GIS-Based Environmental Vulnerability Mapping of Electric Poles in Flood Zones

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Abstract. Flooding poses a persistent threat to the reliability and safety of power distribution infrastructure in the Philippines. This study applies a Geographic Information System (GIS)-based approach to assess the environmental vulnerability of 2,952 electric poles within flood hazard zones in Odiongan, Romblon. Using spatial overlay analysis of historical flood data and topographic parameters, poles were categorized into six risk classes: no risk, very low, low, moderate, high, and very high. Results show that 44.85% of the poles are located within flood-prone zones, with 22.28% classified as very high risk and 6.95% as high risk, primarily concentrated in low-lying coastal barangays such as Tulay, Ligaya, and Tabing Dagat. In contrast, 55.15% are situated in upland zones with minimal exposure. The findings indicate that topographic variation and settlement expansion significantly affect the environmental resilience of the energy distribution system. The study recommends prioritizing pole reinforcement, elevation redesign, and the use of flood-resilient materials in high-risk areas. This research contributes a replicable GIS-based framework for integrating environmental risk assessment into energy infrastructure planning and disaster resilience managements.

1 Introduction

Floods have long been recognized as one of the most persistent and destructive natural hazards worldwide [1]. Over two billion people were affected by floods between 1998 and 2017, and recent studies confirm that their frequency and intensity continue to rise as the climate changes [2]. Nowhere is this trend more visible than in Southeast Asia, where typhoons and monsoon rains regularly overwhelm cities and towns [3]. In the Philippines, flooding is not merely an occasional disaster; it is a recurring reality

For communities, the consequences extend far beyond damaged homes or crops. Floodwaters often strike at the very systems that keep society running. Among these, the electrical grid is especially vulnerable. Power distribution relies heavily on poles and lines that stand directly in harm's way. When floodwaters rise, they compromise the poles' structural stability, corrode their foundations, and in many cases trigger widespread outages that ripple across hospitals, communication networks, schools, and water supply system [4].

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The devastation left by Typhoon Odette in 2021, which cut power to over three million Filipino households, reminds us that the resilience of local distribution networks is as critical as that of large power plants and transmission lines [5]. Yet, while studies often focus on substations or transmission grids, the vulnerability of electric poles themselves, the literal backbone of distribution, has rarely been given the same attention, even though they account for the majority of flood-induced outages [6].

While considerable research has been devoted to the impacts of flooding on large-scale infrastructure such as substations, transmission lines, and power plants, far fewer studies have examined the distribution-level network, particularly electric poles [7]. These poles are the most numerous and directly exposed components of the grid, yet they are often overlooked in resilience planning despite their role in the majority of flood-related service interruptions. This lack of focus represents a critical research gap that needs to be addressed to ensure comprehensive disaster risk management.

This is where tools like GIS can make a difference. GIS provides more than maps; it integrates topography, hydrology, and infrastructure data into a spatial picture that decision-makers can act upon. Previous research has shown GIS to be indispensable in flood risk assessment and disaster preparedness [8,9]. In the Philippine context, GIS has been applied to hazard mapping, land use planning, and climate adaptation [10,11]. Still, its potential to pinpoint which electric poles are most at risk during floods remains largely unexplored.

In the Philippine context, GIS-based studies have primarily been applied to hazard mapping, land-use planning, evacuation mapping, and climate change adaptation. However, their application to energy infrastructure has been limited, and almost none have specifically targeted the vulnerability of distribution poles to flooding. By centering on electric poles, this study introduces a novel contribution that complements existing GIS-based hazard mapping efforts and provides a new lens for strengthening energy resiliency at the community level.

This study takes on that challenge by developing an electric pole vulnerability map in flood hazard zones for Odiongan, Romblon. By overlaying the municipality's electric pole data with historical flood maps, it identifies high-risk areas and quantifies the extent of infrastructure exposure. More importantly, the approach used here is not limited to Odiongan. Small coastal towns, island municipalities, and even expanding urban centres across the Philippines face similar threats. With adaptation, this method can help other localities strengthen their disaster preparedness, prioritize limited resources, and improve the resilience of their power distribution systems. In doing so, it supports not only local disaster risk management but also national energy resiliency goals [12] and global priorities under the Sendai Framework for Disaster Risk Reduction [13].

