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Impacts of Glacial Lake Outburst Floods on Nepal's National Security

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Abstract

Glacial Lake Outburst Floods (GLOFs) are emerging as an acute threat to Nepal, driven largely by the rapid melting of Himalayan glaciers due to climate change. This article explores the diverse impacts of GLOFs on Nepal's national security, emphasizing implications for human security, economic stability, environmental integrity, and social cohesion. Historical events, such as the 1985 Dig Tsho GLOF and the recent 2024 Thame village incident, underscore the devastation caused by these floods, including fatalities, displacement, and destruction of critical infrastructure. The frequency and intensity of GLOF events are increasing, exacerbating risks to communities living downstream of high-risk glacial lakes. Nepal's vulnerability is further heightened by limited infrastructure, insufficient disaster preparedness, and a lack of adequate climate adaptation resources. The study employed a mixed-methods approach, combining quantitative data analysis with qualitative data to assess the complex interplay between GLOFs, infrastructure, vulnerability, and national security. The article identifies key challenges, including the displacement of communities, leading to social unrest, economic instability from infrastructure damage, and environmental degradation impacting local ecosystems. Additionally, geopolitical factors complicate disaster management, particularly regarding cross-border GLOF risks with neighboring countries. To mitigate these threats, the article recommends implementing early warning systems, enhancing infrastructure resilience, promoting community-based disaster preparedness initiatives, and emphasizing the importance of leveraging international platforms. By understanding the multifaceted impacts of GLOFs, policymakers can develop effective measures to mitigate risks, protect critical infrastructure, and enhance Nepal's overall security.

Keywords: *Climate change, conflict, glacier, GLOFs, national security, Nepal, resilience, risk*

Introduction

The Hindu Kush-Himalayan region is a vital source of freshwater for millions downstream; however, climate change, which is also characterized by global warming, has been impacting

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this delicate balance. The Hindu Kush-Himalayan region contains a large proportion of the world's glaciers (Singh et al., 2011, p. 2). The impacts of global warming in the Himalayas have caused the shrinkage and retreat of glaciers, resulting in the formation and expansion of numerous glacial lakes. It has also impacted the overall glacier system of the Himalayan region in terms of shrinkage of areal extent, loss of ice volume by melting rapidly, formation of moraine dams, or drainage of glacier lakes (Bajracharya et al., 2007). Once the formation and expansion processes of these glacier lakes, which are trapped behind unstable moraine dams, may trigger their outburst with a flood anytime, posing a significant threat of catastrophic flooding, endangering the livelihoods of people living downstream, known as GLOFs. Nepal, a country heavily reliant on glacial melt water, has experienced numerous GLOFs in the past, causing devastating loss of life and infrastructure damage (ICIMOD, 2011). Nepal has recorded 27 GLOF events, 11 of which have had trans-boundary effects. The Bhote Koshi and Sun Koshi GLOFs of 1964 and 1981, the Ci-Ren-Ma-Co (Zhangzangbo) outburst of 1981, which originated in the Tibet Autonomous Region, the Dig Tsho GLOF of 1985, the Tampokhari outburst in 1998, and the Thame GLOF of 2024 are stark reminders of the potential devastation (Bajracharya et al., 2020).

The risk of GLOFs is intensified nowadays due to climate change, which accelerates the melting and recession of glaciers. The GLOF events have the potential to cause significant loss of life, widespread destruction of infrastructure, and displacement of communities. The frequency and intensity of GLOFs are projected to increase due to climate change, exacerbating existing vulnerabilities and posing a serious threat to Nepal's national security (GFDRR, 2011). The effects and impacts of GLOF are not only limited within the boundary of Nepal but also may extend to the bordering states of India, and it may even stretch up to Bangladesh. For instance, in 1981, the Ci-RenMa-Co (Zhangzangbo) lake outburst, which originated in the Tibet Autonomous Region, had caused huge damage in downstream areas of Nepal, including damage to the Nepal-China Friendship Bridge, Arniko Highway, and Sunkoshi hydropower. The economic loss caused by this GLOF event alone was estimated at USD 3 million (GFDRR, 2011).The increasing number and size of glacial lakes in Nepal necessitate a comprehensive understanding of this growing threat. 'The glacier study in 2001 revealed that some 3,252 glaciers covering a total area of 5,323 km² and including 481 km³ of estimated ice reserves occur in the Nepal Himalaya. This was the first information on glaciers of Nepal, which served as the important baseline information on glaciers ((Bajracharya et al., 2011, p. 6-7). So, detailed studies are needed to assess the potential hazards of these lakes and the vulnerability of downstream communities. Effective GLOF mitigation strategies require collaboration between Nepal and neighboring countries, especially with China and India, as some glacial lakes originate upstream in these regions. Therefore, it is essential to examine how GLOFs contribute to the degradation of Nepal's infrastructure and exacerbate socio-political vulnerabilities, ultimately threatening national security. In this context, this research will examine the impacts of GLOFs on Nepal's national security and propose measures to the government and other concerned stakeholders.

