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Indigenous Wisdom in Flash Flood Adaptation and Mitigation: Insights from the Gayo Highlands, Indonesia

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Abstract. Flash floods rank among the most catastrophic hydrometeorological disasters, profoundly affecting human lives, infrastructure, and ecosystems. As climate change intensifies their frequency and severity, locally tailored adaptation and mitigation strategies are essential, particularly in regions with limited access to advanced technologies. This study investigates the role of indigenous wisdom in mitigating flash flood risks, focusing on the socio-ecological challenges of the Gayo Highlands in Aceh, Indonesia. The region's steep terrain, high rainfall, and shifting land use contribute to its vulnerability, making community-driven strategies, such as river patrolling, reforestation, and adaptive stilt house construction, vital for disaster mitigation. Using a mixed-methods approach, the research identifies these practices as integrative solutions that blend ecological knowledge with cultural traditions. The findings reveal that these grassroots efforts have successfully prevented major floods over the past nine years, enhancing both ecological stability and societal resilience. Nationally recognized through the Kalpataru Award in 2023 and internationally acclaimed for their innovative community-based approaches, these practices underscore the critical role of traditional knowledge in disaster risk management. However, contextual adaptation is crucial, as such strategies must be tailored to fit diverse socio-ecological conditions in other regions. This research emphasizes the necessity of integrating indigenous wisdom with ecosystem-based frameworks and modern advancements, such as early warning systems and digital mapping tools, to develop scalable and globally relevant mitigation models, offering a practical framework for replication in other disaster-prone regions.

1 Introduction

Flash floods are among the most destructive hydrometeorological disasters, causing significant impacts on infrastructure, the environment, and human lives (Khan et al., 2020; Pascual et al., 2024; Al-Rawas et al., 2024; Rahman et al., 2023). Characterized by sudden and rapid water flow, these disasters frequently occur in areas with steep topography, high rainfall

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

intensity, and poor land-use management (Azizah et al., 2022; Ali et al., 2017; Jodar-Abellan et al., 2019). Globally, the intensity and frequency of flash floods have been increasing (CRED, 2024). Data from the Centre for Research on the Epidemiology of Disasters (CRED) indicates a 30% rise in flash flood occurrences over the past two decades, affecting more than 10 million people annually (Guha-Sapir et al., 2016). This rise is attributed to climate change (Archana et al., 2024; Hussain Shah et al., 2023), deforestation (Dhyani and Dhyani, 2016; Jean Louis et al., 2024; Maqsood et al., 2024), and unplanned urbanization (Hoang and Liou, 2024; Martín-Raya et al., 2024).

Indonesia, with its humid tropical climate, annual rainfall exceeding 2,500 mm, and mountainous terrain, ranks among the countries most vulnerable to flash floods (Azizah et al., 2022; Taufik et al., 2017; Sapan et al., 2023). For instance, the Gayo Highlands in Central Aceh face recurrent risks due to extreme rainfall, land-use changes, and weak watershed management (Amri et al., 2023; Ilhamni et al., 2023). Previous studies highlight the region's physiographic characteristics, such as steep slopes and fragile volcanic soils, which exacerbate landslide risks and natural river damming, often triggering large-scale flash floods (Sukrizal et al., 2019; Murdawati et al., 2024; Azzahra et al., 2021). However, these disasters are not solely driven by natural factors; deforestation significantly reduces the ecosystem's capacity to retain rainfall and stabilize soil (Zhang et al., 2024; Jean Louis et al., 2024; Maqsood et al., 2024).

While modern technologies such as Geographic Information Systems (GIS), hydrological modeling, and early warning systems have been widely implemented (Wahba et al., 2024; Hu et al., 2024; Al-rawas et al., 2024; Rifath et al., 2024; Ding et al., 2021), their effectiveness often remains limited in rural areas with low access to technological infrastructure (Montz and Gruntfest, 2002; Sauer et al., 2024; Iqbal and Nazir, 2023). Alternatively, community-based approaches leveraging local wisdom have gained traction as locally relevant and sustainable solutions (Bucherie et al., 2022; Trogrlić et al., 2019; Rozi, 2017; Tran et al., 2009). In many countries, indigenous knowledge has played a pivotal role in disaster mitigation (Islam et al., 2018; Hiwasaki et al., 2014; Setten and Lein, 2019; Dekenss, 2007). For example, communities in Vietnam integrate local knowledge with GIS to enhance the accuracy of flash flood risk maps (Tran et al., 2009), while in Zimbabwe, communities rely on natural signs to predict floods (Mavhura et al., 2013). In Simeulue, Aceh, the "Smong" tradition saved thousands of lives during the 2004 tsunami by relying on local understanding of earthquake and natural signs (Syahputra, 2019; McAdoo et al., 2006; Syafwina, 2014).

