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Using Spatial Literacy for Disaster Management in Coastal Communities of Small Island Developing States (SIDS): A Case Study from Lavongai, Papua New Guinea

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Abstract: This study investigates the use of participatory geographic information systems (PGIS) for hazard assessment in small island developing states (SIDS), with a focus on spatial literacy and community-based disaster management. By partnering with the Lavongai community on Papua New Guinea, this research aimed to empower community members through skill development in geodata processing. The program leveraged local knowledge and the global positioning system to create participatory maps, enhancing both community capacity and researcher data quality. Workshops and focus group discussions (FGDs) were conducted to assess the community's understanding of spatial concepts related to disaster risks. The core objective was a preliminary assessment of the community's social and economic vulnerability to coastal disasters, using household data and GIS analysis. The results showed varied vulnerability levels within the community, highlighting the need for targeted disaster mitigation training and nature-based solutions. High-resolution satellite imagery and a simple bathtub model simulated sea level rise, identifying land-uses at risk. The program concluded with a community presentation of thematic maps, fostering collaboration and transparency. Future projects will address environmental challenges identified by local leaders and prioritize skill development, social data collection, and water resource mapping.

Keywords: participatory GIS; spatial literacy improvement; coastal disaster management; small island developing states

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1. Introduction

Small island developing states (SIDS) are inherently vulnerable due to their small populations, limited resources, and exposure to environmental hazards [1,2]. Climate change intensifies these vulnerabilities, with SIDS bearing a disproportionate burden of its impacts [2,3]. International policy has responded by promoting climate change adaptation strategies, aiming to reduce these impacts [4–6]. These strategies extend to local communities within SIDS [7,8]. SIDS have a rich history of confronting and adapting to social and environmental challenges, with varying degrees of success [9]. These experiences, both positive and negative, provide valuable lessons for crafting effective climate change adaptation strategies. Studies show that climate-related hazards have impacted nearly 7% of agricultural GDP in SIDS [10]. Notably, communities within SIDS possess considerable experience in adapting to extreme meteorological events, including tropical cyclones and the less-frequent extra-tropical cyclones [11,12]. Additionally, they have navigated sea-level extremes known as "king tides" in the equatorial Pacific, caused by the interaction of spring tides and El Niño Southern Oscillation (ENSO) episodes [13,14]. Understanding these historical experiences is essential to developing effective climate change adaptation strategies for SIDS. Understanding these historical experiences is crucial for informing the development of effective climate change adaptation strategies in SIDS.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) highlights the importance of integrating local communities and their knowledge into disaster risk reduction efforts [15,16]. This research builds on this call by recognizing the valuable spatial knowledge possessed by local communities, especially in regions lacking extensive data collection [17,18]. At the same time, spatial literacy is crucial for effectively utilizing geospatial technologies like geographic information systems (GIS), remote sensing (RS), and global positioning systems (GPS) [18]. These technologies are fundamentally changing how we understand and interact with the world around us. These current scientific methods offer a promising approach for tasks such as environmental monitoring, data collection, mapping, and planning initiatives. Their applications extend beyond environmental concerns, encompassing physical infrastructure and even responses to extreme events [19]. However, a critical gap exists in impact analyses, particularly in rural areas [20]. Further research is needed to bridge this gap and unlock the full potential of combining community science with geospatial technologies for improved environmental management and disaster preparedness across diverse landscapes.

Developing nations have increasingly utilized participatory mapping to empower local communities in environmental management. This approach has proven effective in areas like rural land-use planning, where indigenous communities actively participate in decisions impacting their land [21]. Participatory mapping has also been successful in natural resource inventory and management. By mutually crafted maps, communities identify, locate, and document their resources, aiding in preservation and strengthening claims to resource rights [22,23]. For example, this method has even contributed to the recognition and protection of indigenous territories and their ecosystems by highlighting the vital role these areas play through mapping ecosystem services, thus promoting local conservation efforts [24].

Participatory geographic information systems (PGIS) build upon participatory mapping by integrating local and indigenous knowledge with scientific data using GIS software (ESRI ArcGIS 10.8). This fosters active community engagement in data collection. Through participatory mapping techniques, community members collaborate with researchers to identify and record points of interest with GPS technology. These points are then georeferenced and integrated into a participatory map using GIS applications. This collaborative process can empower communities while providing researchers with valuable spatial information often missing in traditional data sources [25,26]. A critical obstacle to achieving these outcomes is designing appropriate methods to tap into the spatial expertise of SIDS communities and utilize this knowledge for robust hazard management strategies. This research aims to fill this gap by proposing a methodology that integrates local spatial literacy with geospatial technologies for hazard assessment in SIDS.

2. Literature Reviews

2.1. Small Island Developing States (SIDS)

Small island developing states (SIDS) form a distinct group of island nations facing a confluence of environmental and socioeconomic challenges. Designated by the United Nations (UN), SIDS typically share characteristics like limited populations, scarce natural resources, and heightened vulnerability to external disruptions [27,28]. The United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS) recognizes 39 SIDS and also 18 Associate Members of UN regional commissions, including Papua New Guinea (PNG) [27]. While facing formidable challenges, SIDS communities demonstrate remarkable resilience and possess a wealth of local knowledge that can be a valuable resource for adapting to environmental change [2,9].

2.2. Spatial Literacy

Spatial literacy refers to the comprehensive ability to understand and interact with the world through a spatial lens. It encompasses a range of skills, including creating and interpreting maps, developing mental 3D models of the world, and identifying and analyzing spatial patterns [29]. Spatial literacy goes beyond rote memorization of locations. It fosters recognition of geography as a fundamental tool for organizing and uncovering knowledge [30]. Spatial literacy, encompassing the ability to interpret maps, visualize objects in 3D, and analyze spatial patterns, is rapidly becoming a fundamental skill alongside language and numeracy [31]. Accurate representation of spatial data hinges on understanding key concepts like scale and spatial resolution [29]. These concepts are intrinsically linked to location, the core of the spatial domain, as they reveal how direction and distance are portrayed on a map or other spatial representation [32]. While not the sole method, geotechnologies offer a powerful tool for achieving spatial literacy goals [33]. Integrating GIS into education has been shown to enhance students' spatial thinking skills, consequently improving their overall spatial literacy [18,34]. Baker et al. [35] further support this notion, demonstrating that incorporating GIS into education leads to improvements in students' data analysis skills, technological fluency, and scientific self-efficacy.