Hypothesis

Global warming, characterized by climate change, has seriously impacted the rapid shrinkage and retreat of glaciers at an alarming rate, resulting in the increase in size and numbers of glacier lakes in the Himalayan region. These expanded glacier lakes are turning into a ticking bomb endangering downstream lives and property. These fragile lakes may burst anytime, which will have its impact not only on the national security of Nepal but also adversely affect the bordering states of India and may even stretch up to Bangladesh. So, there should be proper policy formulation, a collaborative approach of all national and international stakeholders, and a proper early warning mechanism, as well as public awareness, which will be instrumental to tackling the impact of GLOF effectively.

Review of Literature

There have been significant contributions of literature related to global warming, climate change, and GLOF. The focus has been given to the status of GLOF in Nepal and its impact on national security. The book, "Estimation of Flood and Glacier Lake Outburst Flood: Flood and GLOF Study for Nepali Rivers," by Binod Shakya, provides an in-depth examination of flood risk and GLOFs specifically within Nepal's mountainous river systems. The book offers a comprehensive methodology for estimating flood risks in Nepal's rivers, which are heavily influenced by glacial melt and are increasingly susceptible to GLOFs due to climate change. Shakya delves into the hydrological and meteorological data relevant to flood forecasting, emphasizing the unique topographical and climatic challenges Nepal faces (Shakya, 2012). The United Nations, in its article 'Five ways the climate crisis impacts human security,' highlights the profound impact of climate change on human security, labeling it a 'threat multiplier' that exacerbates social, economic, and environmental vulnerabilities. Key impacts include intensified competition for land and water, disrupted food production, forced migration, and increased poverty and inequality, which amplify existing security challenges. For regions already facing political instability, like Yemen and Somalia, climate change worsens resource scarcity and leads to conflict, displacement, and social unrest (United Nations, 2021).

The article "A comprehensive approach and methods for glacial lake outburst flood risk assessment, with examples from Nepal and the transboundary area" (2015) presents a detailed methodology for assessing GLOF risks in Nepal and adjoining regions. The study combines GIS, remote sensing, and field data to create a multifaceted model that evaluates the physical, social, and environmental impacts of GLOFs. Using case studies of high-risk glacial lakes in Nepal and China, the authors emphasize the cross-border nature of GLOF hazards, highlighting the necessity of integrated policies and regional cooperation for effective risk reduction. The article suggests embedding GLOF mitigation strategies within national frameworks (Khanal et al., 2015). The report, "Inventory of Glacial Lakes and Identification of Potentially Dangerous Glacial Lakes in the Koshi, Gandaki, and Karnali River Basins of Nepal, the Tibet Autonomous Region of China, and India," published by ICIMOD and UNDP, addresses the increasing risks posed by GLOFs due to climate change. It catalogues glacial lakes across these three major river basins, highlighting lakes at risk of outburst due to factors like lake volume, moraine stability, and proximity to vulnerable downstream communities and infrastructure. The report

underscores the urgency of a cross-border approach, emphasizing the need for preparedness strategies to mitigate the potential hazards posed by GLOFs (Bajracharya et al., 2020).

The report "Glacial Lakes and Glacial Lake Outburst Floods in Nepal," by ICIMOD, examines the hazards posed by glacial lake outbursts in Nepal, intensified by climate change. It highlights the impact of past GLOFs on lives, infrastructure, and the economy and stresses the need for continuous monitoring and early warning systems. It also emphasizes regional cooperation, proposing collaborative solutions in the Himalayan region (ICIMOD, 2011). The paper on "Glacial lake outburst floods threaten millions globally" examines the growing threats posed by GLOFs. The authors highlight that increasing glacial melt has led to the formation of large, unstable lakes in mountainous regions, endangering millions of people living downstream. Their review on recent GLOF incidents and the main triggers, such as rising water pressure, landslides, and seismic activity, underscores the need for comprehensive risk management. Despite technological advances in monitoring and prediction, the authors stress that mitigating GLOF risks requires international collaboration, local engagement, and investment in adaptive measures like early warning systems and community education, with a priority on highly vulnerable populations (Taylor et al., 2023).

In the summary, reviewed literature explores the increasing risks of GLOFs and climate-related impacts on human security, particularly in Nepal and other high-altitude regions. Studies underscore the need for cross-border cooperation, technological advancements, and community-based adaptation to manage vulnerabilities in affected areas. With an emphasis on monitoring, early warning systems, and policy integration, these works advocate for proactive measures to protect lives, infrastructure, and ecosystems from GLOF hazards.

Research Gap

Many researches and studies have already focused on and even identified the likelihood and the potentiality of GLOF events in Nepal. So far, there are very few studies which highlight the impact of GLOF on the national security of Nepal. Here, the researcher has tried to correlate the linkage of the triggering of GLOFs with its impact on the national security of Nepal.

