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Development of an interactive database integrating land-use and geotechnical data for sustainable campus infrastructure in State Universities and Colleges

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ABSTRACT

State universities in developing countries, such as those in the Philippines, are rapidly evolving to meet global standards of higher education, with infrastructure development being a critical component of this transformation. This study focuses on the development of land-use and geotechnical information databases to support infrastructure-soil interaction and land-use assessment for new developments in state universities and colleges. Using geographic information systems and field validation, the research established a methodology for monitoring land-use profiles and geotechnical properties across the 11 campuses of Batangas State University. The creation of an interactive web-based platform serves as the study's key contribution, consolidating land-use and geotechnical data to inform decision-making, disaster preparedness, and sustainable campus development. Findings revealed significant variations in built environments, permeable areas, and vegetation coverage, emphasizing the need for tailored land-use strategies. Additionally, geotechnical data analyses highlighted the underutilization of soil information in infrastructure design, advocating for centralized databases to optimize campus planning. By presenting a replicable model for integrating geotechnical and spatial data, this study contributes to global efforts toward sustainable campus development and data-driven land-use planning. Future research should expand the database's scope to include real-time updates and partnerships to enhance its scalability and long-term impact.

Keywords: geospatial analysis, sustainability planning, education facilities, disaster resilience

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1. Introduction

Natural hazards, including earthquakes, typhoons, and floods, present significant challenges to infrastructure development and economic progress worldwide. Countries across the globe have adopted various strategies to address these vulnerabilities. For instance, South Korea has implemented innovative flood and water stream management systems, Japan has advanced earthquake-resilient infrastructure technologies, and the Netherlands leads in flood mapping and adaptive water management [1-3]. These approaches underscore the importance of integrating disaster resilience into land-use planning, which is a universal challenge requiring tailored and innovative solutions. However, while these strategies provide valuable insights, they may not fully address the specific geotechnical and infrastructure challenges faced by developing nations, particularly in Southeast Asia.

In the Philippines, a country highly susceptible to natural hazards such as earthquakes, typhoons, and storm surges, disaster resilience is a critical component of sustainable development. These hazards have the potential to disrupt the delivery of essential goods and services, thereby hindering economic growth. To mitigate these risks, provinces have prioritized disaster preparedness, while national initiatives have sought to enhance vulnerability assessments. Over recent years, the development and accessibility of hazard maps related to earthquakes, landslides, storm surges, and flooding have improved significantly. Despite these advancements, further efforts are required to ensure that existing infrastructure is protected and economic growth remains uninterrupted. This necessitates a holistic approach that incorporates building footprints, road networks, and geotechnical characteristics into land-use planning and disaster risk reduction strategies.

Reliable data on land use, including soil characteristics, embedded infrastructure, and topography, plays a critical role in crafting sound land-use and conservation policies. As the Philippine Statistics Authority (PSA) highlights, land use—defined as the allocation, development, and management of land—can help alleviate the environmental impact of construction activities when properly accounted for [4]. The study by Rogers et al. [5] further emphasizes the importance

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of establishing a comprehensive database of buried and surface infrastructures, as well as geotechnical information, to support effective planning and remote condition assessment surveys. Unfortunately, in the Philippines, such a unified database does not currently exist. The documentation of land usage, infrastructure, and hazard conditions, particularly within state universities and colleges (SUCs), remains fragmented and uncoordinated.

Recognizing this gap, the Philippine Commission on Higher Education (CHED) introduced the SUCs Land Use Development and Infrastructure Plan (LUDIP) Act under Republic Act No. 11396 [6]. This initiative mandates the development of land-use and infrastructure plans within the geographical premises of SUCs to provide the necessary academic and non-academic infrastructure. However, LUDIP primarily addresses the needs of individual SUCs and focuses on land-use and infrastructure planning. As of this writing, there is no updated public information on the progress or accomplishments of this initiative.

