Constructing semi-arid ecological barriers to prevent desertification

Xiaodan Guan[1] **and Jianping Huang**[1,*]

[1]Collaborative Innovation Center for Western Ecological Safety (CIWES), College of Atmospheric Sciences, Lanzhou University, Lanzhou 730000, China

*Correspondence: hjp@lzu.edu.cn

Received: November 13, 2023; Accepted: April 12, 2024; Published Online: April 17, 2024; https://doi.org/10.59717/j.xinn-geo.2024.100067

Citation: Guan X. and Huang J. (2024). Constructing semi-arid ecological barriers to prevent desertification. The Innovation Geoscience 2(2): 100067.

Semi-arid regions worldwide face escalating challenges, including water resource shortages, ecological fragility, and relentless expansion of desertification. Here, we propose the establishment of a worldwide Semi-arid Ecological Barrier (SAEB) as a proactive measure in response to these challenges to curtail desertification and alleviate extreme events. Beyond its immediate benefits, the SAEB holds significant promise for future global carbon control efforts. This perspective offers a case study exemplifying the principles of ecological civilization, focusing on preventing desertification in the Yellow River Basin. Policy of ecological recover, such as the "Grain for Green" project in China, has shown to be effective in strengthening the SAEB. It contributes valuable insights into innovative strategies for addressing water scarcity, ecological fragility, and desertification expansion.

IMPORTANCE AND FRAGILITY OF SEMI-ARID REGIONS

Drylands are home to more than 38% of the global population, with 90% of these inhabitants residing in developing nations. These regions encompass around 20.3% of the Earth's terrestrial land surfaces. Semi-arid regions are typically characterized by annual precipitation ranging from 200 to 600 mm, primarily found in western North America, Central and East Asia, Australia, western South America, and North Africa. In recent decades, there has been a notable expansion of drylands, with over 50% of this expansion occurring in semi-arid regions. The extent of semi-arid regions in the most recent 15-year period (1990–2004) is 7% larger than that observed during the initial 15 years (1948–1962).[1] This expansion amounts to 0.4×10^6 km^2 and 1.2×10^6 km^2 within the American continents and Eastern Hemisphere, respectively. The inherently low fertility of semi-arid soils makes these regions highly susceptible to degradation induced by both climate warming and human activities.[2] Climate change in semi-arid regions has profound impacts on economies and societies, manifesting in various ways such as water scarcity, desertification, ecosystem changes, agricultural challenges, frequent extreme weather events, consequent migration and conflict, along with formidable adaptation challenges. These climate effects permeate multiple processes in the Atmosphere, Hydrosphere, Biosphere, Lithosphere, and Anthroposphere. Consequently, enhancing our understanding and predictive capabilities on climate change in semi-arid regions is of paramount importance.[3]

MULTIFACTOR DRIVERS OF ECOLOGICAL SYSTEM IN SEMI-ARID REGIONS

Semi-arid regions experienced notable warming and pronounced climate change over the past century, which was influenced by a combination of regional and global physical processes. These processes entail interactions between the atmosphere and land, between the atmosphere and ocean, and with the Tibetan Plateau. Collectively, these factors induce temporal and spatial changes in the climate of arid and semi-arid areas, reshaping the ecological systems in arid and semi-arid regions through modifications in energy, water, carbon, nitrogen, and oxygen cycles.[4]

In the process of energy cycle and water cycle, the carbon, nitrogen, and oxygen cycles take obvious changings through matter transport. They perform low primary productivity and high decomposition influence the carbon cycle, affecting the nitrogen and oxygen cycles. Low fixation, high loss, and variable inputs result in limited availability on the nitrogen cycle, heightened leaching, increased pollution. Low photosynthesis, high respiration, and consumption in oxygen cycle will lead to reduced production, increased depletion, and altered distribution of vegetation, and further affect the carbon and nitrogen cycles through oxidation and reduction processes.[5]