Methodology

This research employed a mixed-methods approach, combining quantitative and qualitative techniques to thoroughly examine the impacts of GLOFs on national security in Nepal. The quantitative aspect involves statistical analysis of survey data concerning the frequency, intensity, and infrastructure impacts of GLOFs. In contrast, the qualitative aspect, such as insights, experiences, perceptions, and suggestions. This research methodology allows for the in-depth analysis of both objective data and subjective perspectives to understand the impacts of GLOFs on national security. The study also focuses on the basins to examine the impacts of GLOFs on national security. Moreover, as part of this research, the probability of GLOFs and their impacts in Nepal have been identified as the dependent variables. In addition to this, there are many independent variables which will have a direct link with the dependent variable, and as a whole, they signal the possibility of GLOF in Nepal, India, and other Himalayan countries. The conceptual research framework is depicted in Figure 1.

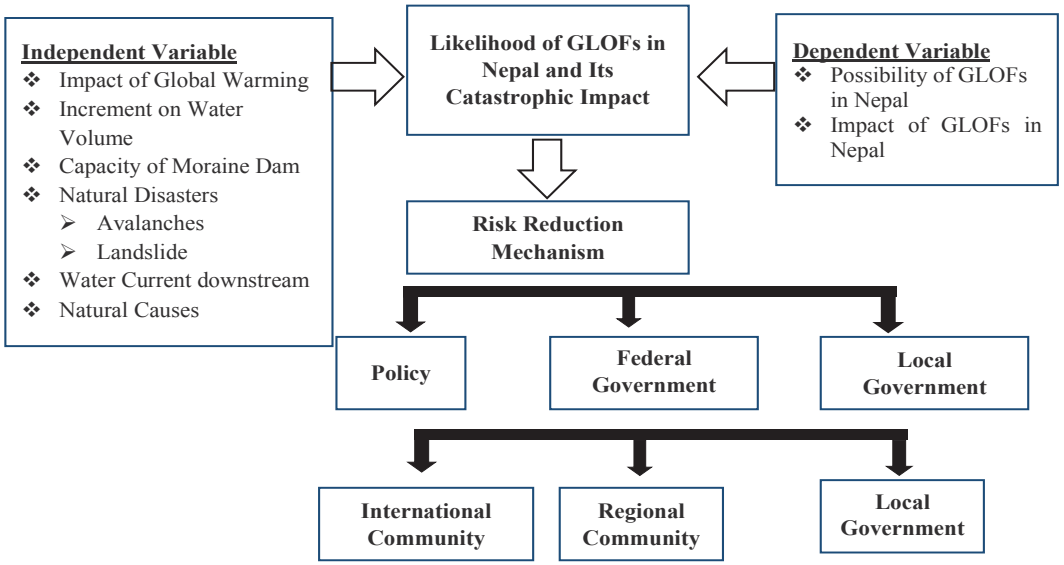

Figure 1. Conceptual Framework
Source: Researcher

GLOFs Event and Damage

In fact, there are both natural and manmade factors that are responsible for global warming and climate change. Volcanic eruptions, ocean currents, the earth's orbital changes, and solar variations are some of the examples of natural causes which are beyond the control of existing human beings. Human activities are major contributors to global warming and climate change. These include the burning of fossil fuels, increasing carbon dioxide and air pollution, widespread use of automobiles, population growth, urbanization, industrialization, deforestation, and coal-burning power plants. As a direct result of global warming and climate change, the frequency of GLOF events has risen significantly over the past four decades. In 2020, the International Centre for Integrated Mountain Development (ICIMOD) identified 47 glacial lakes in Nepal, China, and India as being at high risk of outburst, with 21 of these located within Nepal (ICIMOD, 2024). The significant GLOF incidents that occurred entirely within Nepal, as well as those originating in the Tibet Autonomous Region (TAR) of China but caused damage in Nepal, are listed below.

Table 1: Major GLOFs

SN	Date	River Basin/GLOF	Origin	Remarks
1	450 years ago	Seti Khola / Machhapuchchhre	Nepal	
2	25 August 1964	Trishuli River/ Longda GLOF		
3	1964	Arun Valley/ Gelhaipuco GLOF		
4	1964	Sun Koshi Zhangzangbo Piping	TAR/China	
5	3 September 1977	Dudh Koshi/ Nare	Nepal	
6	23 June 1980	Tamor Nagma Pokhari		

7	11 July 1981	Sun Koshi/ Zhangzangbo-Cho GLOF	TAR/China	
8	27 August 1982	Arun/Jinco		
9	4 August 1985	Dudh Koshi/ Dig Tsho GLOF	Nepal	
10	12 July 1991	Tama Koshi / Chubung		
11	6 Juny 1995	TrishuliZanaco	TAR/China	
12	3 September 1998	Dudh Koshi River/ Tam Pokhari (Sabai-Tsho)	Nepal	
13	15 Aug 2003	Madi River/ Kabache Lake		
14	8 Aug 2004	Madi River/ Kabache Lake		
15	5 July 2016	Bhote Koshi	TAR/China	
16	20 April 2017	Barun Valley	Nepal	
17	21 April 2024	Manaslu region/Birendra Lake		
18	16 August 2024	Khumbu region /Thyanbo		

Source: ICIMOD, 2024

In addition to the specific GLOF events listed in Table 1, there have been other incidents in the Arun, Dudh Koshi, Kali Gandaki, and Mugu Karnali river basins, as well as in Barun Khola and Chokarma, caused by moraine collapses. The ICIMOD dashboard records a total of 54 GLOF events in Nepal (ICIMOD, 2024). The origins of these GLOFs are illustrated by small red dots in Fig. 2, with additional details provided in Table 2.