To support CHED's efforts in implementing LUDIP, Batangas State University – The National Engineering University launched the Infrastructure-Soil Interaction and Land-Usage Assessment for New Developments (ISLAND) project. This project aims to address the fragmented documentation of land usage and geotechnical data by creating a comprehensive database that integrates land use, infrastructure, and hazard-related information from various SUCs across the country. A critical foundational task of the project is the development of a detailed land-use and geotechnical information database.

This study contributes to the global discourse on disaster-resilient infrastructure by providing a replicable model for integrating geotechnical and land-use data in the context of developing nations. By adapting global best practices to local needs, it bridges the gap between international strategies and the unique challenges faced by Southeast Asian countries like the Philippines. Moreover, the outcomes of this study align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11: Sustainable Cities and Communities [7]. The creation of an interactive GIS-based database and its associated methodologies has the potential to inform broader urban planning and disaster management efforts not only in the Philippines but also in other developing countries with similar vulnerabilities.

This work emphasizes the need for comprehensive and coordinated strategies to enhance disaster resilience and sustainable development. Through the ISLAND Project, Batangas State University takes a leading role in fostering innovation, addressing gaps in geotechnical and land-use data integration, and supporting the long-term resilience of infrastructure in the Philippines and beyond.

The objective of this study is to develop a web-based interactive database of profile maps of selected SUCs based on its university profile, site maps, and compiled geotechnical properties, which can be used as an input for an infrastructure -soil interaction and land-usage assessment for site development. Specifically, it aims to (1) present a land usage profile of selected provinces which includes building footprints, traffic and population density, and topography as of 2021 and (2) database the geotechnical properties of soil of selected provinces of the selected SUCs.

Linkages with selected SUCs offering Civil Engineering programs was established to provide technical support in the identification and appropriate land use and development programs of their respective provinces including data collection, soil sampling and analysis. The expected output of the study is a web-based interactive database of profile maps of selected partner SUCs showcasing their university profile, campus location and site maps, and its geotechnical properties as an input to determine the soil-structure behavior which can be used as a basis for site development.

Utilization of geographical information system (GIS) technology and evaluation of engineering properties can be a promising strategy to forecast hazard effect on built and natural environment. The study of El May, et. al [8] demonstrated the capacity of GIS mapping in presenting potential hazard of an urban area based on its mapped and overlaid geotechnical properties and provided technical support for urban planning and foresight extension activities. Zonal categorization was established in this study highlighting the vulnerability of the area to flooding and liquefaction. Similar approach was used in this study in terms of utilizing overlaying of maps using GIS to broaden the vulnerability visualization of the SUC area of soil can result in a more significant zonal mapping of the province.

2. Materials and methods

2.1. Materials

The following materials, tools and equipment were used in the study: (1) Topographic and secondary data: Maps and boring test results sourced from National Mapping and Resource Information Authority (NAMRIA), SUCs, local government units (LGUs), Department of Public Works and Highways (DPWH), and Provincial Engineering Offices (PEOs); (2) Survey and fieldwork tools: GPS devices, total stations, and field sampling kits for geotagging and collecting soil samples; (3) GIS software: QGIS 3.28 Firenze (Open Source) was used for mapping, interactive visualization, and spatial analysis; (4) Soil testing equipment: Liquid and plastic limit apparatus, sieve shakers, permeameters, and direct shear apparatus following ASTM and AASHTO standards (locally sourced from engineering laboratories).; and (5) Computing Tools: High-performance computers (Intel Core i7, 16GB RAM) with data storage and GIS processing capabilities.

2.2. Methods

This study utilized an analytical research design that combined experimental and observational analyses. The research process was divided into three distinct phases to facilitate the simultaneous collection and analysis of data from various SUCs. These phases provided a systematic framework to achieve the study's objectives effectively.

2.2.1. Identification of land usage in selected SUCs

The first phase focused on identifying land usage within selected SUCs. Topographic maps were collected from relevant agencies, including SUCs, LGUs, and the NAMRIA. These maps were reviewed and strategically divided into manageable sections to ensure systematic analysis.