Alterations in one cycle of a particular variable can have cascading effects on the other variables. For instance, changes in vegetation driven by shifts in water availability can impact the water, carbon, and nitrogen cycles. Human activities, and climate variability further complicate these intricate interactions. Comprehension of these cycles in semi-arid regions is imperative for sustainable land and water management, given the susceptibility of these areas to both climate change and anthropogenic influences. In semi-arid regions, factors such as low rainfall, high evaporation, sparse vegetation, and soil erosion influence the interconnected energy, water, carbon, nitrogen, and oxygen cycles. However, a lack of adequate understanding and effective management of these cycles, which is detrimental for addressing environmental challenges in semi-arid regions.[6,7]

THE NECESSITY OF CONSTRUCTING AN ECOLOGICAL SAFETY WALL

In the mid-to-high latitudes of the Northern Hemisphere (23.5–66.5°N), where about 40% of global terrestrial carbon is stored, play a crucial role in mitigating climate change by absorbing atmospheric carbon dioxide.[8] The fragile ecosystem of semi-arid regions plays a pivotal role in global carbon storage as the largest terrestrial biome on Earth, spanning all continents and showcasing immense diversity in soil-forming factors. Variations in parent material of soil, topography, soil age, climate, and organisms contribute to fundamental distinctions in carbon, nutrient and oxygen cycling dynamics from local to continental scales. Local biogeochemical cycling within arid and semi-arid regions is particularly responsive to fluctuations in precipitation and temperature, both inter- and intra-annually, often resulting in biogeochemical cycling and temporal patterns in ecosystem. Gaining a comprehensive understanding of biogeochemical dynamics across spatial dimensions and over time in semi-arid is of paramount importance for enhancing our ability to predict the impacts of climate change on ecosystem structures and functions.

The evolution of the current ecological system can be categorized in terms of directions: "greening" and its counterpart of "yellowing." Greening entails the enhancement of ecological conditions and positive carbon storage within ecological systems, with changes and patterns quantifiable using the global desertification vulnerability index (GDVI).[9] In the typical semi-arid regions of the globe, exemplified by the Yellow River Basin and western United States (including the Great Salt Lake Basin and Colorado River Basin), exhibit distinct GDVI characteristics. Spatially, the GDVI demonstrates an increasing trend over the western United States (Figure 1A). Conversely, the GDVI in the Yellow River Basin shows a significant decline in the upper and middle reaches (Figure 1B). Analyzing GDVI time series over these two semi-arid basins reveals that the GDVI of the Yellow River Basin (depicted by the green line) began decreasing around 1999 and has since maintained a stable declining trend (Figure 1C), which suggests a reduction in desertification risk.

FUTURE PERSPECTIVES

Except for the Yellow River Basin and Colorado River Basin, a considerable portion of the global semi-arid regions has undergone desertification. For instance, in Mexico, more than 71.9% of the land was categorized as degraded in 2019, surpassing the 56.7% recorded in 2015. Over the same period, the proportion of degraded land in India was more than doubled, reaching 9.5%. Meanwhile, notable improvements appeared in Africa, Latin America, and the Caribbean region, which were primarily realized through the restoration of vegetation. This was evidenced by a decrease in the area of degraded land from 21.9% in 2015 to 12.8% in 2019 in Ecuador, and a reduction in degraded land from 36.3% to 17.1% from 2015-2019 in Botswana, while Burkina Faso witnessed a decrease from 34.6% to 8.2% during the same period.[10] These areas changing of degraded land in different countries imply the restoration of vegetation is effective in preventing desertification.