2.3. Disaster Management

Disaster management is an ongoing process that requires continuous effort. Two key concepts explored in the literature to understand community roles in disaster management are resilience and resistance [36], which represent different approaches. Disaster management encompasses not only disaster control planning but also broader elements like risk assessment, training, and financial resources, all crucial for successful implementation [37]. Historically, disaster management has been approached as a four-stage process involving risk reduction, preparedness, response, and recovery. However, there is a growing shift towards empowering communities through community-based disaster risk reduction (CBDRR) [38–40]. Although community-based disaster risk management (CBDRM) and community-based disaster risk reduction (CBDRR) are often used interchangeably with an emphasis on "risk," a slight distinction remains between them [41,42]. The CBDRM approach emphasizes community activities during every phase of a disaster: before, during, and after. In coastal regions, there is a particular urgency to protect and strengthen communities while enhancing both mitigation and preparedness capacities [43]. Therefore, upgrading community capacity through various training and competency improvement programs is essential [44].

2.4. Benefit of Participatory Mapping

Community mapping, also known as participatory mapping, has gained recognition for its ability to integrate local knowledge into geographical understanding. This approach fosters dialogue about community challenges and aspirations by directly involving local residents [45]. PGIS, developed in the 1990s, emerged as a response to the need for mapping tools that could empower communities while incorporating GIS functionality [46]. A key strength of participatory mapping lies in its ability to elicit, symbolize, and validate spatial knowledge that might not be readily captured in conventional maps. This method allows communities to express their concerns and integrate elements specific to their local context [47]. The effectiveness of PGIS has been demonstrated in various applications, including rural land-use planning [21], disaster mitigation efforts [48,49], and natural resource inventories [22,23]. Furthermore, PGIS offers a valuable tool for addressing data scarcity in regions with limited geographic information [50,51].

2.5. Engaging Local Communities in Decision-Making

Engaging local communities is pivotal for effective disaster management especially in small islands [52]. Their profound knowledge of local conditions, including environmental dynamics, social structures, and disaster history, is essential for accurate risk assessment and tailored response planning [53]. By involving community members in decision-making, a sense of ownership and responsibility is cultivated [54], leading to increased compliance with disaster preparedness measures and efficient response efforts. Research indicates that communities with high participation levels demonstrate greater resilience and faster recovery times [55]. Empowering local communities aligns with CBDRM principles, fostering adaptability and sustainability [41,56]. Through collaboration with government agencies, NGOs, and other stakeholders, communities can develop comprehensive CBDRM plans that address their specific needs and priorities, ultimately enhancing their capacity to mitigate the impacts of disasters [57].

3. Study Location

This study is situated on Kaselok village in New Ireland Province and the southern part of New Hanover Island. New Ireland occupies a position within the Bismarck Archipelago, an island arc located in the southwestern Pacific Ocean. The island itself can be described as an elongated feature, with a north–south orientation exceeding 360 km. However, its east–west dimension exhibits significant variation, ranging from a minimum of 10 km to a maximum of 40 km, giving it a slender, almost linear profile. Geologically, New Ireland is characterized by a prominent central mountainous belt. This range exhibits a rugged topography with steep slopes, and its highest peak, Mount Taron, reaches an elevation of 2340 m. New Ireland consists of two local-level governments (LLG), including Kavieng District, which includes the capital city and Namatanai District. Moreover, New Ireland Province has an estimated population of 232,251 based on the 2021 census, with approximately 97,521 residents in the Kavieng region [58].

New Hanover Island is also known as Lavongai or Lovongai (2°30′ S, 150°15′ E) within PNG's Bismarck Archipelago (Figure 1). This tectonically uplifted volcanic island boasts a land area of approximately 1200 km^2 and diverse topography. Lavongai Island is a mountainous volcanic island with a central range, the Tirpitz or Lavongai Range, stretching northwest to southeast along its entire length [59]. This range features prominent peaks rising 2000 to 3000 feet above sea level, while additional mountains slope gently in northwesterly and northeasterly directions [60]. The island's geological makeup is evident in its coastal features. Capes Pati-anging in the south and Mata-nalem to the west are both raised sea beds. Fringing reefs surround the mainland, and a chain of islands borders the north-west and north-east fronts. Lavongai's vegetation varies across its topography. Tropical rainforest covers most of the island, with coconut plantations and sago swamps lining the coast. The south coast features patches of savanna grassland, while low-lying, uninhabited mangrove islands dot the surrounding waters. Roughly 31,882 people inhabit the island, primarily residing in dispersed villages [58]. However, coastal erosion, coral reef degradation, and rising sea levels increasingly threaten their local customs.

Lavongai experiences a tropical climate with high humidity throughout the year. Land-use on the island is a mix of traditional subsistence agriculture and commercial ventures. While three special agriculture and business leases (SABLs) encompass roughly 75% of the island [61], residents continue to generate income through copra, cocoa, and other agricultural products, alongside fishing [62]. Notably, the impact of SABLs, particularly regarding massive forest loss, livelihood transformation, and social change, necessitates adaptation strategies for the Lavongai community [63]. These challenges are further compounded by the effects of climate change.