The maps were transformed into interactive visualizations using QGIS 3.28 Firenze, an open-source GIS software. Road networks and building footprints of the universities were embedded into the GIS platform. Data on traffic and population density within the municipalities where the SUCs are located were also collected from government agencies, such as the PSA and LGU records. The collected data were integrated into the GIS system to identify population density (population/km^2). Density thresholds were calculated using population per square kilometer and categorized into low-, medium-, and high-density areas within the GIS framework.

2.2.2. Characterization of soil properties

The second phase involved characterizing the geotechnical properties of the soil. Two types of data were used: (1) Existing boring test results were obtained from SUC project management offices, LGUs, DPWH, and PEOs (secondary data). (2) Soil sampling and boring tests were conducted at specific SUC sites. The availability of equipment and laboratory capacities within the universities determined the choice of testing locations (primary data).

The laboratory analysis included soil classification, gradation, Atterberg limits, unit weight, and permeability testing. Boring test data provided information on water table depth, soil stratification, Standard Penetration Test (SPT) values, and bearing capacity. Additionally, undisturbed soil samples obtained from boring tests underwent laboratory tests to determine shear strength parameters. All tests followed ASTM and AASHTO standards and specifications for soil testing, with no significant deviations required for local conditions.

The geotechnical properties derived from these tests were integrated into the GIS database, contributing to land-use planning and infrastructure resilience assessments. For example, areas with low bearing capacity were flagged as unsuitable for heavy infrastructure, guiding future development plans and hazard mitigation strategies.

2.2.3. Development of integrated database

The final phase entailed the creation of a centralized database containing all collected data, including land usage, infrastructure footprints, traffic density, population data, and geotechnical properties. The database served as a resource for assessing the suitability of land for various developments and identifying areas at risk from natural hazards such as flooding, landslides, or soil liquefaction.

2.2.4. Quality and reliability of data

Secondary data underwent rigorous quality assessment, including cross-referencing with updated records from LGUs and validating against standards prescribed by DPWH. For primary data, strict adherence to testing protocols ensured consistency and reliability.

3. Results and discussion

Initiatives were done and series of discussions with partner SUCs resulted in parallel execution of the study with the aim of establishing singular website database showcasing progress and land use and built environment information of selected SUCs. The study enjoined seven state universities all over the country with expectations of active participation on data collection and idea exchange. To demonstrate the resulting output, the study focused on Batangas State University's 11 campuses.

3.1. Land usage profile

Maps for the 11 BatStateU campuses were obtained using OpenStreetMap, which served as the base layer in the QGIS file. OpenStreetMap was selected for its accessibility and flexibility, although its community-driven nature introduces potential variability in precision. Digitized and georeferenced site development plans of each campus were carefully aligned to create comprehensive virtual maps. QGIS enabled the integration of key features, including building footprints and lot areas, layered over the virtual map. Ground validation further enhanced the accuracy of features, such as permeable areas, drainage systems, land-use profiles, and concrete infrastructure.

Figure 1 presents the digitized map of the Alangilan Campus, highlighting building footprints and permeable areas. Specific features and dimensions were validated to ensure the accuracy of building locations and sizes. This methodology, applied consistently across campuses, underscores the study's scientific rigor in geospatial analysis. Nevertheless, future studies may explore advanced georeferencing techniques to further enhance precision.

