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Adapting to the new normal: Challenges and strategies for landlocked Asian mountainous countries in the face of extreme climate events

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ABSTRACT

The aim of this investigation is to assess the compounded vulnerabilities of landlocked developing countries (LLDCs) in association with global warming, due to their geographic isolation, limited infrastructure, and socio-economic fragility. Employing a literature review, policy analysis, and comparative case studies, the paper evaluates specific climate impacts and adaptation strategies of Nepal, Bhutan, and Mongolia. Key findings indicate severe hydrological fragility resulting from glacier melt and permafrost degradation, transportation disruptions affecting economic stability, and degradation of essential ecosystem services vital for rural livelihoods. Each country exhibits unique adaptive approaches; Nepal emphasizes ecosystem-based adaptation and integration of local traditional knowledge, Bhutan prioritizes risk assessment and resilient hydropower development supported by innovative financing, and Mongolia focuses on climate-smart herding practices coupled with advanced early warning systems. Conclusions highlight the urgent need for tailored international support, increased regional cooperation, and integrated climate policy frameworks. Practical recommendations include expanding remote sensing technologies for cryosphere monitoring, establishing basin-level councils for coordinated water resource management, scaling community-based adaptation programs utilizing traditional ecological knowledge, transitioning to sustainable tourism models, and advocating for LLDCs issues within international climate negotiations. Addressing these structural vulnerabilities is essential for sustainable development, resilience-building, and regional stability in mountainous LLDCs.

KEYWORDS

Landlocked mountainous countries, National Adaptation plans, Climate adaptation strategies

1. INTRODUCTION

Landlocked mountainous countries are uniquely vulnerable to climate change due to their geographic isolation, complex topography, and fragile ecosystems [1-2]. Climate extremes such as rapid glacier retreat, thawing permafrost, altered hydrological cycles, and frequent natural disasters significantly affect these countries' socio-economic and environmental stability [3-4]. The increasing frequency and severity of climate-induced natural hazards threaten livelihoods, infrastructure, food security, and water availability, thus posing substantial challenges to sustainable development. Specifically, altered precipitation patterns threaten food and water security, infrastructure is damaged by landslides and floods, and traditional livelihoods are destabilized by ecological degradation [5-6].

While the global climate discourse often centers on coastal and island states, mountainous LLDCs like Nepal, Bhutan, and Mongolia receive comparatively less policy and research attention despite their acute vulnerabilities [7-8]. Geographic remoteness, limited infrastructure, and economic constraints further reduce these nations' adaptive capacity.

Recent studies highlight that the effects of climate change in mountainous LLDCs are not isolated events but part of a broader trend towards a "new normal"—a systemic shift characterized by persistent climatic volatility and compounding risks [9-10]. This new normal requires a paradigm shift from coping with episodic hazards to continuously adapting to fundamental environmental transformations. Climate adaptation thus becomes a dynamic process of living with uncertainty, redesigning urban and rural systems, and rethinking socio-ecological resilience [11].

Evidence from the Himalayas illustrates this transition. Thakuri et al. [12] reported that glaciers on the south slope of Mt. Everest have shrunk by 13.0 ± 3.1% between 1962 and 2011, with the snowline rising by 182 ± 22 meters—a clear sign of sustained warming and glacial recession. Moreover, the rapid expansion of glacial lakes, such as Imja Lake, driven by meltwater accumulation, poses growing threats of outburst floods [13]. Similar glacier shrinkage trends are evident across Nepal and Bhutan, with glacier area loss exceeding 20% over three decades [4], [14]. In Bhutan, Kumar et al. [15] found that total glacier area decreased by 2.54% from 1978 to 2017, and Wangchuk and Tsubaki [16] documented a substantial increase in both the frequency and magnitude of glacial lake outburst floods in recent decades. Similarly, in Mongolia, glacier area declined by 35% between 1990 and 2016, with only 627 glaciers covering a total of 334 km² by 2016 [17]. As Avirmed [18] reported that considerable permafrost degradation is occurring along the southern margins of Mongolia, but in other places, like thin permafrost at the Khentii-36 sites in the southern Khentii Mountains, it vanished completely between 1984 and 2008.

Permafrost degradation is rapidly transforming the landscapes of Mongolia and neighboring high mountain regions. For instance, Ma et al. [19] found that Mongolia's permafrost extent has declined markedly from 734,700 km² in the 1950s to 480,100 km² in the 2010s—a loss of 3,200 km² per decade since 1994—driven by significant warming trends and most pronounced in the Hovsgol and Khentii Mountain ranges, as confirmed by high-accuracy simulation models. Baral et al. [20] note that permafrost degradation in High Mountain Asia threatens traditional pastoral systems by altering water availability and land stability.