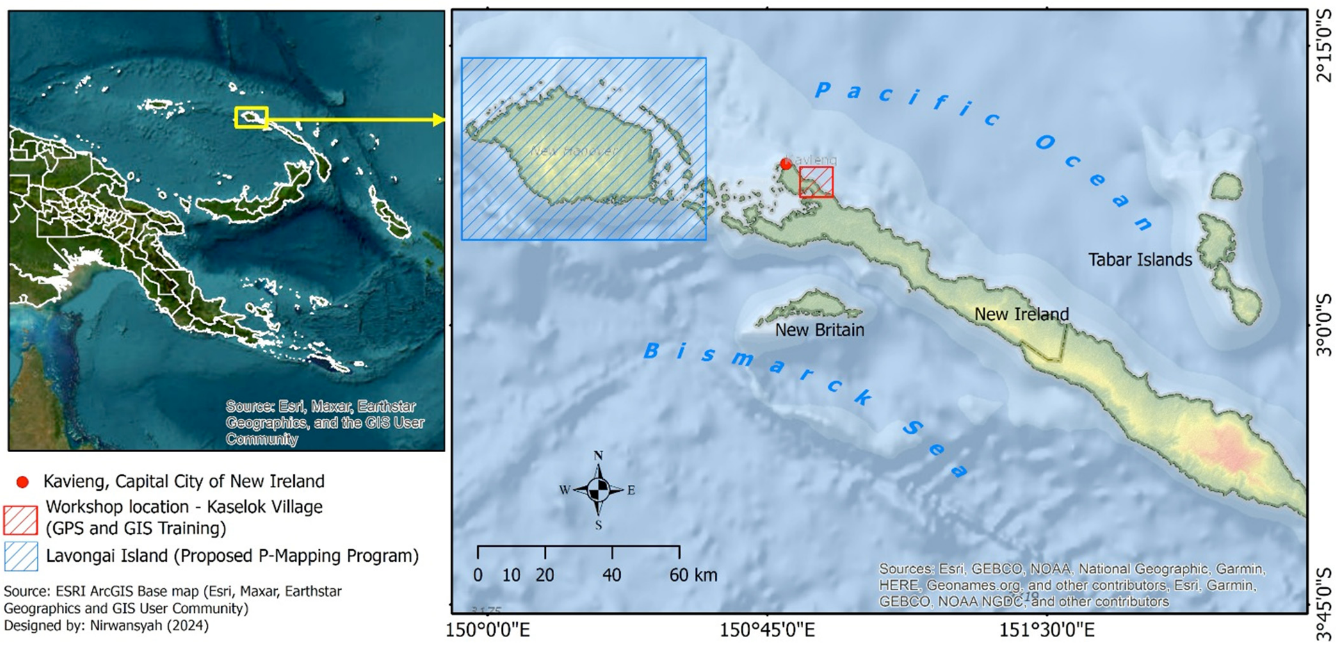

Figure 1. Geographical setting of the study location.

4. Methods

This study employed a PGIS approach to investigate coastal hazards in small island developing states (SIDS). A descriptive approach was used to showcase how GIS can be utilized as a practical tool for spatial literacy exploration in SIDS, like PNG. This approach centers on qualitative GIS that maximize the community understanding but are potentially contradictory to conventional GIS technology [64]. This research project partnered with the Lavongai community from New Hanover Island, PNG, from November 2023 to April 2024. The program was held at Solwara Skul in Kaselok village, New Ireland Province, chosen for its access to electricity and internet connectivity. The project aimed at community empowerment and skill development in geodata processing, aligning with the core principles of PGIS [17,65,66].

The research team collaborated with the People's Planet Project (PPP) to leverage their experience with the Geo Story Camp program, previously implemented in Brazil and Indonesia [67,68]. Here, a trainer with Indonesia nationality and a geography, education, and GIS background collaborated with a cinematographer and documentary film maker with Netherlands nationality. Ailan Awareness (AA) served as a local partner, facilitating communication, logistics, and cultural insights. AA has been well recognized in collaboration addressing social–environmental issues in PNG, including inequalities [69], the coastal and marine ecosystem [70], and conservation practices [71]. Following PPP guidelines, in cooperation with AA and the university, a proposal outlining the research objectives and community benefits was developed with the Lavongai community. Key questions were asked during virtual meetings (3-months before execution). First, who will use the map and how would it be used? Second, how the map will function in disaster management? Legal agreements were established and agreed to ensure informed consent and ethical data collection. Further, this study employed workshops and focus group discussions (FGDs) to assess the community's understanding of spatial concepts related to disaster risks. By implementing guided PGIS [39], the project aimed to empower the community with spatial data collection and analysis skills, ultimately enhancing their ability to manage disaster situations. The following Figure 2 describes the research steps and execution.

