WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

QGIS-Based Mapping and Quantification of Riparian Bamboo as a Nature-Based Strategy for Erosion Control and Flood Resilience in Doña Remedios Trinidad, Bulacan

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DOI : **https://doi.org/10.55248/gengpi.07.1026.3119**

A B S T R A C T :

Riparian bamboo usually grows along rivers and is recognized for its effectiveness in controlling and managing erosion because of its strong root systems, which enhance flood control. In this study, the riparian bamboo identified and mapped was kawayan tinik (*Bambusa blumeana*). However, there is still limited information on its occurrence pattern in Doña Remedios Trinidad (DRT), Bulacan. This study sought to map and quantify riparian bamboo using satellite imagery and Quantum Geographic Information System (QGIS) and to propose a bamboo-based mitigation plan for selected river systems in the municipality. A field survey was conducted across seven selected barangays to locate bamboo clumps, with their positions recorded using Global Positioning System (GPS) technology. The gathered coordinates were then integrated with satellite imagery and analyzed in QGIS to produce distribution maps and assess the relative abundance and elevation of the identified bamboo clumps. The survey documented a total of 52 bamboo clumps. Kalawakan had the highest relative abundance (32.69%), followed by Sapang Bulak and Kabayunan (19.23% each), while Talbak recorded the lowest (1.92%). Bamboo was found in every surveyed barangay, though its distribution differed across various river systems. Based on these findings, a bamboo-based mitigation plan was prepared, with recommendations such as rehabilitating and expanding plantings in areas with limited bamboo coverage and enhancing protection and regular monitoring in areas with more substantial bamboo coverage. The generated maps and inventory provide baseline information that may support riverbank management, watershed protection, and environmental planning efforts in Doña Remedios Trinidad, Bulacan.

Keywords: *Bambusa blumeana;* riparian vegetation; QGIS; relative abundance; elevation gradient; riverbank rehabilitation

INTRODUCTION

Riparian ecosystems maintain environmental stability through the conservation of riverbanks, reduction of soil erosion, regulation of water movement, and support of diverse plant and animal life. Riparian zones are transitional areas between terrestrial and aquatic ecosystems where vegetation, soil, and water interact, supporting nutrient cycling, decomposition, and other ecological processes that help maintain environmental balance (Hu et al., 2022). In selected riparian areas, bamboo, particularly *kawayan tinik* (*Bambusa blumeana*), has been observed along selected river systems in Doña Remedios Trinidad (DRT), Bulacan. Bamboo is considered a nature-based solution due to its dense root system, fast growth, and ability to reinforce soil along riverbanks. Its extensive root system can strengthen soil and improve riverbank stability, reducing erosion-related collapse, although its effectiveness may depend on local conditions such as riverbank slope (Pertiwi et al., 2021).

Riparian forests and vegetation also provide important environmental services, including biodiversity support, water quality improvement, carbon storage, pollution reduction, and riverbank stabilization (Dinca et al., 2025). Bamboo vegetation may further contribute to flood resilience because its presence in floodplains can increase hydraulic roughness, slow floodwater, and reduce downstream discharge (Hayati et al., 2024). However, climate change, desertification, and extreme weather events have increased the need for cost-effective and sustainable approaches to integrated watershed management and disaster risk reduction. Riverbanks are experiencing erosion and sediment buildup, which can compromise the natural services provided by riparian ecosystems. In response, vegetation monitoring integrated with bamboo conservation can support soil stabilization, water filtration, environmental planning, erosion control, ecological restoration, and sustainable watershed management (Eryani et al., 2025).

Riparian ecosystems are threatened by land-use change, vegetation loss, and unsustainable resource use. The loss of riparian vegetation can contribute to erosion, sediment buildup, poor water quality, and ecological disruption. Doña Remedios Trinidad is located within the Angat Watershed, which the Department of Environment and Natural Resources (DENR) considers degraded due to the destruction of forest lands and their conversion to other uses. These conditions highlight the importance of maintaining and restoring vegetation along river systems. Knowledge of the distribution of riparian

bamboo is also important because the occurrence of bamboo species can vary according to environmental conditions. Adriani et al. (2021) documented eight bamboo species in the Kecubung Ulolanang Nature Reserve, including *Bambusa blumeana*, and found that bamboo distribution varied with environmental conditions.

The National Disaster Risk Reduction and Management Council (NDRRMC) has reported that flooding in Bulacan can cause damage to residents, agricultural lands, and properties. Bamboo has therefore been recognized as a nature-based solution for riverbank protection and watershed rehabilitation. This has led to bamboo planting initiatives in Central Luzon and the Bicol Region to reduce soil erosion, improve riverbank stability, and restore degraded areas. In the Philippines, Nucum (2024) reported the presence of six bamboo species along the Pampanga River in San Pedro, San Simon, Pampanga, with 103 out of 127 documented clusters identified as *Bambusa blumeana*. The study also noted that *B. blumeana* was the most widespread species and that its clumped distribution was associated with soil, groundwater, and other environmental conditions. These findings provide relevant context for examining the distribution of *B. blumeana* in selected river systems in DRT, Bulacan.

Despite the ecological functions of bamboo, knowledge of the distribution and extent of riparian bamboo in DRT remains limited. Traditional approaches to identifying and monitoring vegetation are often limited in scale, creating a need for spatial mapping that can provide baseline information for conservation and management. Remote sensing gathers information about the Earth's surface from a distance through satellites, aircraft, and unmanned aerial vehicles, and it can be used for vegetation mapping, land-cover assessment, water-resource monitoring, and environmental management (Ahmadi et al., 2023). Satellite and aerial technologies, including LiDAR and UAV-based systems, can also be used to map riparian vegetation, while satellite imagery provides a practical approach for mapping vegetation over large areas (Huylenbroeck et al., 2021).