The Hindu Kush Himalaya Assessment warns that by the end of this century, even if global warming is limited to 1.5°C, one-third of the glaciers in the region will disappear [4]. The situation is equally alarming in Mongolia, where a 2.24°C rise in average temperature since the 1940s has increased the frequency of droughts, dust, and other storms.[6]. These changes demonstrate that mountainous LLDCs are already living in the "new normal."

The purpose of this review is to analyze and evaluate the climate vulnerabilities faced by landlocked mountainous Asian countries, specifically Nepal, Bhutan, and Mongolia. It aims to identify and assess adaptation strategies, explore gaps in existing responses, and provide practical recommendations for enhancing resilience and sustainable development.

This review first provides an analysis of key vulnerabilities specific to mountainous LLDCs, followed by detailed case studies of Nepal, Bhutan, and Mongolia. It then discusses comparative insights into their adaptive strategies, evaluates policy implications, and concludes with actionable recommendations and future directions to improve adaptive capacities and international support mechanisms. The review is essential to highlight these overlooked vulnerabilities and assess existing adaptation strategies, identifying gaps in knowledge, policy, and implementation.

2. RESEARCH METHODS

The study involved a comprehensive literature review, policy analysis, and case studies conducted in Nepal, Bhutan, and Mongolia. Literature was sourced from international databases including PubMed, Web of Science, and Google Scholar, using keywords such as "climate adaptation," "mountainous countries," and "landlocked countries." Policy documents were reviewed from respective national adaptation plans (NAPs) and international reports from the United Nations Framework Convention on Climate Change (UNFCCC), the International Centre for Integrated Mountain Development (ICIMOD), and the World Bank. Furthermore, during the SRI2024 conference, the authors engaged in a multidisciplinary dialogue with researchers, policy experts, and practitioners to validate key themes and gather insights on emerging adaptation strategies and regional collaboration opportunities. These discussions enriched the analysis with diverse perspectives grounded in practical experience and transdisciplinary knowledge exchange.

3. RESULT AND DISCUSSION

3.1. Climate-Specific Impacts on Landlocked Countries

Hydrological Fragility

LLDCs in Asia frequently serve as headwater regions for major transboundary rivers such as the Koshi, Brahmaputra, and Selenge. Climate-induced glacier retreat and alterations in snowmelt pattems threaten water security and regional stability, with increased occurrences of glacial lake outburst floods (GLOFs) posing significant threats to infrastructure and human lives [21-22].

Delayed Climate Information and Technology Transfer

Due to limited international cooperation and connectivity, LLDCs often face challenges in accessing timely climate information and adaptive technologies. This results in delayed responses during extreme climate events, notably floods, droughts, and dzuds in Mongolia, highlighting the critical need for improved communication infrastructure and international cooperation [23].

Transport and Trade Vulnerability

Transport infrastructure in LLDCs, particularly mountain highways and border crossings, is highly vulnerable to climate-related disruptions, including landslides and monsoon floods. These disruptions significantly delay food imports and inflate commodity prices, underlining the necessity for robust infrastructure investments to mitigate economic vulnerabilities [23].

Dependence on Ecosystem Services

Mountainous LLDCs heavily depend on ecosystem services, including forests, alpine grasslands, and irrigation systems sustained by glacial runoff. Climate extremes, such as glaciers and permafrost degradation in Mongolia and erratic monsoons in Nepal, severely threaten these critical ecosystems, undermining rural livelihoods and pastoral economies [24-25].

3.2. Compound Vulnerability

The geographical isolation of LLDCs exacerbates their exposure to climate risks by limiting economic diversification, restricting swift external assistance, and impeding market access. Consequently, LLDCs face increased vulnerability to climate-induced supply shocks and market volatility, intensifying socio-economic pressures [26].

3.3. Policy Implications

Effectively addressing LLDC climate vulnerabilities requires specific global mechanisms tailored to their unique structural constraints. Recommended actions include preferential access to climate finance and technologies, strengthened regional cooperation to manage transboundary climate risks, resilient trade infrastructure investments, and explicit recognition of LLDCs in global frameworks such as the Loss and Damage Fund.

3.4. Country Perspectives

Nepal experiences significant glacier retreat, particularly in the eastern and central Himalayas, heightening the risk of GLOFs. With over 60% of the population dependent on agriculture, sensitive to climate variability, Nepal's National Adaptation Plan (NAP) emphasizes ecosystem-based adaptation and integrates traditional ecological knowledge to enhance resilience [22], [27], [29].