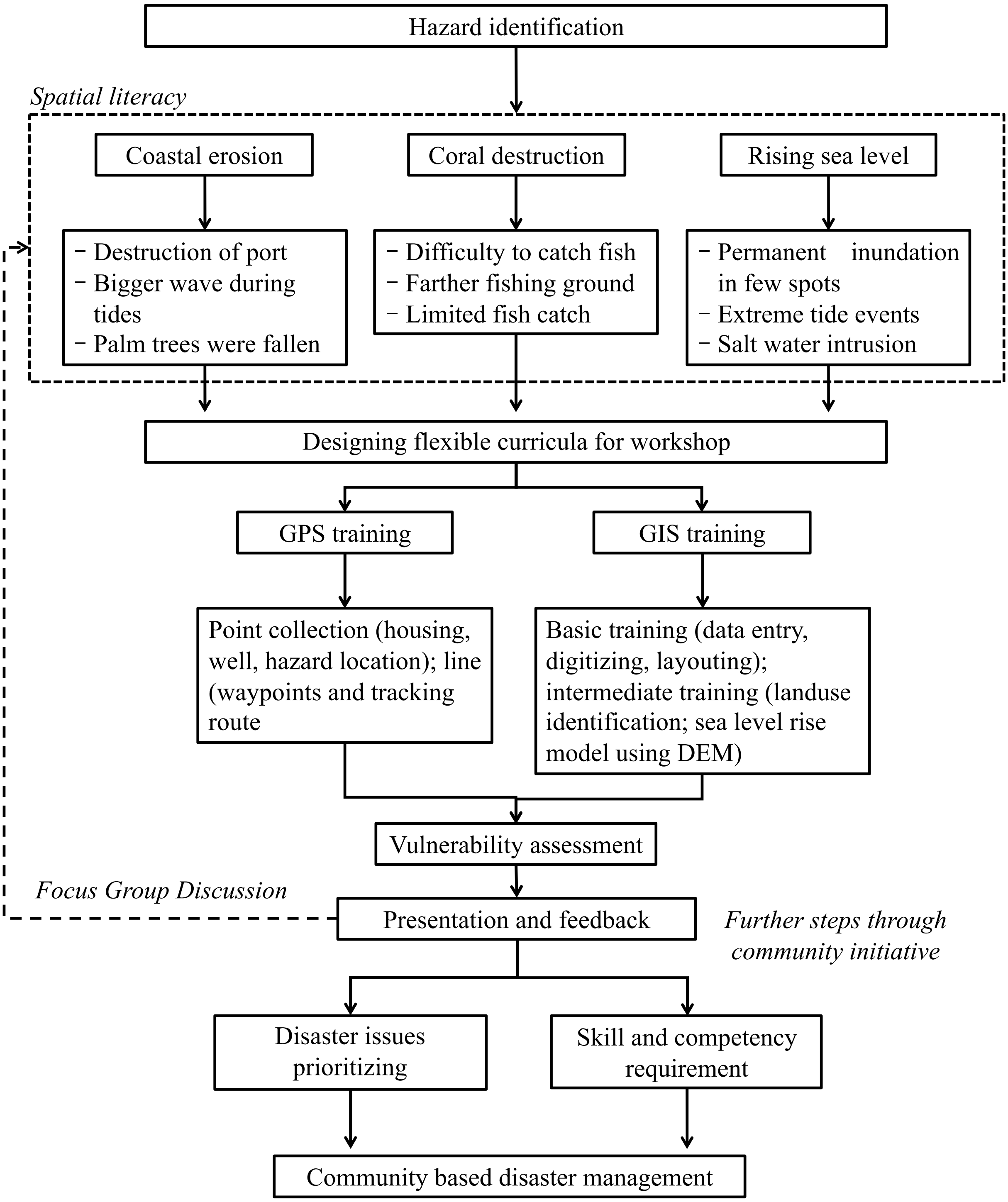

Figure 2. Research flowchart.

4.1. Workshop and Data Collection

A workshop facilitated a collaborative spatial knowledge exchange on recorded hazards impacting the community. To encourage broad participation, organizers employed a multi-modal approach. Traditional paper-based methods, using flipcharts and markers, provided a familiar platform for capturing community knowledge. Due to energy shortage, half-day workshops were used with 1–2 h duration for each session, 3 session per day, involving GPS and GIS skills training within total 42 h of lesson. To enhance the understanding on the spatial context of the study location, printed high-resolution satellite imagery have been pinned on the wall during the workshop. Additionally, technological tools enhanced data collection and spatial analysis. A dedicated session actively engaged 7 participants (6 male and 1 female) in using GPS units for particular data collection. This integration of field data collection with basic remote sensing techniques fostered a well-rounded understanding of spatial data analysis. Those targeted skills were performed to address community issues relating to disasters (tabled in Table 1). The data analysis, incorporating both local knowledge and scientific methods, was presented back to the community for validation, ensuring a collaborative approach throughout the process.

Table 1. Hazard issues addressed by local community and data required.

Issue	Purpose	Data	Type of Data	Source
Hazard inventory				
Coastal erosion	Identify the erosion location spot along the coastline	Shoreline changes in 2 village	Polyline	GPS survey
Coral destruction	Identify the coral destruction through observation	Coral bleaching location	Points	GPS survey
Sea level rise	Identify sea level rise evidence and	Distribution of inundation	– Raster data – Points	SRTM GPS survey
Attribute data				
Household vulnerability	Identify potential impact of hazard to coastal community	Number of family, sex, occupation, age category, and number of income provider	Points	Household survey
Point of interest	Identify impact of coastal hazard to public facilities	Category of public facilities	Points	Satellite image interpretation
Well condition	Identify potential impact of hazard on water resource	Water color	Points	Observation, GPS survey
Land-Use	Land-use monitoring using temporal satellite image	Land-use in 2 villages	Polygon	Satellite data/digitizing

4.1.1. GPS Practice

In this workshop, a GPS survey was held to examine the addressed disaster issues in the community. Here, this study investigated the application of PGIS in empowering the Lavongai community with spatial literacy and environmental management skills [47,66]. A multi-phase approach equipped the community with the knowledge and tools necessary to address social, economic, and environmental challenges. The first phase focused on building a foundation in spatial technology. Trainees, targeted as key data collectors, were introduced to GPS devices, including their components, satellite connectivity, and data accuracy [72,73]. Interactive learning methods, like plotting familiar landmarks with GPS units, solidified this knowledge base and emphasized data collection methodologies. Phase two transitioned to active community participation. Students led the development of social and economic surveys to capture data relevant to the well-being of Kaselok village. The data collection examined issues related to coastal erosion, potential coral destruction, and rising sea levels. The collected data generated a detailed map of Kaselok, pinpointing households and revealing demographic information. Additionally, students mapped well locations and water quality data to understand access to clean water. All tailored training has been applied, including the tasks on data collection.

4.1.2. GIS Training

After finishing the GPS practice, the trainees also learned of GIS as a tool for spatial literacy education. Here, the study examines the use of GIS through a phenomenological approach. It explores how GIS empowers communities facing environmental challenges to leverage their local spatial knowledge for advocacy. This approach aligns with qualitative GIS, prioritizing community understanding even if it deviates from conventional, technology-centric GIS methodologies [64]. This research was actively engaging students in the learning process. This fostered a collaborative environment wherein researchers and community members established knowledge. The syllabus focused on "learning by doing," providing students with practical spatial analysis skills [74].

