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Enhancing Evacuation Planning in High-Risk Areas: A Case Study of Laurel, Batangas, Philippines, Post-2020 Taal Volcano Eruption

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ABSTRACT

Effective evacuation planning is vital for safeguarding lives and minimizing damage during natural disasters. This study explores the challenges and opportunities associated with evacuation planning in Laurel, Batangas, Philippines, following the 2020 eruption of Taal Volcano. Anchored in the framework of the UNDRR's Making Cities Resilient Campaign, the research focuses on evaluating evacuation route management and emergency shelter placement in a high-risk volcanic setting.

The study critically reviews historical eruption data and past evacuation responses, identifying key issues such as delayed response times, transportation limitations, and the area's complex terrain. It further assesses the adequacy of existing evacuation centers and proposes improvements to optimize accessibility and safety.

Utilizing Geographic Information Systems (GIS) and spatial analysis, the research maps local street networks to identify optimal rescue points and alternative evacuation routes, particularly for the most vulnerable zones. These findings contribute to enhancing disaster preparedness and community resilience.

The study underscores the importance of developing context-specific evacuation strategies that reflect the unique characteristics of volcanic hazards. By addressing existing gaps in evacuation planning and integrating spatial tools, this research aims to support more effective and adaptive disaster risk reduction efforts in Laurel and other similarly vulnerable communities.

Keywords: evacuation planning, Taal Volcano, spatial analysis, disaster risk reduction, volcanic hazards, Laurel Batangas, GIS, emergency shelters

INTRODUCTION

Natural disasters, both natural and anthropogenic, pose significant challenges to communities worldwide. In the Philippines, the increasing frequency and severity of such events have highlighted the necessity for comprehensive disaster risk reduction (DRR) strategies, particularly in evacuation planning for communities situated in hazard-prone areas.

Established in 2010, the United Nations Office for Disaster Risk Reduction's Making Cities Resilient campaign aims to promote disaster-resistant and sustainable urban environments. A critical component of this initiative is the development of effective evacuation plans, especially in regions susceptible to volcanic hazards.

Taal Volcano, located on Luzon Island, is among the most active and hazardous volcanoes in the Philippines. Its eruptions, notably those in 1754, 1911, and the recent event in January 2020, have underscored the urgency for enhanced community preparedness and response mechanisms. The 2020 eruption, following 43 years of dormancy, led to the evacuation of thousands within a 14-kilometer radius. However, the evacuation process faced challenges, including delays, limited transportation, and inadequate route connectivity, particularly in the municipality of Laurel, Batangas.

Laurel, a lakeside municipality approximately 10 kilometers from Taal Volcano, is characterized by its economic activities in agriculture, fisheries, and ecotourism. Its complex topography, with settlements along the shoreline and reliance on narrow, sloped road networks, exacerbates its vulnerability during volcanic events. While evacuation centers have been designated, several are located within the risk zone, raising concerns about their safety and effectiveness.

Existing literature emphasizes the importance of pre-disaster evacuation mapping, public risk perception, and spatial analysis in improving disaster response strategies (Marzocchi & Woo, 2007; Lindsay et al., 2011; Sandri et al., 2012). However, there is a scarcity of studies focusing on the integration of geospatial tools and connectivity-based planning to enhance evacuation efficiency in the Philippine context, particularly at the municipal level.

This study aims to address this gap by employing Geographic Information Systems (GIS) and spatial network analysis to improve evacuation planning in Laurel, Batangas. The objectives are to:

1. Assess household preparedness and its impact on evacuation outcomes during the 2020 Taal eruption.
2. Identify barriers hindering safe and timely evacuation.
3. Propose connectivity-based evacuation routes and optimize open space networks as rescue points for high-risk barangays.

By focusing on the intersection of spatial planning and disaster management, this research seeks to integrate geospatial data and local knowledge into evacuation strategy development. The findings aim to offer practical insights for urban planners, policymakers, and disaster response agencies working to enhance community resilience in multi-hazard environments.

LITERATURE REVIEW

Effective disaster preparedness and evacuation planning, particularly in volcanic-prone areas, necessitate a multi-dimensional approach that integrates policy, spatial analysis, community engagement, and technological innovation. This literature review synthesizes both international and Philippine-based scholarship, offering insights into frameworks, tools, and localized strategies used to mitigate disaster risk.