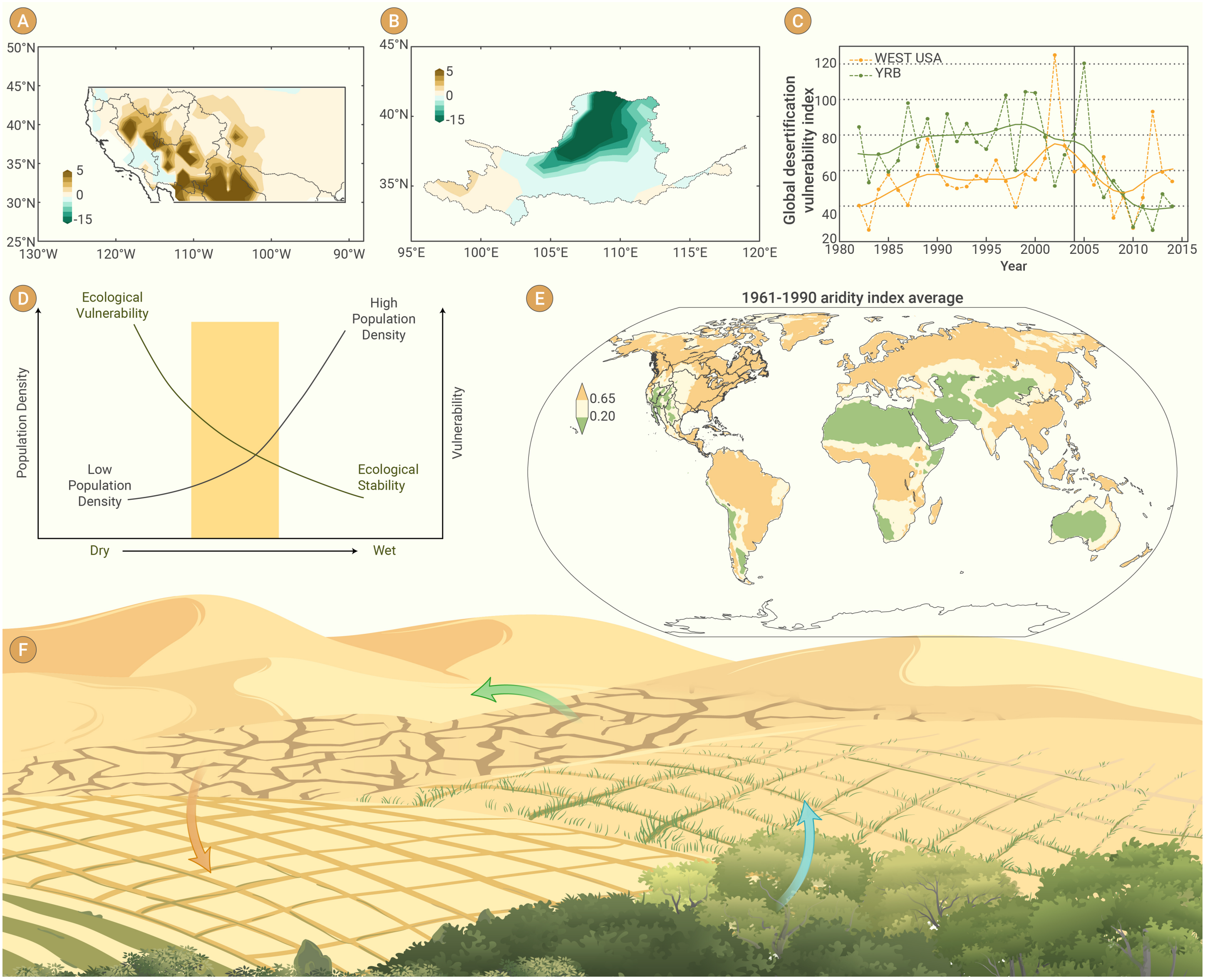

Figure 1. Desertification expansion and shrinkage after policy intervention.

The "Grain for Green" program in China, acknowledged as the world's largest ecological restoration initiative, has played a pivotal role in addressing global climate change and ecological challenges. This program has positively impacted the regional water cycle and ecological environment, resulting in a marked enhancement of ecological conditions. Notably, there has been a substantial 4% increase in vegetation cover, contributing to an annual total economic income from ecological benefits amounting to 1.42 trillion yuan. (http://paper.people.com.cn/rmrbhwb/html/2023-02/04/content_25963032.htm)

Furthermore, the project has led to significant improvements in soil erosion, particularly in the areas surrounding crucial lakes and reservoirs in the upper and middle reaches of the Yellow River Basin. It has effectively managed land desertification in the northern regions and rocky desertification in the southwestern regions. These achievements underscore the program's success in mitigating ecological challenges and contributing to sustainable environmental practices.