In this training, household survey data equipped with GPS were incorporated into GIS by joining the MS Excel 2021 sheet with survey information linked to the sample ID GIS layer. Participants were introduced to ESRI ArcGIS 10.8 [75], a widely used GIS platform. The initial session focused on georeferencing transparencies generated during the fieldwork against high-resolution satellite imagery procured from ESRI ArcGIS. This process established a spatial reference for the data, enabling its integration with the GIS. Participants actively participated in data input exercises, working with various formats such as points and polylines. This solidified their comprehension of data collection methodologies and their subsequent integration within the GIS framework. The comprehensive training culminated in equipping participants with the skills necessary to digitize land-use patterns within the designated study area. This involved a strong emphasis on interpreting land-use characteristics utilizing the available satellite imagery.

4.1.3. Vulnerability Assessment

A vulnerability assessment was conducted in Kaselok village to evaluate the community's susceptibility to coastal hazards, specifically coastal erosion, utilizing data obtained from household surveys administered by training participants using GPS. The assessment targeted social–economic vulnerability (SEV) aspects, employing a selected set of indicators adapted from Tasnuva et al. [76]. The indicators included the number of females, children (considered more vulnerable due to their numbers), elderly individuals (considered more vulnerable due to their age), and income unavailability (with a higher number indicating greater vulnerability based on the rationale presented in [77]).

The assessment utilized a categorical scoring approach, incorporating four primary indicators identified earlier. These indicators were expressed as female dependency (*fem_dep*), child dependency (*child_dep*), elderly dependency (*elder_dep*), and no-income dependency (*no-income_dep*). Each of these variables was normalized by dividing it by the total number of family members to account for household size variations. To derive a comprehensive vulnerability score, the mean value of the four normalized dependency indicators was calculated for each household. Subsequently, these mean values were normalized to a scale of 0 to 1, where 0 represents the minimum vulnerability and 1 signifies the maximum vulnerability [78]. This normalization process facilitated comparative analysis and ranking of households based on their vulnerability levels. The vulnerability score for a household can be represented by the following formula:

$$Zi = \frac{xi - \min(x)}{\max(x) - \min(x)}.$$

The normalized vulnerability score (Zi) for each household was calculated as previously described, with Zi representing the individual household score, $\min(x)$ denoting the minimum score among all households, and $\max(x)$ indicating the maximum score. To facilitate interpretation, vulnerability levels were categorized into four distinct classes: very low (0–0.25), low (0.26–0.50), high (0.51–0.75), and very high (0.76–1.00). Finally, this classification was utilized to represent the vulnerability levels using proportional symbology in the vulnerability map.

4.2. Evaluation

The program incorporated daily evaluations as a cornerstone of its assessment strategy. These evaluations served a dual purpose: gauging the effectiveness of training modules and solidifying daily learning. Each day, participants actively engaged in reflecting on the delivered lessons by addressing their experiences and any difficulties encountered [79,80].

This approach fostered a more iterative learning process. Additionally, daily evaluations were combined with feedback from assigned mentors throughout the program. Finally, the AA director provided comprehensive insights during a dedicated final session. By triangulating this multi-faceted data (daily evaluations, mentor feedback, director's insights), participants were encouraged to reflect critically on their learning journey. This reflection process not only addressed the effectiveness of the training program itself but also yielded valuable suggestions for improvement in future iterations, ensuring the program's continued effectiveness in achieving its desired outcomes.

Drawing inspiration from the recent training program held in Kaselok, a community gathering is taking place to discuss future project design for Lavongai Island. This initiative aims to empower the local population to address environmental and disaster challenges on their island. The gathering serves as a platform for community members to propose ideas and brainstorm a structured approach that leverages their traditional knowledge alongside geospatial technology. This collaborative approach holds the potential to create a comprehensive understanding of Lavongai's specific environmental issues, particularly those affecting the coastal regions. By combining the wisdom of the community with the power of geospatial tools, the hope is to develop effective solutions to safeguard Lavongai's environment and ensure the well-being of its inhabitants.

5. Results and Feedback

5.1. Participatory Mapping Practices for Spatial Literacy Improvement

This project investigated the potential of PGIS in enhancing spatial literacy within the Lavongai community. Over a short period, participants learned practical GIS skills and collaboratively mapped approximately 9 km^2 of Kaselok village using a combination of terrestrial surveys and GPS. Here they used the Universal Transverse Mercator (UTM) projection system and available satellite data from ESRI ArcGIS to guide spatial understanding on land-use characteristics. Household survey data (as listed in Table 1) used the distribution of 10 houses as an exercise, representing a total of 49 family members, with 57.14% male and 42.86% female. Most of the community in Kaselok work as merchants, selling commodities such fish products, fruits, vegetables, pigs, and betel nut or Areca catechu (locally called buai). Some of them also work formally as employees in multi-national companies and also as teachers. All mentioned groups provide income to their family or households. Based on the survey, most of the households have one income provider with around 3.7 dependents in average. The following Table 2 provides household condition in Kaselok village, New Ireland.

Table 2. Household survey training data in participatory mapping by the team.

Collected Data	Max Number	Min Number	Total Number	Mean	Standard Deviation (SD)
Number of family members	6	1	49	4.90	1.58
Sex					
– Male	5	1	28	2.80	1.33
– Female	4	0	21	2.10	1.13
Age categories					
– Child	5	0	30	3.00	1.48
– Adult	3	0	18	1.80	0.98
– Elder	1	0	1	0.10	0.30
Income					
– With income	2	1	12	1.20	0.40
– No income	5	0	37	3.70	1.67

The predominant housing materials were woven bamboo walls with wooden supports, with some dwellings utilizing wickerwork (coconut leaves/aluminum) or traditional stilted houses for protection against high tides. Dug wells (nine wells serving two households on average) equipped with electric pumps or manual buckets were the primary source of water. Daily water consumption for drinking and washing was estimated at 21.5 L per household, with most wells remaining untreated but seemingly protected. Additionally, some households collected rainwater using tanks, drums, PVC pipes, hoses, and electric pumps. Observations documented coral bleaching along the Kaselok coastline, impacting local fishing practices. As Foale [81] points out, coral bleaching episodes are becoming more frequent and less dependent on El Niño events. While these events may be less severe in extent, they still disrupt the marine ecosystem. The decline of Acropora corals, evidenced by Andra islanders shifting to harvesting less-preferred and slower-growing Porites corals [82], highlights the vulnerability of these communities. This disruption reduces fish populations, impacting traditional fishing practices and threatening food security and income. Concurrently, the team observed coastal recession, potentially caused by rising sea levels. However, a complex quantitative evaluation of the changes is currently beyond the scope of this study.