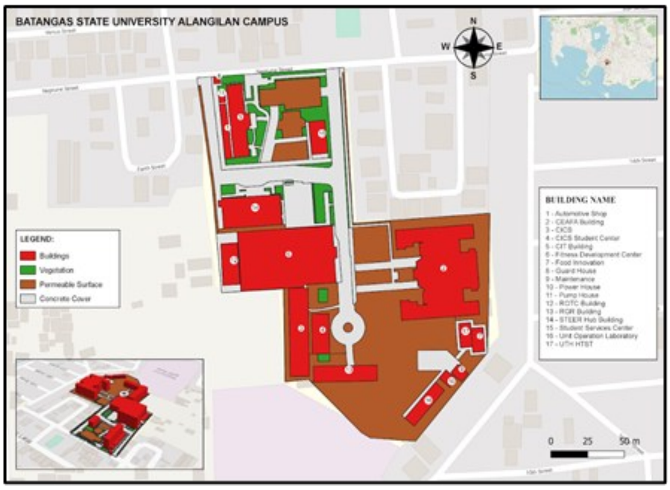


Figure 1. Digitized virtual map with building footprint and permeable area of BatStateU Alangilan Campus

3.1.1. Land-use data of the university

The building demography of the campuses reveals that Batangas State University-ARASOF Nasugbu has the most number buildings (30), while Batangas State University-Mabini has the least (3). This indicates that ARASOF Nasugbu is the most developed campus in terms of built structures and facilities. Compared to other SUCs or international universities, this variation highlights diverse land-use planning strategies.

Building classifications follow the International Building Code, which identifies five occupancy categories. Across the 11 BatStateU campuses, 24 buildings are categorized as Category I (essential facilities), one as Category II (hazardous facilities), 80 as Category III (special occupancy), and 32 as Category IV (standard occupancy structures). These classifications reflect adherence to functional and safety standards, though the limited presence of hazardous facilities may constrain certain research activities.

The tallest building among the campuses is the CALABARZON Integrated Research and Training Center at BatStateU Pablo Borbon, standing at seven floors and 26.14 m. The smallest building, Pump House II at BatStateU Lipa, measures 2.45 m in height. The largest building footprint belongs to the College of Accountancy, Business Economics, and International Hospitality Management at BatStateU Pablo Borbon, spanning 2,674.68 m^2. In contrast, the Guard Office at BatStateU-JPLPC Malvar occupies the smallest footprint of 4.42 m^2. These variations provide insights into infrastructure development priorities, especially in accommodating larger student populations or specialized functions.

Architecturally, several buildings require maintenance due to aging conditions, such as chipped paint, termite-damaged doors and windows, and corroded handrails. Fire safety concerns include insufficient firefighting equipment, such as fire extinguishers and sprinklers, as required by Section 709 of R.A. No. 6541 [9]. Electrical assessments highlight the absence of emergency lighting and outdated fixtures in some buildings, emphasizing the need for compliance with the Philippine Electrical Code [10]. On a positive note, ventilation systems were generally functional, and sanitation facilities were adequately maintained.

3.1.2. Spatial features of each campus

The Batangas State University Pablo Borbon campus has the highest built-environment coverage, accounting for 88.46% of its total land area. In contrast, Mabini Campus exhibits the lowest built-environment coverage at 0.34%. This significant variation underscores the need for tailored infrastructure planning across campuses.

In terms of permeable surfaces, Mabini Campus has the largest percentage (99.66%), while Pablo Borbon Campus has the least (7.16%). These findings emphasize opportunities for biodiversity conservation and water management at Mabini Campus, while Pablo Borbon may require green infrastructure interventions to address urban heat and stormwater challenges.

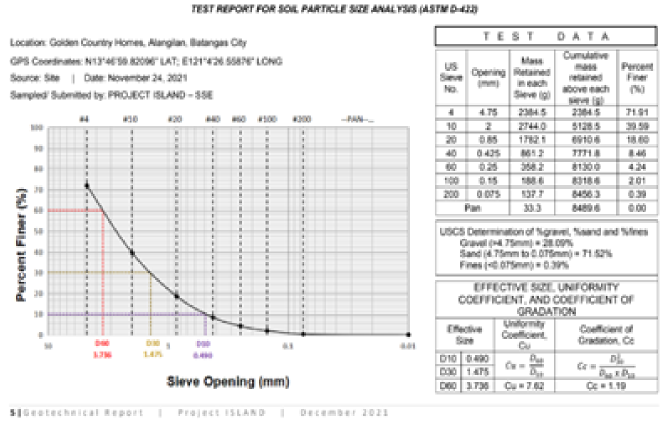
The Rosario Campus has the highest vegetation coverage (27.11%), supporting biodiversity and carbon sequestration. Conversely, San Juan Campus has the least vegetation (0.67%), presenting opportunities for landscape enhancement. Accessibility assessments reveal that the longest route between campuses is from ARASOF-Nasugbu to San Juan, spanning 113 km and approximately 2 h and 20 min. Proximity to essential facilities varies, with BatStateU Lemery being closest to its municipal hall (0.35 km) and BatStateU JPLPC-Malvar nearest to a fire station (0.12 km). These insights are crucial for emergency preparedness and campus planning.