Geospatial technologies provide practical approaches for watershed management. Geographic Information Systems (GIS) can integrate spatial and attribute data and examine relationships among land cover, vegetation, and environmental conditions, supporting environmental studies and natural-resource management (Sharma et al., 2024). Quantum Geographic Information System (QGIS), as an open-source GIS software, supports the use of raster and vector data, satellite imagery, thematic mapping, and geoprocessing, providing an accessible alternative for spatial analysis and mapping (Flenniken et al., 2020). Remote sensing and GIS can also be applied to monitor river systems, riparian vegetation, and land-cover conditions across large areas (Chatrabhuj et al., 2024).

Previous studies have demonstrated the potential of satellite imagery and GIS for mapping bamboo distribution. Dida et al. (2021) used Sentinel-1 and Sentinel-2 satellite imagery, vegetation indices, and Random Forest classification to map bamboo in Iloilo. Their study demonstrated that satellite imagery and vegetation indices can be used to estimate bamboo distribution, abundance, and area coverage, with field validation used to assess mapping accuracy. Similarly, Cauba et al. (2024) applied remote sensing and GIS to bamboo mapping in Agusan del Norte using field observations and accuracy assessment. These studies demonstrate the usefulness of geospatial technologies in identifying and quantifying bamboo resources.

However, prior studies have largely focused on the ecological functions of bamboo, extensive bamboo forests, or remote-sensing applications in other locations. Philippine studies on the spatial distribution and quantification of riparian bamboo using satellite imagery and QGIS remain limited, particularly in Doña Remedios Trinidad. In addition, suitability mapping using GIS can incorporate factors such as slope, soil, land use, and distance from rivers to support watershed management (Mubeen et al., 2021). Thus, there is a need to generate localized spatial information on the distribution and extent of riparian bamboo in selected river systems of DRT.

This study addresses this gap through the use of satellite imagery, field survey data, and QGIS to map and quantify riparian bamboo stands, particularly *Bambusa blumeana*, in selected river systems of Doña Remedios Trinidad, Bulacan. The study aims to provide baseline information that can support future research, environmental studies, and local river management. The maps generated can help identify the distribution and extent of riparian bamboo and provide spatial information that may be used in conservation and rehabilitation planning. The use of geospatial technologies can also help identify areas where bamboo resources occur and support the prioritization of conservation and rehabilitation activities. Through mapping and quantification, the study seeks to contribute to the understanding of riparian bamboo as a nature-based strategy for erosion control and flood resilience.

This research aligns with Sustainable Development Goals (SDGs) 13 and 15. In relation to SDG 13 (Climate Action), the study employs satellite imagery and Quantum Geographic Information System (QGIS) to map and quantify riparian bamboo stands in Doña Remedios Trinidad, Bulacan. The spatial information generated helps identify areas that are vulnerable to soil erosion and flooding, providing information on the extent of riparian ecosystems that can be used in climate change adaptation and disaster risk reduction planning. At the same time, the study contributes to SDG 15 (Life on Land) through the conservation, restoration, and sustainable management of riparian ecosystems that help maintain biodiversity and environmental stability. The maps and findings produced through this research can assist local government units, environmental agencies, and other stakeholders in planning conservation activities, rehabilitating degraded riverbanks, and improving management of bamboo resources. Through the use of geospatial technologies and nature-based solutions, the study contributes to environmental protection while supporting the long-term resilience of both communities and natural ecosystems.

CONCEPTUAL FRAMEWORK OF THE STUDY

The conceptual framework of the study presents how spatial information on riparian bamboo can be used to support flood and erosion management in Doña Remedios Trinidad. The framework begins with the identification of *Bambusa blumeana* along the selected river systems through field surveys and GPS recording. These field observations are combined with satellite imagery and processed using QGIS to map the spatial distribution of bamboo clumps. The recorded bamboo resources are then described according to their relative abundance and elevation, allowing differences among the surveyed barangays to be examined. This process connects the location of bamboo with its documented abundance and distribution across the study area.

The information gathered from the mapping and quantification serves as the basis for the proposed bamboo-based mitigation plan. Barangays with limited or fragmented bamboo resources are considered for rehabilitation, buffer establishment, or enrichment planting, while areas with more established bamboo stands are considered for maintenance, conservation, and monitoring. In this way, the framework connects the input of field and spatial information, the process of mapping and quantifying bamboo using QGIS, and the output of barangay-specific management recommendations. The framework therefore provides a simple guide for using localized bamboo information to support future riparian rehabilitation, conservation, and river management in Doña Remedios Trinidad.

MATERIALS AND METHODS

3.1. Establishing the Study Site

This study took place in the municipality of Doña Remedios Trinidad (DRT), Bulacan, within the Angat Watershed. DRT was chosen because it holds several river systems with riparian zones where bamboo grows on its own. These rivers offered good locations for mapping and counting bamboo through satellite imagery, field survey, and QGIS. Before heading out for the field survey, the researchers first set the boundaries of the study area to fix the extent of the research and decide which locations would be included in the spatial assessment.