This phase emphasized the importance of understanding local knowledge systems, often rooted in cognitive maps [47,83]. Transparency and respect for local traditions were prioritized, adhering to ethical considerations for community-based research [66]. Students jointly produced social and economic surveys tailored to the Kaselok community's needs, fostering a sense of agency and ensuring the data collected addressed their priorities and concerns [66,84]. Similarly, phase three concentrated on coastal hazards, a critical environmental concern for Lavongai. While scientific data collection using GPS surveys was crucial, the project recognized the invaluable knowledge of the local community [50]. Figure 3 depicts some of the community contexts covered in the GPS surveys.

5.2. Spatially-Based Information for Disaster Management

As can be seen in Table 3, the results indicate a pronounced vulnerability gradient among residents. A significant 40% of the population is classified as having very high vulnerability, implying a critical level of risk. An additional 20% falls within the high vulnerability category, suggesting a substantial threat. Conversely, 30% of the community resides in areas deemed low vulnerability, indicating a moderate risk profile. Only 10% of the population occupies areas are categorized as very low vulnerability, representing a relatively safe demographic. These findings underscore the imperative need for comprehensive strategies to enhance the community's resilience to coastal hazards. To mitigate the identified vulnerabilities, a multi-faceted approach is recommended. Prioritizing the implementation of targeted disaster mitigation training programs is essential to equip community members with the necessary knowledge and skills for disaster preparedness and response. Concurrently, exploring and integrating nature-based solutions, such as coastal ecosystem restoration and mangrove reforestation, can provide crucial protection against the destructive forces of coastal hazards. A spatial analysis of vulnerability, as visualized in Figure 4, is instrumental in informing the strategic allocation of resources and the prioritization of interventions in high-risk areas. By combining human capacity building with ecological restoration, Kaselok village can significantly enhance its resilience to future coastal disasters.

Figure 3. Data collection process in the participatory mapping exercise: (**a**) household survey; (**b**) well condition observation; (**c**) rain water harvesting installation; and (**d**) coastal recession issue in part of island.

Table 3. Vulnerability assessment on sampled household during PGIS training.

Household Sample	Fem_dep	Child_dep	Elderly_dep	No-income_dep	Vuln_Score	Norm_Vuln_Score
H-1	0.2	0.40	0	0.80	0.35	0.34
H-2	0.33	0.83	0	0.83	0.50	0.86
H-3	0.60	0.60	0	0.80	0.50	0.86
H-4	0.60	0.60	0	0.33	0.45	0.69
H-5	0.67	0.67	0	0.67	0.42	0.59
H-6	0.17	0.17	0	0.83	0.38	0.45
H-7	0.67	0.67	0	0.83	0.54	1
H-8	0.50	0.50	0	0.83	0.54	1
H-9	0.33	0.33	0	0.83	0.42	0.59
H-10	0	0	1	0	0.25	0

High-resolution satellite imagery analysis facilitated the identification of land-use categories within the study area. At least eight land-use types were distinguished within Kaselok village, while a broader categorization encompassing fifteen types was established for the southern region of Lavongai Island. This comprehensive land-use inventory serves as a crucial baseline for further assessments. Furthermore, a simple bathtub model [28] was employed to simulate a sea level rise scenario with a one-meter water level increase (see Figure 5). This model effectively identified the land-uses likely to be impacted within the southern portion of Lavongai Island. Based on the GIS analysis, there are eight land uses affected by the 1 SLR scenario within 2.51% of the total area (as presented in Table 4). This information provides valuable insights into community priorities and potentially vulnerable locations. The primary concerns raised by the local residents centered on the environmental consequences of coastal hazards, particularly the potential loss of fishing grounds and fishponds. Additionally, concerns emerged regarding the potential threat to coastal settlements. Building upon the land-use inventory and sea level rise model, the analysis revealed that the area adjacent to coast infrastructure in the southern part of Lavongai Island is projected to be disrupted by the simulated SLR scenario. This quantitative assessment underscores the significant potential impact on infrastructure and emphasizes the need for mitigation strategies.

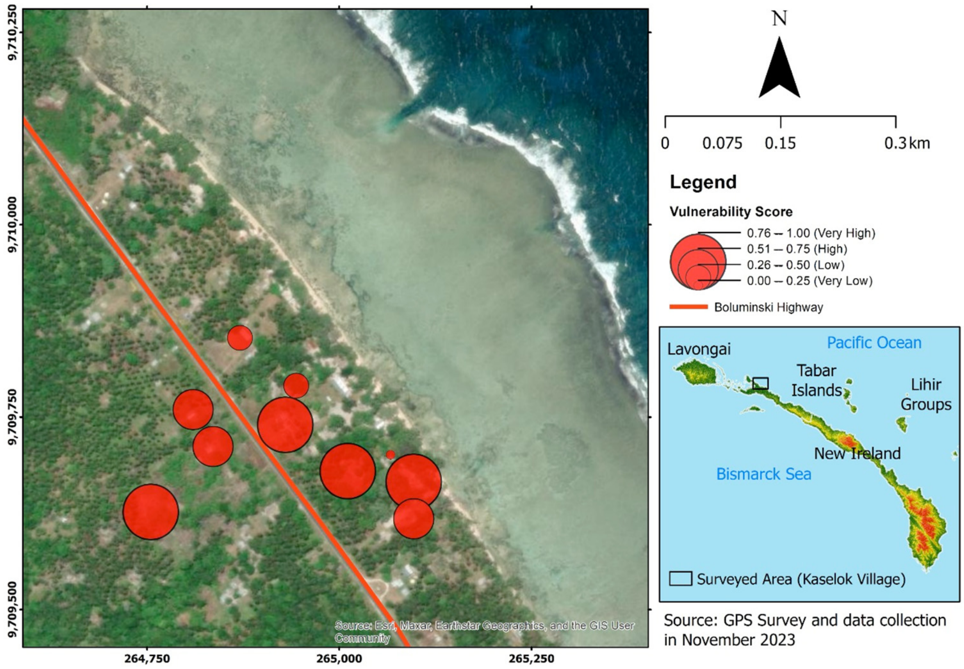

Figure 4. Vulnerability status in Kaselok Village identified via household survey and GIS analysis.