Global Frameworks for Disaster Risk Reduction

Internationally, the Hyogo Framework for Action (2005–2015) and the succeeding Sendai Framework for Disaster Risk Reduction (2015–2030) serve as foundational blueprints for enhancing resilience to natural hazards. These frameworks advocate for risk-informed development, stronger governance, and people-centered early warning systems. Key priorities include understanding disaster risk, strengthening risk governance, investing in resilience, and enhancing preparedness for effective response and recovery. Such frameworks emphasize the necessity of translating global principles into localized action plans and preparedness protocols, particularly in high-risk zones.

Disaster Risk Governance and Legislation in the Philippines

In alignment with global protocols, the Philippines institutionalized Republic Act No. 10121, establishing a proactive paradigm in disaster risk reduction and management (DRRM). The Act underscores the need for institutional structures—from the National Disaster Risk Reduction and Management Council (NDRRMC) to local DRRM offices—and promotes community-based disaster preparedness. The Department of the Interior and Local Government's (DILG) Operation Listo program exemplifies this approach, offering a

checklist-based readiness system for local governments to enhance their risk awareness, planning, and response capabilities.

GIS-Based Approaches in Evacuation Planning

Geographic Information Systems (GIS) and spatial modeling have become essential in risk assessment and evacuation planning. GIS enables the mapping of hazard-prone areas, demographic vulnerabilities, transportation networks, and shelter locations. By overlaying risk data with infrastructure maps, planners can identify optimal evacuation routes and staging points. Recent studies also advocate for integrating GIS with agent-based modeling (ABM) to simulate human behavior during volcanic crises, allowing dynamic and adaptive evacuation modeling that reflects real-world uncertainties.

Volcanic Hazards and Community Behavior

Evacuation behavior is profoundly influenced by residents' previous disaster experiences, trust in authorities, and perceptions of risk. Empirical studies on Taal Volcano in the Philippines show a nuanced relationship between hazard proximity, community response, and the effectiveness of early warning dissemination. The Alert Level scheme, while central to public safety messaging, often requires further calibration to reflect a broader range of volcanic activity, including effusive eruptions or quiet dome growth. Community education, participatory planning, and sustained risk communication emerge as vital components of any successful evacuation protocol.

International & Local Case Studies on Volcanic Preparedness

Several global case studies illustrate diverse yet complementary approaches to volcanic disaster management:

Taiwan: Tsai and Chang (2023) emphasize revisiting spatial structures over merely expanding shelter capacity, highlighting the role of updated road networks and spatial reconfiguration to improve emergency accessibility.

Japan: Nakao (2005) details effective zoning and engineering interventions at Mt. Usu, including sabo dams and land-use planning, which collectively minimized volcanic impacts through proactive spatial governance.

Indonesia: Research on Mt. Merapi underscores the need for integrated physical and social risk frameworks. The proposed use of agent-based models, combined with GIS, reflects a more comprehensive approach to evacuation planning under uncertain and rapidly evolving volcanic threats.

Chile: The eruption of Calbuco Volcano reveals the value of scientific coordination and contingency planning. Lessons include managing large volumes of volcanic material, enhancing interagency communication, and tailoring responses to socio-cultural contexts.

Philippines: The cases of Mayon and Camiguin illustrate both behavioral and institutional dimensions of evacuation. In Mayon's case, risk perception and historical memory strongly influenced community compliance with evacuation orders. Camiguin, on the other hand, showcases best practices through its detailed contingency plans, early warning systems, and stakeholder coordination.

MATERIALS AND METHODS

This study investigates evacuation preparedness in the Municipality of Laurel, Batangas, during the 2020 Taal volcanic eruption. A mixed-methods approach integrating both qualitative and quantitative data was employed, supported by Geographic Information Systems (GIS) to analyze evacuation logistics, road networks, and the spatial configuration of emergency shelters.