However, despite widespread recognition of local wisdom in various contexts, its documentation and integration into formal policies remain limited, particularly in Indonesia. Most previous research has focused on technical or technological approaches without addressing the unique socio-ecological dimensions of indigenous communities. Studies on the local knowledge of the Gayo people, specifically regarding flash flood adaptation and mitigation, remain scarce, despite their rich traditions in natural resource management and risk mitigation. For instance, the Gayo community employs a combination of revegetation, river monitoring, and community cooperation to mitigate flash flood impacts, yet these practices remain largely undocumented and unincorporated into formal policy frameworks.

This study aims to identify and analyze the local wisdom-based mitigation and adaptation strategies employed by the Gayo people in facing flash floods. It not only documents local practices such as revegetation, river monitoring, and adaptive housing

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

design but also explores how these practices can be integrated with modern technologies to create more effective mitigation systems. By adopting a multidisciplinary approach that combines social, ecological, and technological dimensions, this research seeks to contribute significantly to the global literature on community-based disaster mitigation and offer a replicable model for other regions facing similar risks.

2 Study Area

The Gayo Highlands in Aceh, Indonesia, encompass three main regencies: Central Aceh, Bener Meriah, and Gayo Lues. Situated along the Barisan Mountain Range, which stretches from north to south across Sumatra Island, the area is located approximately between 4°0'–5°0' N latitude and 96°30'–98°0' E longitude. The upper reaches of the Peusangan Watershed dominate this region, with elevations ranging from 561 to 2,859 meters above sea level (see Fig. 1). The combination of steep topography, volcanic soils with low infiltration capacity, and high annual rainfall (2,500–3,000 mm) makes the region highly vulnerable to hydrometeorological hazards, particularly flash floods.