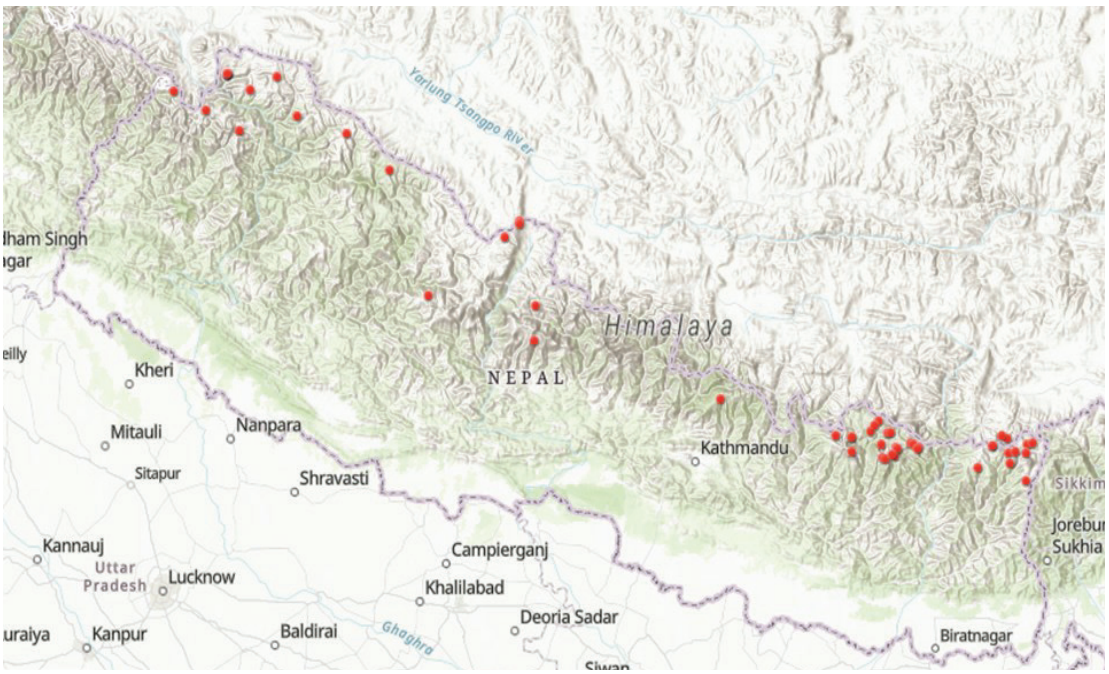

Fig 2. GLOFs Incidents in Nepal

Source: ICIMOD Dashboard (ICIMOD, 2024)

Table 2. GLOFs Incidents in River Basin

River Basin	GLOFs	Fatalities	Injuries	Displaced People	Livestock Lost	Remarks
Arun	4	0	0	50	24	
Bheri	1	0	0	0	0	
Dhauliganga	1	0	0	0	0	
Dudh Koshi	16	7	0	0	0	
Humla	11	0	0	0	0	
Kali Gandaki	1	0	0	0	0	
Marsyangdi	1	0	0	0	0	
Melamchi	1	25	0	1,000	0	
Mugu Karnali	1	0	0	0	0	
Seti	1	0	0	0	0	
Tama Koshi	1	0	0	0	0	
Tamor	12	0	0	0	3	
Total	**54**	**36**	**0**	**1,050**	**27**	

Source: ICIMOD Dashboard (ICIMOD, 2024)

Although the damage associated with GLOFs, as reported by the ICIMOD dashboard, may seem relatively minor, it has inflicted considerable harm to fertile land, resulting in property losses, displacement, and other adverse effects. For instance, the Zhangzangbo-Cho GLOF event on July 11, 1981, at the headwaters of the Sun Koshi River, destroyed the Friendship Bridge on the China-Nepal Highway and the diversion weir at the Sun Koshi hydropower plant, leading to significant economic losses for Nepal. Similarly, the Dig Tsho GLOF on August 4, 1985, devastated the nearly completed Namche hydropower plant, agricultural land, and other infrastructure, resulting in numerous fatalities (Kantipur Media Group, 2024). On August 18, 2024, an unprecedented GLOF event inundated Thame village in the Everest region of Nepal. The Thame River overflowed with mud, gravel, and boulders, destroying 20 houses, an elementary school, and a clinic in Ward 5 of Khumbu Pasang Lhamu Rural Municipality. This flood displaced 135 residents and left the riverside settlement covered in debris, serving as a stark reminder of the persistent threat posed by GLOFs (Gyawali, 2024). Such events have been reported periodically.