3.2. Geotechnical properties

Geotechnical data for selected buildings were sourced from the BatStateU Project Management Office and organized in a Google Sheet as presented in Figure 2. It shows data on borehole locations, sample depths, soil properties, classifications (based on the Unified Soil Classification System [USCS]), and soil bearing capacities. The analysis revealed significant variations in soil types, influencing structural integrity and future development plans. For instance, areas with low soil bearing capacities may necessitate reinforced foundations, impacting construction costs.

Figure 2. Sample geotechnical dataset of Batangas State University

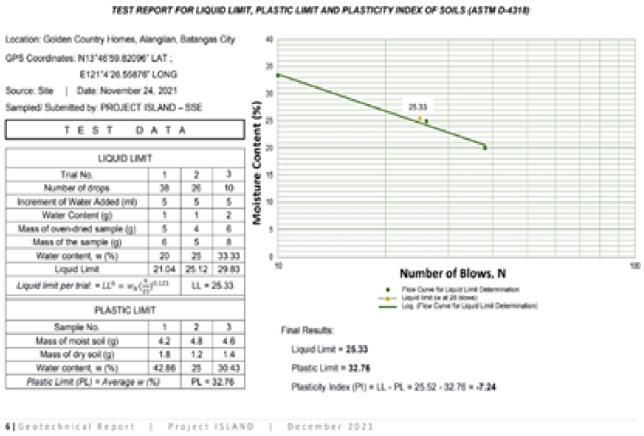
To validate the secondary data, soil samples were collected using shallow excavation methods and tested in the laboratory. These tests included specific gravity, Atterberg limits, particle size distribution, optimum moisture content, field density, and permeability, all conducted in accordance with ASTM Standards [11]. The results, presented in geotechnical reports (Figures 3 and 4), highlight compliance with engineering standards and provide a basis for infrastructure planning.



US Sieve No.	Opening (mm)	Mass Retained in each Sieve (g)	Cumulative mass retained above each sieve (g)	Percent Finer (%)
4	4.75	2384.5	2384.5	71.91
10	2	2744.0	5128.5	39.59
20	0.85	1782.1	6910.6	18.60
40	0.425	861.2	7771.8	8.46
60	0.25	358.2	8130.0	4.24
100	0.15	188.6	8318.6	2.01
200	0.075	137.7	8456.3	0.39
Pan		33.3	8489.6	0.00

Effective Size		Uniformity Coefficient, Cu	Coefficient of Gradation, Cc
D10	0.490	$Cu = \frac{D_{60}}{D_{10}}$	$Cc = \frac{D_{30}^2}{D_{60} \times D_{10}}$
D30	1.475		
D60	3.736	Cu = 7.62	Cc = 1.19

Figure 3. Sample geotechnical report for soil particle size distribution.