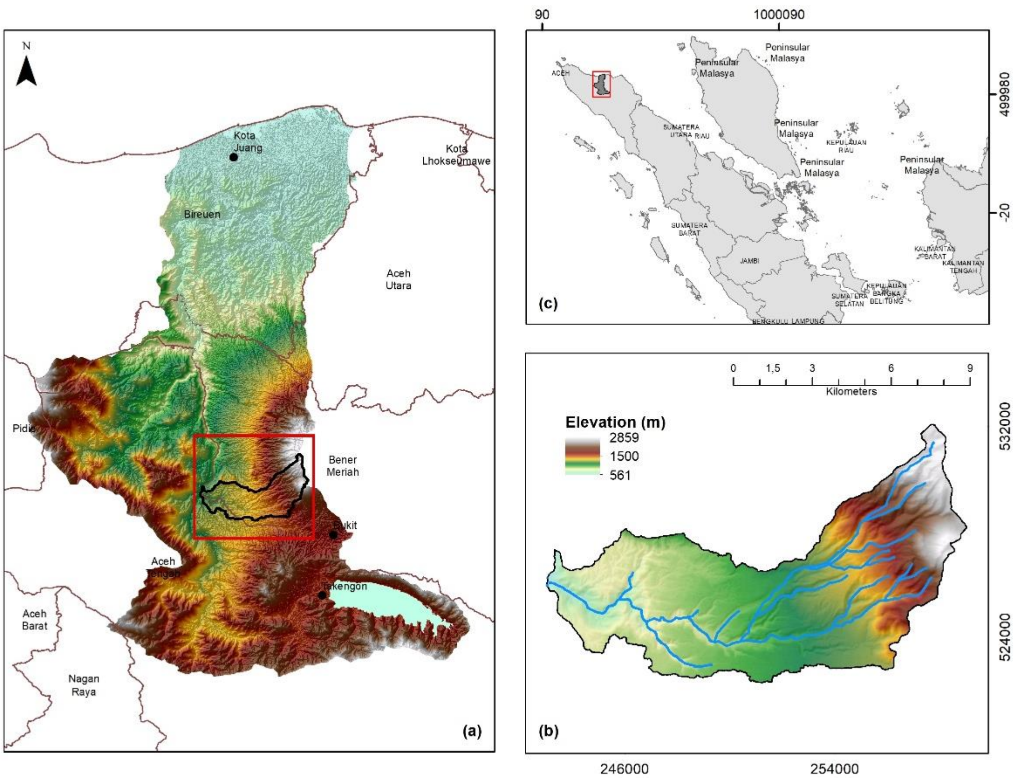

Figure 1: (a) The Gayo community resides in the upper reaches of the Peusangan Watershed, located in Bener Meriah and Central Aceh Regencies, Aceh Province. (b) Wih Gile is a sub-watershed of the Peusangan Watershed. (c) Geographically, Aceh Province is part of the island of Sumatra, Indonesia.

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

The average slope gradient in the region is approximately 20%, with the steepest areas concentrated in the upstream hills of the Peusangan Watershed. This rugged terrain, coupled with heavy rainfall and environmental degradation, frequently triggers landslides that often lead to river blockages. A study by Ilhamni et al. (2023), highlights that deforestation, driven by the expansion of coffee plantations, has significantly reduced the ecosystem's capacity to absorb rainfall, thereby increasing the risk of flash floods, especially in the Wih Gile sub-watershed (see Fig. 1).

In addition to being a disaster-prone region, the Gayo Highlands are renowned for producing world-class Arabica coffee. This area serves as a hub for coffee cultivation, which not only sustains the local economy but also significantly impacts the environment. According to Amri et al. (2023), forest-to-coffee plantation conversion has increased by 10% over the past decade, resulting in the loss of 5,000 hectares of forest cover.

Beyond its physical and environmental complexities, the Gayo Highlands are home to the indigenous Gayo community, who possess unique local wisdom for disaster risk mitigation. Through community-based social practices, the Gayo people have developed adaptive mitigation strategies that address local challenges. This region serves as a critical case study for understanding how the interplay between hydrometeorological risks, environmental changes, and local knowledge can inform globally relevant, community-based solutions.

3 Materials and methods

This study employed a mixed-methods approach, emphasizing qualitative data collection complemented by quantitative data to strengthen the analysis. Conducted between 2023 and 2024, the research aimed to explore the local wisdom of the Gayo community in flash flood mitigation and to analyze data-driven empirical findings.

Qualitative data were collected through in-depth interviews, focus group discussions (FGDs), and participatory observation. A total of 20 interviews were conducted with key informants, including traditional leaders, community representatives, members of the Forest Management Group (Lembaga Pengelola Hutan Kampung, LPHK), and individuals with extensive knowledge of environmental signals, mitigation practices, and cultural values. Additionally, three FGD sessions, each involving 10 to 15 participants from diverse occupational backgrounds, were organized to explore collective perceptions of disaster risks and adaptive measures. Participatory observations documented activities such as forest patrols, revegetation efforts, and river maintenance.

Quantitative data were obtained through structured questionnaire surveys involving 94 respondents selected via snowball sampling. Respondents included household heads and active members of LPHK groups. The questionnaire was designed to assess perceptions of risk, flood experiences, participation levels, and the impact of mitigation activities on reducing flash flood risks. Secondary data, such as land-use maps and watershed maps, were sourced from the Regional Disaster Management Agency (BPBD) of Bener Meriah, the Forest Management Unit (KPH) Region II Aceh, and the HAkA Foundation (Forest, Nature, and Environment Aceh).

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

Data analysis involved thematic methods for qualitative data and descriptive statistical analysis for quantitative data. Interview transcripts and FGD recordings were examined to identify patterns in community adaptation and community-based mitigation strategies. Quantitative data supported qualitative findings by providing empirical insights into participation rates and the effectiveness of mitigation initiatives. Additionally, spatial analysis using Geographic Information Systems (GIS) was conducted to map the study location and analyze land-use changes.

4 Results and Discussion

4.1 Flash Flood Disaster Adaptation

4.1.1 Symbolic Naming Practices

The tradition of geographical naming with symbolic meanings has long been an integral part of local communities' adaptation strategies to natural disaster risks. One notable example is the Wih Gile River (see Fig. 2), which translates to "Mad River" in the Gayo language. This name serves as a symbolic warning of the potential dangers posed by the river's unpredictable and turbulent flow. The term "mad" vividly describes the river's erratic and deadly currents, presenting a significant threat to surrounding communities. This naming practice promotes public awareness of the river's characteristics, encouraging residents to avoid activities or construction along its banks (Bucherie et al., 2022).

