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Sustainable Grassland Agro-ecosystems Management in a Changing Climate: A Comparative Study of China and Pakistan

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ABSTRACT

The importance of grasslands lies in their ability to store carbon in the soil, nourish livestock, and provide a livelihood to millions of rural families. However, the drought, increasing temperatures, population increase, and overgrazing of these lands are pressing in both nations. The largest initiatives in China, including grazing prohibitions and subsidies in Inner Mongolia and the Qinghai-Xizang Plateau, have aided in the recovery of grasses as well as diminished soil erosion. The situation in Pakistan is a different combination; pastures are severely affected by drought and poor land tenure, but local people survive through rotational grazing and traditional knowledge. This is a comparative study between the two methods that is informed by policy reviews and evidence in the field. It demonstrates that ecological benefits increase with time when they also defend incomes, such as by decreasing herd sizes but enhancing the quality of fodder, or by planting trees with grass to reclaim soil. The main idea is straightforward: grasslands are best revived in circumstances where policies do not disregard local realities in favor of climate science.

Introduction

Grasslands are important agricultural ecosystems that contribute to maintaining global biodiversity, regulating water cycles, and storing large amounts of carbon (Ghosh & Mahanta, 2014; Mei et al., 2025). They form the basis of the livelihoods of millions of people, especially herders and farmers. Unfortunately, these ecosystems are facing severe threats from climate change, land use transformation, and unsustainable management practices, which have led to degradation, desertification, and reduced productivity in many areas (Liu et al., 2025; Shokri et al., 2025).

The relationship between China and Pakistan is a very interesting case for comparative study. The two states share a common substrate of agricultural economy and environmental security, both having large grassland ecosystems. On the Qinghai-Xizang Plateau, a key element in the world's ecological stability, the most extensive grasslands are located in China. On the other hand, the Pakistani pastures are situated in the Hindu Kush-Himalaya region and arid zones, hence the foundation of the livestock industry.

Both countries face similar issues, such as climate-related weaknesses, population stressors, and the challenge of promoting socio-economic growth and maintaining natural environments. However, the different forms of governance are very incongruent. China has also launched massive, state-directed ecological rehabilitation projects, as seen in the reversion of agricultural lands to forest and grasslands and the introduction of incentive-based, compensation ecological protection systems. (Liu et al., 2024; Uchida et al., 2005). In contrast, Pakistan's management is

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a mixture of different fragments, relying more on traditional community management systems, and has received varying degrees of support from the state through projects such as grassland and livestock management (Mansoor et al., 2018).

Problem Statement

Grassland degradation is a significant borderless environmental challenge that has an impact on food security, rural poverty, and regional stability. Despite the mountains of research funding, the Chinese state of affairs continues to worsen due to complex social-ecological feedback mechanisms. Lack of land ownership policies and lack of coordination in policies in Pakistan have led to overgrazing and unchecked conflicts. The largest missing link of information is how governance structures, economic drivers, and local ecological knowledge interact in order to better manage these ecosystems. This study aims to fill this gap through the implementation of in-depth comparative analysis, thereby providing policy-oriented recommendations for both countries and the rest of the region.

Research Objectives

Comparatively analyze the effectiveness of grassland management paradigms in China and Pakistan and draw up a coordinated framework to facilitate environmental and socio-economic resilience. This study aims to map and compare the climatic, socio-economic, and policy-driven factors contributing to grassland degradation in China and Pakistan, and to assess the ecological conditions measured by biomass, soil health, and biodiversity under national management, community management, and open access systems. At the same time, the study evaluates the impact of current management policies on the livelihoods, well-being, and adaptive capacity of pastoralists, and identifies successful and innovative practices, technologies, and institutional arrangements for sustainable management. Finally, the study integrates these findings into a conceptual policy framework to facilitate the integration and cross-disciplinary learning of replicable and contextually appropriate grassland management strategies.

