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Tropical Equatorial Peatland Demarcation and Land Use Analysis in Borneo's Pontianak Delta Using Geospatial Approach

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ABSTRACT

This investigation addresses critical deficiencies in Indonesian Indicative Map of Delay in Granting New Permits (IMDGNP) peatland boundary estimations through systematic verification of peat soil distributions in Pontianak City, West Kalimantan Province. Preliminary IMDGNP cartographic products at 1:250,000 scale identified four administrative districts containing peatland formations totaling 23.8649 km², exhibiting documented accuracy limitations requiring comprehensive field validation. The research methodology integrated systematic field reconnaissance encompassing 614 observation points at 250-meter intervals, laboratory classification testing of 68 undisturbed soil specimens following ASTM D4427 (organic content > 75% threshold) and ASTM D2974 (ash content < 25% threshold) standardized procedures, and Geographic Information Systems (GIS) spatial analysis for refined boundary demarcation at 1:50,000 scale. Results demonstrate that peat soil formations are confined to only two districts—Southeast Pontianak (5.798 km², 35.95% of district area) and North Pontianak (17.320 km², 42.14% of district area)—contrary to preliminary four-district estimations. Contrary to the preliminary four-district IMDGNP estimate of 23.8649 km², verified peatland formations total 23.118 km² and are confined to only two districts. Within North Pontianak District specifically, the verified extent (17.320 km²) exceeds the preliminary district-level IMDGNP estimate (12.7683 km²) by 35.76%, while Pontianak City and East Pontianak districts contain organic soils rather than peat formations. The updated demarcation mapping incorporates peat layer depth information within a comprehensive geospatial database suitable for infrastructure planning, foundation design optimization, and building conservation, thereby supporting evidence-based urban development and environmental management aligned with tropical peatland ecosystem governance principles.

1. INTRODUCTION

Peatlands constitute globally significant terrestrial ecosystems, occupying approximately 400 million hectares worldwide and storing approximately 30% of terrestrial soil carbon despite covering only 3% of the Earth's land surface [1], thereby functioning as critical components of global carbon cycling, climate regulation, and biodiversity conservation [2]. Indonesia harbors the world's most extensive tropical peat formations, encompassing approximately 14.9 million hectares and storing an estimated 57 gigatons of carbon, representing approximately 30% more carbon than the biomass contained within all Indonesian forests [3], with West Kalimantan Province containing approximately 1.68 million hectares of these organic soil formations [4]. Pontianak City, as the provincial capital, contains peatland areas preliminarily estimated at 23.8649 km² (representing 20.15% of the city's total area of 118.44 km²) according to assessments by the Indonesian Ministry of Agriculture's Center for Agricultural Land Resources Research and Development, using 1:250,000-scale cartographic data [5]. Tropical peatlands exhibit distinct geotechnical characteristics compared to temperate counterparts [6], including exceptionally high water content frequently exceeding 1000%, void ratios ranging from 6.946 to 28.535, diminished unit weights (0.780-0.938 g/cm³), low bearing capacity typically 5-20 kPa [7], and pronounced compressibility that present substantial challenges for urban development and infrastructure construction in equatorial regions [8].

Soil investigations to obtain topographic and geological data on soil layers in Pontianak City have a long historical record dating back to 1904 (Figure 1). Over the decades, mapping efforts have been refined by researchers such as Wing Easton, Van Es Jr., Van Bemmelen, and the Pontianak

City Planning Geological Team [9]. Beginning in the late twentieth century, systematic drilling and resistivity logging provided stratigraphic data and enabled detailed identification of surface conditions such as alluvium, granite, and most importantly, extensive peat formations [10]. Recent geoelectric surveys in Pontianak City show that the average peat thickness ranges from 3 to 4 meters, with clay layers found at depths of 3 to 10 meters below the surface [11]. This peat thickness information is directly utilized for urban infrastructure planning in residential and building construction [12]. Urban development in Pontianak areas continues to be constrained by the physical challenges of building on thick peat layers, and surface expansion remains limited at times [13]. Additionally, recent field investigations and morphological studies further confirm and document the distribution of peat and other geological formations [14], with urban transformation now trending towards balancing development with a detailed understanding of subsurface conditions [15].