TEST REPORT FOR LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS (ASTM D-4318)

Location: Golden Country Homes, Alangilan, Batangas City
GPS Coordinates: N13°46'59.82096" LAT ;
E121°4'26.55876" LONG
Source: Site | Date: November 24, 2021
Sampled/ Submitted by: PROJECT ISLAND – SSE

TEST DATA

LIQUID LIMIT			
Trial No.	1	2	3
Number of drops	38	26	10
Increment of Water Added (ml)	5	5	5
Water Content (g)	1	1	2
Mass of oven-dried sample (g)	5	4	6
Mass of the sample (g)	6	5	8
Water content, w (%)	20	25	33.33
Liquid Limit	21.04	25.12	29.83
Liquid limit per trial: $= LL^n = w_n(\frac{N}{25})^{0.121}$		LL = 25.33	

PLASTIC LIMIT			
Sample No.	1	2	3
Mass of moist soil (g)	4.2	4.8	4.6
Mass of dry soil (g)	1.8	1.2	1.4
Water content, w (%)	42.86	25	30.43
Plastic Limit (PL) = Average w (%)		PL = 32.76	

Final Results:
Liquid Limit = 25.33
Plastic Limit = 32.76
Plasticity Index (PI) = LL - PL = 25.52 - 32.76 = -7.24

6 | Geotechnical Report | Project ISLAND | December 2021

Figure 4. Sample geotechnical report for Atterberg limit test.

3.3 Interactive webpage of the ISLAND database

The primary output of this study is the ISLAND website, which consolidates data from participating SUCs. This interactive platform serves as a decision-making tool for policymakers, urban planners, and researchers, particularly in disaster preparedness, sustainability initiatives, and collaborative research. The homepage (Figure 5) highlights BatStateU as the website manager and partner SUCs as contributors. Secondary pages (Figure 6) showcase detailed land-use maps, while interactive buttons (Figure 7) enable intuitive navigation.

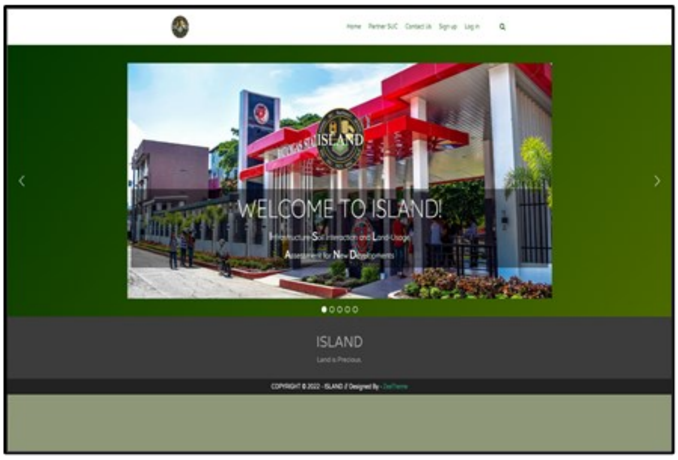


Figure 5. ISLAND homepage.

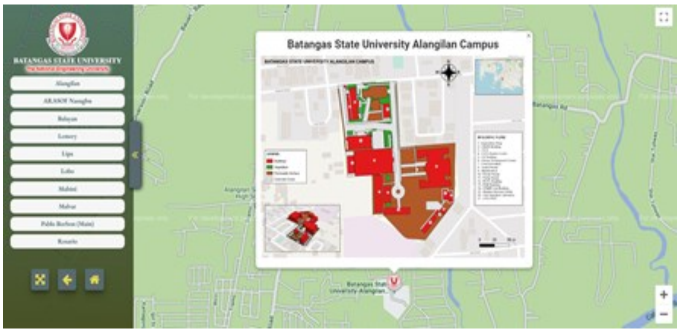


Figure 6. Sample of secondary webpage accessed through interactive buttons.

Similar with the phase-type approach of this study, the website is designed as interactive presentation based on location maps compiled and layered according to significant attributes. Figure 6 shows the secondary pages of the website, showcasing land-use maps of BatStateU.

Interactive buttons are placed on the right side of the webpage (Figure 7) and the SUC logos were used as buttons to signify their participation in this study.