Table 1. Selected Barangays in Doña Remedios Trinidad (DRT), Bulacan

Barangay	Municipality	Region
Kalawakan	Doña Remedios Trinidad	Bulacan
Sapang Bulak	Doña Remedios Trinidad	Bulacan
Kabayunan	Doña Remedios Trinidad	Bulacan
Camachin	Doña Remedios Trinidad	Bulacan
Camachile	Doña Remedios Trinidad	Bulacan
Pulong Sampalok	Doña Remedios Trinidad	Bulacan
Talbak	Doña Remedios Trinidad	Bulacan

Presented on Table 1 is the list of barangays chosen in Doña Remedios Trinidad (DRT), Bulacan. Once the study area was set, the researchers picked seven barangays for field investigation, based on whether they had river systems, visible riparian vegetation, and were reachable during the survey period. These seven barangays became the locations where bamboo occurrence was recorded and mapped for the rest of the study.

Setting up the study site early gave the whole research a fixed spatial boundary to work within. The seven barangays became the main locations for field observation, coordinate collection, and bamboo documentation. Fixing the study area from the start also meant that the satellite imagery, field observations, and geographic coordinates all lined up with the same reference area. With this groundwork in place, the study moved into its next stage: collecting field data for spatial mapping and bamboo quantification.

3.2. Data Collection

Data collection began with satellite imagery covering Doña Remedios Trinidad, Bulacan, which was used to identify river systems and riparian areas where bamboo was likely to occur. The imagery was reviewed before fieldwork to plan survey routes and observation points. Field surveys were then conducted in seven selected barangays: Kalawakan, Sapang Bulak, Kabayunan, Camachin, Camachile, Pulong Sampalok, and Talbak. Accessible sections of the selected river systems were surveyed, and each observed bamboo clump within the riparian zone was recorded through direct observation and ground validation. The location of each clump was recorded as latitude and longitude using a handheld GPS device or GPS-enabled mobile application. The researchers also recorded the barangay, estimated elevation, date of observation, field remarks, and photographs of the surveyed locations.

The field records were organized in a spreadsheet, with each bamboo clump assigned an identification number and its coordinates checked for completeness and consistency. The resulting attribute table contained the coordinates, barangay, elevation, and clump identification, providing an organized dataset for spatial processing in QGIS. The verified coordinates and attribute information were then used for spatial mapping, while the recorded clumps were used for quantification, distribution assessment, and development of the proposed bamboo-based mitigation plan. This sequence connected the field observations with the spatial analysis and management recommendations presented in the study.

3.3. Spatial Mapping Using Quantum Geographic Information System (QGIS)

After field data collection, the recorded coordinates and attribute information were imported into QGIS for spatial processing and map generation. The GPS records were saved as a comma-separated values (CSV) file containing latitude, longitude, barangay, elevation, and bamboo clump identification number. The CSV file was imported as a point layer using longitude as the X-coordinate and latitude as the Y-coordinate, followed with the assignment of an appropriate Coordinate Reference System (CRS). The point layer was then overlaid with satellite imagery, administrative boundaries, and river networks of Doña Remedios Trinidad, Bulacan. Each mapped point was checked against the field records to confirm the location and associated attributes of each bamboo clump.

The spatial processing used coordinate geometry to represent the position of mapped features. The straight-line distance between two geographic locations can be expressed using the Euclidean Distance Formula:

$$d = \sqrt{(x_2 - x_1)^2} + (y_2 - y_1)^2$$

Where:

d = distance between two geographic locations

x_1, y_1 = coordinates of the first location

x_2, y_2 = coordinates of the second location

After verification, the bamboo points were symbolized and layered with the river network and barangay boundaries to produce the final distribution maps. Map elements such as the legend, north arrow, scale bar, coordinate grid, and title were included for clear presentation. The completed maps were then used to examine bamboo distribution across the seven barangays and served as the spatial basis for the succeeding quantification, relative abundance analysis, and proposed bamboo-based mitigation plan.

3.4. Bamboo Quantification

After the bamboo clumps were mapped in QGIS, the recorded point features and their attribute data were reviewed to determine the total number of bamboo clumps in each selected barangay. The QGIS attribute table was used to organize the observations while retaining the geographic reference of each clump. The total number of clumps recorded in each barangay was then used to describe the distribution of bamboo resources across the study area.

Relative abundance was then calculated to compare the contribution of each barangay to the total number of bamboo clumps recorded in the study. It refers to the percentage of bamboo clumps in a barangay relative to the total number of clumps documented across the study area. The relative abundance was computed using the following formula:

$$Relative\ Abundance\ (\%) = \frac{Number\ of\ Bamboo\ Clumps\ in\ a\ Baramgay}{Total\ Number\ of\ Bamboo\ Clumps} \times 100$$

Where:

Relative Abundance (%). Refers to the percentage of bamboo clumps in a barangay relative to the total bamboo clumps recorded in the study
Number of Bamboo Clumps in a Barangay. Total bamboo clumps recorded within a selected barangay.
Total Number of Bamboo Clumps Recorded. Total bamboo clumps recorded from all selected barangays during the field survey.
This calculation provided a common measure for comparing bamboo abundance among the seven surveyed barangays, regardless of differences in their recorded number of clumps. The resulting abundance values were then used together with the spatial distribution and elevation information for the succeeding analysis and proposed mitigation plan.

3.5. Distribution Assessment

The distribution of bamboo clumps was assessed using the QGIS maps generated from the verified GPS coordinates. The mapped points were

examined in relation to the selected river systems, barangay boundaries, and surrounding land features to describe how bamboo occurred within each surveyed barangay. The assessment considered whether bamboo stands appeared as continuous stretches, separated groups, or localized clusters. The seven distribution maps were then compared to describe differences in bamboo occurrence across the selected river corridors.