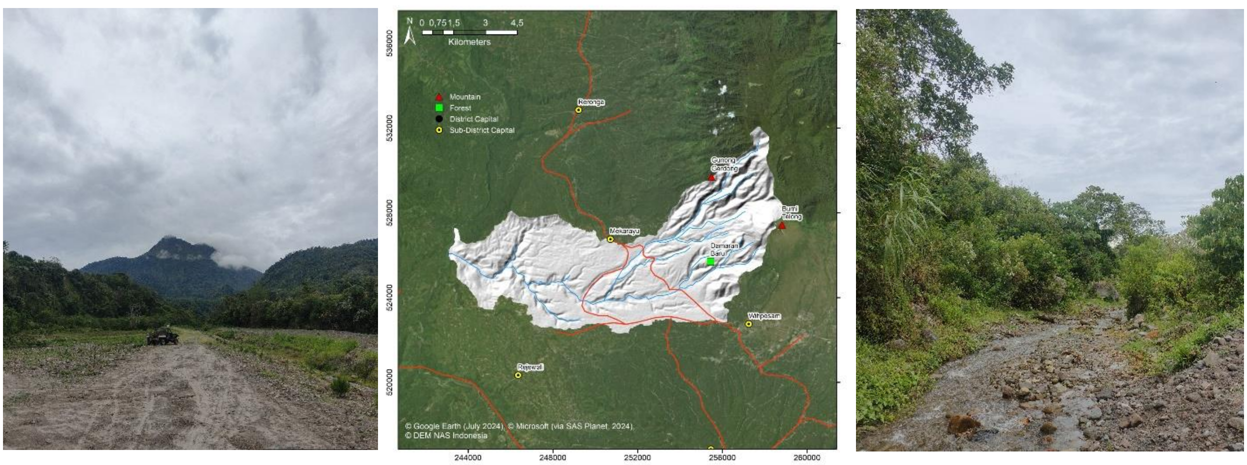

Figure 2: Wih Gile River, located at the foothills of Mount Gerdong and Mount Berapi (the two highest peaks in Aceh), serves as the main channel for flash floods impacting the Damaran Baru community. The map illustrates the geographical location of the river and its surrounding ecosystem.
Source (middle image): © Google Earth (Imagery Date: July 2024), © Microsoft (via SAS Planet, Imagery Date: 2024), © DEM NAS Indonesia. Overlays and modifications by the authors.

This cultural tradition reflects a long-standing heritage passed down through generations. Dove (2008) described a similar practice in Mount Merapi, Indonesia, where geographical naming serves as a traditional warning tool to enhance awareness of volcanic disaster risks. Comparable findings were reported by Rahman et al. (2023) in Bangladesh, where river names with symbolic meanings helped communities heighten their vigilance during the monsoon season. Additionally, Smith and Petley (2009) emphasized that local knowledge-based approaches play a pivotal role in mitigating natural disaster risks in vulnerable communities.

Interviews with local residents revealed that this naming practice effectively discourages development near the river, thus reducing vulnerability to flash floods. Bucherie et al. (2022) also highlighted that such traditions strengthen the community's connection with their environment, fostering ecological awareness critical for risk mitigation. In modern contexts, these practices could be integrated with risk maps or technology-driven early warning systems to enhance community-based disaster risk management, as recommended by UNDRR (2023).

4.1.2 Residential Houses

Traditional houses serve not only as dwellings but also as a reflection of local wisdom in adapting to environmental risks. The traditional architecture of the Gayo people, known as Umah Pitu Ruang (see Fig. 3a), exemplifies structural adaptation to the threat of flash floods (Iswanto et al., 2022; Zahrah et al., 2021). These houses are elevated structures designed on stilts, allowing water to flow beneath without damaging the main building (Wulandari et al., 2024). This design is comparable to traditional stilt houses in Thailand and Vietnam, which are constructed to withstand seasonal floods and mitigate soil erosion, as described by Saengpanya and Kintarak (2019) and (Pham and Oh 2021).