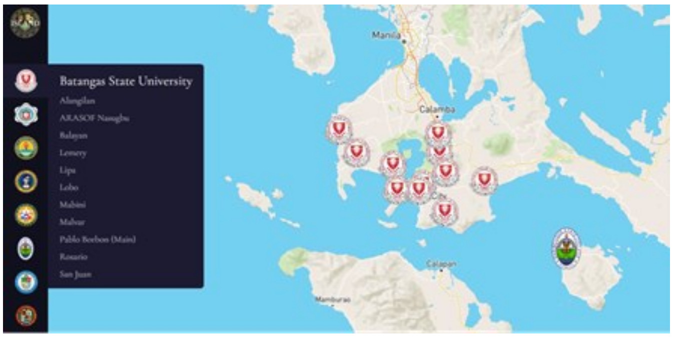


Figure 7. Logo of partner SUCs as button on the webpage.

The website's design prioritizes accessibility, allowing partner SUCs to upload data via contributor-specific accounts (Figure 8). The platform's scalability and potential for real-time updates make it a valuable resource for national and international applications. Challenges, such as ground validation and georeferenced data precision, were identified as limitations, suggesting areas for future improvement. Expanding the database to include environmental impact assessments and green infrastructure metrics could further enhance its utility.

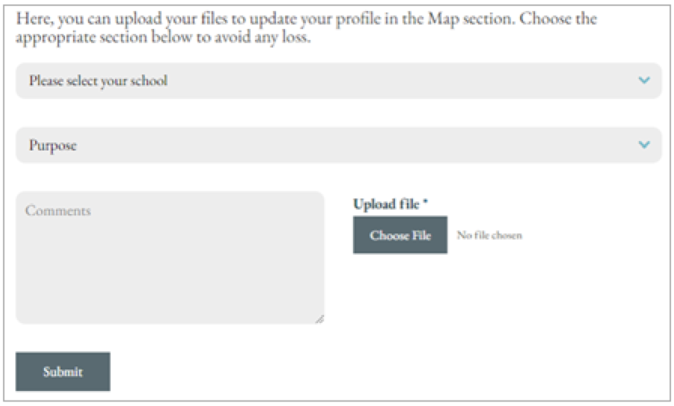


Figure 8. Contributor webpage for the ISLAND website.

Overall, the ISLAND database represents a transformative tool for fostering collaboration among SUCs and advancing sustainable development goals. The spatial and geotechnical data integrated into the platform provide a rich resource for research, policy formulation, and institutional growth.

4. Conclusions

This study highlights the critical importance of integrating comprehensive land-use monitoring and geotechnical data management into the development strategies of SUCs. The findings emphasize the need for increased awareness and systematic monitoring of land use to ensure sustainability and effective land-use management. By closely tracking the distribution of built areas, permeable surfaces, and open spaces, SUCs can better align their practices with principles of sustainable development and environmental stewardship.

Geotechnical data, while often available, remains underutilized, primarily regarded as a compliance requirement. This study underscores the potential of such datasets in informing foundational design and infrastructure planning. Developing a centralized geotechnical database across SUCs is essential to enhance decision-making, ensure site sustainability, and support future developments. Training programs for SUC personnel are also recommended to maximize the effective use and interpretation of geotechnical data, empowering institutions to make informed decisions regarding campus development.

Additionally, the creation of an interactive, web-based database platform demonstrates the feasibility and value of visualizing land-use and geotechnical information. Expanding this platform to include real-time updates, environmental impact assessments, and disaster risk metrics would further enhance its utility. Collaboration with government agencies, private institutions, and international organizations is vital to ensure the platform's scalability, interoperability, and long-term relevance. By adopting GIS-based tools and fostering such partnerships, SUCs can better address the challenges of sustainable campus development and disaster resilience while enabling informed decision-making and collaborative planning.

This research contributes to the broader discourse on sustainable campus development and data-driven land-use planning. Future studies should further refine and expand these strategies, ensuring their continued relevance and adaptability to emerging challenges in land-use management and environmental stewardship.

Acknowledgment

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