Research Methodology

This study employs a robust mixed-method approach to facilitate a comprehensive comparison between China and Pakistan. It incorporates qualitative insights into local knowledge and adaptive practices, while also basing its analysis on systematic policy and document reviews, to map and compare the governance frameworks of the two countries. This method aims to achieve social-ecological analysis through triangulating the data from literature research, evaluating the biological-physical outcomes of management and their impact on community resilience, thereby fulfilling the core comparative goals of the study.

Literature Review

This literature review compiles the existing research on the management of sustainable grassland agricultural ecosystems under climate change: a comparison between China and Pakistan. Both countries have extensive pastures and are severely affected by climate change and human activities. The study adopts a comparative framework to explore the interactions among national policies, grassroots practices, and the resilience of pastoral livelihoods. The study finds that both countries recognize the ecological and economic value of grasslands; however, there are significant differences in their policy

attitudes and the difficulties they face during implementation.

This study reveals the differences in policy decision-making and implementation between the two countries, despite both recognizing the ecological and economic value of grasslands. The study points out a significant gap in the comprehensive strategy of coordinating ecological restoration, climate adaptation, and livelihood security, and accordingly sets out the core issues for subsequent research and bilateral learning.

The grassland-agriculture ecosystem plays a crucial role in global biodiversity, carbon sink function, and the livelihoods of millions of nomadic people (Martins et al., 2024). These ecosystems are, however, in effect, grappling with climate change and unsustainable land use, and they are hyper-vulnerable. The extreme weather, which includes rising temperatures and changes in rainfall, among others, is accelerating land degradation. It translates to increased desertification, reduced productivity, and communities whose livelihoods are reliant on such lands are more vulnerable.

The Pamir Plateau, which is situated between China and Pakistan, is where some of the largest and most significant grassland ecosystems on the planet are located. China has the greatest grasslands, consisting of Inner Mongolia and the Qinghai Xizang Plateau, whilst the pastures of Pakistan are located in Balochistan, Khyber Pakhtunkhwa, and Gilgit-Baltistan, which are important in its agriculture and pastoral economy. The two countries should address issues related to climate, population increase, overgrazing, and competition for land use. The thing is that their political systems, policy frameworks, and structures of governance are different.

The government is the key driver in the way China defends its expansive grasslands. The shift started in the late 1990s when the large-scale sandstorms caused a radical change in the way people thought (Yanli Lyu et al., 2016). Individuals began to consider such regions not only as pastures but also as delicate environments that require protection. In this regard, authorities introduced some significant programs. The biggest is the Return Grassland/Pasture program, which was initiated in the year 2003 (Wu et al., 2014). This program aids herders to decrease the number of their livestock by giving them money, aiding them to move to new regions, and creating large no-grazing zones or planned grazing. The ecological conservation red line policy supports the program and provides strict rules on development and human activities in ecologically important regions, including grassland regions. A subsidy system gives herders some money in case they follow the new rules and maintain the number of their livestock.

Research shows that this strategy is indeed effective for the environment, with measurable improvements in plant growth and reductions in soil erosion in places like Inner Mongolia. However, its cost to humans has drawn widespread criticism from scholars (Ayumi, 2013; Zhizhong & Wen, 2012). They claim that the imposition of these rules in a top-down manner erodes the centuries-old nomadic culture, ignores local knowledge, and could put families into a cycle of dependence on government subsidies instead of encouraging more sustainable development of pastoral activities. Strict, blanket prohibitions on grazing are also generally decried because of their inability to enforce them effectively and failure to consider the complexity of the

flexible, mobile pastoral activities that have been historically practiced in these areas.

Climate vulnerability and rural livelihood security are the two issues that intersect at a critical point in sustainable grassland management in Pakistan. As indicated, such ecosystems form the basis of the livestock and agricultural economy of the country, yet they are facing extreme stress at the moment. Climate change is not a far-off menace anymore; it is a reality that can be observed by the alteration of the precipitation pattern and an increase in the incidence and severity of droughts, which have a direct impact on the yield and quality of the forage (Lal, 2011). This environmental pressure is also exacerbated by human factors such as overgrazing and land conversion, forming a vicious cycle of degradation, which weakens the land's ability to support livestock and biodiversity (Ekka et al., 2023).