The distribution assessment was also considered together with the recorded bamboo abundance and elevation of each barangay. This allowed the researchers to compare the spatial pattern of bamboo with the number of clumps recorded in each area and to identify barangays with more established or limited bamboo resources. The resulting spatial patterns were used as a basis for interpreting bamboo distribution and for developing the proposed bamboo-based mitigation plan. In this way, the assessment connected the mapped locations with the quantification results and provided spatial information for selecting appropriate management strategies for the surveyed barangays.

3.6. Proposal of Bamboo-Based Mitigation Plan

The proposed bamboo-based mitigation plan was developed from the spatial mapping, quantification, and distribution assessment of the documented bamboo resources. The QGIS maps provided information on the location and arrangement of *Bambusa blumeana* clumps along the selected river systems, while the field inventory provided their number, relative abundance, and elevation. These information were combined to identify barangays with more established bamboo cover and those with limited or fragmented occurrences. The interventions were then matched with the existing bamboo conditions in each barangay rather than applying the same strategy across all surveyed areas.

The barangays were classified into five management categories: Very High Priority, High Priority, Moderate Priority, Low Priority, and Conservation Zone. The classification was based on the abundance and spatial distribution of bamboo recorded during the field survey. Barangays with fewer clumps and more fragmented vegetation were assigned higher priority levels, while areas with greater abundance and more continuous stands were assigned lower priority levels or designated as conservation areas. This classification provided a basis for identifying areas that may need rehabilitation and areas where existing bamboo stands should be maintained and protected.

The assigned interventions varied according to the condition of bamboo resources in each barangay. Talbak was classified as Very High Priority and proposed for immediate bamboo rehabilitation, while Camachile and Pulong Sampalok were classified as High Priority and proposed for riparian bamboo buffer strips and enrichment planting, respectively. Camachin was assigned Moderate Priority for expansion of existing bamboo stands, while Sapang Bulak and Kabayunan were assigned Low Priority for maintenance and protection and community-based conservation, respectively. Kalawakan, which recorded the highest bamboo abundance and more continuous stands, was designated as a Conservation Zone for protection and monitoring. These recommendations connect the mapped distribution and quantified abundance of bamboo with site-specific management actions for the selected river systems.

4. RESULTS

4.1. The Spatial Distribution of Bamboo Was Mapped Using QGIS

Figures 1 to 7 lay out the spatial distribution of bamboo clumps along the selected river systems in the seven surveyed barangays of Doña Remedios Trinidad. These maps came from the GPS coordinates gathered during the field survey and processed in QGIS. Looking at the mapped locations makes it possible to examine bamboo distribution within each barangay and compare it across the study area.

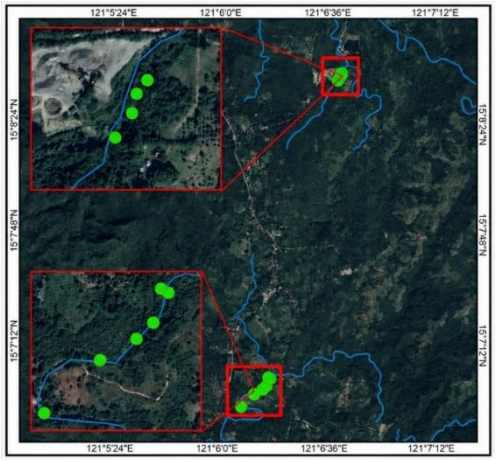

Figure 1. Spatial Distribution of Bamboo Clumps in Barangay Kalawakan

Figure 1 presents the spatial distribution of bamboo clumps in Barangay Kalawakan. Of the seven surveyed barangays, Kalawakan had the heaviest concentration of mapped bamboo clumps. Most of the recorded locations lined up in continuous strips following the river, while several stretches had bamboo growing in tight clusters. This pattern suggests the riverbanks here offer good conditions for bamboo over longer sections of the river corridor. The close tie between bamboo and the river channel also fits the natural growth pattern of riparian vegetation, where moisture, water availability, and workable soil support plant establishment. The mapped bamboo clumps stayed concentrated near the river rather than spreading into the surrounding landscape, which shows how closely bamboo sticks to the riparian environment in this barangay.

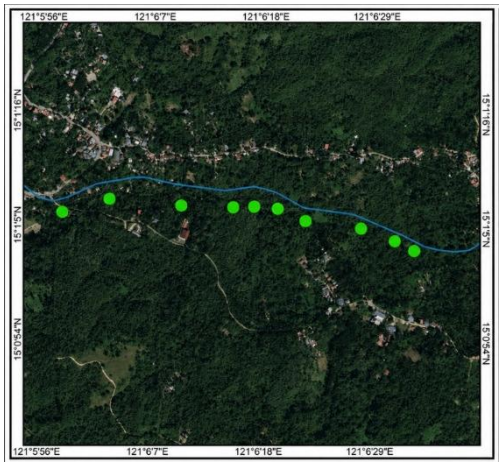

Figure 2. Spatial Distribution of Bamboo Clumps in Barangay Sapang Bulak

Figure 2 shows the spatial distribution of bamboo clumps in Barangay Sapang Bulak. Much like Kalawakan, the mapped clumps mostly followed the river, forming a linear pattern along the banks. The distribution was less continuous here, though, with wider gaps between groups of bamboo in several sections. Bamboo was still present throughout the surveyed river system, but its occurrence was more scattered in some spots. This variation points to differences in environmental conditions within the barangay, letting bamboo take hold in some sections while holding back its growth in others. Even so, the mapped clumps stayed closely tied to the river channel, which shows bamboo continuing to occupy areas where moisture and riverbank conditions work in its favor. Compared with Kalawakan, Sapang Bulak had a less concentrated but still clearly defined riparian bamboo distribution, another case of bamboo following the course of a river system while adjusting to local conditions.