The Gayo community often associates flash floods with the term letot, interpreted as a dragon descending from the mountains due to upstream river disruptions (Setianingsih et al., 2017). The dragon (nege) symbol featured in Umah Pitu Ruang represents the forces of nature that must be respected and preserved. This symbolism resembles the dragon myths in Chinese culture, which are often linked to rain and flood protection. However, in Gayo, the dragon myth carries a profound moral message to maintain the ecological balance of river systems, serving as a medium for promoting environmental conservation values within the community (Dove 2008).

Additionally, the use of local durable materials such as ulin hardwood enhances the resilience of Umah Pitu Ruang to extreme weather conditions, similar to practices in the Philippines, where traditional houses employ local materials like bamboo and hardwood to withstand typhoons and floods (See et al., 2024). Research by Biswas et al. (2015) in Bangladesh also highlights the role of traditional stilt houses in community adaptation to floods, particularly in reducing damage to properties and infrastructure.

The steeply pitched roofs of Umah Pitu Ruang, designed to facilitate rapid rainwater runoff, share a functional similarity with traditional houses in Japan. In mountainous regions of Japan, as noted by Tamura (2024), steep roofs prevent the accumulation of snow or rain, showcasing ecological adaptation based on local environmental conditions.

Umah Pitu Ruang is not merely a cultural representation of the Gayo people but also a form of local wisdom-based adaptation relevant to hydrometeorological disaster mitigation. Integrating this traditional design with modern approaches, such as early warning systems and risk mapping, can create community-based mitigation models adaptable on a global scale.

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

Similar practices have been proposed by Montz and Gruntfest (2002), who emphasized the importance of combining local traditions with technological innovations to develop more effective disaster adaptation solutions.

4.1.3 Awareness of Natural Signs

Awareness of natural signs has been an integral part of the Gayonese community's adaptive strategies in mitigating flash flood risks. This knowledge, passed down through generations, emphasizes recognizing environmental cues associated with impending floods. Flash floods frequently occur during heavy rainfall in upstream areas, especially in the late afternoon when dark, dense clouds gather over mountain slopes. These clouds serve as visual indicators of increased water flow in the upper reaches, which may lead to a flash flood downstream.

In addition, the Gayonese observe auditory signs, such as roaring sounds or rumbling noises from upstream rivers. These sounds signal surging water flows carrying large debris, including boulders, logs, and sediment. Upon noticing such signs, the community immediately moves away from the riverbanks and warns others to seek safety. This practice reflects an ingrained lifestyle and a natural form of disaster mitigation passed through oral traditions (Dove, 2008; Rahman et al., 2023).

The Gayonese approach aligns with practices observed in Karonga, Malawi, where communities also rely on meteorological and hydrological indicators for disaster preparedness. Bucherie et al. (2022) found that Karonga residents recognize changes in wind patterns, the appearance of black convective clouds, and rising temperatures as early warnings of flash floods. Hydrologically, sudden changes in river flow velocity, increased water volume, discoloration to brown or black, and floating debris serve as critical signals. This local knowledge allows communities to prepare and reduce risk effectively.

These observations underline the importance of local knowledge in disaster risk reduction. Both the Gayonese and Karonga communities demonstrate a reliance on subtle environmental changes to enhance alertness and prompt timely responses, thereby minimizing disaster impacts. This underscores the dual role of local wisdom in preserving cultural identity and serving as a vital disaster mitigation tool in flash flood-prone regions (Syuryansyah and Habibi, 2024).

4.2 Mitigation of Flash Flood Disasters

4.2.1 Establishment of Forest Management Institutions

Mitigating natural disasters, particularly flash floods, requires an integrated approach that combines environmental conservation with community empowerment. In the context of local wisdom, collective natural resource management has proven to be an effective strategy for reducing disaster risks. A prime example is the establishment of the Forest Management Institution (LPHK) in 2017 by the Gayonese community in Kampung Damaran Baru, Aceh. This group, known locally as Mpu Uteun or Forest Guardians, stands out due to its composition of female members, often referred to as Women Rangers.

The formation of LPHK was a direct response to the destructive flash flood that struck the region on September 13, 2015. This disaster devastated 25 homes, destroyed roads, and damaged coffee plantations—the community's primary livelihood—while underscoring the critical need for forest protection as a mitigation measure.

