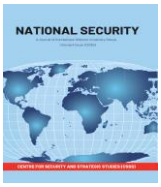

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Interface Between Glacial Lake Outburst Floods and National Security in Nepal

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Abstract

This study investigates the implications of Glacial Lake Outburst Floods (GLOFs) on national security in Nepal, with a particular focus on their cascading effects on human security. The central research question guiding this inquiry is: How do GLOFs impact human security, and what are their cascading effects on national security in Nepal? A mixed-methods research approach was employed, utilizing an explanatory sequential design. The quantitative component involved statistical analysis of secondary data and survey responses, focusing on the frequency and intensity of GLOFs and their impacts on infrastructure, livelihoods, and socio-economic stability. The qualitative component consisted of semi-structured interviews and focus group discussions with key stakeholders, including disaster management officials, climate experts, and community representatives, to contextualize and enrich the quantitative findings. The study was conducted across eight high-risk Himalayan districts. A sample of 450 respondents was determined using Cochran's formula. In addition, three focus group discussions were conducted to gain deeper qualitative insights. The findings underscore the exacerbating influence of climate change and accelerated glacial melting in the Himalayas, which heighten the risks associated with glacier lake outburst floods (GLOFs). These events have profound consequences for human security, thereby contributing to broader national security vulnerabilities. The study identifies significant gaps in Nepal's disaster risk management framework and calls for a paradigm shift in preparedness strategies. Recommendations include implementing comprehensive risk assessments, establishing robust early warning systems, developing climate-resilient infrastructure, and implementing community-based adaptation measures to enhance resilience.

Keywords: *Climate change, disaster management, GLOFs, glacier melting, Himalayas, human security, Nepal*

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Introduction

Climate-induced disasters are increasingly recognised as significant security threats, reshaping the global discourse on environmental risks and their implications for national and human security. The accelerating impacts of climate change—particularly the rapid retreat of glaciers and the formation of unstable glacial lakes—are giving rise to new and intensifying threats across the world's mountainous regions. One such threat is Glacial Lake Outburst Floods (GLOFs), which have emerged as acute hazards in high-altitude regions with the potential to cause widespread destruction. Globally, GLOFs have been reported in the Andes, the Alps, and the Himalayas, where they have resulted in loss of life, destruction of infrastructure, and long- term economic setbacks (Haeberli et al., 2017; Veh et al., 2019). As highlighted by the Intergovernmental Panel on Climate Change (IPCC), the frequency and severity of GLOFs are projected to rise with continued global warming, posing multi-dimensional risks to both human and state security systems (IPCC, 2021).

Regionally, the Hindu Kush Himalaya (HKH) is considered a hotspot for climate vulnerability. It holds one of the largest reserves of frozen water outside the polar regions and supports the livelihoods of nearly two billion people downstream (Wester et al., 2019). The Himalayas are experiencing accelerated glacial retreat, resulting in the expansion of glacial lakes and an increased likelihood of GLOF events (Bajracharya et al., 2020). In countries such as Bhutan, India, Pakistan, and China, GLOFs have already led to transboundary tensions and infrastructure damage, underscoring the regional security implications of such events. Moreover, the management of GLOF risks in this region is complicated by shared river basins, limited coordination mechanisms, and varying levels of national preparedness (ICIMOD, 2019). The necessity for regional cooperation in early warning systems, climate adaptation, and risk mitigation is therefore pressing.

GLOFs are a recurring phenomenon in Nepal's Himalayan region, driven by the dynamic interactions between glacial melt and environmental factors. Over the years, their frequency and intensity have posed growing threats to local communities, infrastructure, and ecosystems (ICIMOD, 2011; Bajracharya et al., 2020). With the accelerating pace of climate change, these risks have become more severe. Glaciers are melting rapidly, temperatures are rising, and precipitation patterns are shifting, leading to the destabilization of glacial lakes and increasing the likelihood of catastrophic floods (IPCC, 2021; Veh et al., 2019). While the environmental and economic consequences of GLOFs have been widely studied, their broader implications for national security remain insufficiently explored (Khanal et al., 2021). There is a critical need to understand how such disasters could affect regional stability, resource management, border integrity, and the resilience of strategic infrastructure. The lack of integrated analysis at this intersection limits effective policy-making and weakens national preparedness. This study seeks to address these gaps by examining the cascading impacts of GLOFs on human and national security in Nepal, highlighting the urgency of incorporating climate-induced disaster risks into comprehensive security planning.

Nepal is particularly vulnerable to GLOFs due to its steep terrain, high glacial concentration, and rapidly growing population in downstream areas. With over 3,000 glacial lakes, many of which are potentially dangerous, Nepal faces a disproportionate level of risk from GLOFs (See Figure 1). Historical events, such as the 1985 Dig Tsho GLOF, have already demonstrated the devastating impacts of such disasters on human settlements, infrastructure, and hydropower development (Ives, 1986). More recent studies underscore how GLOFs threaten not only environmental systems but also key components of national security—namely, food and energy security, social cohesion, economic resilience, and public safety (Khanal et al., 2021; Rijal et al., 2020). The displacement of vulnerable populations, disruption of livelihoods, and erosion of state capacity to respond to cascading climate hazards can foster social instability and weaken national resilience. Despite these risks, national security frameworks in Nepal often treat GLOFs and climate-induced disasters as peripheral to traditional security concerns, resulting in gaps in risk governance and strategic planning. Against this backdrop, this article investigates the critical implications of GLOFs on Nepal’s national security by analysing the environmental, social, and

economic dimensions of GLOF risks. The study aims to provide a comprehensive understanding of the challenges posed by these events and to develop actionable mitigation strategies that align with broader national interests.