2 Methods

2.1 Study Area

The study was conducted in the municipality of Odiongan, Romblon, a first-class coastal community located on the western side of Tablas Island in the MIMAROPA Region of the Philippines (Figure 1). Odiongan covers a total land area of 185.67 square kilometers and is divided into 25 barangays, with a population of 49,284 residents based on the 2020 census [14]. As the commercial and educational hub of Tablas Island, the municipality hosts vital infrastructure and services that support surrounding towns, making the reliability of its power distribution system a critical concern. Its terrain is characterized by rolling hills, coastal plains, and upland areas, which, combined with its location along river systems and the coast, increase its exposure to flooding, storm surges, and typhoon-related hazards.

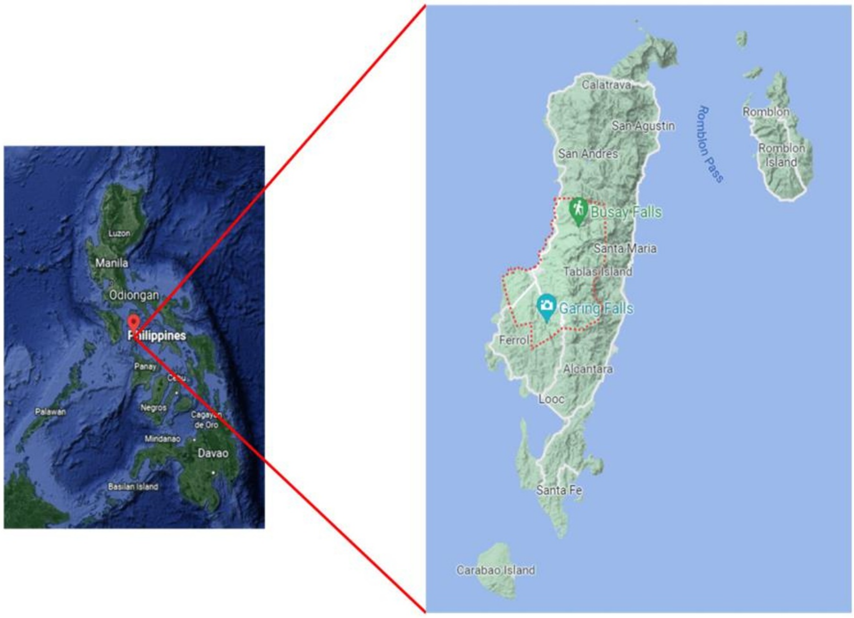

Fig. 1. Location of the study area in Odiongan, Romblon, Philippines, delineating its geographic boundaries.

Climatically, Odiongan falls under Type III of the Philippine Climate Classification, with relatively dry months from November to April and wet months during the rest of the year. Its geographical position places it along the track of tropical cyclones that frequently enter the Philippine Area of Responsibility, subjecting the municipality to 10–15 typhoons annually. Past events, such as the floods brought by Tropical Storm Ramon in 2019, have caused neck-deep inundations in barangays like Tulay and Poctoy, leading to mass evacuations and damage to public facilities. Electricity in Odiongan is supplied by the Tablas Island Electric Cooperative (TIELCO) through a network of overhead distribution poles that are highly exposed to flood impacts. Because most power outages in the Philippines during typhoons are due to distribution line failures rather than generation or transmission issues, Odiongan provides a critical case study for assessing electric pole vulnerability to flooding and for developing strategies that can be adapted by other similarly exposed municipalities across the country.

2.2 Research Methodology

This study adopted a spatial analysis approach using GIS tools to evaluate the vulnerability of electric poles to flooding in the municipality of Odiongan, Romblon. The research process was organized into three phases, as shown in Figure 2. The first phase focused on data collection. It involved gathering geographic coordinates and technical attributes of electric poles and distribution lines from the TIELCO and validating them through online mapping services. Alongside this, historical flood hazard data were collected from the past study conducted. These datasets provided the baseline for spatial analysis and the development of maps.

The second phase involved the development of maps using GIS technology. A pole location map was produced to visualize the distribution network, while a flood hazard map was generated to represent historical flood extents and frequencies in Odiongan. These layers were then overlaid to create a vulnerability map, which identified poles situated within flood hazard zones and classified them according to their degree of exposure. This integration offered a comprehensive visualization of the distribution network's strengths and weaknesses in relation to flood risks.