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

The main objective of Mpu Uteun is to safeguard and sustainably manage forests to prevent flash floods and restore the forest's ecological functions. This initiative was facilitated through the Village Forest Program (Hutan Desa) under Indonesia's Ministry of Environment and Forestry, which provided a robust legal and institutional framework for community-based forest management (Shrestha et al., 2008; Trogrlić et al. 2019).

The initiatives led by Mpu Uteun have received widespread recognition both nationally and internationally. In 2023, the group was awarded the prestigious Kalpataru Award by the Indonesian government for their environmental conservation efforts. Additionally, Mpu Uteun gained global recognition, being included in Time Magazine's "100 Most Influential People," highlighting their vital role in community-based disaster mitigation.

As Women Rangers (see Fig. 3b,c), Mpu Uteun members have challenged traditional gender roles by actively patrolling forests, preventing illegal logging, and restoring degraded ecosystems. This aligns with findings from Tran et al. (2009) and Sopiawati and Hatuti (2019), which highlight that involving women in environmental management enhances the success of community-based mitigation programs.

Globally, similar examples can be found among women's groups in Nepal and India engaged in community forest management. In Nepal, Community Forest User Groups (CFUGs) empower women by involving them in decision-making processes and forest protection, providing access and control over natural resources (Leone, 2019). In India, the Chipko Movement led by women in the 1970s became an iconic success story in conservation, safeguarding forests from commercial exploitation. These parallels underscore the natural role of women as ecosystem stewards, driven by their motivation to protect their families and communities from environmental risks (Crowley, 2013).

Figure 3: (a) Umah Pitu Ruang, the traditional house of the Gayo people, designed as a stilt structure to adapt to flash floods. (b) The head of LPHK Damaran Baru at a revegetation site as part of community-based mitigation efforts. (c) Female rangers of Mpu Uteun Damaran Baru actively engaged in forest patrols and ecosystem conservation.

As a model of community-based management, LPHK Kampung Damaran Baru integrates environmental conservation, disaster mitigation, and community empowerment into a holistic approach. This reflects findings by Trogrlić et al. (2019), who emphasized that community-based institutions enhance adaptive capacity through the integration of local knowledge and

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

institutional support. Henriksen et al. (2023) further highlighted the importance of community-based management in disaster mitigation, particularly through forest protection and locally driven governance.

LPHK Kampung Damaran Baru demonstrates how local communities can independently manage disaster risks while significantly contributing to environmental conservation and societal resilience. The Women Rangers of LPHK exemplify community-based mitigation efforts that prioritize active community participation in environmental stewardship.

4.2.2 Revegetation and Landslide

Revegetation serves as a critical strategy in mitigating landslide risks in mountainous regions, including the 251-hectare Damaran Baru Forest, which forms the upstream area of Wih Gile River (see Fig. 4). Landslides in this region often carry soil and rocks that contribute to hydrological changes, including the risk of damming. In this context, revegetation plays a dual role: reducing erosion on slopes and restoring hydrological stability in critical areas (Zhao et al., 2018; Thapa et al., 2024).

The core of this strategy involves planting native tree species on landslide-prone slopes. These species are selected for their deep root systems, which strengthen soil structure and reduce erosion risks. Research by Amri et al. (2023) in Aceh demonstrated that multistrata vegetation, including grasses in the lower stratum and trees in the upper stratum, provides optimal protection against landslides by anchoring soil on steep slopes. Similarly, studies by Dhyani and Dhyani (2016) in the Himalayan region highlighted the effectiveness of layered vegetation in reducing runoff that triggers erosion in mountainous terrains.