Table 4. Flood impact from the 1 m SLR scenario analyzed in participatory mapping workshop.

Identified Land-Use	Area (In ha)	Inundated Area (In ha)	Percentage *
Catholic mission station	2.90	-	-
Coconut plantation	23.26	0.5	2.15
Coral reef	28.04	23.33	83.20
Forest	131.67	-	-
Garden area	6.19	-	-
Grassland area	2.99	-	-
Mangrove area	68.94	0.71	1.03
Mixed vegetation	406.05	0.02	0.005
River	9.12	0.31	0.06
Salt water lake	13.12	10.49	79.95
Scattered trees and grassland	549.71	0.31	0.06
Sea water	5.85	-	-
Secondary forest	4.21	-	-
Settlement area	173.10	0.35	0.20
Swampy area	7.24	-	-
Total area	1432.38	36.02	2.51

* Value estimated using a GIS model.

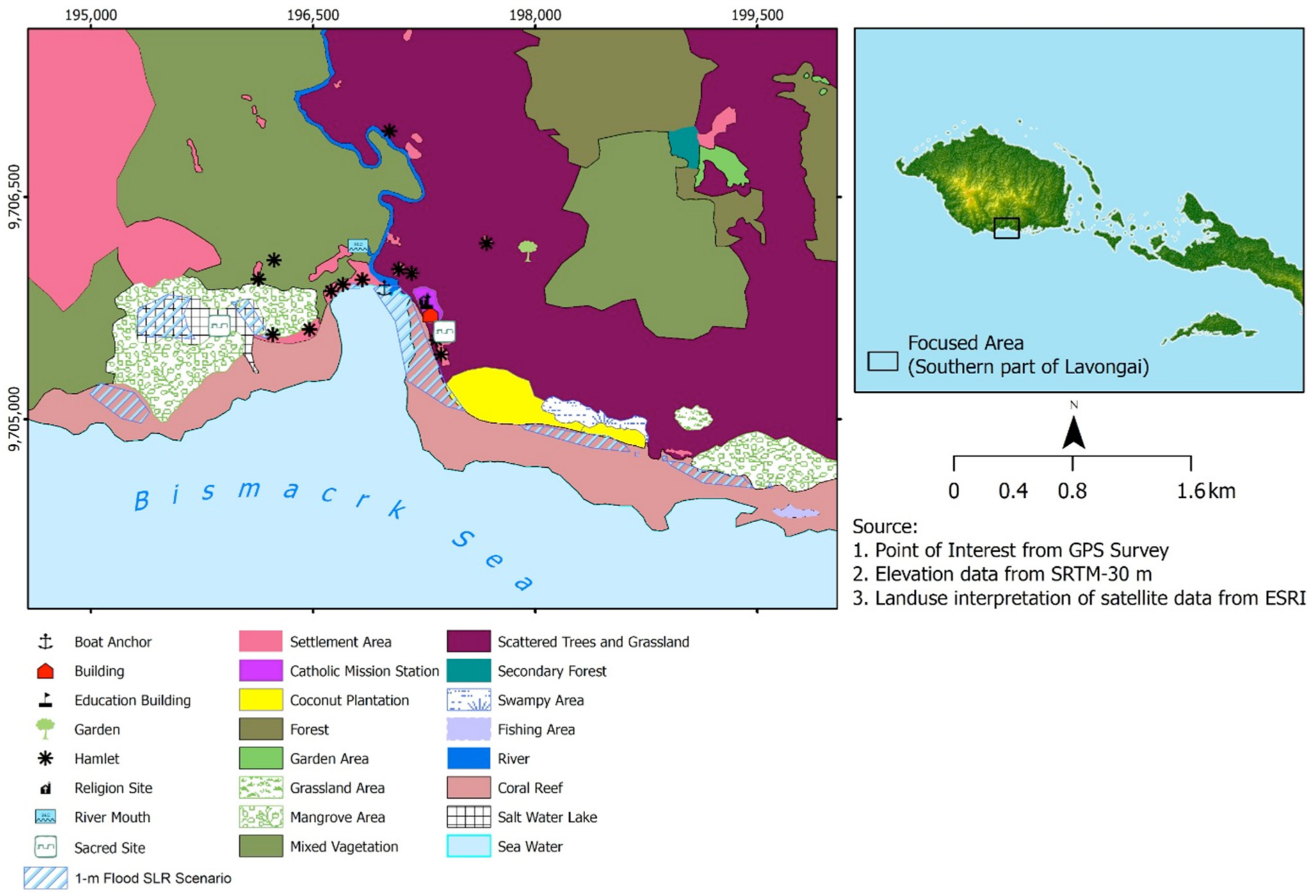

Figure 5. Land-use inventoried by the community during workshop and flooded area in a 1 m SLR scenario (shaded area).

5.3. Comments and Feedbacks

The program concluded with a community gathering where students presented their findings, including thematic maps on household distribution, well conditions, shoreline characteristics, and land-use. These maps were meticulously crafted from scientific data and local knowledge gathered through focus group discussions, aligning with PGIS concepts [25,66,84]. This knowledge exchange fostered collaboration with over 30 participants from Kaselok village and increased transparency, strengthening trust. Discussions with local leaders identified environmental challenges in Lavongai, including coastal erosion, coral reef destruction, and the need for a fishing ground inventory. These challenges informed a proposal for a future project that addresses these issues. The proposed project ideas considered the context of Lavongai's environmental issues and prioritized skillset development based on input from the local community and government representatives who participated in the gathering. Community members highlighted the need for additional social data collection through GIS surveys. These data could include perceptions of hazards and potential evacuation routes. Additionally, participants expressed interest in water resource mapping, including hydrological conditions and stream routes, which could be achieved through GPS surveys and digitization. Finally, the gathering identified the need for the team to receive further training and practical experience to better support the development of a disaster mitigation plan. The PPP and AA have committed to providing ongoing support for the Lavongai community through programs targeting various skill levels, including basic mapping and movie making, as well as legal advocacy to address community and environmental rights. This local initiative was also recognized by the Wildlife Conservation Society (WCS) as it aligns with conservation efforts that can be promoted through grassroots actions. A community spiritual leader emphasized the importance of a collaborative program with the local government to address environmental issues in New Ireland, suggesting that such initiatives could be proposed by the local community.