In response, contemporary research advocates a shift from purely extractive approaches to adaptive, knowledge-based management models. Evidence shows that combining local grass species with community-based rotational grazing plans can significantly improve soil health and enhance carbon storage capacity (Sanderman et al., 2015). The technological intervention's success is directly associated with the socio-economic empowerment of the local herders, which is achieved through the creation of policies aimed at facilitating the fair distribution of resources and alternative sources of income. Finally, a comprehensive approach of ecological restoration, adaptation to the climate, and community control is needed to make sure that the Pakistani grasslands can be sustained long enough to become permanent.

The paper made comparisons and contrasts of the policies, management practices, and how the two countries in the grassland agricultural region of China and Pakistan are influenced by how people cope with challenges around them. The purpose of this methodology was to establish the lessons that can be applied and define the spheres where more research and policy work should be done.

Comparative Analysis

It has shown the extreme vulnerability of the South Asian region, especially in Pakistan. Nevertheless, the country has a relatively small contribution to the total greenhouse gas emissions around the globe: it was ranked 12th in 2012, 8th in 2015, and 7th in the overall performance in the climate risk analysis over the long term. In the meantime, its greenhouse gas emissions per capita had been ranked 135th. (Iqbal et al., 2025). This vulnerability poses a significant threat to sustainable development, affecting areas such as food, water resources, energy, forests, and biodiversity.

Climate change in Pakistan is very harmful to the agricultural sector, especially the rain-fed farming system. The farmers in Pakistan are primarily affected by both the natural and policy risks, which affect the productivity of farms. It is unlike in China, where the risk factors are largely technological and information-related (Shah et al., 2026). The adaptive responses of the farmers to climate change depend on their attitudes towards risks and the strategic distribution of their livelihood resources. As an example, the fatalistic attitude of the farmers can be a barrier to implementing the climate change adaptation strategy, which underlines the significance of climate

resilience education and agricultural extension services.

Pakistan is also experiencing a lot of ecological challenges, where the forest ecosystem is shrinking and being affected. The increased population of more than 208 million has further strained the food production systems and the forest resources. To curb this, agro-forestry has been identified as a viable approach that can boost agricultural output, better economic performance, ecological advantages, and keep social approval. Agroforestry functions by pairing trees and bushes with crops or animals to enhance soil well-being, safeguard biodiversity, and give mitigation/adaptation advantages to climate change.

In Pakistan, the policy responses are largely based on climate change adaptation. Nonetheless, there is an imminent need to integrate the national invasive species management plans, national climate adaptation plans (NAPs), and national biodiversity management plans (NBSAPs) (Shimwela & Katera, 2025). Such policy consistency is crucial for optimizing resource allocation and improving expenditure efficiency. Studies comparing the policy consistency of countries such as Pakistan, China, Zambia, Kenya, and Ghana have shown that there are many opportunities to interrelate these different planning processes.

The key to a successful response to climate change is economic resilience. Despite the fact that resilience is traditionally discussed in the ecological context, it needs to be applied to social systems, in particular, to climate change, considering human livelihoods more thoroughly (Baloch et al., 2025, pp. 8–4). This entails the normative, political, and social aspects of the process of adaptation. In the case of farmers in Pakistan, awareness of the effects of climate change, availability of knowledge and skills, and access to financial resources are the most important determinants of their adaptation behaviors and resilience of their livelihoods. Climate-specific extension services and training may greatly increase the capacity of farmers to deal with the changing climatic conditions (Khan et al., 2024).