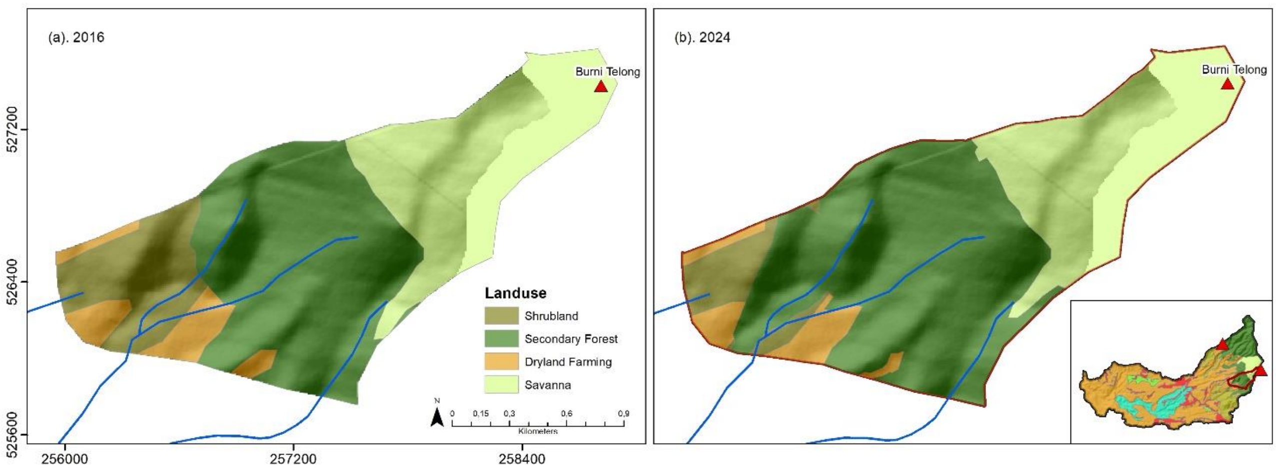

Figure 4: (a) Land conditions in 2016 after the 2015 flash flood, showing the dominance of shrubs and savanna before the revegetation program began. (b) Current conditions in 2024, with an 18% increase in forest cover after nine years of the revegetation program carried out by LPHK Kampung Damaran Baru. This program successfully restored the ecosystem in the Burni Telong area and strengthened flash flood risk mitigation efforts.

The success of the revegetation program initiated by LPHK Kampung Damaran Baru is evident in both ecological and disaster mitigation outcomes. Since the devastating flash flood of 2015, no similar incidents have occurred in the region.

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

Routine revegetation activities by LPHK have significantly reduced landslide occurrences, strengthened soil stability, and maintained the river ecosystem's balance.

Revegetation also supports broader ecosystem restoration. A study in Wenchuan, China, found that deciduous tree species are more effective in improving soil quality compared to evergreen species (Fusun et al., 2013). This aligns with the experience in Damaran Baru, where local vegetation has reduced erosion risks while maintaining the hydrological quality of rivers. Moreover, the revegetation program is guided by local wisdom, emphasizing community collaboration. Activities are often initiated based on observations made during forest patrols conducted by LPHK members. Comparatively, the Community Forest User Groups program in Nepal, as reported by Leone (2019), emphasizes involving local communities in vegetation selection to ensure ecosystem sustainability. Similarly, Marzuki and Gayo (2022) highlighted that successful environmental mitigation depends on integrating local knowledge with modern approaches.

As a community-based disaster mitigation model, the Damaran Baru revegetation program mirrors global findings. For instance, Canavesi and Dos Santos Alvalá (2012) demonstrated that community involvement in revegetation projects enhances the effectiveness of soil and water conservation efforts. By utilizing native tree species and encouraging active community participation, the revegetation efforts in Damaran Baru not only protect the environment but also strengthen community resilience against disaster risks.

4.2.3 River Patrolling for Preventing Damming

Flash floods are among the most destructive hydrological threats in mountainous regions, often triggered by damming of river flows due to landslides or other debris. Their devastating impacts include widespread physical damage and the loss of livelihoods. In Kampung Damaran Baru, a community-based river patrolling program, organized by LPHK, serves as a mitigation measure to prevent the formation of natural blockages in river channels (see Fig. 5). This program not only strengthens disaster risk management but also empowers the community to protect forest and river ecosystems.

Extreme rainfall is a primary trigger of damming and subsequent breaches of natural blockages. Research by Hou et al. (2020) highlights that high precipitation intensifies water pressure behind blockages, significantly increasing the risk of structural failure and flash floods. Similarly, Yang et al. (2020) demonstrated that rainfall intensity and duration influence blockage formation, particularly in areas with steep topography and high erosion rates. In Kampung Damaran Baru, persistent rainfall has been identified as an early warning indicator of damming risks, forming the basis for proactive mitigation through river patrolling.

