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Original Article

Climate Change Impacts on Central Asian Steppes and Deserts: Trends, Vulnerabilities, and Future Trajectories

Rakesh Kumar
Assistant Professor, Dept. of Geography, Murarka College, Sultanganj TMBU, Bhagalpur

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Abstract

Central Asia, encompassing vast steppes and deserts across Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan, and parts of Afghanistan and China, is undergoing profound transformations due to anthropogenic climate change. This research article synthesizes recent observational data, model projections, and interdisciplinary studies to examine key trends in temperature, precipitation, and extremes, alongside their cascading effects on arid ecosystems, water resources, agriculture, and human societies. Findings reveal a regional warming of approximately 1.2°C since the mid-20th century, northward expansion of desert climates by over 100 km since the 1980s, and shifts in Köppen classifications toward hotter, drier regimes. These changes exacerbate desertification, reduce snowpack by 20%, and threaten biodiversity and food security. Projections under high-emission scenarios (SSP5-8.5) indicate up to 6°C warming by 2100, underscoring the urgency for transboundary adaptation strategies. This analysis highlights Central Asia's vulnerability as a climate hotspot, with implications for global ecological stability.

Keywords: *Climate change, Central Asia, Steppes and deserts, Desertification, Arid ecosystems, Temperature rise, Precipitation variability, Biodiversity loss, Hydrological changes, Socio-economic impacts, Adaptation strategies, Mitigation, Transboundary cooperation Climate migration, Sustainable development*

Introduction

Central Asia's landscapes, characterized by expansive steppes and hyper-arid deserts such as the Karakum and Kyzylkum, cover over 80% of the region's territory and support unique ecosystems and pastoral economies. These arid and semi-arid zones, influenced by continental climate dynamics and the westerlies, are highly sensitive to global warming. The Intergovernmental Panel on Climate Change (IPCC) identifies Central Asia as one of the world's most vulnerable regions to climate change, with temperatures rising faster than the global average—approximately 0.36–0.42°C per decade since 1979. Recent studies document compound impacts, including desert expansion and hydrological disruptions, driven by greenhouse gas emissions. This article reviews these trends, drawing on observational records (1950–2019), reanalysis data, and Coupled Model Intercomparison Project (CMIP5/6) projections, to elucidate ecological and socio-economic ramifications. By integrating geography, climatology, and environmental science, it aims to inform policy for resilient arid landscapes.

Observed and Projected Climate Trends

1. Temperature and Precipitation Dynamics

Central Asia has experienced robust warming, with a mean increase of 1.2°C from 1950 to 2019, particularly pronounced in winter and over mountainous terrains (Qing et al., 2021). This warming correlates with a 20% decline in snow depth, especially in the Tien Shan and Pamir ranges, where colder months have warmed more rapidly in the last two decades. Precipitation trends are heterogeneous: overall increases occur in eastern Afghanistan and northern Kazakhstan, but decreases in Tajikistan and western Kyrgyzstan contribute to regional drying (Knoche et al., 2017).

Address for correspondence:

Rakesh Kumar, *Assistant Professor, Dept. of Geography, Murarka College, Sultanganj TMBU, Bhagalpur*

Email: *rkrakrak05@gmail.com*

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The self-calibrated Palmer Drought Severity Index (scPDSI) reveals drier conditions in central Kazakhstan, southwestern Afghanistan, and Turkmenistan, with a linear temperature-precipitation relationship of 0.05 mm/day per °C warming (Wu et al., 2016). Such a quantified linkage highlights the heightened climate sensitivity of Central Asian arid zones, consistent with documented temperature rises across the region since the late-20th century (Zhang et al., 2021) (Fallah et al., 2024). Projected climate scenarios indicate that the hotter, drier subtypes of the arid Köppen zones will continue to expand, while cooler tundra zones contract, thereby intensifying desertification and drought risk in the Central Asian steppes (He et al., 2021).