The ability of farmers to implement climate change adaptation and mitigation strategies is also influenced by various factors and practices related to climate-smart agriculture and other sustainable agricultural methods. In both developed and developing countries, the foundation for effective adaptation lies in awareness, knowledge, and skills. New market opportunities and strong legislative support are crucial for expanding these efforts, while in developing countries such as Pakistan, access to funds and training services is particularly critical (Rashid et al., 2025, pp. 2–6).

With respect to climate change, the sustainable management of grassland agricultural ecosystems in Pakistan needs a multi-faceted approach to achieve this. This involves improving the resilience of farmers by creating awareness, skills, increasing access to finances, and creating supportive legislative environments. The general popularization of agroforestry practices is a viable solution to ecological and economic gain. Furthermore, the combination of climate change adaptation, invasive species management, and biodiversity planning, as well as the improvement of policy coordination, is the key to effective resource use and the enforcement of effective measures to address the issues of national response. The work of creating specific and effective adaptation strategies will be based

on addressing the specific natural and policy risks of Pakistani farmers (unveiled by the cross-border analysis). The constant problems of grassland degradation and ecological stress in Pakistan demonstrate the great necessity of implementing adaptive management strategies that combine both scientific knowledge and local knowledge in order to achieve long-term sustainability and climate-resiliency. (Rashid et al., 2025, p. 37).

With the climate change scenario, the sustainable management of the grassland ecosystems in China is a very important measure of protecting the vast grassland in China, which has an area of about 400 million hectares. These grasslands occur in Inner Mongolia, Xinjiang, Qinghai-Xizan plateau, the Loess plateau, and the Karst areas and play a role in supporting the livestock production of more than 20 million herders, storing much of the carbon emission, and controlling the hydrological cycle under the progressively mounting pressure of climate-related drought, erratic precipitation, extreme temperatures, and extreme events. (Dai et al., 2024). Grasslands and related ecosystems are of vital importance for food supply and wildlife biodiversity, but over 90% of the grasslands have been damaged due to overgrazing, intensive land use, and climate change (Han et al., 2008), resulting in a 10-30% reduction in grassland growth in threatened areas. Recent studies call for the adoption of better approaches, focusing on healthy soil, diverse plant genetics, and robust systems to address these issues.

It is helpful to cultivate stronger alfalfa varieties that can cope with saline or acidic soils in the eastern and southwestern parts of China, especially by using beneficial soil bacteria such as Bacillus subtilis to enhance resilience (Fan et al., 2023; Shi et al., 2017). The incorporation of organic matter in leguminous pastures has the potential to fix carbon, and intelligent management of weeds is superior in preserving nutrients in the soil as compared to plowing. The former Bermuda grass fields in the Qinghai-Xizang area are also good at balancing carbon, nitrogen, and phosphorus. These are steps geared towards helping the climate in China. Farmer-oriented policies promote planting of greater amounts of feed in mixed farmlands-grasslands, to connect crops and livestock with a view of reducing emissions and recycling nutrients, and intercropping of oats with alfalfa in dry regions to get the maximum yield. Pre-corn alfalfa/clover intercropping can enhance yields and nutrient use in the Yunnan-Guizhou Plateau. (Gao et al., 2024).

Policies such as the 2003 grazing ban, subsidies (22.7 yuan per hectare for the grazing ban, 7.5 yuan per hectare in the balanced area), and the World Bank pilot project in the Qilian Mountains region, all involved the use of funds for grassland monitoring and the pastoral communities (Wei et al., 2025). These policies shifted from strict regulations to intelligent rewards, establishing cooperatives, improving sheep breeds, and adopting technologies such as satellite tracking. Challenges still exist, including the obstruction of pastoral mobility by land ownership fragmentation, funding gaps, and the unclear relationship between climate and human factors. Solutions need to find a balance model among production, ecology (pest control, no-till farming), and social needs. Overall, mixed diverse grass species, improving soil, motivating farmers, and using climate-adaptive varieties can all maintain the productivity and resilience of

these systems (Wijerathna-Yapa & Pathirana, 2022).