The establishment of artificial afforestation stands out as a key approach for creating future land-based carbon sinks through human activities. It is imperative to evaluate the soil carbon sink capacity of different typical desert soil types, including sandy deserts, rocky deserts, and saline-alkali lands, while calculating the contribution of inorganic carbon sink in dryland soils. Besides, assessing the carbon sequestration capacity of typical sand-fixing tree species in semi-arid regions and elucidating the evolving patterns and key driving mechanisms of artificial sand-fixing and carbon sequestration functions will contribute to enhancing inorganic carbon sequestration capacity and the overall carbon sink of ecosystems. Therefore, comprehending the interaction between plant carbon and soil carbon and its impact on the carbon sequestration capacity of ecosystems in semi-arid areas is crucial for climate change and anthropogenic desertification control efforts.

Furthermore, it is crucial to acknowledge that portraying ecological restoration as an unequivocal benefit may not accuracy, as it holds the potential for adverse impacts on water availability and food security. This includes areas such as water-use competition, altered hydrological patterns, land-use changes, trade-offs in ecosystem services, and social and economic impacts. It is imperative to undertake comprehensive assessments and carefully evaluate potential consequences before presenting ecological restoration as a universally positive endeavor. Sustainable and well-planned restoration initiatives should consider the intricate interactions between ecosystems, water availability, and food security (Figure 1D).

CONCLUDING REMARKS

This perspective proposes a promising avenue for research, marking a significant step towards advancing our understanding of processes and sustainability within semi-arid regions. Moreover, the influence of policies on the delicate ecological development within the Yellow River Basin has been expounded upon from this viewpoint, unveiling a more pronounced ecological recovery in typical semi-arid regions. This underscores that land-focused policies hold the potential to alleviate the impacts of climate change (Figure 1F).

REFERENCES

1. Huang, J.P., Ji, M.X., Xie, Y.K., et al. (2016). Global semi-arid climate change over last 60 years. Clim Dyn 46(3-4): 1131–1150. DOI: 10.1007/s00382-015-2636-8.
2. Zhou, L.M., Chen, H.S., Hua, W.J., et al. (2016). Mechanisms for stronger warming over drier ecoregions observed since 1979. Clim Dyn 47(9-10): 2955–2974. DOI: 10.1007/s00382-016-3007-9.
3. Qi, J.G., Chen, J.Q., Wan, S.Q., et al. (2012). Understanding the coupled natural and human systems in Dryland East Asia. Environ Res Lett 7(1): 015202. DOI: 10.1088/1748-9326/7/1/015202.
4. Huang, J., Li, Y., Fu, C., et al. (2017). Dryland climate change: Recent progress and challenges. Rev Geophys 55(3): 719–778. DOI: 10.1002/2016rg000550.
5. Lian, X., Piao, S.L., Chen, A.P., et al. (2021). Multifaceted characteristics of dryland aridity changes in a warming world. Nat Rev Earth Environ 2(4): 232–250. DOI: 10.1038/s43017-021-001440.
6. Zhou, T.J. (2021). New physical science behind climate change: What does IPCC AR6 tell us. The Innovation 2(4): 100173. DOI: 10.1016/j.xinn.2021.100173.
7. Sun, J., Wang, Y., Piao, S.L., et al. (2022). Toward a sustainable grassland ecosystem worldwide Comment. The Innovation 3(4): 100265. DOI: 10.1016/j.xinn.2022.100265.
8. Friedlingstein, P., O'Sullivan, M., Jones, M.W., et al. (2020). Global Carbon Budget 2020. Earth Syst Sci Data 12(4): 3269–3340. DOI: 10.5194/essd-12-3269-2020.
9. Huang, J.P., Zhang, G.L., Zhang, Y.T., et al. (2020). Global desertification vulnerability to climate change and human activities. Land Degrad Dev 31(11): 1380–1391. DOI: 10.1002/ldr.3556.
10. Editorial. (2023). Swathes of Earth are turning into desert - but the degradation can be stopped. Nature 623(7988):666. DOI: 10.1038/d41586-023-03621-2.

FUNDING AND ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (42041004).

DECLARATION OF INTERESTS

The authors declare no competing interests.