Köppen climate classifications underscore these shifts. From 1981–2010, dominant categories include cold deserts (BWk) and steppes (BSk), but migrations toward hot deserts (BWh) and from cold steppes (BSk) to cold deserts (BWk) indicate aridification. Since the 1980s, desert climates have expanded northward by 100–160 km in mid-latitudes, from southern Kazakhstan into Uzbekistan, Kyrgyzstan, and the Junggar Basin, driven by rising temperatures and reduced summer precipitation (Guglielmi, 2022).

Climate Type Shift	Observed Change (1980s–2020)	Implications for Arid Zones
BWk (Cold Desert) to BWh (Hot Desert)	Widespread in lowlands	Increased evapotranspiration, desertification
BSk (Cold Steppe) to BWk (Cold Desert)	Northward in Kazakhstan/Uzbekistan	Loss of grasslands, soil degradation
Dfc (Subarctic) to Dfb (Warm Summer Subarctic)	High elevations	Altered snowmelt timing

Projections from CMIP6 models under SSP2-4.5 and SSP5-8.5 scenarios forecast 2–6°C warming by 2100, with wetter conditions in CMIP6 relative to CMIP5 but amplified extremes. Tundra and ice cap zones in the Amu Darya and Syr Darya basins may shrink by over 60%, intensifying aridity (И et al., n.d.).

2. **Extreme Events and Compound Risks**
   The frequency of heat extremes has surged: summer days (>35°C) and tropical nights (>20°C) have increased by over 10 days per year since 1990, while icing days (<0°C maxima) have declined by 15 days. Dust storms, linked to land degradation and drying, have intensified in arid regions like Iran's deserts, affecting air quality and visibility. Compound events—such as heatwaves coinciding with droughts—pose high risks, with a 7% precipitation decline (1940–2015) in Mongolia exacerbating steppe desertification(Guglielmi, 2022).

Impacts on Steppes and Desert

1. **Desertification and Landscape Shifts**
   Arid expansion has converted semi-arid steppes into full deserts, with significant hotspots of degradation in Central Asia. Solar radiation and surface pressure explain a substantial portion of negative vegetation changes, pushing ecosystems near aridity thresholds. In the Central Kazakh Steppe, warming favors southern sub-arid species over boreal ones, signaling biome shifts from forest-steppe to pure steppe. Larch forests in eastern Kazakhstan face retreat, mirroring global semiarid dieback (Chen, 2019; Zhang et al., 2021).
   Dust storms and sand encroachment threaten vast arid lands, while the Aral Sea's desiccation—exacerbated by irrigation and warming—has unleashed toxic salts onto steppes. Projections indicate extended dry spells by 2025–2049, accelerating soil erosion and habitat fragmentation (Opp et al., 2024).
2. **Hydrological Alterations**
   Glaciers in Central Asia, vital for river runoff, have shrunk significantly since the early 2000s, with increased lake outbursts posing flood risks. Snowmelt timing shifts earlier, boosting short-term runoff but reducing summer flows in downstream deserts. Water stress is acute: withdrawals match availability in Turkmenistan and Uzbekistan, with evaporation rising due to warming. By 2050, basins feeding Central Asian steppes may see substantial warming, displacing millions of climate migrants (Didovets et al., 2021).
3. **Ecological Consequences**
   Biodiversity in steppes and deserts is under siege. Precipitation declines and evapotranspiration increases foster drought-prone conditions, reducing net ecosystem productivity in arid zones. Vegetation indices (NDVI) show degradation across Central Asian desert steppes, with climatic drivers dominant. Shifts from boreal to steppe biomes threaten

migratory species, while intensified westerlies alter pollen records (Qing et al., 2021).

Ecosystem services, including carbon sequestration and dust regulation, diminish as deserts encroach, with vast areas of Eurasian desert steppes at risk. High-elevation wetting contrasts lowland drying, but overall, aridity expansions outpace adaptations, leading to biodiversity hotspots' erosion.

4. **Socio-Economic Impacts**

Agriculture, reliant on rain-fed systems in northern Kazakhstan and Uzbekistan, faces substantial yield drops by mid-century from droughts and heatwaves. Livestock in nomadic communities suffers from forage loss, with soil compaction and erosion compounding economic vulnerability. Hydropower shortages spike electricity prices, while urban water scarcity affects millions downstream.