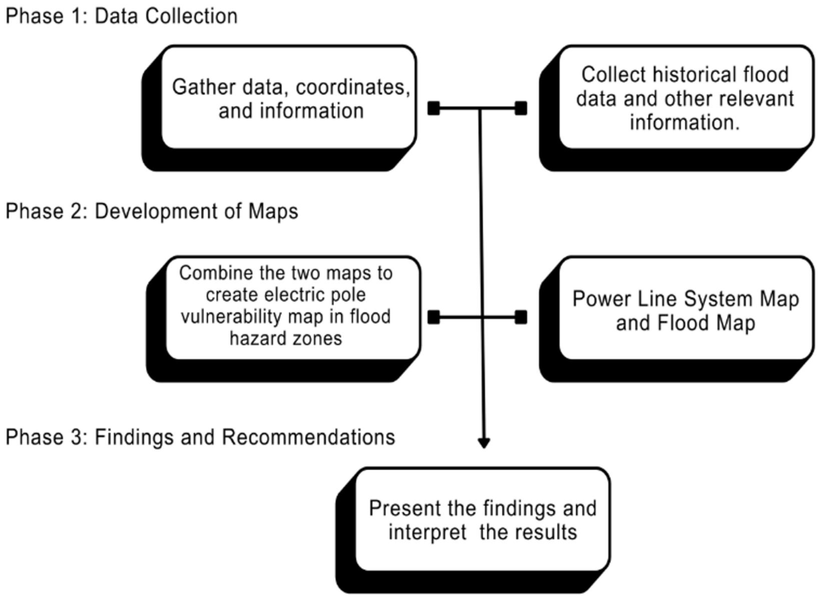

Fig. 2. The research process followed three phases: Data Collection, Development of Maps, and Findings and Recommendations.

Finally, the third phase dealt with the analysis and interpretation of findings. The vulnerability map was assessed using frequency and percentage distribution to quantify the number of poles exposed to flooding relative to the total distribution network. This analysis provided insights into the resilience of Odiongan's electric grid and revealed critical areas where interventions were most urgently needed. A frequency and percentage distribution analysis was performed to determine the proportion of poles located within flood hazard zones relative to the total network. This was calculated using the formula:

$$\%F=(f\,/\,N)\ x\ 100 \tag{1}$$

Where f = frequency of class interval and N = total number of observations. The results of this analysis were interpreted to draw insights into the resilience of Odiongan's electric distribution system, identify critical areas requiring urgent intervention, and recommend strategies for strengthening infrastructure resilience. These findings also provide a replicable framework that can be applied in other municipalities facing similar hazards. Pole coordinates and technical attributes obtained from TIELCO were validated using online mapping services (Google Earth, OpenStreetMap) to ensure positional accuracy. A random subset of poles was further cross-checked through field verification in selected barangays to confirm location and attribute accuracy. Historical flood hazard maps were sourced from previous studies and verified against local government reports of past flood events. This combination of cooperative data, secondary validation, and limited ground-truthing increased confidence in the reliability of the dataset used for GIS analysis.

3 Results and Discussion

The analysis followed the study's methodological framework, beginning with the collection of pole and flood data, followed by spatial overlay in GIS, and ending with classification of poles into five risk categories: very high, high, moderate, low, and very low, with a sixth category for poles outside flood zones. The results are discussed in terms of network composition, flood hazard exposure, and implications for power grid resilience.

The dataset included a total of 2,952 electric poles across the 25 barangays of Odiongan (Figure 3a). GIS mapping revealed a diverse distribution system composed of several line types: Double Circuit Lines (2.30%), Three Phase Lines (23.44%), Two Phase Lines (0.81%), Single Phase Lines (36.04%), and Open Secondary Lines (37.40%). Single-phase and open secondary lines accounted for nearly three-quarters of the network, reflecting their widespread use in residential and neighbourhood-level distribution. This pattern is consistent with distribution practices in other provincial grids in the Philippines, where the majority of consumers are residential or small-scale commercial users. The high dependence on low-capacity distribution lines also highlights their vulnerability during flooding, as these poles are often located in built-up or low-lying barangays where drainage is limited.

