



Geocological-Based Strategy for Ecosystem Improvement in Volcanic Zones: A Preliminary Study from Jurang Jero Area, Merapi National Park

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Abstract

Mount Merapi, one of Indonesia's most active volcanoes, has repeatedly altered surrounding river ecosystems through frequent eruptions, with the 2010 event producing over 140 million cubic meters of pyroclastic material. This preliminary study aims to analyze the geocological dynamics of the Jurang Jero sector in Merapi National Park, which has experienced severe impacts on river morphology, sedimentation, water quality, and riparian vegetation. A desk study approach was employed, synthesizing secondary data that included geological and hazard maps, remote sensing imagery, hydrological records, and published scientific reports. Findings indicate that lahar-induced sedimentation after 2010 resulted in aggradation, channel widening, and a reduction in river capacity, with some sabo dams quickly reaching their limits. Water quality deteriorated due to extremely high suspended solids, increased turbidity, and elevated heavy metals, although these effects were partly temporary. Riparian vegetation suffered extensive damage, followed by natural succession dominated by invasive species such as *Acacia decurrens*, which hinders native regeneration. Nevertheless, signs of ecological recovery have emerged, as evidenced by the presence of pioneer species and the implementation of rehabilitation programs. This study highlights the need for a geocology-based adaptive conservation strategy that integrates river morphology rehabilitation, sediment management, water quality improvement, and riparian vegetation restoration while involving local communities. The proposed framework provides a conceptual basis for future field research and practical river ecosystem management in volcanic landscapes.

Keywords: Mount Merapi, Jurang Jero, lahar sedimentation, riparian vegetation, geocological restoration

INTRODUCTION

Mount Merapi, one of Indonesia's most active volcanoes, has a long record of destructive eruptions (Global Volcanism Program, 2025). The 2010 eruption alone produced over 140 million m³ of pyroclastic material, which is highly erodible (Surjono et al., 2012). During the rainy season, this loose debris is easily remobilized into lahars that flow rapidly through river channels. Merapi's rivers serve not only as lahar pathways but also as vital freshwater ecosystems that support biodiversity and meet human needs. In the Krasak watershed, they provide water for over 28,000 residents and farmland (Sunardi et al., 2017). However, volcanic activity degrades water quality, alters habitats, and introduces toxic materials that stress aquatic life and ecosystem services (Sunardi et al., 2024).

Sediment influx from Merapi's eruptions has caused river aggradation and morphological change. After 2010, pyroclastic deposits filled rivers like Kali Gendol, Pabelan, and Opak, making them shallower and braided (Ikhsan & NK, 2021). Several sabo dams quickly reached capacity, and river valleys nearly lost their carrying capacity due to volcanoclastic deposits (Surjono et al., 2012). Riverbed aggradation and heavy sediment loads degrade habitats, water clarity, and aquatic life cycles. This study presents a preliminary geocological analysis of the geology, sedimentation, and

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river conditions in the Jurang Jero area of Mount Merapi National Park, Srumbung District, Magelang Regency (see Figure 1), aiming to link volcanic processes with ecological outcomes and inform adaptive conservation strategies.