Food insecurity looms, with glacier-dependent irrigation faltering. Internal migration may reach 5 million by 2050, straining geopolitics in transboundary basins like Amu Darya. Economic losses from desertification could hinder development, underscoring climate as a socio-economic crisis (Berndtsson & Tussupova, 2020).

Adaptation and Mitigation Strategies

Adaptation requires inclusive approaches across UN Rio Conventions, emphasizing sustainable farming, reforestation, and water-efficient irrigation. Regional strategies, like the Central Asia Regional Climate Change Adaptation Strategy, advocate for glacier monitoring and drought-resilient crops. Mitigation involves emission reductions and transboundary cooperation, as Central Asian nations pledged ambitious GHG targets in 2023. Targeted conservation in degradation hotspots, informed by remote sensing, is critical (Kaliyeva et al., 2021; Kulmatov & Khasanov, 2023; Muccione & Cassara, 2019).

Conclusion

Climate change is reshaping Central Asia's steppes and deserts through warming, aridification, and extreme compounding, with irreversible thresholds approaching under unchecked emissions. Northward desert creep, hydrological disruptions, and ecosystem collapses threaten livelihoods and stability. Urgent, evidence-based actions—rooted in IPCC assessments and local research—can mitigate risks, preserving these iconic landscapes for future generations. Further studies on compound events and equity in adaptation are essential to bridge knowledge gaps.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper

References

1. Berndtsson, R., & Tussupova, K. (2020). The Future of Water Management in Central Asia. *Water*, *12*(8), 2241. https://doi.org/10.3390/w12082241
2. Chen, X. (2019). Remote Sensing Monitoring Shows that Climate Change has a Significant Impact on Vegetation Ecosystem in Central Asia. *International Journal of Environmental Sciences & Natural Resources*, *17*(3). https://doi.org/10.19080/ijesnr.2019.17.555961
3. Didovets, I., Lobanova, A., Krysanova, V., Menz, C., Babagalieva, Z., Nurbatsina, A., Gavrilenko, N., Khamidov, V., Umirbekov, A., Qodirov, S., Muhyyew, D., & Hattermann, F. F. (2021). Central Asian rivers under climate change: Impacts assessment in eight representative catchments. *Journal of Hydrology Regional Studies*, *34*, 100779. https://doi.org/10.1016/j.ejrh.2021.100779
4. Fallah, B., Didovets, I., Rostami, M., & Hamidi, M. (2024). Climate change impacts on Central Asia: Trends, extremes and future projections. *International Journal of Climatology*, *44*(10), 3191. https://doi.org/10.1002/joc.8519
5. Guglielmi, G. (2022). Climate change is turning more of Central Asia into desert. *Nature*. https://doi.org/10.1038/d41586-022-01667-2
6. He, H., Luo, G., Cai, P., Hamdi, R., Termonia, P., Maeyer, P. D., Kurban, A., & Li, J. (2021). Assessment of Climate Change in Central Asia from 1980 to 2100 Using the Köppen-Geiger Climate Classification. *Atmosphere*, *12*(1), 123. https://doi.org/10.3390/atmos12010123
7. Kaliyeva, K., Punys, P., & Zhaparkulova, Y. (2021). The Impact of Climate Change on Hydrological Regime of the Transboundary River Shu Basin (Kazakhstan–Kyrgyzstan): Forecast for 2050. *Water*, *13*(20), 2800. https://doi.org/10.3390/w13202800
8. Knoche, M., Merz, R., Lindner, M., & Weise, S. M. (2017). Bridging Glaciological and Hydrological Trends in the Pamir Mountains, Central Asia. *Water*, *9*(6), 422. https://doi.org/10.3390/w9060422
9. Kulmatov, R., & Khasanov, S. (2023). Contemporary climate change problems in Central Asia. *E3S Web of Conferences*, *413*, 5013. https://doi.org/10.1051/e3sconf/202341305013