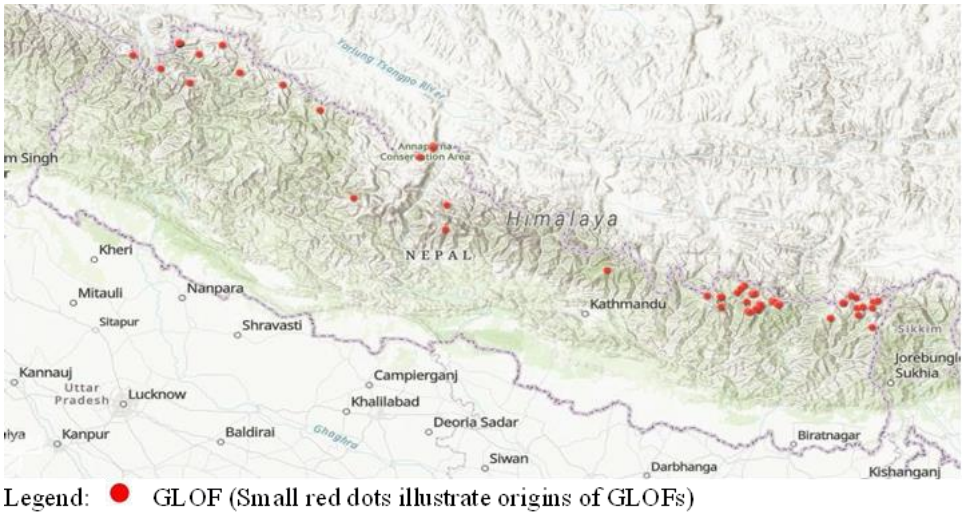

Figure 1: GLOFs Incidents in Nepal (ICIMOD, 2024)

Empirical Literature Review

A substantial body of research underscores the influence of climate change on the increasing frequency and magnitude of GLOFs across the Himalayan region. Studies by Bajracharya et al. (2019) and Bolch et al. (2019) establish a strong correlation between rising atmospheric temperatures and accelerated glacial retreat, while Immerzeel et al. (2020) emphasize that the Himalayas are warming at nearly twice the global average. This rapid warming has led to the formation and expansion of moraine-dammed glacial lakes, many of which are inherently unstable due to their geological and geomorphological characteristics, including susceptibility to seismic activity and erosion (Shrestha et al., 2018; Nie et al., 2021). Although these environmental drivers are well-documented, there remains a paucity of research exploring the long-term implications of GLOFs for national security and systemic stability.

The destructive impacts of GLOFs on critical infrastructure and human livelihoods are extensively reported. GLOFs cause widespread damage to roads, bridges, and hydropower facilities, undermining development gains and economic resilience (Thapa et al., 2022; Dixit et al., 2020). Byers et al. (2020) estimate that post-GLOF recovery diverts substantial resources from national development priorities, thus contributing to economic instability. Environmental degradation resulting from GLOFs, such as soil erosion, sedimentation, and water contamination, has been shown to exacerbate food insecurity and public health risks (Acharya et al., 2016; Nepal & Pandey, 2021). Although some studies document localized adaptation efforts, such as community-based early warning systems and risk mapping (Acharya et al., 2016), these initiatives often lack longitudinal evidence and replicability across diverse socio-ecological settings, limiting their broader policy relevance.

Khatri (2025) outlines how GLOFs jeopardise critical infrastructure and challenge national preparedness, framing them as emerging security risks. Kapri (2024) builds on this by examining how climate-induced disasters, such as GLOFs, intensify existing vulnerabilities in Nepal's national security framework. Barua, Mitra, and Eslamian (2022) emphasise the need for improved detection and risk reduction strategies using scientific tools to mitigate Himalayan GLOF hazards. Similarly, Chapagain et al. (n.d.) highlight significant adaptation and response gaps in the Hindu Kush Himalaya region, emphasising the need for coordinated, community- inclusive disaster management systems. Together, these studies reinforce the importance of integrating climate resilience into Nepal's national security planning.

The national policy landscape in Nepal remains inadequate in integrating environmental security concerns, particularly those posed by global warming-induced floods (GLOFs), into mainstream development and security planning. Shakya et al. (2021) argue that GLOFs are still primarily perceived as isolated natural hazards rather than systemic security threats with cascading socio-economic consequences. Institutional fragmentation, limited financial resources, and capacity constraints further hinder coordinated disaster risk management (Acharya et al., 2019). Although strategic frameworks such as the National Adaptation Programme of Action (NAPA) and the Local Adaptation Plans of Action (LAPA) exist, their implementation remains inconsistent and underfunded (ICIMOD, 2019). Moreover, heavy reliance on external funding and technical support for climate adaptation (Sharma et al., 2021) raises concerns regarding the sustainability and ownership of resilience-building efforts.