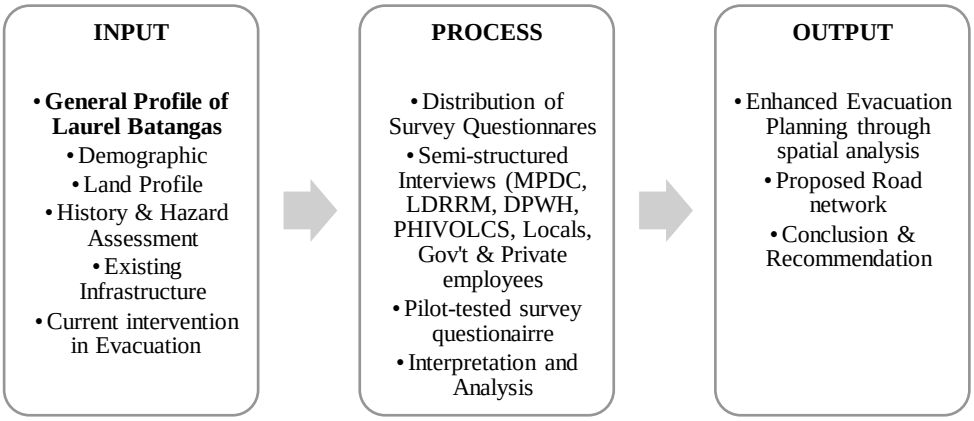


Figure 1: Research Paradigm

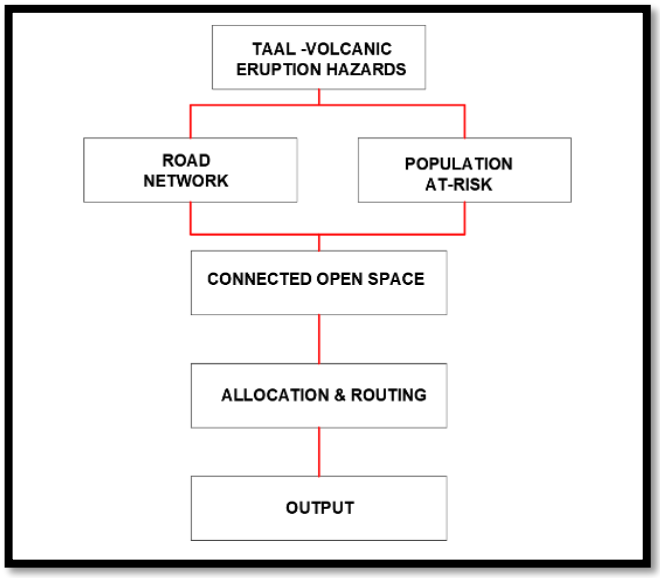


Figure 2: Research framework

Research Design

A mixed-methods design was adopted to comprehensively examine the multiple dimensions of disaster preparedness. Quantitative data were obtained through household surveys, while qualitative data were collected from semi-structured interviews with local government officials, emergency responders, and key stakeholders.

The study was guided by a research framework that incorporated hazard assessment, road network analysis, population vulnerability mapping, and the design of networked evacuation spaces. GIS was used to evaluate spatial accessibility, identify critical infrastructure gaps, and support data-driven planning for evacuation routes and rescue points.

Data Collection

Primary Data

- Household Surveys: A structured questionnaire was distributed to 100 residents aged 18 and above, with a target composition of 60% local residents, 20% livestock owners, and 20% LGU representatives. Convenience sampling was employed due to logistical constraints.

- Semi-Structured Interviews: Conducted with relevant authorities to supplement and contextualize survey data.

The survey consisted of five key sections: (1) socio-economic and household characteristics, (2) risk perception, (3) evacuation experience and accessibility, (4) knowledge and use of networked spaces, and (5) open-ended comments for future recommendations.

Secondary Data

Secondary sources included scholarly articles, local disaster risk reduction plans, hazard maps, legal frameworks, and government reports. These sources helped frame the contextual background and supported spatial analysis.

Data Analysis

Quantitative Analysis

- Descriptive statistics (frequency, percentage, mean, standard deviation) were used to analyze household preparedness, evacuation behavior, and accessibility. Likert scales helped quantify perceptions and experiences related to the 2020 eruption.

Qualitative Analysis

- Thematic analysis was conducted on interview transcripts to identify recurring themes in institutional coordination, shelter readiness, and public communication.

GIS-Based Spatial Analysis

- Map street networks to assess road conditions, identify bottlenecks, and analyze route efficiency. Evaluate shelter locations by analyzing spatial connectivity and accessibility for both humans and livestock.

Design networked evacuation points based on proximity to risk zones, open space suitability, and accessibility via multiple transport modes. The spatial analysis informed the formulation of optimized evacuation routes and strategically located rescue points to improve community safety and resilience.