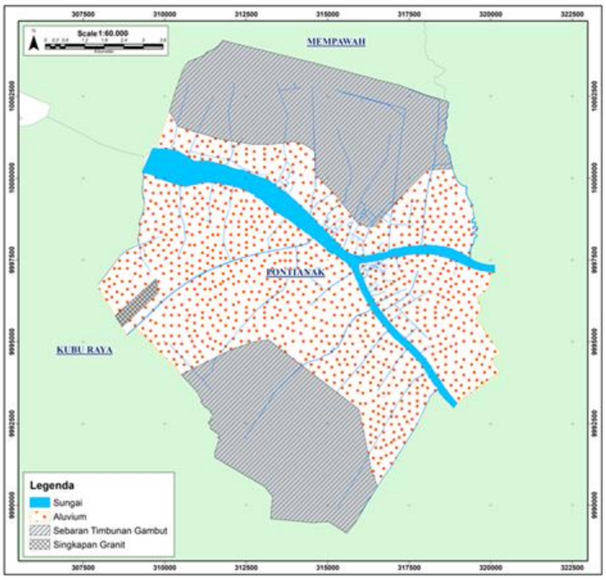

Figure 1. Geological map of Pontianak City

Pontianak City, located at the confluence of the Kapuas and Landak rivers at coordinates 0°02'24" South latitude and 109°20'01" East longitude, experiences accelerating urban development and population growth, generating increasing demands for residential, commercial, and infrastructure expansion within areas with substantial peatland distributions [16]. The city's low elevation, ranging from 0.00 to 1.00 meters above sea level, combined with elevated groundwater tables characteristic of peatland environments, creates unique challenges for infrastructure planning, construction management, and environmental sustainability, particularly regarding wastewater disposal systems and seasonal flooding associated with Pontianak's equatorial climate [17]. Despite these significant geotechnical constraints, systematic research examining the comprehensive characteristics of peat soils specifically in Pontianak City remains notably limited in published literature, impeding the development of evidence-based engineering solutions and appropriate technological interventions to address unfavorable properties, including exceptionally high moisture content, pronounced compressibility, diminished bearing capacity, and prolonged consolidation settlements that fundamentally affect foundation performance and structural stability [18]. The absence of detailed geotechnical databases specifically characterizing Pontianak's peatland formations constrains evidence-based decision-making for infrastructure design, foundation optimization, spatial planning [19], and sustainable urban development strategies that must accommodate complex interactions between urbanization priorities and ecological conservation requirements in tropical peatland environments [20].

The spatial distribution of peatlands in Pontianak City has been preliminarily documented through the Indonesian Indicative Map of Delay in Granting New Permits (IMDGNP), derived from the Indonesian Ministry of Agriculture's Center for Agricultural Land Resources Research and Development (2011) and subsequently incorporated into the Ministerial Decree of Environment and Forestry February 15, 2021, at a cartographic scale of 1:250,000 (Figure 2) [21]. The preliminary IMDGNP assessment identified four administrative districts in Pontianak City as containing peatland formations: Pontianak City District (0.9072 km², representing 5.66% of district area), Southeast Pontianak District (6.7569 km², 41.90%), East Pontianak District (3.4325 km², 28.46%), and North Pontianak District (12.7683 km², 31.07%), collectively accounting for 23.8649 km² or approximately 20.15% of Pontianak City's total area [22]. The substantial uncertainties inherent in coarse-scale cartographic estimations, combined with documented accuracy deficiencies in IMDGNP mapping products, necessitate comprehensive field verification procedures employing systematic observation protocols at 250-meter intervals, laboratory testing following standardized geotechnical classification criteria (ASTM D4427: organic content > 75%, ash content < 25% on dry weight basis), and GIS-based spatial analysis at enhanced scales approaching 1:50,000 to establish accurate peatland demarcation boundaries essential for sustainable urban planning and infrastructure development [23] in Pontianak City.

A thorough literature analysis identifies three significant information gaps that hinder adequate geotechnical characterisation and sustainable development of the peatland regions in Pontianak. Initially, confirmed peatland demarcation borders at engineering-relevant scales (1:50,000) are still lacking, as existing national peatland maps at 1:250,000 demonstrate significant accuracy shortcomings. The Indonesian peatland map, at a scale of 1:250,000, achieved an overall accuracy of approximately 88% and a Kappa coefficient of 0.68, which falls short of the 85% threshold for accurate spatial characterization in foundation design, infrastructure routing, and comprehensive geotechnical assessments [24]. Recent studies recognize that enhanced peatland mapping at a semi-detailed scale (1:50,000) is crucial for delivering precise information and addressing disputes over peat extent and thickness characteristics [25]. The low resolution of initial cartographic assessments hinders precise site characterization necessary for construction planning [26], resulting in significant discrepancies between mapped peatland boundaries and actual field conditions, which impact land use permit applications, conservation designations, and infrastructure development planning [27] in Pontianak City. Secondly, there is a conspicuous lack of systematic examination of geotechnical characteristics specific to Pontianak peat soil formations in the published literature, as previous studies have primarily focused on other Indonesian regions—especially Sumatra and various