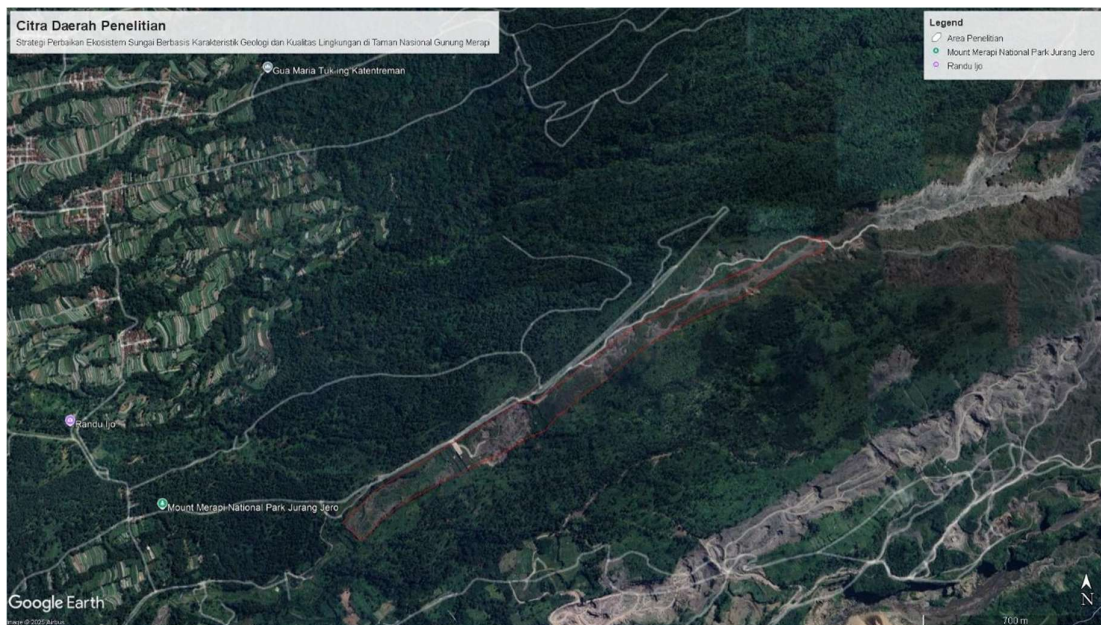


Figure 1. Satellite image of the research area (Jurang Jero and surrounding areas). The study area is marked with a red box. (Source: [Google, 2025](#))

LITERATURE REVIEW

Mount Merapi, situated in the Indo-Australian–Eurasian subduction zone, is highly active, characterized by lava domes, avalanches, and lahars. Its eruptions disperse ash, sand, and pyroclastic blocks that supply sediment to rivers ([Harijoko et al., 2023](#)). Rivers such as Gendol, Kuning, Opak, and Boyong have steep radial flows, serving as hydrological channels and main conduits for volcanic sediment transport. The 2010 eruption produced massive pyroclastic deposits that, during the wet season, eroded into cold lava flows, accelerating riverbed sedimentation ([de Bélizal et al., 2013](#)). Post-eruption effects include silting, delta formation, and morphological changes ([Ville et al., 2015](#)), leading to avulsion, lateral erosion, and heavy deposition that reduce river capacity and increase ecological and socioeconomic risks.

Volcanic sedimentation causes river silting that degrades benthic habitats, reduces aquatic biota, and damages riparian vegetation ([Ikhsan & NK, 2021](#); [Sunardi et al., 2024](#)). Water quality declines due to high TSS, turbidity, and chemical changes, while natural recovery processes like succession and flow stabilization are slow and often ineffective in dynamic volcanic environments.

River rehabilitation in volcanic regions combines technical measures—such as sabo dams, embankment reinforcement, and sediment removal—with ecological strategies like revegetation using native species adapted to volcanic substrates ([Wohl et al., 2024](#)). [Ishaq et al. \(2020\)](#) showed that *Parasponia rigida*, a non-leguminous nitrogen-fixing tree, exhibits significant natural regeneration potential on volcanic ash substrates. Effective rehabilitation also requires local community involvement and alignment with economic needs.

Geoecology-based restoration aligns ecosystem recovery with geology, geomorphology, and natural dynamics, considering factors such as eruption frequency, sediment characteristics, and river transport capacity ([Wohl et al., 2024](#)). It emphasizes process-based restoration—allowing

natural channel reformation, restoring riverbank connectivity, and adapting revegetation to eruption disturbances—offering greater long-term flexibility and sustainability.

RESEARCH METHOD

The study was conducted as a preliminary desk study on river systems in Merapi National Park, specifically focusing on the Jurang Jero sector in Srumbung District, Magelang Regency. It synthesizes secondary datasets and literature to build a geoecological framework for volcanic river restoration. Data sources included geological and hazard maps from the Geological Agency of Indonesia and BPPTKG, as well as scientific articles and technical reports on sedimentation, water quality, and post-eruption vegetation, combined with reports from newspapers. Additional case studies on river restoration and geoecology were reviewed to identify applicable frameworks for this study. Analytical methods comprised geomorphological assessment using DEMs and reports, sediment dynamics evaluation through literature on grain size and transport, water quality analysis from monitoring studies, and review of riparian vegetation with attention to invasive species such as *Acacia decurrens*. All findings were integrated into a geoecological framework linking geological processes, ecological responses, and management strategies, while also highlighting research gaps for future field validation.

FINDINGS AND DISCUSSION

This section presents preliminary findings on river ecology in Jurang Jero, southwestern Mount Merapi, based on secondary data from reports, academic studies, and geospatial interpretations. The study encompasses the upper Kali Putih River and its surrounding areas, concentrating on river morphology, post-eruption sedimentation, water quality, and riparian vegetation.

River Morphology

Rivers on Merapi's southwest slopes, including Jurang Jero, are characterised by steep gradients, narrow canyons, and loose pyroclastic deposits, making them highly dynamic and prone to rapid morphological change during lahars or flash floods. The Putih River, flowing southwest from Merapi's summit (~2,968 m asl), exemplifies this vulnerability due to the combination of steep slopes and erodible volcanic materials.