Theoretical Perspectives

Relevant theoretical frameworks offer critical insights into the multidimensional nature of GLOF risks. The Human Security framework (UNDP, 1994) calls for a broader interpretation of security that encompasses protection from environmental threats and the safeguarding of livelihoods, particularly for vulnerable populations. Systems Theory, as articulated by Bertalanffy (1968) and further developed by Sterman (2000), offers a valuable lens for understanding the complex interlinkages between climatic, social, and economic systems that influence GLOF risks and resilience. Nevertheless, the operationalization of these theories in Nepal's policy and planning mechanisms remains limited, particularly in addressing cross- border dynamics and leveraging advanced technological tools such as remote sensing and predictive modelling (Khanal et al., 2015).

GLOFs can be better understood by applying key environmental theories such as the Milankovitch Theory, the Ecological Theory, and the Environmental Stress Theory. Milankovitch Theory explains natural climate variability through orbital changes, offering a long-term context for glacier formation and retreat. However, current accelerated glacial melt is primarily driven by anthropogenic climate change (Berger, 2001). On the other hand, the Ecological Theory highlights the disruption GLOFs cause to ecosystems, including the destruction of habitats, loss of biodiversity, and interruption of ecological processes and services (Chapin et al., 2011). Finally, the Environmental Stress Theory posits that GLOFs are acute environmental stressors that challenge the adaptive capacity of vulnerable mountain communities, resulting in cascading effects such as infrastructure damage, resource scarcity, and social instability (Turner et al., 2003). Together, these theories provide a comprehensive understanding of the natural, ecological, and societal dimensions of GLOF impacts.

Despite notable advancements in the study of GLOFs and their associated impacts, several critical research gaps persist, impeding the formulation of comprehensive mitigation strategies. Among these, the most prominent is the limited exploration of the long-term security implications of GLOFs, particularly about national security and systemic stability. Addressing this gap is imperative for Nepal to develop an integrated and holistic approach to GLOF risk management, thereby safeguarding national security and enhancing long-term resilience in the context of intensifying climate-induced hazards.

Methodology

This study employed a mixed-methods research approach utilizing an explanatory sequential design to investigate the implications of GLOFs on national security in Nepal. The approach integrated both quantitative and qualitative methods to ensure a comprehensive analysis of the complex relationships between environmental hazards, human security, and national security— the quantitative component involved collecting and statistically analyzing primary survey data and secondary data sources. A final sample size of 450 respondents was determined using Cochran's formula, ensuring statistical adequacy and accounting for potential non-response. Structured questionnaires were administered to assess the frequency and intensity of GLOFs and their impacts on infrastructure, livelihoods, displacement, and socio-economic stability. The sample composition included affected populations and relevant

stakeholders from disaster- prone areas. Data was collected from eight high-risk Himalayan districts, Solukhumbu, Rasuwa, Dolpa, Mustang, Sankhuwasabha, Manang, Dolakha, and Sindhupalchowk, which were selected from three regions, Karnali, Gandaki, and Koshi (See Figure 2) due to their high concentration of glacial lakes and documented vulnerability to GLOFs.

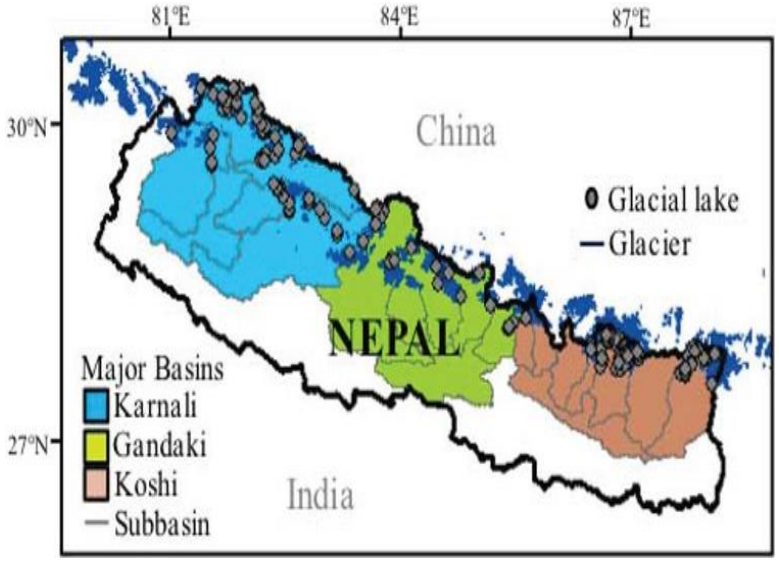

Figure 2: Area of Study and Glacial Lakes in Nepal (ICIMOD, 2011)

To complement and contextualize the quantitative findings, the qualitative component involved conducting semi-structured interviews and three focus group discussions (FGDs). Each FGD comprised seven participants, totaling 21 discussants. The participants included subject matter experts such as disaster management officials, climate scientists, local government representatives, security personnel, and community members with field-level experience and technical expertise in GLOF-related risks. The qualitative inquiry focused on gathering experiential insights, stakeholder perceptions, institutional preparedness, and recommendations for improved risk governance. A purposive sampling technique was employed to select participants with relevant expertise and exposure to GLOF impacts, ensuring representation from both institutional actors and local communities. Secondary data sources used in the study included scientific publications, government reports, meteorological records, and disaster risk assessments, which provided historical data on GLOF events, glacial changes, and associated impacts on human and infrastructural systems.