Bhutan, characterized by steep mountainous terrain, faces acute vulnerability to climate hazards such as landslides and glacier-related events. Despite minimal emissions, Bhutan maintains a carbon-negative status, prioritizing resilient hydropower infrastructure and innovative financial mechanisms in its NAP to manage climate risks effectively [28].

Mongolia, with extensive permafrost zones and mountain glaciers, faces severe threats from

permafrost thaw and glacier melting, affecting pasturelands, traditional irrigated crop production, infrastructure, and traditional herding livelihoods. Mongolia's NAP focuses on climate-smart herding practices and robust early warning systems, responding effectively to desertification and extreme winter conditions exacerbated by rapid temperature increases [24-25].

3.5. National Adaptation Plan (NAP) Comparative Analysis

Mongolia: National Adaptation Plan (2024-2030)

Mongolia's NAP addresses the nation's significant vulnerabilities to climate change, particularly focusing on its ecological integrity and socio-economic stability. The plan emphasizes adaptive strategies in key sectors, including agriculture, water resources, and disaster risk reduction. Mongolia's primary sectors, notably forest, agriculture, and water resource management, are prioritized to enhance resilience against climate-induced stresses. Implementation strategies outline clear criteria and baseline conditions for adaptation measures, aiming to integrate climate change considerations thoroughly into national development policies. Moreover, a comprehensive monitoring and evaluation framework is established to systematically assess the effectiveness of implemented adaptation strategies and inform necessary future adjustments [30].

Nepal: National Adaptation Plan (2021–2050)

Nepal's NAP represents a detailed and comprehensive approach designed to enhance the country's adaptive capacity and resilience to climate change impacts across diverse sectors. The plan specifies nine thematic sectors, such as agriculture, water resources, and public health, each accompanied by targeted adaptation actions. It delineates clear adaptation goals within distinct timeframes, categorized into short-term (2021–2025), medium-term (2026–2035), and long-term (2036–2050) objectives. Additionally, Nepal's NAP integrates seamlessly with the National Climate Change Policy, thereby embedding adaptation strategies within broader national and local development frameworks [31].

Bhutan: National Adaptation Plan (2023)

Bhutan's inaugural NAP focuses explicitly on enhancing resilience across sectors significantly vulnerable to climate impacts, emphasizing sustainability and environmental conservation. Detailed sectoral analyses evaluate climate risks in water resources, agriculture, forestry, and biodiversity. The plan leverages Bhutan's previous adaptation experiences, advocating a coordinated approach to achieve established adaptation priorities effectively. Additionally, Bhutan's NAP highlights innovative financial mechanisms, such as the establishment of a dedicated Bhutan Climate Fund, to secure sustainable funding for adaptation initiatives [32].

Commonalities and Differences

All three countries underline the critical importance of integrating climate adaptation into national development planning, particularly prioritizing agriculture and water resource sectors. However, distinctive differences exist: Mongolia specifically targets adaptation within agriculture, with a focus on livestock, Nepal adopts a broader thematic approach across multiple sectors, and Bhutan emphasizes learning from past experiences and establishing robust financial mechanisms to sustain adaptation initiatives.

4. CONCLUSION

This review analyzed the specific climate vulnerabilities and adaptive strategies of landlocked Asian mountainous countries, focusing on Nepal, Bhutan, and Mongolia. These nations are disproportionately affected by glacier retreat, permafrost thaw, and climate-induced ecosystem degradation, exacerbated by their geographic isolation and limited adaptive capacities. The comparative assessment of their National Adaptation Plans (NAPs) shows strong alignment with sustainable development priorities and a focus on agriculture, water, and rural resilience. However, the structural disadvantages of LLDCs underscore the necessity for tailored international interventions. Addressing these vulnerabilities requires strengthened climate finance, regional cooperation, and resilient infrastructure development.

To move forward, investments must be directed toward real-time cryosphere monitoring using technologies like Synthetic Aperture Radar (SAR), Global Navigation Satellite System (GNSS), and remote sensing. Basin-level cooperation should be institutionalized through adaptive councils to enhance transboundary resource management and disaster response. Community-based adaptation must be scaled up by incorporating traditional ecological knowledge (TEK), particularly in pastoralist regions, supported by localized resilience funding. Simultaneously, tourism strategies must evolve into sustainable, climate-aware models. Most importantly,

LLDC-specific challenges must be mainstreamed into global climate agendas, particularly under financing and loss and damage frameworks. These coordinated actions are crucial for strengthening resilience and ensuring inclusive development in some of the world's most vulnerable mountain systems.

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