GLOFs as a Growing Threat in Nepal

Downstream Impacts GLOFs generate multifaceted impacts, including the immediate downstream impacts. Here, let's take the example of the Rolwaling River, which originates from TshoRolpa Lake, and it passes through Naa, Beding, and Nimare villages. 26 km away from the lake, the river meets the Tamakoshi River, where one of Nepal's biggest hydro projects is. There are many human settlements along the downstream of Tama Koshi. Because of the increase in the density of population and the human settlements, the critical impacts of GLOFs are becoming more serious and dangerous (Shrestha et al., 2011). After the outburst of the lake,

the picture below describes the calculated depth of flood inundation in the river that ranges mostly from 20 to 30 m. The depth is more likely to increase in narrow river valleys along the downstream river.

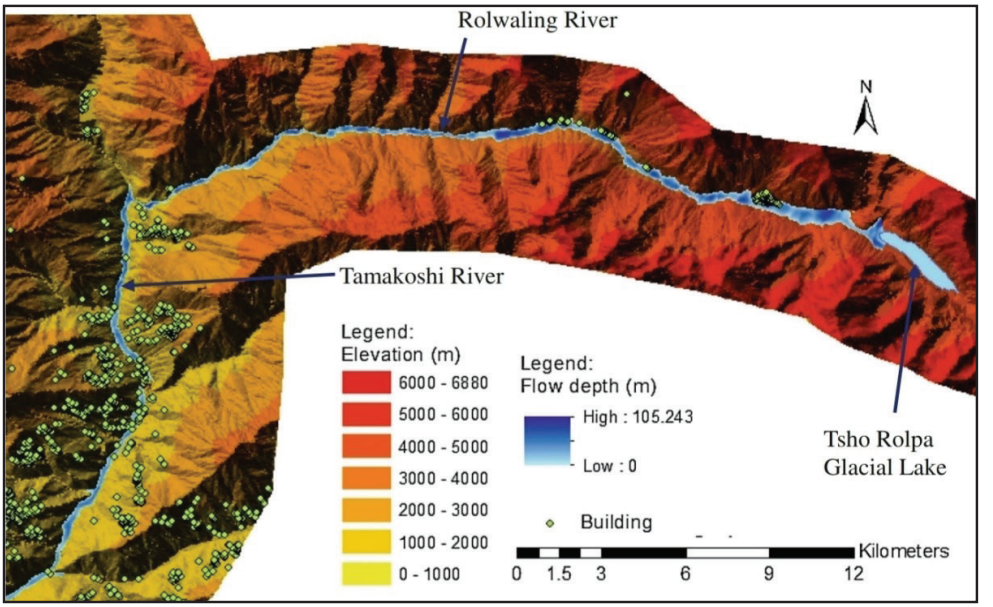

Figure 3. Flood Inundation Due to Likely GLOF of TshoRolpa
Source: (Shrestha et al., 2011)

The figure illustrates building structures like residential houses, schools, health centres, and others along these Rolwaling and Tamakoshi river valleys are considered to be at high risk from potential GLOF. It also seriously impacts the human settlements, agricultural lands, hydroelectric projects, roads, bridges, airports, and other infrastructures concentrated along and nearby areas of the riverside. Furthermore, the terrible discharge of water with its tremendous height and speed will sweep away all human lives, properties, and infrastructures along its route. In addition, it will also have its prolonged flooding impact in the downstream of Koshi, affecting the food basket of Nepal, the Terai region, and even neighbouring states of India.

Recent GLOF events, such as the devastating incident in Thame village, exemplify the catastrophic potential of complete devastation of essential infrastructure like schools and clinics and further illustrate the direct implications for local populations. The cumulative damage to fertile land and agricultural assets poses a long-term threat to food security and local economies. As glacial melt continues due to climate change, the likelihood of more frequent and severe GLOFs increases, further jeopardizing livelihoods in affected areas. Therefore, there is a pressing need for government intervention, including the establishment of early warning systems, improved infrastructure resilience, and community awareness programs to mitigate the risks associated with these natural disasters.

Impacts on National Security

GLOFs significantly impact the national security of Nepal in various ways, including environmental, economic, social, and political dimensions.

Human Security and Displacement

GLOFs can lead to the sudden displacement of communities living near glacial lakes and downstream areas, creating internally displaced persons (IDPs) who may require urgent humanitarian assistance and resettlement support. Similarly, immediate threat to life from flooding events exacerbates existing vulnerabilities, creating a sense of insecurity among affected populations. This influx of IDPs can strain local resources and services, leading to increased competition for limited supplies, such as food, water, and shelter (Allen et al., 2022). The inability of the government and local authorities to adequately respond to these needs can exacerbate social tensions and unrest, undermining social cohesion and potentially leading to conflict.

Individuals living in constant fear of GLOFs may experience psychological stress and anxiety, impacting their overall well-being and ability to function in daily life. This pervasive sense of insecurity can lead to a breakdown in community trust and resilience, further destabilizing the social fabric of affected areas. In addition, the government may face increased pressure to respond effectively to disasters, which can divert attention and resources away from other critical national security needs. If the government is perceived as incapable of managing disaster risks and providing adequate support to displaced populations, it can erode public confidence in governance and create a legitimacy crisis (Wester et al., 2019). This situation can ultimately threaten national stability and security, making it crucial for Nepal to develop robust disaster risk reduction strategies and enhance its capacity to respond to GLOF events.

