity insurance effects," where functional redundancy within species pools enables compensation and maintains ecosystem stability under climatic stress.

Sangsefid Region (Vulnerable Profile): Identified as the most vulnerable area despite having the highest initial

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vegetation cover (46.15%), this region experienced substantial declines across most scenarios. The most pronounced reduction occurred during the 2041–2060 period under SSP2-4.5, decreasing to 42.37%. This high sensitivity originates from a strong dependence on snowmelt-derived moisture, making it particularly susceptible to shifts in precipitation patterns and earlier spring melt. Vegetation loss initiates a destructive feedback loop: reduced cover diminishes soil organic matter and water retention capacity, which intensifies water stress and leads to further degradation—a manifestation of the "dryland amplification feedback" mechanism recognized by the IPCC.

Qomishlu Region (Dynamic/Adaptive Profile): This region displayed complex, non-linear dynamics with intermediate vulnerability. An initial stable cover (31.07%) gradually transitioned to moderate declines, particularly under high-emission scenarios in mid-century periods. However, it demonstrated notable ecological resilience, with partial recovery observed in the final period (reaching 31.29% under SSP5-8.5). This pattern illustrates the concept of "ecological memory" and potential adaptation, where natural selection may favor genotypes better suited to new conditions, leading to a gradual shift in community composition.

For resistant regions (e.g., Marjan), a conservative management strategy is recommended, focusing on continuous monitoring and preventing additional anthropogenic pressures, particularly overgrazing. Managers must avoid "ecological complacency"—a false sense of security derived from apparent short-term stability that could lead to the neglect of essential long-term adaptation investments.

For vulnerable regions (e.g., Sangsefid), active, interventionist management is urgently required. Strategies should prioritize climate-resilient restoration using drought-tolerant native species, implementation of runoff harvesting systems, and precise, controlled grazing regimes. The overarching goal should be "threshold-based management" to prevent the ecosystem from crossing irreversible tipping points.

For dynamic regions (e.g., Qomishlu), an adaptive and flexible management framework is essential. This approach necessitates developing early-warning systems to detect indicators of declining resilience and implementing preventive measures proactively, before critical thresholds are reached.

At a macro level, integrating these ecological forecasts into national and regional land-use planning is crucial. Aligning rangeland management strategies with international commitments, such as the UN Decade on Ecosystem Restoration and the Paris Agreement, can facilitate access to necessary financial mechanisms and technical resources for large-scale implementation.

General Conclusion: This research demonstrates that climate change will exert diverse and complex impacts on vegetation cover across dry and semi-arid rangelands. The findings confirm that ecosystem responses are not uniform but are instead mediated by site-specific ecological characteristics. The Marjan region exhibited patterns of ecological resistance, with positive adaptation and increased vegetation cover under future scenarios. In contrast, the Sangsefid region showed high vulnerability, marked by a gradual decline in cover. The Qomishlu region demonstrated ecological resilience through dynamic, non-linear behavior and partial recovery.

From a management perspective, the study underscores the critical need for region-specific, adaptive strategies. Conservative management is recommended for resistant areas, focused on monitoring and preventing additional stressors. For vulnerable areas, active and interventionist management is imperative to mitigate degradation and avoid tipping points. For dynamic areas, flexible and adaptive management is essential to navigate non-linear changes and support natural resilience processes.

Keywords: Climate change, Ecological modeling, Rangelands, SSP scenarios, Vegetation.