Kalimantan provinces [28]. Extensive datasets detailing the physical characteristics, categorization criteria, and engineering attributes of the peatlands in Pontianak City are currently unavailable to engineers and urban planners. Recent geotechnical investigations in Southeast Asian peatlands reveal that tropical peat soils possess highly variable characteristics [29], including elevated water content, low specific gravity, considerable compressibility, and diminished bearing capacity; however, location-specific correlations and design parameters [30] for Pontianak have yet to be established. Third, GIS-based spatial analysis frameworks that incorporate peatland delineation, geotechnical parameter distributions [31], land use classifications, and engineering design parameters have not been systematically established or made publicly available to facilitate infrastructure planning, risk assessment, and geotechnical design activities [32] in Pontianak City. Although the efficacy of Geographic Information Systems (GIS) in managing diverse soil conditions and facilitating evidence-based decision-making in civil engineering is acknowledged [33], a comprehensive GIS platform that integrates peat thickness mapping, groundwater level data, and geotechnical properties [34] is absent for Pontianak. The collective knowledge deficiencies obstruct evidence-based engineering practices, restrict foundation design methodologies, diminish spatial planning precision [35], and impede sustainable urban development strategies essential for meeting infrastructure demands while safeguarding ecological functions within Pontianak's vast peatland ecosystems, ultimately impacting the safety, economy, and environmental sustainability of construction projects in tropical peatland settings.

Figure 2. Peatland map of Kuburaya and Pontianak
Source: Modified from Environmental Service Public Housing Service West Kalimantan

This investigation provides substantial contributions across scientific, practical, and policy domains for the sustainable development and environmental management of Pontianak City's peatland ecosystems. The practical contributions include the production of a 1:50,000 scale peat demarcation map suitable for engineering applications that require high-precision spatial characterization, foundation design guidelines that explicitly account for very high water content, large void ratios, and low bulk unit weight of peat soils, spatial planning tools that support sustainable infrastructure development in peat-constrained environments, and an accessible geotechnical parameter database for use by practicing engineers and urban planners in Pontianak City. On the policy side, the investigation enhances the accuracy of land-use permit evaluations by basing decisions on verified peat distribution rather than preliminary cartographic estimations, proposes conservation zoning based on peat depth classification to distinguish protected ecosystem functions (peat thickness > 3.0 m) from production or cultivation functions (peat thickness < 3.0 m), formulates an implementation framework to operationalize regulations on peat ecosystem protection within the development context, and outlines environmental management strategies that balance infrastructure development needs with ecological preservation requirements in tropical peatland regions. The corrected spatial peat boundaries and comprehensive geotechnical characterization produced by this study enable evidence-based decision-making for sustainable urban planning, infrastructure design optimization, risk assessment procedures, and environmental conservation policies that are essential to accommodate Pontianak City's development pressures while maintaining the critical ecosystem functions provided by tropical peat formations.

2. RESEARCH METHODS

2.1 Study area

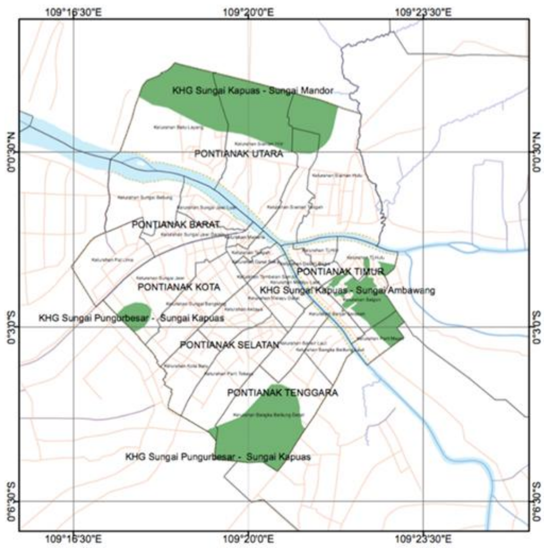

Figure 3. Peatland map of Pontianak City
Source: Modified from Indonesian Indicative Map of New Permit Granting Delays IMDGNP

Pontianak City in West Kalimantan Province constitutes the primary investigation area, wherein peatlands represent a substantial component of existing soil formations according to Indonesian Peat Restoration Agency (2016) data documenting peatland ecosystems occupying approximately 23.8649 km², representing 20.149 percent of Pontianak City's total area of 118.44 km². The preliminary peatland distribution map adopted from the Center for Agricultural Land Resources Research and Development, Indonesia Ministry of Agriculture (2013) (Figure 3), identified four administrative districts containing peatland formations: Pontianak City District (0.9072 km², representing 5.66% of district area), Southeast Pontianak District (6.7569 km², 41.90%), East Pontianak