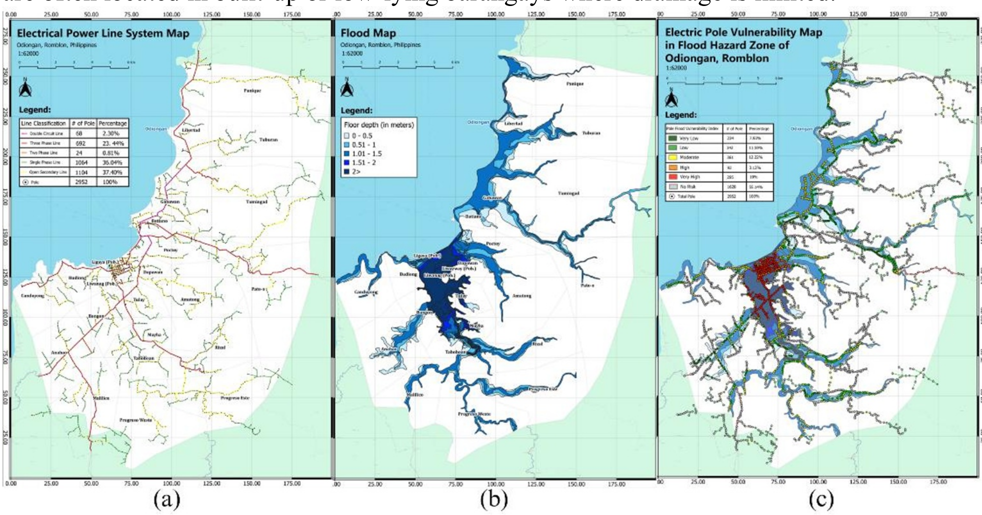

Fig. 3. Spatial maps of Odiongan, Romblon showing (a) the electrical power line system, (b) the flood hazard map by depth classification, and (c) the electric pole vulnerability map in flood hazard zones. These GIS-based maps illustrate the integration of infrastructure and hazard data to assess the flood vulnerability of the municipality's power distribution network.

Flood hazard mapping classified the municipality into five depth ranges: 0–0.5 m, 0.51–1 m, 1.01–1.5 m, 1.51–2 m, and >2 m (Figure 3b). The GIS analysis showed that large portions of Odiongan's coastal barangays fall within the 1–2 meter flood depth category, while inland rolling areas were less exposed. Barangays such as Tulay and Poctoy, which have historically reported neck-deep flooding during typhoons, were confirmed as highly flood-prone zones in the hazard map. These areas represent critical locations where distribution poles face repeated exposure to inundation, increasing the risk of pole failure and power outages.

By overlaying the pole location map with the flood hazard map, electric poles were classified into vulnerability categories. Results, as shown in Figure 3c, showed that a significant number of poles fell into the moderate to high risk levels, with smaller clusters identified in the very high-risk category along coastal areas and river-adjacent barangays. Poles classified as very high risk (red category) were concentrated in low-lying communities near the coastline, where flood depths frequently exceed 2 meters. High-risk poles (orange) were more widely distributed across areas with 1–1.5 meter flood depths, while moderate-risk poles (yellow) were found in transition zones between elevated barangays and floodplains. On the other hand, low and very low risk poles were typically located in upland or well-drained areas, while a substantial number of poles (gray) fell outside identified flood zones.

The GIS-based analysis of Odiongan's distribution network revealed that out of 2,952 electric poles, 44.85% (1,324 poles) were classified as at risk of flooding, while 55.15% (1,628 poles) were found in no-risk areas (Figure 4a). Among the at-risk poles, 27.27% were moderate risk, 25.83% low risk, 22.28% very high risk, 17.67% very low risk, and 6.95% high risk (Figure 4b). Spatial mapping showed that poles located in low-lying coastal barangays such as Tulay, Ligaya, and Tabing Dagat were the most vulnerable, with flood depths exceeding 1.5–2 meters. In contrast, poles in upland barangays were generally less exposed due to higher elevation and better drainage conditions. These results confirm that the municipality's grid resilience is powerfully shaped by topography and settlement patterns, with critical infrastructure clustered in flood-prone areas.