Economic Stability

GLOFs can destroy critical infrastructure such as hydro projects, water reservoirs and dams, airports, roads, bridges, schools, and health facilities. The destruction of these assets disrupts economic activities and can lead to long-term economic instability. The immediate consequences include hindered access to transportation, education, and healthcare services. This disruption can cripple local economies, particularly in remote areas where infrastructure is already limited (Mool, 2001). As economic activities decline, the potential for unemployment and poverty increases, creating a cycle of economic vulnerability that can destabilize communities and, by extension, the nation.

Similarly, flooding can wash away fertile land and agricultural resources, threatening food security and the livelihoods of communities' dependent on farming. Communities that rely on farming as their primary source of income face severe challenges when their land is compromised. This loss of agricultural productivity can lead to food shortages, price inflation, and increased dependence on food imports, further straining the economy. As food insecurity rises, social unrest can follow, with marginalized communities becoming more susceptible to conflict over dwindling resources. The cumulative effects of infrastructure destruction and agricultural loss can exacerbate existing vulnerabilities within the population, leading to a rise in internal displacement, social tensions, and conflict (Wester et al., 2019). Ultimately, undermining the overall security framework of Nepal.

Environmental Degradation

GLOFs can significantly disrupt local ecosystems, impacting biodiversity and the natural resources that communities rely on for their livelihoods, which in turn increases competition for

these limited resources. When communities' dependent on these resources experience shortages, it may lead to conflicts among themselves or with state authorities, especially if resource management policies are seen as ineffective or inequitable (Allen et al., 2022). The disruption of ecosystems by GLOFs can result in a decrease in the availability of essential resources such as water, timber, and medicinal plants, intensifying competition among communities and raising social tensions, particularly in areas where resources are already scarce.

As climate change accelerates glacial melt, the frequency and intensity of GLOFs are anticipated to rise, escalating the environmental risks confronting the nation. These increasing GLOF events not only jeopardize the physical safety of communities but also threaten their economic stability and food security. The destabilization of ecosystems can lead to reduced agricultural productivity, further exacerbating competition for land and water (Wester et al., 2019). Overall, the ecological changes induced by GLOFs can undermine community livelihoods, escalate resource competition, and contribute to social unrest, all of which pose a threat to national security.

Political and Social Stability

Displacement and resource scarcity resulting from GLOFs pose significant threats to national security in Nepal by exacerbating tensions among communities. The unequal distribution of assistance, where certain groups receive aid while others are overlooked, fosters feelings of resentment and inequality, thereby undermining social cohesion. Such disparities can escalate into conflict, as marginalized populations, feeling abandoned, may resort to protests or violent actions to articulate their grievances (Mool, 2001).

Moreover, the government's capacity to respond effectively to disasters comes under heightened scrutiny in the wake of these crises. Should the government fail to manage disaster risks or adequately address the needs of displaced populations, it risks losing public trust and legitimacy. This erosion of confidence can lead to political instability and social unrest, further complicating the government's efforts to maintain order and security (Bajracharya et al., 2015). The complex interplay between displacement, resource scarcity, and governmental response cultivates a volatile environment that poses substantial risks to the overall stability and security of Nepal.

National Security Resilience

The need to address GLOF (Glacial Lake Outburst Flood) events in Nepal can redirect resources from other critical national security areas, such as defense and law enforcement, which affects the country's overall security framework. Responding to GLOF-related emergencies requires that military and disaster response agencies invest considerable time, resources, and coordinated effort, potentially stretching their current capabilities. As these agencies assign personnel and resources to GLOF preparedness and management, their ability to respond to other security threats may be limited (Wester et al., 2019). This shift in resource allocation can reduce their readiness for conventional security functions, heightening susceptibility to other risks and complicating efforts to sustain a strong national security posture.

Transboundary Impacts & International Relations

The way GLOFs from Nepal can impact the bordering states of India and Bangladesh in the same way, GLOFs from Tibet, China can impact Nepal. GLOFs originating in neighboring countries,

such as China and India, present national security challenges for Nepal by potentially straining diplomatic relations if cross-border flooding affects Nepali communities and infrastructure. These incidents may complicate bilateral ties, underscoring the necessity of cooperative disaster management strategies to address shared risks. Moreover, Nepal's susceptibility to GLOFs could lead to increased reliance on international aid for disaster preparedness and response, which may impact national sovereignty and reduce decision-making autonomy (Ives et al., 2010). This dependence raises concerns about sustainable resilience, emphasizing the strategic importance of developing strong, independent disaster management systems to uphold both security and sovereignty.

Impacts on Human Health

GLOFs as the outcome of global warming and climate may bring serious health issues, i.e., spreading diseases like malaria, transmitted by mosquitoes, and other tropical diseases like dengue fever, yellow fever, and encephalitis as well (Gautret et al., 2017).