Sediment control structures further shape the Putih River's morphology. Since the late 1990s, sabo dams built upstream have played a key role in retaining volcanic material (Nurmans, 2022). These infrastructures, together with natural bank heights, influence channel stability and flood risks, where lower banks increase the likelihood of overflow during lahar events (Gob et al., 2016). Thus, river valley morphology results from interactions between hydrological dynamics, volcanic valley forms, and human interventions such as sabo dams and sand mining.

Post-2010 eruption studies show significant morphological changes in Jurang Jero, particularly in Kali Putih. Cold lahars widened the riverbed—at Jumoyo, channel width expanded from ~20 m pre-eruption to 50–60 m afterward (Sinombor & Rukmorini, 2011). Upstream, aggradation raised the riverbed, while elsewhere erosion deepened channels by ~8 m and deposition raised beds by ~10 m (Gob et al., 2016; de Bélizal et al., 2013). These vertical and lateral adjustments reflect the river's adaptation to high sediment loads, with channels later narrowing as vegetation stabilises banks and flows reshape channels. However, equilibrium remains fragile, depending on sediment supply and the frequency of new disturbances.

Post-Eruption Sedimentation

The 2010 eruption of Mount Merapi produced ~140 million m³ of pyroclastic material deposited on the summit and slopes, much of which was transported as lahars during the 2010–2012 rainy seasons. Over 250 lahar events were recorded, with the Putih River experiencing at least 29, making it one of the most affected channels, along with the Pabelan, Lamat, and Krasak rivers (Attamami & Eka, 2011; de Bélizal et al., 2013).

These lahars caused severe environmental and infrastructural impacts in Jurang Jero. Dozens of sabo dams on the Putih River overflowed or were destroyed, such as the Jengglik Dam, which failed on November 8, 2010, diverting flows into the Batang River and burying five hamlets. In the Pabelan River, lahars eroded the riverbed by 3–5 m and destroyed the Srowol Bridge (Attamami & Eka, 2011). These events highlight that lahars not only deposit sediment (aggradation) but also cause deep bed erosion, altering channel capacity.

Downstream, vast sediment deposits buried hundreds of hectares of farmland, with thickness ranging from tens of centimetres to several metres; in Klumpukan Hamlet, sand exceeded 2 m, submerging houses (Sinombor & Rukmorini, 2011). Satellite imagery showed ~2 km² of the Putih River was directly covered by lahar deposits in 2011. BPPTKG estimated that only ~30% of the erupted sediment had been transported by early 2011, allowing lahars to persist for years (Attamami & Eka, 2011). Although lahar frequency decreased after 2012, elevated riverbeds continue to reduce channel capacity, raising flood risks during high flows.

Water Quality (Physical and Chemical)

The 2010 Merapi eruption severely degraded the water quality of the Jurang Jero river. Suspended volcanic ash and fine lava materials caused extreme turbidity, with water appearing like “coffee with condensed milk” and TSS levels far above standards (Budianta, 2016). Chemical changes also occurred, including a lower pH and elevated concentrations of Fe, Mn, Pb, Cd, and Se; however, these effects were generally temporary, as conditions normalized within weeks to months (Budianta, 2016).

In the medium term, pyroclastic deposits continued to affect rivers by releasing ions such as sulphate and increasing oxygen demand from buried organic matter. About two months after the eruption, several parameters—including iron, acidity, turbidity, and TSS—remained above thresholds, indicating that volcanic impacts persisted through the first post-eruption rainy season (Budianta, 2016).

In later years, water quality deterioration was increasingly driven by human activities. A study in the Krasak River Basin showed current conditions classified as class III–IV, suitable only for irrigation or limited fisheries. Upstream, mining areas contributed high TDS and TSS, while downstream, agricultural and residential runoff raised nitrate, phosphate, and faecal coliform levels, with coliform counts reaching tens of thousands MPN/100 mL (Sunardi et al., 2024). These findings confirm that, beyond volcanic residues, anthropogenic pollution has become the dominant factor, exceeding the river’s self-purification capacity and classifying its water as “heavily polluted” (Sunardi et al., 2024).

Riparian Vegetation

Riparian vegetation in Jurang Jero plays a vital role in stabilising land and supporting habitat quality, but volcanic disturbances and land-use history have strongly shaped it. Before the 2010 eruption, the southwest slopes of Merapi were likely covered by secondary forests and cultivated land, while canyon edges in Jurang Jero were dominated by *Pinus merkusii* from former Perhutani production forests. These pine stands could withstand light ashfall but were vulnerable to pyroclastic flows and heavy debris (Nurmans, 2022).

The 2010 eruption caused extensive damage to riparian vegetation. Pyroclastic flows and ashfall destroyed vegetation in directly affected zones, burning or burying nearly all plants along impacted rivers (Sutomo et al., 2015). On the southwest slopes, though pyroclastic flows did not reach the Putih/Pabelan Rivers, heavy ashfall and lahar floods uprooted trees and shrubs, leaving large stretches of bare sand and gravel along riverbanks.