To enhance the validity and reliability of findings, methodological triangulation was employed by integrating multiple sources and methods of data collection. This enabled a comprehensive understanding of the cascading effects of GLOFs on human and national security, informing the formulation of actionable recommendations for Nepal's disaster risk governance framework. This methodological framework enabled a comprehensive analysis of the complex interconnections among environmental hazards, human vulnerability, and national security within the context of Nepal's fragile mountain ecosystems and escalating climate risks.

Results and discussion

The study received 450 complete and valid responses. The respondent group consisted of 257 males (57.1%) and 193 females (42.9%), selected through purposive sampling (See Figure 3). Special emphasis was placed on including individuals residing in areas vulnerable to GLOFs, such as high-risk districts, and key stakeholders involved in disaster response efforts. These respondents represented a diverse array of professional and academic backgrounds, enabling a comprehensive understanding of the implications of GLOFs in Nepal (See Figure 4).

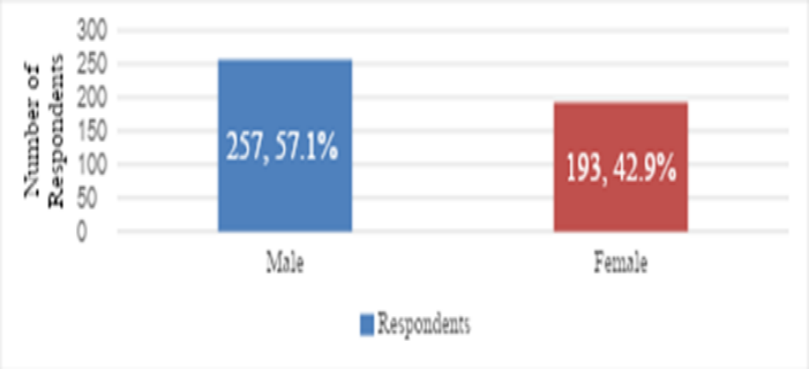

Figure 3: Gender Distribution of Respondents. Source: Authors (2025)

There was a significantly greater representation of men in this study (as represented in Figure 3), a phenomenon that indicates the potential limits of relying on purposive sampling in constituting a sample. The data illustrated in Figure 4 displays survey responses from a number of Nepalese stakeholder groups; the largest shares are represented by local communities (19.33%, 87 respondents) and Disaster Management Authorities (7.77%, 35 respondents). Academic Institutions (13.11%, 59 respondents) and Local Committees (9.77%, 44 respondents), among others, participated less frequently but significantly. This distribution points to unequal participation across sectors, which may be a result of varying institutional involvement levels or a different order of importance for the survey's topic.

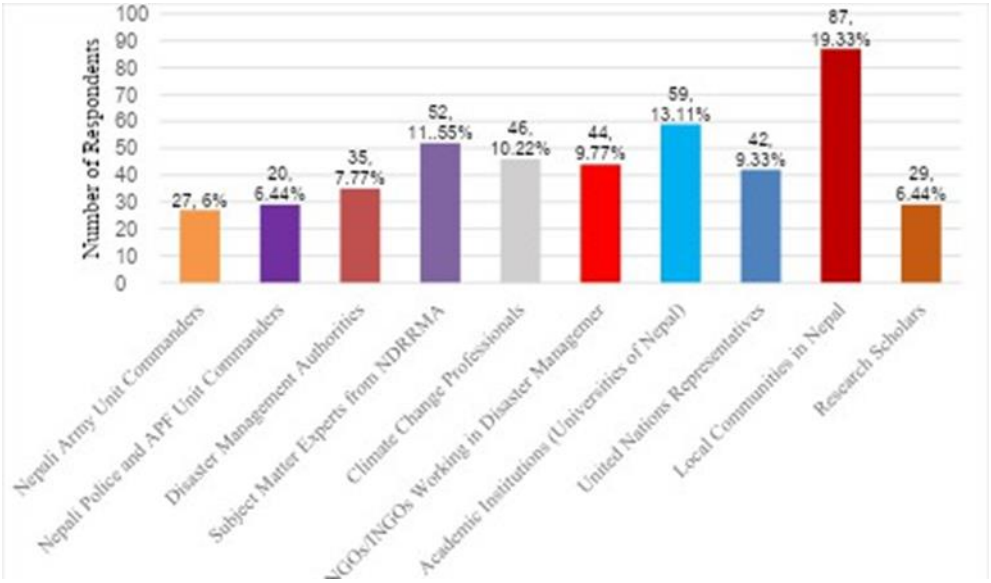

Figure 4: Classification of respondents by occupation. Source: Authors (2025)

Effects of GLOFs on Human Security

The research findings on the effects of GLOFs on human security and their cascading impacts on national security in Nepal are deeply insightful, drawing on the perspectives of 450 respondents from diverse sectors. These research respondents provided unique insights into the multifaceted implications of GLOFs, highlighting the interconnected nature of environmental, social, and security challenges. The findings of the study are presented below, based on the responses provided by the respondents (See Figure 5).