District (3.4325 km², 28.46%), and North Pontianak District (12.7683 km², 31.07%), with North Pontianak containing the largest absolute peatland extent covering approximately 53.5% of the city's total preliminary peatland distribution. The spatial distribution of these peatlands reflects varying geological characteristics across Pontianak's urban landscape, forming part of the broader peat ecosystem in West Kalimantan Province encompassing approximately 1.73 million hectares. The presence of extensive peatlands within the urban environment creates unique challenges for city development, infrastructure planning, and environmental management, particularly regarding wastewater disposal systems and seasonal flooding attributable to Pontianak's low elevation (0.00-1.00 meters above sea level) and elevated groundwater tables characteristic of peatland environments.

2.2 Field investigation and data collection

Comprehensive field observation protocols were developed to facilitate comprehensive visual assessments and spatial verification procedures across the study area, involving 614 observation points spaced at 250-meter systematic intervals within four initially identified peatland districts (Table 1), as per IMDGNP preliminary estimations. The spatial distribution of observation points encompassed Pontianak City District (42 points), Southeast Pontianak District (159 points), East Pontianak District (128 points), and North Pontianak District (285 points), thereby ensuring comprehensive coverage of areas initially identified as containing peatland formations by the Ministry of Agriculture and the Indonesian IMDGNP. Spatial data collection employed Global Positioning System (GPS) technology combined with aerial imagery acquired via drone, enabling GIS analysis through integration with Android devices and the Google Earth platform for accurate identification of research sites and systematic field observations. The main objectives of the field survey encompass the assessment of current land use patterns in accordance with the 2013 Pontianak Mayor Regulation as the foundational spatial planning framework, the evaluation of the consistency between peat distribution as documented in the IMDGNP and actual field conditions, comprehensive data collection on current land use practices, documentation of land use changes, and an evaluation of the implementation of existing spatial planning regulations within the peatland ecosystems of Pontianak City (Figures 4-7).

Prior scholars addressing inaccuracies in coarse-scale Indonesian peatland cartography have employed several field-based correction approaches relevant to the present investigation. Wahyunto et al. [21] documented an overall IMDGNP accuracy of approximately 88% (Kappa = 0.68), concluding that systematic ground-truth verification is essential to resolve boundary discrepancies at engineering-relevant scales. Anda et al. [28] demonstrated through semi-detailed remapping at 1:50,000 across multiple Indonesian provinces that laboratory-verified field transects substantially reduce peat extent uncertainties compared to national 1:250,000 cartographic products. Within the Borneo region specifically [26], Vernimmen et al. [36] mapped peatlands in Kubu Raya District—directly adjacent to Pontianak City—using transect-based field measurements at 200-meter intervals proximal to peat dome boundaries, achieving a validation accuracy of ± 0.55 m standard deviation and confirming that dense boundary-proximal sampling is necessary to accurately delineate complex peat margins in coastal West Kalimantan lowlands. Hirose et al. [37] further identified systematic over- and underestimation patterns in West Kalimantan peatland maps, reinforcing the necessity of district-scale field verification over reliance on national cartographic estimations. These methodological precedents collectively justify the 250-meter systematic grid interval adopted in the present investigation, which yields an effective sampling density of approximately 5.18 observation points per km²—approximately 8–12 times denser than the maximum intervals prescribed by the Regulation of the Minister of Environment and Forestry (P.14/MENLHK/SETJEN/KUM.1/2/2017) and substantially higher than the landscape-scale sampling densities reported in comparable Kalimantan studies [38]. In urban peatland environments such as Pontianak City, where drainage infrastructure, compacted fill material, and fragmented land use introduce peat boundary variability at sub-500-meter scales, this spacing represents the minimum interval necessary to detect boundary transitions with sufficient spatial precision for 1:50,000 engineering-grade mapping, infrastructure routing, and foundation design applications.