5.4. Discussion

The project acknowledged the importance of the Lavongai community's indigenous knowledge systems, which often align with the emphasis on integrating local practices and scientific expertise for effective CBDRM in SIDS. The initial phase focused on demystifying GPS technology, creating a bridge between spatial understanding of the environment and modern data collection tools. This fostered a sense of ownership and ensured that collected data resonated with the community's existing knowledge base. The second phase empowered students to take ownership of the data collection process. Through it represents a collaborative approach, the study also conducted social and economic surveys specific to the needs of the Kaselok community. This approach aligns with the UN's focus on programmatic approaches with sustained accompaniment [4,9], ensuring the project addresses Lavongai's specific vulnerabilities and priorities. For example, surveys could gather information on evacuation routes, the vulnerabilities of specific community structures (critical for understanding risks associated with sea level rise), and resource availability in the aftermath of a disaster.

Similarly, phase three focused on coastal hazards, a critical concern for Lavongai and many SIDS. While students were equipped with scientific data collection skills, the project recognized the invaluable knowledge of the local community regarding past events [49,51]. Integrating this local knowledge through interviews with community members enriched the scientific approach. These data could include first-hand accounts of past coastal erosion or flooding events, helping us to identify areas at high risk and thus informing future mitigation strategies [85,86], as highlighted by the UN as a key aspect of CBDRM [38–40]. The gathering, attended by community members, fostered a space for knowledge exchange and collaborative decision-making regarding disaster preparedness plans [87]. Additionally, the project transitioned to a more technical exploration of GIS functionalities, equipping the community to evaluate information critically and participate in ongoing data collection efforts, aligning with the UN's call for strengthening capacities for data collection and analysis in SIDS [4]. While PGIS offers a valuable approach, the project acknowledges the limitations identified, such as the digital literacy gap [33]. To ensure equitable access to technology, this project can be adapted to incorporate non-digital methods alongside GIS training [35]. Furthermore, time constraints can be addressed by developing peer teaching activity within the Lavongai community; said peer teachers can act as trainers and mentors, ensuring knowledge dissemination beyond the project's timeframe.

Disaster preparedness is an ongoing process. To ensure the project's long-term sustainability and empower the Lavongai group to manage future environmental hazards effectively, securing sustained funding and support from NGOs, government agencies, or research institutions is crucial. By addressing these limitations and fostering long-term engagement, PGIS has significant potential. In this context, a commitment has been established between PPP and Ailan Awareness to implement a follow-up program over the next five years. This program includes advanced GIS training, such as shoreline analysis using high-resolution satellite imagery and land-use and land cover (LULC) change assessment. These efforts are intended to address environmental issues and support litigation processes through environmental law. Here, PGIS can empower indigenous communities like Lavongai with the tools and knowledge they need to navigate their environmental future and build resilience against natural disasters. This approach fosters collaboration, where traditional ecological knowledge and scientific expertise converge. Ultimately, this leads to a more sustainable and disaster-resilient Lavongai community, aligning with the vision for CBDRM in SIDS.

6. Conclusions

This participatory mapping through PGIS study exemplifies a mechanism by which to cultivate spatial literacy within communities, as well as its potential application in community-based disaster management, particularly in the context of small island developing states (SIDS). This study significantly enhanced the capacity of the Lavongai community in New Ireland, PNG, through a training trajectory utilizing GPS for practical exercises. These exercises included household data collection and GIS practice for data processing, covering land-use analysis and sea level rise simulations using a simple method. Both established approaches have been crucial in extracting spatial literacy within the community. Additionally, this collaborative action raised awareness about future hazards and ultimately proposed disaster planning and management at the local community level. Community gatherings fostered a space for knowledge exchange and collaborative decision-making regarding disaster preparedness plans.

This stage prioritized data visualization by transforming the collected field data into vectorized datasets through a digitizing procedure. These datasets included point locations, polylines representing linear features, and polygons depicting areal extents. A mentor-facilitated, step-by-step tutorial ensured efficient data processing and addressed specific concerns raised during earlier community discussions. The core objective of this phase was to conduct a preliminary assessment of the community's social and economic vulnerability to coastal disasters, using household data as the primary source. By leveraging the available variables within this dataset, the GIS processing facilitated the evaluation of vulnerability using established metrics. The vulnerability assessment yielded specific quantitative results across different categories of vulnerability.

These challenges informed a proposal for a future project that addresses these issues. The proposed project ideas considered Lavongai's environmental context and prioritized skillset development based on input from the local community and government representatives who participated in the gathering. Community members highlighted the need for additional social data collection through GIS surveys, including perceptions of hazards and potential evacuation routes. Future studies could explore leveraging the community's enhanced spatial knowledge to evaluate decision-making processes within CBDRM application. Additionally, incorporating drone technology could address potential data scarcity in SIDS while further developing practical skills within the community.

Finally, this study recommends that national and local authorities integrate PGIS training into disaster management strategies, particularly SIDS. These programs should focus on enhancing community spatial literacy through hands-on GPS training, land-use analysis, and sea level rise simulations, thereby empowering local participation in disaster preparedness. Additionally, authorities should develop and utilize advanced data collection tools, such as digitized GIS datasets and drone technology, to improve vulnerability assessments. These tools can transform field data into actionable insights, strengthening disaster planning and response efforts at the community level.

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