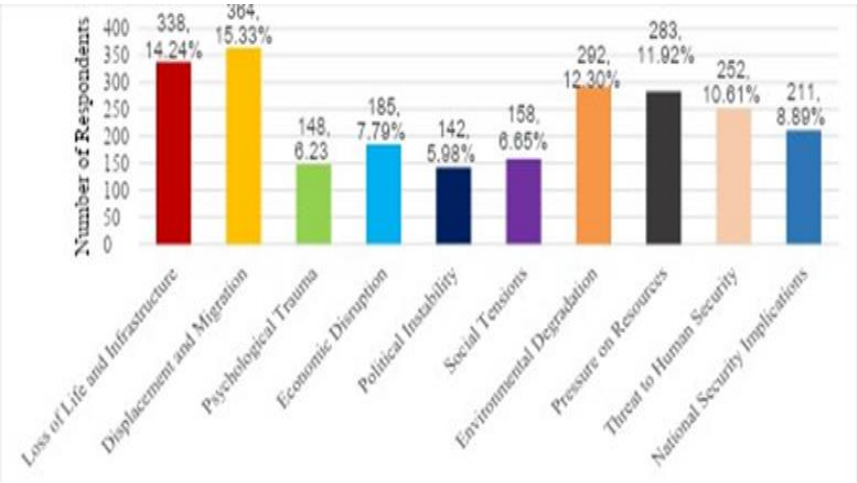

Figure 5: Effects of GLOFs. Source: Authors (2025)

Regarding the impact of GLOFs on human life and safety, the survey highlighted several critical consequences as given in Figure 3. Loss of life and injuries, displacement, and resource constraints were widely recognised as primary outcomes of GLOF events. Psychological trauma and other related impacts, such as social tensions and economic disruptions, were similarly noted, although with slightly less intensity. These findings indicate that GLOFs have had a profound and multifaceted impact on human safety and well-being, underscoring the urgent need for enhanced disaster preparedness and climate resilience strategies to mitigate the effects of such events in Nepal.

Survey findings on the human impacts of GLOFs in Nepal are strongly supported by insights from focus group discussions and secondary literature. Participants from high-risk districts consistently highlighted these consequences, noting long-term disruptions to livelihoods and heightened social tensions. Historical events, notably the 1985 Dig Tsho GLOF, further exemplify the destruction of infrastructure and the emergence of economic instability and food insecurity (Ives, 1986; Khanal et al., 2021). These findings align with studies emphasising the compounding effects of GLOFs on human security, particularly in already vulnerable mountain communities (Byers et al., 2020; Nepal & Pandey, 2021). The convergence of qualitative and quantitative evidence underscores the urgent need for integrated disaster preparedness and climate adaptation strategies in Nepal's national security planning (ICIMOD, 2019; Shakya et al., 2021).

Threats to Human Security

GLOFs have severe and immediate impacts on human security, particularly in vulnerable downstream communities. Local community respondents (19.33%, or 87 participants) reported significant losses, including displacement, destruction of homes, and damage to agricultural land, which directly threaten livelihoods and food security. Research scholars (6.44%, or 29 respondents) and academic institutions (13.11%, or 59 respondents, including Tribhuvan University) emphasised that the lack of early warning systems and inadequate disaster preparedness at the community level exacerbate these impacts. Academics further highlighted the disruption of essential infrastructure, such as roads, schools, and healthcare facilities, which contributes to long-term insecurity in already vulnerable regions.

Figure 6: Thame Village (Thyanbo Glacial Lake Area after GLOF), Nepal. Source: The Kathmandu Post, (2024), (Note: Thame Flooding was an unusual flooding in the Everest region of Nepal, which swept a village downstream).

Findings from focused group discussions substantiated the survey results, emphasizing that GLOFs pose immediate threats to human security, particularly in downstream communities. One Subject Matter Expert (SME) (Interview 1, GLOF Expert, 4th Nov 2024) reported "widespread displacement, destruction of homes, and loss of agricultural land," directly impacting livelihoods and food security. Another SME (Interview 2, GLOF Expert, 14th Feb 2025) noted that "the absence of early warning systems and poor disaster preparedness exacerbate community vulnerability." They (Interview 2, GLOF Expert, 14th Feb 2025) further highlighted that "damage to roads, schools, and health facilities contributes to long-term insecurity in already fragile regions." These qualitative insights align with existing literature on GLOF-induced risks and underscore the urgent need for integrated, community-based resilience strategies.