Figure 3. Spatial Distribution of Bamboo Clumps in Barangay Kabayunan

Figure 3 presents the spatial distribution of bamboo clumps in Barangay Kabayunan. As with the first two barangays, most of the recorded clumps sat close to the river channel, again showing how closely bamboo sticks to riparian areas. Compared with Kalawakan and Sapang Bulak, though, the distribution in Kabayunan looked less continuous. Several bamboo clumps formed small groups along the river, while other sections had noticeable gaps with no bamboo recorded at all, giving a mix of clustered and fragmented patterns within the same river system. The continuity of bamboo cover varied, but the mapped locations still followed the general direction of the river. This points to local riverbank conditions shaping bamboo establishments in Kabayunan, letting it thrive in some areas while holding it back in others. The map also made these variations easier to spot, since each bamboo clump could be viewed together with the river network instead of as a separate, isolated observation.

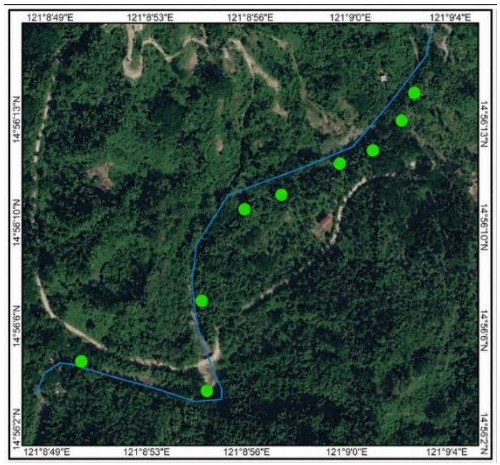

Figure 4. Spatial Distribution of Bamboo Clumps in Barangay Camachin

Figure 4 shows the spatial distribution of bamboo clumps in Barangay Camachin. Compared with the barangays before it, the mapped clumps here were more scattered along the river corridor. Rather than forming long, continuous strips, bamboo showed up as several small groups, with wider open stretches between them. Bamboo was still present along the riverbanks, but the breaks between clusters suggest vegetation cover shifts from one part of the river to another. This variation could be tied back to differences in riverbank characteristics, surrounding vegetation, and available growing space. The mapped distribution also shows bamboo doesn't cover every part of the riparian zone, even within a single barangay. QGIS made these shifts easier to pick out, since the mapped points clearly showed where bamboo was concentrated and where the riverbanks had little or none recorded.

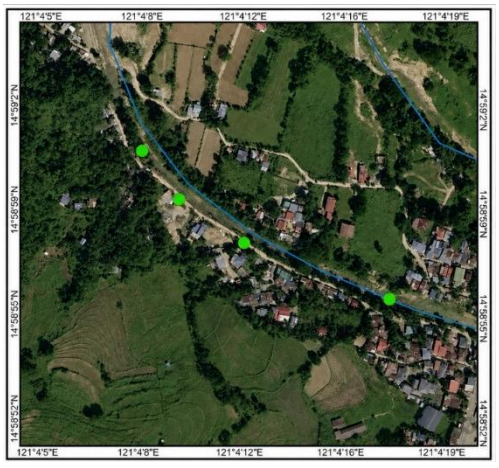

Figure 5. Spatial Distribution of Bamboo Clumps in Barangay Camachile

Figure 5 presents the mapped bamboo clumps in Barangay Camachile. The pattern stayed fairly similar to what turned up in Camachin, with bamboo occurring in separated groups instead of continuous stretches. Some parts of the river held only a handful of bamboo clumps, while other sections showed localized clusters near the riverbanks. This suggests good growing conditions only turn up in specific parts of the river corridor. The scattered arrangement also shows bamboo distribution shifting even between neighboring barangays, despite both sitting within the same municipality. Comparing Camachin and Camachile further shows how riparian vegetation responds to local environmental differences rather than following one uniform pattern across the study area. Together, these observations give a better sense of how bamboo naturally spreads across different sections of the selected river systems.

Figure 6. Spatial Distribution of Bamboo Clumps in Barangay Talbak

Figure 6 shows the spatial distribution of bamboo clumps in Barangay Talbak. Of all the surveyed barangays, Talbak had the fewest recorded clumps within its mapped river section. The distribution map showed only a limited bamboo presence, with the recorded clump sitting close to the river channel and no continuous bamboo stands anywhere in the surveyed area. This differs a lot from the more extensive distributions seen in Kalawakan, Sapang Bulak, and Kabayunan. This limited occurrence suggests only a small stretch of the surveyed river corridor that currently supports bamboo growth. The exact reason can't be pinned down from the mapping results alone, but differences in riverbank conditions, surrounding vegetation, land use, or other environmental factors could have shaped bamboo establishment here. The QGIS output makes these differences clear and lets Talbak's spatial distribution be compared directly with the other surveyed barangays, before moving on to the final distribution map in Pulong Sampalok.