RESULTS & DISCUSSION

This study analyzed the evacuation preparedness and experiences of 84 residents of Laurel, Batangas during the 2020 Taal Volcano eruption. Using convenience sampling, the research focused on mobility patterns, risk perception, and logistical barriers to evacuation. The findings directly inform a proposed evacuation planning framework tailored to volcanic contexts.

Demographic Profile and Risk Context

Respondents represented a cross-section of the community: 49% were residents, 33% livestock owners, and 18% LGU officials. Most respondents were male (57%) and aged 40–60 (46%), with 78% residing in Laurel for over two decades. Educational attainment varied, with 55% finishing high school and 30% completing higher education. Households were primarily medium-sized (5–10 members, 55%), and 72% lived within 14 kilometers of Taal Volcano.

***Implication*:** The maturity, long-term settlement, and community embeddedness of respondents point to strong place attachment—a known factor in evacuation hesitancy. Planning must therefore include culturally sensitive messaging and participatory decision-making.

Risk Awareness and Perceived Threat

Approximately 83% of respondents acknowledged Taal Volcano as a serious threat, and 61% reported being moderately informed. However, 6% had no knowledge of volcanic hazards.

***Implication*:** While general awareness is high, gaps remain in hazard-specific education. Targeted disaster education campaigns should be institutionalized at the barangay level, supported by LGU-led drills, especially for those in the 7–10 km high-risk zones.

Evacuation Experience and Mobility Patterns

Evacuation was predominantly conducted on foot (36%), followed by private vehicles (24%), motorcycles (18%), and rescue vehicles (22%). No respondents used public transportation. The duration of evacuation varied significantly: 43% reported delays exceeding five hours, particularly among those without motorized transport. Seventy-five percent evacuated to areas outside Laurel, while none accessed local evacuation centers.

***Implication*:** The absence of accessible public transport and localized shelters contributed to significant delays and risk exposure. Proposed solutions include:

- Dedicated evacuation transport routes, especially for households without private vehicles.
- Partnerships with local transport operators to mobilize public transit in future eruptions.
- Decentralized evacuation centers, strategically placed outside the 14-km danger zone yet within municipal jurisdiction.

Evacuation Barriers and Psychological Factors

Respondents rated emotional distress (mean = 4.82), concerns over livestock (4.68), traffic congestion (4.57), and lack of transport (4.26) as the most severe challenges. Physical access limitations (mean = 3.04) were also cited. These findings reflect both logistical and psychosocial vulnerabilities during crises.