Loss of Lives and Infrastructure

Respondents from the Nepali Army (6% or 27 unit commanders) and Nepal Police/Armed Police Force (6.44% or 29 unit commanders) highlighted the devastating loss of lives and infrastructure caused by GLOFs. They noted that critical infrastructure, such as roads, bridges, and hydropower projects, is often destroyed, disrupting transportation, energy supply, and communication networks. These disruptions not only hinder immediate rescue and relief efforts but also have long-term economic consequences. Nepali Army commanders emphasized the need for improved preparedness and early warning systems to mitigate the impacts on both human security and national stability.

Figure 7: Infrastructural Damage Due to Off-Season Downpour in Nepal. Source: AP Photo/Gopen Rai, (2025).

This perspective was strongly reinforced by insights gathered during the FGDs. One SME (Interview 2, GLOF Expert, 14th Feb 2025) emphasised that "the destruction of essential infrastructure not only isolates communities but also delays emergency response operations and disrupts national connectivity". Another SME (Interview 3, GLOF Expert, 22nd March 2025) further highlighted the "profound implications on economic continuity and national resilience", particularly in remote Himalayan districts. Across the discussions (Interview 3, GLOF Expert, 22nd March 2025), there was broad consensus on the urgent need for "institutionalized early warning systems and enhanced preparedness at both the local and national levels to reduce casualties and safeguard strategic assets".

Displacement and Migration

Disaster management authorities (7.7% or 35 respondents) and representatives from NGOs/INGOs working in disaster management (9.78% or 44 respondents) reported that GLOFs have led to the displacement of communities, forcing them to migrate to safer areas. This internal migration places additional pressure on urban centres and host communities, leading to resource scarcity and potential social tensions. UN representatives (9.33% or 42 respondents) emphasised that such displacement undermines social cohesion and poses challenges for national stability. Local communities expressed fear and psychological distress due to the recurring threat of GLOFs, further exacerbating their sense of insecurity.

These findings are affirmed by insights from the FGDs, where participants emphasised the broad social impacts of GLOFs. One participant (Interview 1, GLOF Expert, 04th Nov 2024) observed that "the displacement caused by GLOFs often overwhelms already strained services, leading to heightened competition over resources and potential conflict." The displacement triggered by GLOFs intensifies socio-psychological vulnerabilities and places substantial pressure on infrastructure and host communities, thereby undermining social cohesion.

Economic and Developmental Setbacks

Climate change professionals (10.22%, or 46 respondents) and SMEs from the National Disaster Risk Reduction and Management Authority (NDRRMA) (11.56%, or 52 respondents) highlighted the cascading economic impacts of GLOFs. The destruction of agricultural land, livestock, and infrastructure has a severe impact on local economies, while the costs of reconstruction and rehabilitation strain national resources. These economic setbacks hinder developmental progress and exacerbate poverty in affected regions. SMEs stressed the need for comprehensive disaster risk reduction plans that integrate climate change adaptation, disaster preparedness, and response strategies to ensure resilience against such hazards.

These observations align with scholarly analyses, which argue that GLOFs significantly hinder economic development by damaging productive assets, increasing fiscal pressure on governments, and exacerbating poverty in vulnerable regions (Byers et al., 2020; Khanal et al., 2021). The FGDs further reinforced the urgent need for "integrated disaster risk reduction frameworks that embed climate adaptation and preparedness at the local and national levels" to strengthen economic resilience in GLOF-prone areas.

Environmental Degradation and Resource Scarcity

GLOFs have been identified as significant contributors to environmental degradation, including soil erosion, loss of biodiversity, and contamination of water resources. According to 13.11 % of respondents (59 respondents) from academic institutions and 6.44 % of respondents from research scholars, GLOFs are directly linked to these environmental impacts. Local communities, particularly 19.33% of respondents (87 respondents), reported that these changes exacerbate resource scarcity, especially in terms of water and arable land. The Nepali Army 27 Unit Commanders (6% of total respondents) also highlighted that the growing scarcity of resources, especially water, has created increased competition among local populations, potentially leading to conflicts.

In addition to the environmental impacts, there is a widespread recognition of the need for improved data collection and monitoring systems. Twenty-nine respondents (6.44%) of research scholars and 7.78% of respondents (35 respondents) from disaster management authorities strongly advocated for more rigorous monitoring systems to understand glacial lake behaviour better and predict potential GLOFs. This call for enhanced data collection is critical, as it would help in developing more effective mitigation and adaptation strategies to manage the risks associated with GLOFs. The survey revealed a strong consensus among respondents that GLOFs represent a significant security threat to both local communities and national security.

The findings are strongly supported by insights from focus group discussions (FGDs) and scholarly literature. FGD participants (Interview 3, GLOF Expert, 22nd March 2025) emphasised that "frequent GLOFs have led to irreversible degradation of agricultural land and contamination of local water sources, directly affecting food and water security." Similarly, these findings are echoed in academic studies, which highlight how GLOFs contribute to soil erosion, loss of biodiversity, and the disruption of hydrological systems, thus undermining ecological stability and increasing the risk of environmental conflict (Bajracharya et al., 2019; Shrestha et al., 2018).