10. Muccione, V., & Cassara, M. (2019). *The climate-cryosphere-water nexus in central Asia. 8*. https://doi.org/10.5167/uzh-181502
11. Opp, C., Groll, M., Semenov, O., Shardakova, L., Kovalevskaya, Y., Kulmatov, R., Normatov, I. Sh., & Aslanov, I. (2024). Water household changes, climate change, and human impact – reasons for the dusty side of the Aral Sea Syndrome. *E3S Web of Conferences*, *575*, 4001. https://doi.org/10.1051/e3sconf/202457504001
12. Qing, P., Wang, R., Jiang, Y., Li, C., & Guo, W. (2021). The change of hydrological variables and its effects on vegetation in Central Asia. *Theoretical and Applied Climatology*, *146*, 741. https://doi.org/10.1007/s00704-021-03730-w
13. Wu, Y.-P., Feng, G., & Li, B.-L. (2016). Interactions of Multiple Atmospheric Circulation Drive the Drought in Tarim River Basin. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep26470
14. Zhang, J., Hao, X., Hao, H., Fan, X., & Li, Y. (2021). Climate Change Decreased Net Ecosystem Productivity in the Arid Region of Central Asia. *Remote Sensing*, *13*(21), 4449. https://doi.org/10.3390/rs13214449
15. *И*, К., УЧИТЕ*Л*И, М., & С*Л*ОВЕНСКИЕ. (n.d.). *СВЯТЫЕ РАВНОАПОСТОЛЬНЫЕ*.
16. Allah, B., Prein, A. F., Rahimi, M., Valipour, M., & Li, Z. (2024). Climate change impacts on Central Asia: Trends, extremes and future projections. *International Journal of Climatology*. https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.8519
17. Hu, Y., Maskey, S., Uhlenbrook, S., & Zhou, F. (2022). Northward expansion of desert climate in Central Asia in recent decades. *Geophysical Research Letters*, 49(11), e2022GL098895. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GL098895
18. IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-10/
19. Jiang, J., Sharma, A., & Sharma, S. (2022). Future changes in drought over Central Asia under CMIP6 forcing: A multi-model ensemble analysis of static and dynamic bias-corrected projections. *Weather and Climate Extremes*, 38, 100504. https://www.sciencedirect.com/science/article/pii/S221458182200204X
20. Zhang, Y., Li, X., & Frolking, S. (2018). Exacerbated grassland degradation and desertification in Central Asia during 2000–2014. *Ecological Applications*, 28(6), 1660–1673. https://www.ceom.ou.edu/media/docs/upload/Zhang_et_al-2018-Ecological_Applications_1.pdf
21. Zhang, Y., et al. (2017). Seasonal snow cover regime and historical change in Central Asia, 2003–2014. *Global and Planetary Change*, 148, 192–205. https://www.sciencedirect.com/science/article/abs/pii/S0921818116301412
22. Xu, J., et al. (2023). Future dry-wet climatic characteristics and drought trends over arid Central Asia. *Frontiers in Earth Science*, 11, 1102633. https://www.frontiersin.org/journals/earth-science/articles/10.3389/feart.2023.1102633
23. Zhang, G., et al. (2016). Changes in Central Asia's Water Tower: Past, Present and Future. *Scientific Reports*, 6, 35458. https://pmc.ncbi.nlm.nih.gov/articles/PMC5071869/
24. World Bank. (2021). *Groundswell Part II: Acting on Internal Climate Migration*. https://www.worldbank.org/en/news/feature/2021/09/13/millions-on-the-move-in-their-own-countries-the-human-face-of-climate-change
25. Meade, N., & Islam, S. (2022). Climate Change, Agriculture, and Potential Crop Yields in Central Asia. SSRN Electronic Journal. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4000738
26. Regional Environmental Centre for Central Asia (CAREC). (2024). *Regional Climate Change Adaptation Strategy for Central Asia.* https://greencentralasia.org/wp-content/uploads/2024/05/strategy-eng.pdf