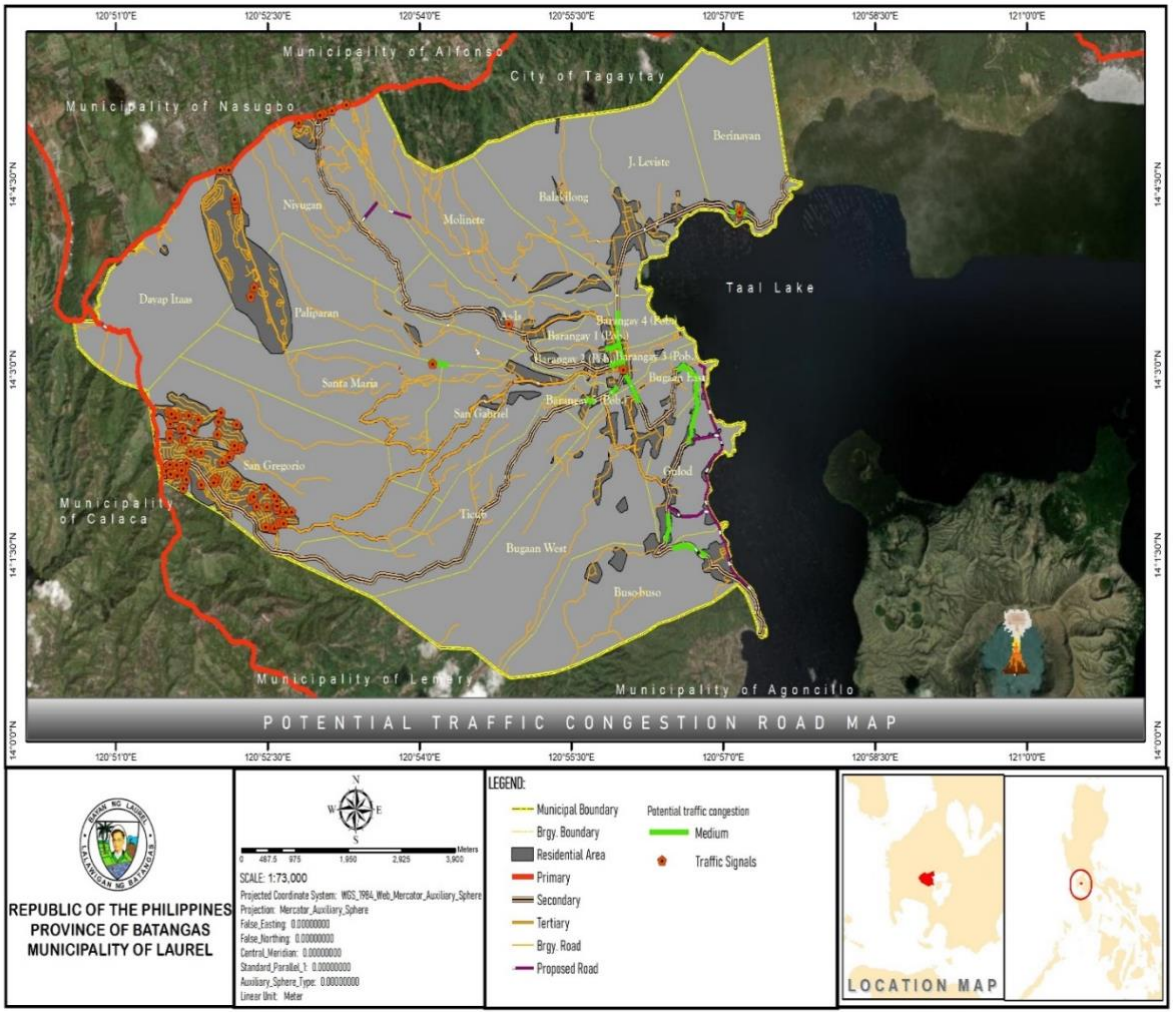
***Implication*:** Evacuation planning must move beyond physical infrastructure to integrate:

- Mental health supports pre- and post-disaster mechanisms.
- Animal rescue protocols to address livestock-dependent households.
- Community-based early warning systems to offset last-minute evacuations.
- Evacuation time modeling using GIS to optimize route planning and reduce bottlenecks.