Water Scarcity

The Himalayan region plays a pivotal role in the overall ecological balance of this planet, and all the glaciers in the Hindu-kush Himalayas are the big source of fresh water in this region. On one side, shrinkage and retreat of all these glaciers have resulted in melting these glaciers rapidly, and on the other side, potential outbursts of the glacier lakes have threatened the water reserves for hundreds of millions of people in the region (Bajracharya et al., 2015).

GLOFs pose a multifaceted threat to national security in Nepal, affecting human security, economic stability, environmental integrity, and social cohesion. Addressing these risks through comprehensive disaster risk reduction strategies, community resilience building, and international cooperation is essential to safeguarding the nation's security and promoting sustainable development.

Findings

GLOF is a significant source of flash and seasonal flooding in Nepal, primarily driven by the serious impacts of climate change, such as the melting of Himalayan ice. These floods are more extensive and destructive than other types of flooding, necessitating a more robust and coordinated response. The sudden release of large volumes of water results in devastating floods that can breach river channels, endangering nearby population centers and infrastructure, such as bridges. Due to the often-inaccessible terrain, most risk mapping is done using satellite imagery to monitor glacial lakes and their changes over time.

The study shows that current efforts to mitigate climate risks are insufficient, and there is a lack of adequate disaster preparedness programs, prevention strategies, comprehensive risk mapping, and risk assessments. The priorities of politicians, primarily centered on personal gain and political ambitions, have not only overlooked these critical issues but have also exacerbated them. Action is needed urgently to prevent further disasters that could devastate lives and property.

Glacial Lake Outburst Floods (GLOFs) present a complex threat to Nepal's national security by affecting human security, economic stability, environmental sustainability, and political stability. Human security is challenged as GLOFs displace communities, creating

internally displaced persons (IDPs) who strain local resources and exacerbate social tensions, especially when aid distribution appears unequal. The immediate psychological impact of GLOF risks also erodes community trust and social cohesion. The government's response capacity is critical; inadequate disaster management can undermine public trust, sparking potential conflict and instability.

Economically, GLOFs disrupt local economies by damaging critical infrastructure such as roads and agricultural lands, risking long-term economic decline, and threatening food security. Environmentally, GLOFs alter ecosystems, intensifying competition for scarce resources like water and timber, which may lead to conflicts among resource-dependent communities. Politically, the government's response effectiveness is under scrutiny, and failures can destabilize public confidence, affecting governance and stability. Additionally, GLOFs from neighboring countries like China can strain diplomatic relations, requiring cross-border disaster cooperation and increasing reliance on foreign aid, which impacts Nepal's sovereignty. Developing resilient disaster management and risk reduction strategies is essential for safeguarding Nepal's security and autonomy.

Conclusion

GLOFs represent a severe and multifaceted threat to Nepal, with profound implications for national security, environmental stability, and economic resilience. The escalating frequency and impact of GLOF events, exacerbated by climate change, jeopardize human security through displacement and infrastructure destruction, threatening local livelihoods, food security, and regional stability. These floods have not only caused direct losses of life and property but also inflicted long-term damage on critical sectors such as agriculture and infrastructure, creating cascading effects on Nepal's economy and social fabric.

Nepal's response to the GLOF threat must be comprehensive, incorporating risk assessment, early warning systems, infrastructure fortification, and disaster preparedness programs. Equally crucial is enhancing community resilience and fostering regional collaboration with neighboring countries, particularly in areas where GLOF risks cross borders. International support through climate adaptation funds, alongside a strategic emphasis on self-sustaining disaster management practices, will help mitigate dependency on external aid and preserve national sovereignty.

To address the dynamic challenges posed by GLOFs, Nepal requires an integrated approach that strengthens the capacity of governmental and security institutions, prioritizes equitable resource distribution, and implements robust disaster risk reduction measures. By doing so, Nepal can safeguard its people, environment, and economic stability, ensuring a more resilient and secure future in the face of growing climate-related hazards.

Recommendations

The study has identified the following recommendations for reducing the impacts of GLOFs.

Strengthen Human Security and Resilience

To address displacement and community insecurity, the government should establish early warning systems in vulnerable regions and develop efficient evacuation and resettlement protocols. Investing in community-based disaster preparedness programs can enhance local

resilience, improve resource distribution, and foster social cohesion. Additionally, integrating psychological support services within humanitarian assistance frameworks can mitigate mental health impacts and support long-term community well-being.

Build Economic Resilience and Infrastructure

To safeguard economic stability, prioritize the construction of resilient infrastructure, such as flood-resistant roads, bridges, and emergency shelters, particularly in GLOF-prone areas. Supporting sustainable agricultural practices and creating alternative livelihood options in affected areas can help mitigate food security risks. The government should also explore insurance mechanisms and economic safety nets for communities affected by GLOF-induced losses.

Enhance Environmental and Resource Management

Protecting local ecosystems and biodiversity requires proactive resource management policies that include community input, ensuring fair access to essential resources. The government can also invest in ecological restoration projects to stabilize vulnerable landscapes. Collaborating with local communities to implement sustainable land and water use practices will help prevent resource competition and mitigate social tensions.