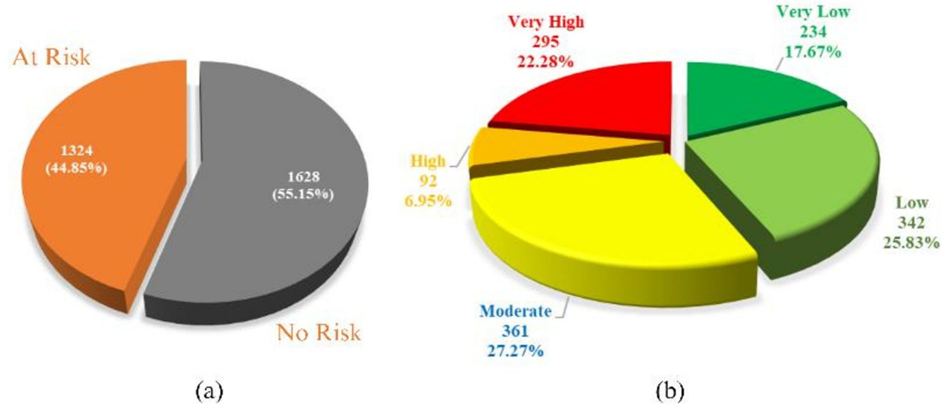

Fig. 4. Distribution of electric poles in Odiongan, Romblon, by flood vulnerability. (a) Overall classification of poles as at-risk or no risk, and (b) detailed categorization of at-risk poles.

The implications of this vulnerability are significant. Poles categorized as high and very high risk supply power to essential facilities such as schools, health centers, and commercial districts, meaning damage in these areas could lead to widespread service interruptions. Moderate- and low-risk poles, while less immediately threatened, remain susceptible to cumulative impacts of recurring floods if preventive measures are not implemented. By integrating flood hazard data with pole distribution, the study provides a spatial decision-support tool that allows local government units, disaster risk managers, and TIELCO to prioritize maintenance, reinforce critical poles, and plan future infrastructure with resiliency in mind. More broadly, the findings demonstrate how GIS-based vulnerability mapping can be applied in other flood-prone municipalities to strengthen power distribution systems against the growing risks posed by climate change and extreme weather events. In practical terms, the pole vulnerability data generated in this study can be directly integrated into Municipal Disaster Risk Reduction and Management Plans (MDRRMPs), enabling local governments to identify priority zones for infrastructure reinforcement and ensure continuity of power supply to critical facilities during disasters. For utility providers such as TIELCO, the classification of poles into distinct risk levels provides a technical basis for resource allocation, preventive maintenance, and phased reinforcement projects. At a broader scale, this approach contributes to the Department of Energy's energy resiliency policy framework and aligns with the Sendai Framework for Disaster Risk Reduction by transforming hazard mapping into actionable strategies that reduce service disruptions and safeguard community lifelines.

4 Conclusion

This study assessed the vulnerability of Odiongan's electric distribution poles to flooding through the integration of spatial data and hazard information in GIS. Out of 2,952 poles mapped across the municipality, nearly half (44.85%) were found to be at some level of flood risk, with 22.28% classified as very high risk and 6.95% as high risk. The analysis revealed that the most vulnerable poles are concentrated in low-lying coastal barangays such as Tulay, Ligaya, and Tabing Dagat, where flood depths often exceed 1.5 to 2 meters. Conversely, upland barangays benefited from natural elevation, resulting in lower exposure levels. These findings emphasize that Odiongan's grid resilience is strongly shaped by topography, settlement distribution, and the location of critical infrastructure. The results highlight the urgent need for targeted mitigation strategies. High- and very high-risk poles supplying critical services such as schools, hospitals, and commercial areas require immediate reinforcement measures, including pole elevation, foundation strengthening, or the adoption of flood-resilient materials. Moderate- and low-risk poles should also be prioritized for regular monitoring to mitigate cumulative long-term damage.

Beyond Odiongan, this study demonstrates the broader value of GIS-based vulnerability mapping as a decision-support tool for disaster risk management and infrastructure planning. Its replicability allows other flood-prone municipalities to adopt the same approach to strengthen energy resiliency. At the national scale, the findings provide evidence that can support the Department of Energy's resilience directives and inform energy policy aimed at reducing disaster-related service interruptions. At the regional scale, the methodology offers insights relevant to ASEAN coastal towns and island municipalities facing similar flood hazards, where local grids often rely on vulnerable distribution poles. By applying science-based, spatially informed strategies, governments and utility providers can enhance community resilience, protect critical infrastructure, and contribute to both national and regional disaster preparedness and climate adaptation goals.

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