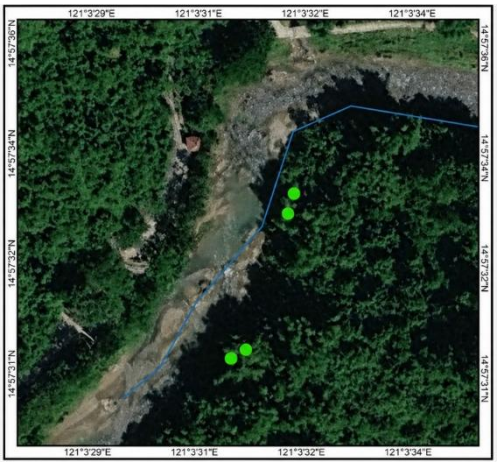

Figure 7. Spatial Distribution of Bamboo Clumps in Barangay Pulong Sampalok

Figure 7 presents the spatial distribution of bamboo clumps in Barangay Pulong Sampalok. Unlike Talbak, where only a few clumps turned up, Pulong Sampalok had several bamboo clusters spread across different sections of the river. The stands weren't as continuous as those in Kalawakan, but they still stayed close to the riverbanks and formed localized groups within the riparian corridor. Some sections of the river had multiple clumps growing close together, while other stretches were open, with no bamboo recorded. This suggests bamboo establishment in Pulong Sampalok depends on the conditions found along different parts of the river. The mapped distribution also shows that bamboo doesn't cover the entire river corridor, developing instead where the surrounding environment favors growth. Together with the earlier figures, the map of Pulong Sampalok rounds out the spatial picture of bamboo distribution across the seven selected barangays in Doña Remedios Trinidad.

4.2. Description of the Bamboo Clumps Based on Relative Abundance and Elevation

To describe the bamboo resources identified during the field survey, the recorded bamboo identified as *Bambusa blumenea* (kawayan tinik), were quantified using their relative abundance and the elevation of each surveyed barangay. Table 2 presents the number of bamboo clumps documented in each location together with their corresponding relative abundance (%) and elevation measured in meters above sea level (masl). Relative abundance was used to determine the proportion of bamboo clumps contributed by each barangay to the total recorded population, while elevation was included to examine whether differences in terrain were associated with bamboo occurrence. Combining these measurements provides a more complete description of bamboo resources because it considers not only where the clumps are located, as presented in the previous section, but also how many were recorded in each barangay and how they are distributed across different elevations.

Table 2. Quantification of Bamboo Clumps Along River Systems in DRT

Barangay	Number of Bamboo Clumps	Relative Abundance (%)	Elevation (masl)
Kalawakan	17	32.69	150
Sapang Bulak	10	19.23	250
Kabayunan	10	19.23	235
Camachin	6	11.54	105
Camachile	4	7.69	80
Pulong Sampalok	4	7.69	43
Talbak	1	1.92	123
Total	**52**	**100.00**	—

As shown in Table 2, 52 Bambusa blumenea were found in the seven selected barangays of Doña Remedios Trinidad. The bamboo clumps were unevenly distributed throughout the study area, with a significant variation in both abundance and contribution from the surveyed locations. The relative abundance was between 1.92% to 32.69%, while the elevation of the surveyed barangays was between 43 to 250 meters above sea level. These differences indicate that bamboo resources are concentrated in certain parts of the municipality and are not evenly distributed in each river system. Examining the data in terms of both abundance and elevation provides a clearer picture of how bamboo resources are distributed across different parts of the municipality and serves as a basis for comparing the characteristics of each surveyed barangay.

Among the surveyed barangays, Kalawakan had the highest number of *Bambusa blumeana*, with 17 clumps or 32.69% of the 52 clumps recorded in the study area. Located at approximately 150 meters above sea level, Kalawakan had a mid-range elevation compared with the other surveyed barangays, yet it recorded the highest bamboo abundance. This suggests that bamboo abundance in the municipality does not depend on elevation alone, as other environmental conditions along the river systems may also support its establishment. This finding is further supported by the spatial distribution observed in findings 1, where Kalawakan had relatively continuous bamboo stands along the river corridors. The next highest abundance was recorded in Sapang Bulak and Kabayunan, with 10 clumps each, representing 19.23% per barangay and a combined 20 clumps or 38.46% of the total recorded clumps. Sapang Bulak and Kabayunan were located at approximately 250 and 235 meters above sea level, respectively, which were among the highest elevations surveyed. Although both barangays had considerable bamboo abundance and established stands along their river corridors, their bamboo distribution was less continuous than that of Kalawakan. The higher abundance recorded in Kalawakan despite its lower elevation further suggests that elevation alone does not explain the differences in bamboo abundance among the surveyed areas.

This pattern continued in the barangays with lower numbers of bamboo clumps. Camachin, located at approximately 43 meters above sea level, recorded six clumps or 11.54% of the total, which was higher than the counts in Camachile, Pulong Sampalok, and Talbak despite having the lowest elevation in the study. Its bamboo stands were distributed in separated groups along the river rather than in continuous stretches. Meanwhile, Camachile recorded four clumps or 7.69%, Pulong Sampalok recorded three clumps or 5.77%, and Talbak recorded only one clump or 1.92%. These three barangays had the lowest bamboo abundance, with the spatial distribution maps showing mostly isolated groups or small clusters separated by open sections along the riverbanks. Talbak had the most limited occurrence, with only one documented clump. The differences in abundance across the seven barangays, together with their varying elevations and spatial patterns, suggest that the presence and distribution of *Bambusa blumeana* may be associated with a combination of local environmental conditions rather than elevation alone.