Strengthen Political Stability and Social Cohesion

Ensure equitable distribution of aid and disaster relief by establishing transparent mechanisms and involving local leaders in decision-making. This can reduce resentment and prevent conflicts among affected groups. Training officials in disaster risk reduction and crisis communication will enhance the government's capacity to respond effectively, maintaining public trust and political stability.

Prioritize Security Operations

Expand the capabilities of military and disaster response agencies through specialized GLOF response training and adequate resource allocation. Establish multi-agency coordination frameworks to enable joint response efforts without compromising other security roles. Strengthening the overall preparedness of security agencies can ensure readiness for both GLOF events and other national security threats.

Promote Regional Cooperation and Minimize Aid Dependency

Foster cross-border disaster management cooperation with neighboring countries, particularly China and India, to manage shared GLOF risks. Collaborative efforts, such as shared monitoring systems and joint response protocols, can help mitigate diplomatic tensions. Developing self-sustaining disaster response systems can reduce dependency on international aid, preserving Nepal's sovereignty and decision-making autonomy in the long term.

Comprehensive Disaster Risk Reduction

Establish a national disaster risk reduction (DRR) strategy focused on GLOF risks, encompassing preventive, preparative, and recovery measures. Building community resilience through education, training, and resources will be essential for sustaining national security and stability in the face of increasing GLOF events.

Expand and Strengthen GLOF Mitigation Intervention

Building on successful initiatives, such as the Nepali Army's Imja Glacial Lake outflow channel and the Department of Hydrology and Meteorology's lowering of Tso Rolpa Lake, similar interventions should be systematically implemented at other high-risk glacial lakes. This requires establishing monitoring teams equipped with advanced hydrological and geological tools to assess risks in real time. Deploying robust early warning systems in these areas will ensure rapid response capability for at-risk communities downstream, reducing the potential impact of GLOF events.

Leverage International Mechanisms and Advocate for Climate Adaptation Support

Nepal should utilize platforms like the UN Climate Change Conference (COP) to secure more significant funding for loss and damage from developed nations, advocating for financial resources that reflect the scale of the climate challenges faced. Increased international support should focus on GLOF-specific adaptation strategies, risk assessments, and enhanced monitoring. Encouraging public awareness on the effects of climate change, along with promoting sustainable practices, is essential for fostering community resilience and long-term commitment to environmental stewardship.

Comprehensive Public Awareness Campaign

To enhance national security in Nepal, it is essential to prioritize awareness-raising initiatives regarding Glacial Lake Outburst Floods (GLOFs). Local communities must be educated about the hazards posed by GLOFs and trained in effective response strategies to warnings. The government should implement a comprehensive public awareness campaign that utilizes various communication channels, such as press reports, FM radio stations, television programs, news articles, and scientific forums. This campaign should aim to disseminate accurate and timely information about glacial lakes, GLOF risks, and management practices, fostering a culture of preparedness and resilience. Engaging local leaders and community organizations in these efforts can enhance trust and ensure that information reaches those most at risk. By empowering individuals to respond effectively to potential GLOF events, these initiatives will help reduce the likelihood of displacement and socio-economic disruption, ultimately contributing to the broader national security framework of Nepal.

National Policy

To enhance national security, it is essential to develop a comprehensive national policy that focuses on increasing awareness, early warning systems, and risk mitigation concerning GLOFs. Such a policy should prioritize immediate action response strategies. Conducting extensive vulnerability assessments is crucial for identifying areas most at risk. Furthermore, establishing routine airborne and satellite monitoring, complemented by intensive and repeated geophysical surveys, will facilitate the tracking of glacial lake conditions and improve predictions of potential outburst events. Recognizing the transnational nature of these hazards, the policy must also emphasize the necessity for international cooperation to effectively address cross-border risks.

Proactive Approach and Training

It is essential to establish a comprehensive training program for security forces. This program should emphasize preparedness for relocation activities during GLOF events, equipping personnel with the necessary skills and knowledge to respond effectively. Regularly conducted drills that simulate evacuation scenarios in collaboration with local communities are vital for fostering familiarity and coordination among both residents and responders. Identifying and designating safe zones for evacuation should be integral to this training, ensuring that security forces and the public understand their respective roles and responsibilities during emergencies. By prioritizing these training initiatives, Nepal can enhance its resilience to GLOF incidents, ensuring a more organized and efficient response that minimizes risks to life and property. Furthermore, this proactive approach will contribute to building community trust in security operations and reinforce overall disaster preparedness within the nation.

Early Warning and Hazard Monitoring Mechanism

The government should focus on an effective early warning and Hazard Monitoring mechanisms to make life and property safe in likely impacted areas of GLOFs. In this regard, early warning systems with remote sensors and sirens have already been established in Tshorolpa and along the Rolwaling and Tamakoshi river valleys. The government, in collaboration with concerned national and international stakeholders, should engage immediately to set up this type of early warning and hazard monitoring mechanism in all glacier lakes and river systems in Nepal.

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