National Security Implications

The cascading impacts of GLOFs in Nepal extend beyond immediate environmental and human security risks, posing significant challenges to national security. Nepali Army Unit Commanders (6% or 27 respondents) and Nepali Police and APF Unit Commanders (6.44% or 29 respondents) highlighted the destruction of critical infrastructure, such as roads, bridges, and communication networks, as a key vulnerability. Respondents from the Nepali Army and Police noted that these disruptions weaken the national security infrastructure, making it easier for non-state actors to exploit these gaps. Additionally, Nepali Army Unit Commanders pointed out that the economic setbacks caused by GLOFs further compound national vulnerabilities, as weakened local economies can exacerbate social and political tensions. These tensions may create fertile ground for conflict, increasing the risk of instability in the affected regions.

Disaster Management Authorities (7.78%, or 35 respondents) and subject matter experts from NDRRMA (11.56%, or 52 respondents) emphasised the strain on national resources caused by GLOFs, which can undermine governance systems and political stability. Approximately 20% of Disaster Management Authorities expressed concerns about the potential for large-scale displacement, which could overwhelm the country's capacity to manage internal migration, further destabilising regions already vulnerable to natural disasters. Furthermore, 9.78%, or 44 respondents, from NGOs and INGOs working in disaster management reported that the humanitarian crises triggered by GLOFs often lead to broader national security concerns, particularly migration, and an increased strain on public services such as healthcare, education, and housing. This migration, as emphasised by 9.33%, or 42 respondents, from United Nations representatives, could increase the burden on urban areas, leading to social unrest and exacerbating existing issues such as poverty and inequality. In conclusion, the survey respondents collectively indicated that the far-reaching effects of GLOFs on infrastructure, governance, and social systems significantly challenge national security, necessitating urgent attention to disaster risk reduction and management strategies. The findings were reinforced by insights from the focus group discussions (FGDs) and scholarly literature, which highlight the complex and interconnected challenges that GLOFs present to national security in Nepal. These challenges underscore the urgent need for the development and implementation of integrated disaster risk reduction and management strategies to address the cascading impacts of such events effectively.

Call for Integrated Strategies

Respondents across all sectors, including UN representatives, NGOs/INGOs, and academic institutions (totaling 32.22% of respondents), called for integrated strategies to address the multifaceted impacts of GLOFs. Key recommendations included strengthening early warning systems, enhancing community-based disaster preparedness, and fostering transboundary cooperation to manage shared risks. Additionally, there was a strong emphasis on integrating environmental security into national planning and policies to build long-term resilience. UN representatives (9.33% of respondents) emphasized the importance of international cooperation and funding to support local communities in implementing early warning systems, disaster preparedness, and sustainable development initiatives.

The research findings reveal a clear consensus among respondents that GLOFs pose significant threats to human security, with cascading impacts on Nepal's national security. The direct effects on local

communities, including loss of life, infrastructure, and livelihoods, exacerbate existing vulnerabilities. Moreover, the broader implications for national security, including strained response systems, civil unrest, migration, and long-term economic instability, demand a coordinated and comprehensive approach that integrates disaster risk reduction, climate change adaptation, and national security planning. By addressing these challenges through collaborative and interdisciplinary efforts, Nepal can enhance its resilience to GLOFs and safeguard the security and well-being of its communities.

The findings were corroborated by insights from the FGDs and scholarly literature, which emphasize the need for integrated strategies to mitigate the multifaceted impacts of GLOFs. The consensus among respondents reinforces the argument that a coordinated, interdisciplinary approach, combining disaster risk reduction, climate change adaptation, and national security planning, is essential for building resilience against GLOFs and safeguarding Nepal's national security and community well-being.

Government Response and Preparedness

The survey results on government response and preparedness for GLOFs reveal diverse levels of satisfaction and concern among stakeholders. While all security personnel and Disaster Management Authorities expressed moderate satisfaction with the government's response, subject matter experts from NDRRMA and climate change professionals highlighted gaps in efficiency and long-term mitigation strategies. NGOs/INGOs and United Nations representatives acknowledged progress in early warning systems but emphasized the need for greater community engagement. Academic institutions and research scholars were more critical, citing insufficient integration of scientific research into policy frameworks. Local communities, the most affected group, exhibited mixed opinions, with some recognizing improvements in early warning systems while others pointed to delays in emergency response and recovery efforts.

Regarding government preparedness to mitigate GLOF risks, responses varied from agreement to strong disagreement. Security forces and disaster management authorities acknowledged some preparedness through policies and risk assessments. However, subject matter experts, climate professionals, and NGOs/INGOs expressed concerns about inadequate infrastructure, limited funding, and poor scientific integration in policy planning. Academic institutions and research scholars emphasized deficiencies in risk mapping, early warning dissemination, and sustainable mitigation strategies. Local communities noted weaknesses in localized preparedness and post-disaster recovery efforts. The findings suggest that, while progress has been made in response mechanisms and early warning systems, significant gaps remain in infrastructure development, inter-agency coordination, and community-based preparedness. Strengthening policy implementation, increasing investment in mitigation strategies, and enhancing local engagement will be critical to improving Nepal’s GLOF response and resilience.