Comparing the abundance values with the recorded elevations indicates that *Bambusa blumenea* is present at a wide elevations range of 43 to 250 meters above sea level. Among barangays at higher elevations,such as Sapang Bulak (250 msl) and Kabayunan (235 msl), contained relatively high numbers of bamboo clumps. Although Kalawan has a relatively low elevation of 150 msl, it has the greatest abundance among the barangays. Similarly, Camachin has a larger number of bamboo clumps than Camachile, Pulong Sampalok, and Talbak despite being the barangay with the lowest elevation among the surveyed barangays. Based on these observations, bamboo may grow under varying elevation conditions within Doña Remedios Trinidad. The data suggest that the elevation appears to be associated with bamboo occurrence in some areas, but it does not consistently correspond to greater abundance. The observed difference indicates that bamboo distribution is influenced by many environmental factors as opposed to only elevation, which agrees with the spatial patterns described in the previous section.

4.3. Proposed Bamboo-Based Mitigation Plan to Reduce Flood and Erosion Risks

The proposed bamboo-based mitigation plan was formulated using the findings obtained from the spatial mapping and quantification of bamboo resources. The distribution maps generated through QGIS identified the location and arrangement of *Bambusa bluemenea* clumps along the selected river systems, while the field inventory provided information on their relative abundance and elevation. Combining these datasets made it possible to identify barangays with extensive riparian bamboo cover and those with limited bamboo occurrences. Rather than recommending the same management approach for every location, the proposed interventions were matched with the existing condition of bamboo resources observed during the survey. Table 3 presents the proposed bamboo-based flood and erosion mitigation plan, showing the existing number of bamboo clumps, relative abundance, assigned priority level, and the recommended intervention for each surveyed barangay.

Table 3. Proposed Bamboo-Based Flood and Erosion Mitigation Plan

Barangay	Existing Clumps	Relative Abundance (%)	Priority Level	Proposed Intervention
Talbak	1	1.92	Very High	Immediate bamboo rehabilitation
Camachile	4	7.69	High	Establish riparian bamboo buffer strips
Pulong Sampalok	4	7.69	High	Bamboo enrichment planting
Camachin	6	11.54	Moderate	Expansion of existing bamboo stands
Sapang Bulak	10	19.23	Low	Maintenance and protection
Kabayunan	10	19.23	Low	Community-based conservation
Kalawakan	17	32.69	Conservation Zone	Protection and monitoring

As shown in Table 3, the barangays surveyed were categorized into five management namely: Very High Priority, High Priority, Moderate Priority, Low Priority, and Conservation Zone. The categories were assigned based to the abundance and spatial distribution of bamboo recorded during the field survey. Barangays with fewer bamboo clumps and fragmented riparian vegetation were placed under higher priority because they have more limited bamboo resources along the surveyed river systems. In contrast, barangays with higher abundance and more continuous bamboo stands were given lower priority levels or designated as conservation areas. This classification provides a practical means of identifying where rehabilitation activities may be required and where existing bamboo stands should instead be maintained and protected. This also enables the available resources to be focused on areas requiring more attention and avoids unnecessary interventions where bamboo is already well established.

Talbak was classified as a Very High-Priority area because it recorded only one bamboo clump, or 1.92% of the total 52 clumps, and had very limited bamboo occurrence along the surveyed river corridor. Because of its limited bamboo cover, immediate bamboo rehabilitation was proposed to increase vegetation along vulnerable riverbank sections. Camachile and Pulong Sampalok were classified as High-Priority areas, with four clumps (7.69%) and three clumps (5.77%), respectively. Their bamboo stands were mostly found in small groups separated by open sections along the riverbanks. For this reason, riparian bamboo buffer strips were recommended for Camachile, while enrichment planting was proposed for Pulong Sampalok to increase existing bamboo cover while retaining naturally established stands.

Compared with these higher-priority areas, Camachin was classified as Moderate Priority after recording six clumps or 11.54% of the total population. Since bamboo was already established in several sections, expansion of existing stands was considered more appropriate than full rehabilitation. Sapang Bulak and Kabayunan were classified as Low-Priority areas, with 10 clumps each or 19.23%, and both had relatively continuous bamboo stands along their river systems. Thus, protection and regular maintenance were recommended for Sapang Bulak, while a community-based conservation approach was proposed for Kabayunan. Kalawakan had the highest abundance, with 17 clumps or 32.69%, and was designated as a Conservation Zone. Unlike the areas with limited bamboo cover, Kalawakan was recommended for protection and continuous monitoring rather than additional planting. Overall, the proposed interventions varied according to the amount and distribution of bamboo recorded in each barangay, with rehabilitation and planting suggested for areas with fewer clumps and conservation measures for areas with more established stands.

5. DISCUSSION

5.1. Spatial Distribution of Riparian Bamboo in the Study Area

The seven distribution maps showed that bamboo occurred along the selected river systems in all surveyed barangays, although its spatial pattern varied across the municipality. Kalawakan had the most extensive and continuous stands, while Sapang Bulak and Kabayunan had well-established stands with only a few gaps. In contrast, Camachin and Camachile showed more fragmented groups, Talbak had very limited occurrence, and Pulong Sampalok had localized clusters along different river sections. This variation is consistent with Dida et al. (2021), who described naturally growing bamboo as occurring in patches and clusters rather than as continuous vegetation. Cauba et al. (2024) also noted that bamboo distribution in the Philippines varies with local landscape conditions and existing vegetation, while Hu et al. (2022) associated differences in riparian vegetation with water availability, soil conditions, and surrounding land features. The occurrence of bamboo along the riverbanks is also consistent with Pertiwi et al. (2021), who associated bamboo growth in these areas with its adaptation to moist soils and changing river conditions.