According to the academic literature, these climate pressures essentially make management difficult, be it the top-down management system that is characterized as centralized in China or the more devolved and community-based management system in Pakistan. To explain this dynamic, researchers tend to refer to the lens of political ecology that demonstrates that the ability or inability to access the ever-growing scarce resources is eventually decided by national power and policy decisions. Other researchers refer to the shared resource theory and apply the principles of Eleanor Ostrom to evaluate in what conditions the local communities in Pakistan can manage themselves, and compare this with the state-centered approach of China. Meanwhile, remote sensing technology has brought a revolution in science on how to monitor these vast lands. Through the satellite data on vegetation health and surface temperature, researchers can now trace the level of degradation with more clarity than ever before, thus becoming an important piece of evidence as to the changes that herders experience firsthand daily.

Table 1: Author's Source through desk research

Aspect	China	Pakistan
Policy Approach	Centralized, top-down, large-scale investment.	Fragmented, decentralized, project-based, influenced by donors.
Primary Driver	Ecological security and national stability.	Livelihood security and local resource conflict mitigation.
Tenure System	State-owned, with use rights allocated to households.	Complex mix of state, communal, and private; often contested.
Role of Local Knowledge	Often marginalized in favor of scientific/technical solutions.	Central to traditional practice, but eroding under modern pressures.
Impact on Livelihood Resilience	Mixed; ecologically positive, but can reduce socio-economic adaptability and increase dependency.	Mixed; community-based approaches can be robust but are vulnerable to institutional failure and tenure insecurity.

Expected Outcomes and Significance

This project aims to bring about meaningful academic progress by introducing a novel perspective on the grassland social ecosystem. It will pave the way for the publication of peer-reviewed papers and reveal how national-led and community-driven governance led to different outcomes. In terms of policy, it provides concise and evidence-based policy briefs to key stakeholders such as the *National Forestry and Grassland Administration of China, the Climate Change Department of Pakistan, and provincial animal husbandry departments*, proposing reasonable adjustments to ecosystem service payment plans and community arrangements. At the practical level, it consolidates feasible strategy toolkits from both countries, which can be applied in other regions, and enhances local skills through practical research. Ultimately, it helps to strengthen the ecological security of key grassland areas in the China-Pakistan Economic Corridor.

Gaps in the Literature and Future Research Directions

Studies on grassland management in regions such as Pakistan and China often fail to achieve their objectives because they rarely link specific policies, such as grazing bans or subsidies, directly to measurable changes in nature and human life, such as an increase in soil carbon content, greater biodiversity, or broader sources of income for herders and greater flexibility in coping with shocks. There are almost no field, concurrent comparative studies conducted using the same standards to assess the conditions of similar grasslands in different countries, which leaves many unanswered questions regarding truly effective methods for cross-border grassland management. Looking to

the future, research on modeling different future climate paths can predict the effectiveness of current strategies. Filling these gaps will enhance tools for coordinating ecological, economic, and fairness aspects, ensuring that grasslands not only survive but also thrive for communities facing more severe droughts, floods, and pressures.

Conclusion

Compared analysis of China and Pakistan shows that when it comes to climate change, there is no solution that can be applied to all scenarios to achieve sustainable management of grasslands. The advantage of China is that it is capable of doing such large-scale ecological mobilization and investment, but its problem is that it struggles to integrate at the local level and improve the livelihoods. Conversely, Pakistan has the advantage of a tradition of mature community management, though the primary problems are institutional fragmentation and unstable land ownership rights.

The future strategy will be a combination of different models. More adaptive and collaborative management characteristics can be embraced by China, and, therefore, local communities will be freer. Pakistan, however, requires greater assistance of national policies and land use reformation to establish an atmosphere in which community actions can occur. Future policies in both instances ought to be climate-sensitive, since they will not only seek to preserve ecological integrity, but also to improve the diversified adaptation of livestock livelihoods. The knowledge sharing between the two countries, which is based on mutual problems, can result in a win-win game that will safeguard their valuable grassland agricultural ecosystems.

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