Proposal

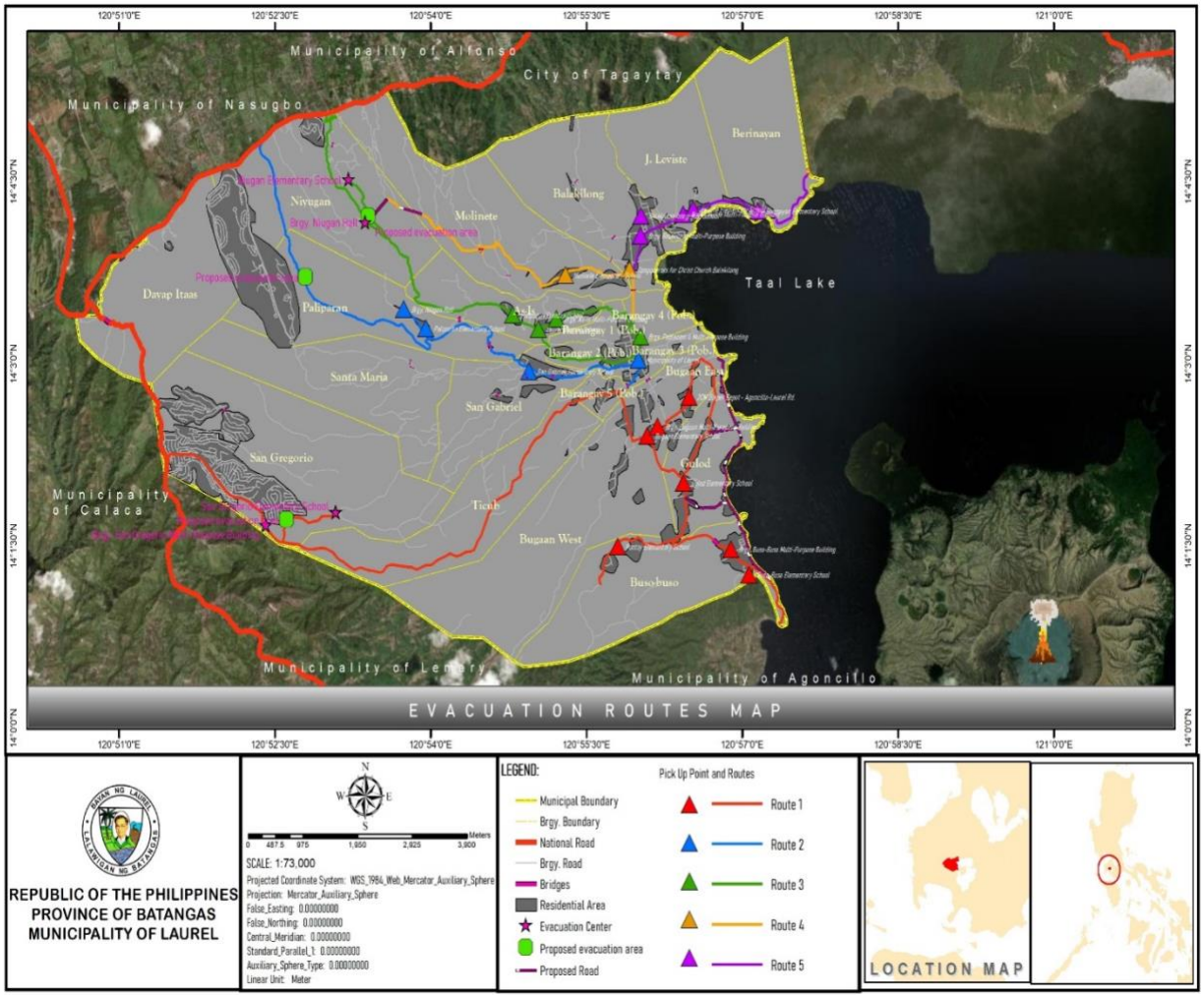
- ***Map of Identified Congestion-Prone Areas and Proposed Alternate Evacuation Routes in Laurel, Batangas***

This map illustrates high-risk traffic zones within the municipality, particularly around the urban center and key intersections near schools. Overlaid with satellite imagery and road network data, the figure also shows proposed alternate evacuation routes to ease congestion during emergencies.



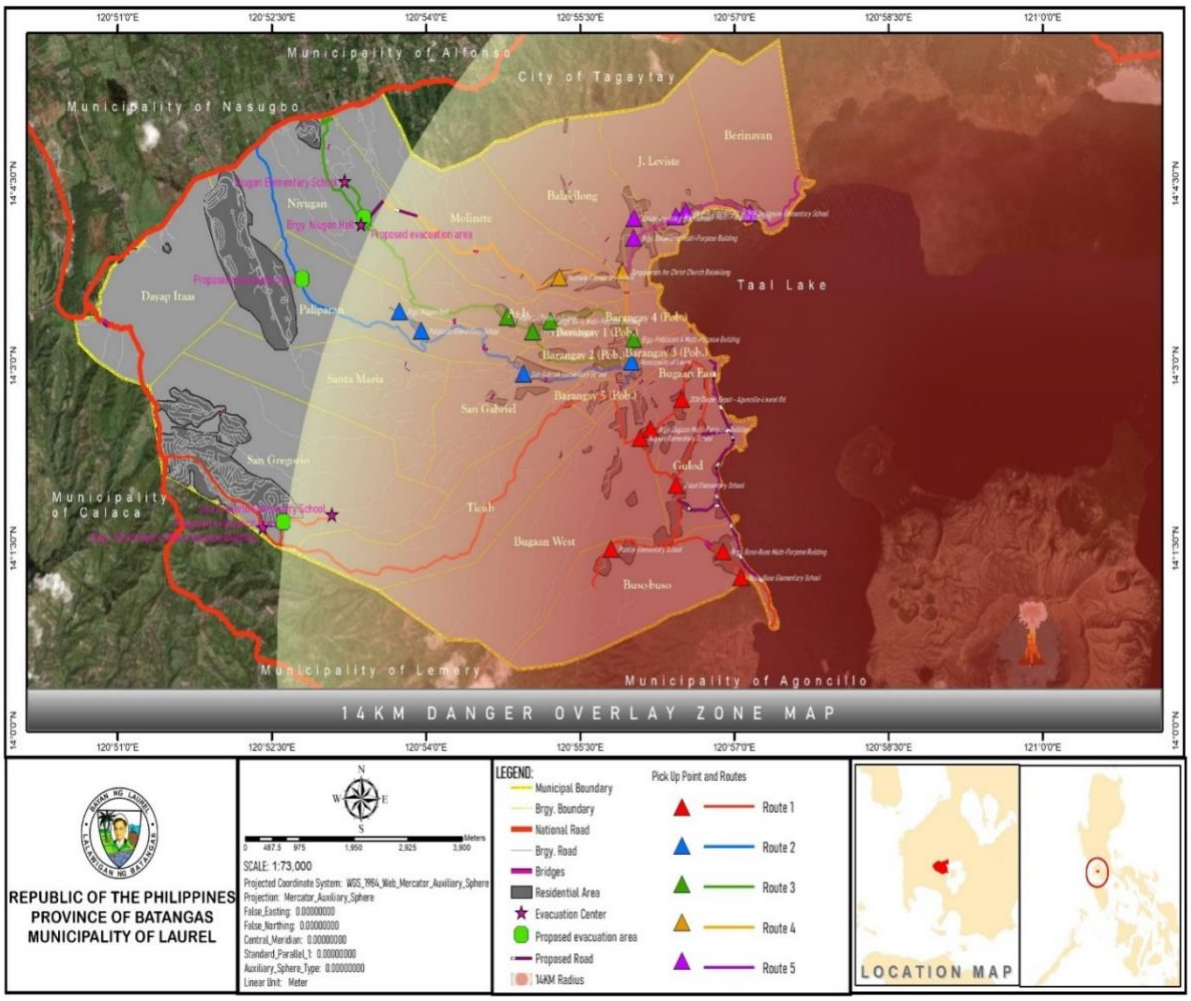
- ***Proposed Evacuation Routes and Their Corresponding Target Barangays***