The mapped patterns were further supported through the use of QGIS, which organized the GPS locations into distribution maps and allowed comparison of bamboo occurrence in relation to the river network. This approach is consistent with Sharma et al. (2024), Chatrabhuj et al. (2024), and Reddy (2023), who used GPS and GIS-based methods to document and examine the spatial distribution of natural resources. The resulting maps provide baseline information on the location and distribution of riparian bamboo across the seven barangays. These spatial patterns also provide a basis for the next analysis, which quantifies bamboo abundance and examines its variation across the surveyed areas.

5.2. Relative Abundance and Elevation Patterns of Riparian Bamboo

The abundance patterns in Table 2 are consistent with previous studies describing bamboo as occurring in clusters and patches that vary across landscapes (Dida et al., 2021; Cauba et al., 2024). In the present study, 52 bamboo clumps were recorded across the seven surveyed barangays, with Kalawakan having the highest relative abundance at 32.69% and Talbak the lowest at 1.92%. Bamboo was recorded across elevations ranging from 43 to 250 m above sea level, yet its abundance did not consistently increase or decrease with elevation. This pattern supports the observations of Hu et al. (2022) and Pertiwi et al. (2021), who described bamboo as a riparian species that can grow along riverbanks under suitable local conditions. The use of

GPS field surveys and QGIS also follows the approaches of Sharma et al. (2024), Chatrabhuj et al. (2024), and Reddy (2023), showing how GIS can organize and compare bamboo resources across different locations.

The differences in abundance provide baseline information for monitoring and managing riparian bamboo in Doña Remedios Trinidad. Kalawakan, Sapang Bulak, and Kabayunan had relatively higher abundance, with established bamboo stands along the surveyed river systems, whereas Talbak had the fewest documented clumps. These differences do not necessarily mean that one barangay is in better condition than another, but they show that bamboo resources are unevenly distributed across the municipality. The inventory and spatial analysis can therefore help identify areas where existing stands may be monitored, maintained, or included in future riparian conservation activities. With bamboo abundance quantified across different barangays and elevations, the discussion can next examine how these spatial patterns relate to the proposed management interventions.

5.3. Bamboo-Based Strategies for Flood and Erosion Risk Reduction

The proposed mitigation plan is supported by previous studies on bamboo and riparian management. Pertiwi et al. (2021) described bamboo as suitable for riparian environments because its extensive root system can help stabilize riverbank soil. Hayati et al. (2024) also discussed bamboo as a nature-based approach that can increase the ability of floodplain areas to resist flowing water, while Goswami et al. (2022) associated well-managed bamboo with soil stability, erosion reduction, and additional environmental and economic benefits. The use of spatial information to identify priority areas is also consistent with Mubeen et al. (2021), who applied GIS for watershed management, and Gooden and Pritzlaff (2021), who discussed the improvement of watershed conditions through restoration of natural features along river systems. These studies support the use of mapped bamboo resources to guide site-specific management rather than applying the same intervention to all barangays.

In the present study, the proposed interventions were based on the spatial distribution and relative abundance of the 52 documented bamboo clumps, together with their elevation patterns. Areas with limited bamboo, such as Talbak, Camachile, and Pulong Sampalok, were assigned higher priorities for rehabilitation, buffer establishment, or enrichment planting, while Camachin was assigned a moderate priority for expansion of existing stands. In contrast, Sapang Bulak and Kabayunan were recommended for maintenance and conservation, while Kalawakan, which had the highest abundance and more continuous stands, was designated as a Conservation Zone with continued protection and monitoring. These different recommendations aim to increase bamboo cover where it is limited while maintaining established vegetation where it is already abundant. The resulting plan provides baseline guidance for future riparian rehabilitation, conservation, and monitoring activities in Doña Remedios Trinidad.

6. CONCLUSION

The study mapped the spatial distribution of riparian *Bambusa blumeana* across seven selected barangays in Doña Remedios Trinidad, Bulacan using satellite imagery, field surveys, GPS, and QGIS. Bamboo was recorded along the selected river systems in all surveyed barangays, although its distribution varied from continuous stands to fragmented groups and localized clusters. Kalawakan had the most extensive and continuous occurrence, while Talbak had the most limited occurrence.

The field inventory recorded 52 bamboo clumps, with differences in relative abundance across the seven barangays. Kalawakan had the highest relative abundance at 32.69%, while Talbak had the lowest at 1.92%. Bamboo was recorded across elevations ranging from 43 to 250 meters above sea level, but its abundance did not consistently increase or decrease with elevation.

Based on these findings, a bamboo-based mitigation plan was proposed with management strategies suited to the existing bamboo conditions of each barangay. Areas with limited or fragmented bamboo resources were assigned rehabilitation, buffer establishment, or enrichment planting strategies, while areas with more established stands were assigned maintenance, conservation, or monitoring measures. The plan provides baseline information that may support future riverbank rehabilitation, watershed management, erosion control, and flood resilience activities in Doña Remedios Trinidad. However, the proposed interventions were not implemented or evaluated in this study, so their actual effectiveness in reducing erosion and flood impacts still requires future field testing and monitoring.

Acknowledgements

The researchers would like to express their sincere gratitude to their research teachers, Sir Fidel Hernandez and Sir Jayson Eugelio, for their invaluable guidance, encouragement, patience, and support throughout the completion of this study. The researchers also extend their heartfelt appreciation to San Miguel National High School for providing the necessary support and opportunity to conduct this research. Their continued guidance, assistance, and encouragement greatly contributed to the successful completion of this study.

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