Post-eruption succession soon followed, with pioneer species colonising the nutrient-poor volcanic deposits. However, many were invasive alien species, notably *Acacia decurrens*, which spread widely across Merapi National Park and dominated open riverbanks (Sunardi et al., 2017). Other aggressive weeds, such as *Ageratina riparia*, also thrived and persisted even as other plants began to regenerate (Sutomo et al., 2015). These invasives threatened the recovery of native species and could alter long-term riparian habitat composition.

Despite this, signs of native ecosystem recovery appeared in subsequent years. Seedlings of local trees such as bay leaves, native acacias, and bamboo began to establish in less disturbed riparian zones. Vegetation growth has contributed to sediment stabilisation and channel narrowing after lahars, as roots strengthen riverbanks and trap fine sediments (Gran et al., 2015 in Gob et al., 2016). In Jurang Jero, residual pine stands and pioneer species provide shade and favourable microclimates for succession.

Active rehabilitation efforts have also been introduced. Since 2013, the national park authority and local farmer groups have implemented initiatives, such as the “Adopt a tree” program, to restore native vegetation (Nurmans, 2022). Although vegetation density is improving, the riparian zone remains a mosaic of pine stands, pioneer grasses, invasive exotics, and regenerating natives. While this offers hope for river stability, the dominance of invasives remains a significant challenge for biodiversity conservation and riparian ecosystem restoration.

Conservation Plan and Further Research Strategy

The conservation of river ecosystems in Jurang Jero, situated on the southwestern slope of Mount Merapi, requires an adaptive and data-driven approach that considers the dynamic geological setting and recurring volcanic disturbances. Four main strategies are proposed: river morphology rehabilitation, active sediment management, water quality improvement, and riparian vegetation restoration. Interventions include channel normalization, strengthening of riverbanks with vegetative and structural measures, sediment removal from overfilled sabo dams, installation of simple water purification systems, and the replanting of native vegetation while controlling invasive species such as *Acacia decurrens*.

Community and stakeholder engagement is recognized as central to the success of these initiatives. Conservation planning emphasizes participatory approaches through education, collaboration with local farmer groups and volunteers, and the creation of watershed communication forums. Partnerships with the Merapi National Park Authority, environmental agencies, and technical institutions are critical to ensuring effective and sustainable implementation.

Further research is recommended to refine and validate conservation strategies. Suggested activities include detailed geomorphological mapping with drones, seasonal water quality monitoring, comparative studies of native versus exotic vegetation, small-scale restoration trials, and socioeconomic assessments of community involvement in river management. These efforts will generate evidence-based insights to guide adaptive ecosystem restoration.

To ensure long-term effectiveness, a monitoring and evaluation framework is essential. Proposed indicators include changes in river morphology, water quality parameters (TSS, pH, DO, coliform), vegetation recovery rates, and community participation levels. Findings should be reported regularly through technical documents and visual formats to maintain transparency and

accountability. Overall, the framework emphasizes a geoecological approach that integrates geological dynamics, ecological processes, and social participation to achieve sustainable river restoration in volcanic environments.

CONCLUSIONS

Based on the preliminary study above, it can be concluded that the river ecosystem on the southwest slope of Mount Merapi (especially Jurang Jero and its surroundings) is still in the adjustment phase following the major eruption of 2010. The river morphology has undergone drastic changes due to lahar sedimentation, with the channel cross-section widening and shallowing in many places, although natural stabilisation is slowly starting to occur. The abundant volcanic sediment deposits constitute a significant challenge, also impacting the decline in water quality physically (high turbidity) and chemically (metal and nutrient contamination). Riparian vegetation exhibits a process of regeneration, but is characterized by the dominance of invasive pioneer species that have the potential to hinder succession toward the original ecosystem condition. These findings emphasize the need for a comprehensive river ecosystem improvement strategy based on geological characteristics (morphology and sedimentation) and environmental quality (water and biota).

The river conservation plan in Jurang Jero, on the southwest slope of Mount Merapi, emphasizes a geoecologically based adaptive approach with key strategies including river morphology rehabilitation, sediment management, water quality restoration, and riparian vegetation restoration using local species and invasive species control. Conservation success depends on community participation and stakeholder synergy through education, reforestation collaboration, and watershed communication forums.

LIMITATIONS & FURTHER RESEARCH

Further research focuses on geomorphological mapping, water quality monitoring, studies of local versus exotic vegetation, restoration experiments, and socioeconomic studies. Effectiveness is maintained through a measurable monitoring system encompassing morphological conditions, water quality, vegetation, and community participation, which is reported periodically in both technical and visual formats.

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