This map presents the five optimized evacuation routes overlaid on Laurel's municipal map, highlighting the target barangays served by each route and their end destinations at designated evacuation centers.



- ***Proposed Evacuation Center Locations Relative to the 14-Kilometer Danger Zone***

Caption: Evacuation center proposals are visualized with reference to the Phivolcs-declared 14-kilometer danger zone. The selected sites—San Gregorio, Paliparan, and Niyugan—are strategically located outside or at the edge of the danger zone to ensure safety while maintaining accessibility.



CONCLUSION

Evacuation planning is a vital component of urban development, particularly in hazard-prone areas. In Laurel, Batangas—a high-risk municipality near Taal Volcano—this study highlights the role of urban planners in developing evacuation strategies that enhance public safety and disaster resilience. By integrating land use zoning, transport infrastructure, and open spaces into evacuation design, planners can minimize travel time to safety and ease congestion in emergencies.

The study builds upon local government initiatives post-2020 eruption, emphasizing community engagement and GIS-driven analysis. GIS proved instrumental in identifying hazard zones, optimizing evacuation routes, and allocating rescue points and centers based on terrain and accessibility. While current evacuation centers lie within the 14-km danger zone, they remain usable during lower alert levels and serve multiple hazard functions, including flood response.

Although the research focuses on previous eruption patterns, it remains adaptable to future volcanic events. The assignment of evacuees per rescue point is beyond this study's scope and is recommended for further research.

RECOMMENDATIONS

To strengthen Laurel's evacuation planning framework, this study proposes the following:

- Alleviate Traffic Congestion: Support infrastructure projects like the TLCR Road and adopt traffic management strategies to ensure smooth evacuation during emergencies.
- Rescue Point Optimization: Locate rescue points in accessible areas with sufficient capacity, and regularly update residents on their locations and functions
- Route Improvement: Upgrade existing evacuation routes and develop alternative paths to reduce bottlenecks and improve response times.
- Evacuation Center Siting: Prioritize the development of evacuation centers outside the danger zone. Barangays San Gregorio, Paliparan, and Niyugan offer safer, flood-resistant sites for future facilities
- Enhance Community Preparedness: Strengthen public awareness through disaster education, drills, and participatory planning to ensure timely and informed response during crises.
- These recommendations aim to guide Laurel and similar municipalities toward a more resilient, data-informed, and community-centered evacuation planning model.

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