Local wisdom also plays a crucial role in identifying signs of flash flood risks. Before the 2015 flash flood, the woman who now leads LPHK observed the formation of a large pool in the Wih Gile River, an indication of increasing water pressure behind a blockage. Unfortunately, this warning was ignored at the time, leading to unavoidable disaster. This experience became a vital lesson, and such knowledge now guides river patrols in identifying and addressing potential hazards.

LPHK's river patrolling activities extend beyond monitoring to include the manual clearing of blockages obstructing river flow. Debris such as fallen trees, landslide material, and large rocks are removed using simple tools by LPHK members.

https://doi.org/10.5194/egusphere-2024-3774
Preprint. Discussion started: 17 February 2025

Research by Zain et al. (2021) confirms that clearing blockages in small catchments can significantly reduce flash flood risks at a much lower cost compared to large-scale infrastructure projects like dams.

The program's effectiveness is evident in its outcomes: since its implementation in 2015, no major flash floods have occurred along the Wih Gile River up to 2024. Over the past nine years, the program has successfully reduced disaster risks while strengthening community resilience to hydrological threats. However, despite its proven effectiveness, this initiative has yet to be incorporated into the local government's core disaster mitigation policies.

Globally, LPHK's river patrolling and blockage-clearing practices align with findings by Bronstert et al. (2018), which emphasize that removing debris from river channels reduces hydraulic pressure and enhances ecosystem stability. Additionally, research by Khan et al. (2020) highlights the importance of integrating community-based approaches into formal policies to enhance disaster mitigation effectiveness.

The success of LPHK Kampung Damaran Baru's river patrolling demonstrates that simple community-based measures can have a significant impact on mitigating hydrological disasters. This approach offers a low-cost, sustainable solution that can be replicated in other regions facing similar flash flood risks. Their experience provides valuable insights for developing broader community-based mitigation policies.

Figure 5: (a) Landslide conditions blocking the river flow, creating potential damming that can increase the risk of flash floods. (b) River patrol activities conducted routinely by LPHK members to monitor water flow and detect potential blockages. (c) Mpu Uteun members collaboratively removing blockages, such as fallen trees and landslide materials, to maintain smooth river flow and prevent damming risks.

5 Conclusions

This study demonstrates that the indigenous wisdom of the Gayo community in the Gayo Highlands, Aceh, significantly contributes to the adaptation and mitigation of flash flood risks. Community-based strategies, such as river patrolling, reforestation, and the use of traditional architecture, have proven effective in reducing flash flood risks over the past nine years since 2015. These initiatives not only enhance community resilience but also sustainably preserve the ecological functions of the local environment.

The findings underscore the importance of integrating indigenous knowledge with ecosystem-based approaches and modern technology to develop disaster mitigation models that are globally relevant. These strategies also offer flexibility in their application, allowing adaptation based on the socio-ecological characteristics of different regions. However, the success of these strategies is highly context-dependent, and their generalization requires a cautious approach. Consequently, further research is needed to explore the potential for replicating these strategies in regions with diverse ecological and social characteristics. Additionally, collaboration between local communities, governments, and global institutions is critical to ensure effective knowledge transfer and support the development of community-based mitigation strategies.

As a practical recommendation, integrating community-based practices into national disaster mitigation policies is essential to ensure sustainability and scalability. Supportive policies, such as resource allocation, incentives for community-based practices, and technology-focused training, are crucial to guaranteeing long-term sustainability. Through a synergy of local and global approaches, indigenous wisdom can emerge as a universal solution to address hydrometeorological threats in the era of climate change.

Author Contributions. CA served as the principal investigator, prepared the research proposal, conducted the research, performed data analysis, and led the writing and revision of the manuscript. CAL assisted in data collection and reviewed the manuscript. Sarif Robo performed GIS analysis, contributed to data interpretation, and reviewed the manuscript. Z served as the architectural and spatial planning expert, analyzed the traditional Umah Pitu Ruang houses, and reviewed the manuscript. IA is a researcher from the Gayo ethnic group who provided in-depth insights into the cultural characteristics of the community, contributed to the interpretation of local practices, and reviewed the manuscript. MI and RM are experts in social and cultural studies who analyzed the sociocultural dimensions of the Gayo community, contributed to the interpretation of community practices, and reviewed the manuscript. Ismahadi assisted in the research process as a graduate student, supported field activities, and reviewed the manuscript.

Competing interests. The contact author declares that neither they nor their co-authors have any competing interests.

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