The research findings from the FGDs with SMEs reveal critical insights into the impacts of GLOFs on human and national security in Nepal. One expert (Interview 3, GLOF Expert, 22nd March 2025) identified, “Significant consequences, including loss of life, displacement, infrastructure damage, and resource scarcity, which intensify vulnerabilities in affected communities.” Another expert (Interview 3, GLOF Expert, 22nd March 2025) highlighted, “The lack of early warning systems and insufficient disaster preparedness are key factors exacerbating these risks.” Next, experts (Interview 3, GLOF Expert, 22nd March 2025) emphasized, “The need for improved monitoring, enhanced community-based preparedness, and stronger collaboration between government, local communities, and international organizations to effectively mitigate GLOF impacts and enhance resilience.”

In summary, the research highlights the significant impact of climate-induced glacier retreat on the frequency and intensity of glacial lake outbursts (GLOFs) in Nepal. By applying Human Security theory, the study demonstrates how these environmental changes pose direct threats to the safety, livelihoods, and well-being of local populations, particularly in downstream areas. GLOFs lead to the destruction of critical infrastructure, displacement of communities, and disruptions in agriculture and tourism, undermining economic, food, and health security. The cascading effects of these disasters exacerbate

existing vulnerabilities and emphasize the urgent need for integrated strategies combining scientific research and community-based adaptation approaches to build resilience.

From a systems theory perspective, the research reveals the interdependence of environmental, social, and economic systems in the context of GLOFs. Climate-induced changes destabilize glacial lakes, triggering floods that disrupt infrastructure, strain resources, and amplify environmental degradation. The lack of systematic monitoring and risk assessment further exacerbates the challenges. Effective management of GLOF risks requires a coordinated, cross- sectoral approach that integrates local knowledge, scientific expertise, and international cooperation to mitigate risks. Enhanced early warning systems, disaster preparedness, and monitoring frameworks are crucial for mitigating these risks and building long-term resilience in vulnerable communities.

Conclusion and Recommendations

This study has examined the escalating threat posed by GLOFs to Nepal's national security, revealing their complex and multidimensional impacts across environmental, human, and geopolitical domains. Intensified by the accelerated retreat of Himalayan glaciers due to climate change, GLOFs pose acute risks to human security, socio-economic stability, critical infrastructure, and broader state resilience. While traditionally regarded as localized natural hazards, GLOFs increasingly represent systemic threats with cascading effects on national development, strategic assets, and cross-border dynamics. These findings emphasize the urgent need for mitigation strategies to address the environmental consequences of GLOFs and underscore the importance of integrating environmental security into national security discourse and strategic planning frameworks.

To address these challenges, the study recommends a comprehensive, anticipatory approach to disaster risk governance. Central to this approach is the development and institutionalization of advanced risk assessment mechanisms. These should employ geospatial technologies, such as satellite-based remote sensing, geographic information systems (GIS), and real-time ground monitoring, to facilitate dynamic tracking of glacial lake evolution. Such data-driven systems must be integrated into a centralized national early warning architecture, capable of generating timely, actionable alerts to inform decision-makers and safeguard at-risk populations. The research findings underscore the need for urgent action to improve risk mitigation strategies, strengthen preparedness, and enhance response mechanisms to address these environmental challenges.

Equally critical is the expansion of community-based early warning systems, particularly in remote and hazard-prone areas where institutional presence is limited. These systems should be supported by targeted public awareness campaigns and capacity-building initiatives to empower local actors and foster a culture of preparedness. Regular, iterative risk assessments should also be institutionalized to ensure adaptive management and responsiveness to evolving climate threats. Furthermore, the study emphasizes the need to strengthen human security and build local resilience as core components of a holistic GLOF risk mitigation strategy. This includes formulating robust evacuation and resettlement protocols, constructing climate-resilient infrastructure such as flood-resistant transport networks and emergency shelters, and providing psychosocial support to affected communities. Investments in localized disaster preparedness initiatives will also promote social cohesion and equitable risk distribution, reducing the potential for social unrest in the aftermath of climate-induced displacement.

At the policy level, urgent reforms are required to mainstream environmental and climate security into Nepal's national development and security agendas. This entails addressing institutional fragmentation, enhancing inter-agency coordination, ensuring sustainable financing, and strengthening regulatory frameworks to achieve these objectives. Given Nepal's geostrategic position and the transboundary nature of glacial hazards, regional cooperation, particularly with China and India, should be prioritized. Mechanisms for real-time information sharing, joint monitoring, and coordinated disaster response must be institutionalized to enhance regional stability and uphold national sovereignty. These

recommendations from various stakeholders also underline the importance of strengthening research, monitoring, and collaboration to address both the environmental and resource-related challenges posed by GLOFs.

In conclusion, this study advocates for a multi-sectoral, forward-looking strategy that embeds climate adaptation, disaster risk reduction, and environmental security within national and regional security frameworks. Such an integrated approach is essential to enhance Nepal's resilience, protect its population, and preserve critical infrastructure in the face of intensifying climate-induced threats, particularly those posed by glacier lake outburst floods (GLOFs). By aligning scientific innovation with strategic foresight, Nepal can transition from a reactive disaster response to a proactive, sustainable risk governance approach.

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