Table 1. Points of land use observation for each district in Pontianak

Location (District)	Number of Points
Pontianak City	42
Southeast Pontianak	159
East Pontianak	128
North Pontianak	285

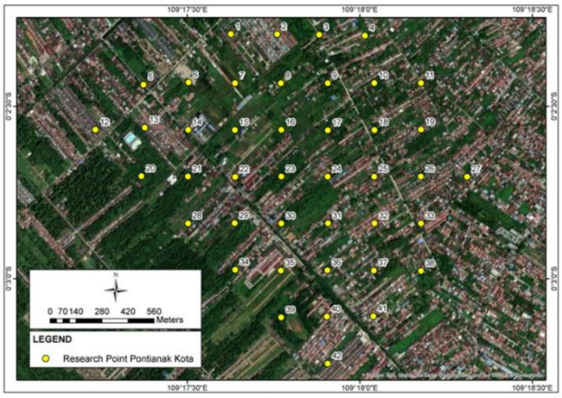

Figure 4. Land use observation points of Pontianak City district

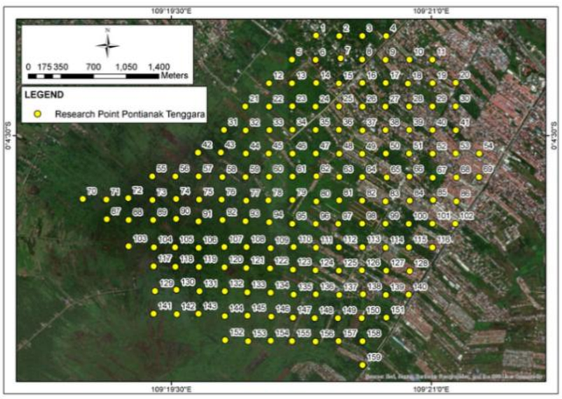

Figure 5. Land use observation points of Southeast Pontianak District

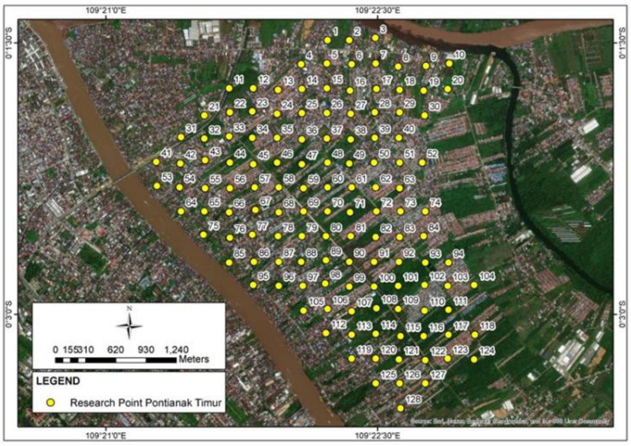

Figure 6. Land use observation points of East Pontianak District

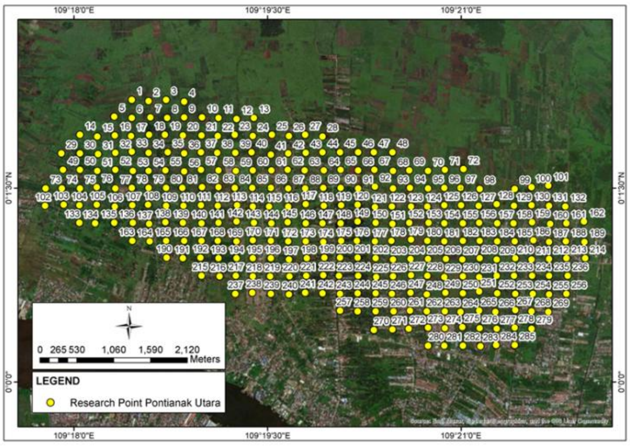

Figure 7. Land use observation points of North Pontianak District

2.3 Sampling strategy

2.3.1 Sampling location determination

Building upon the 614 systematic observation points established at 250-meter intervals as described in Section 2.2, sampling location determination for laboratory specimen collection followed a two-stage spatial refinement process consistent with standardized procedures stipulated in the Regulation of the Minister of Environment and Forestry (P.14/MENLHK/SETJEN/KUM.1/2/2017), specifying maximum longitudinal distances of 2.00 km and maximum transverse distances of 3.00 km between sample points. In the first stage, a provisional GRID framework proportional to each district's total area yielded 68 candidate points distributed as follows: 13 points in Pontianak City District, 18 in Southeast Pontianak District, 14 in East Pontianak District, and 23 in North Pontianak District, reflecting the relative extent of preliminary IMDGNP peatland designations within each administrative boundary. In the second stage, the provisional GRID was refined through GIS-based multi-layer overlay analysis integrating the topographic base map at 1:50,000 scale (Geospatial Information Agency of Indonesia), the City Spatial Plan 2013 land use classification — identifying settlement, agriculture, green open space, and urban forest zones where peat boundary transitions were anticipated — and drone-based orthophotographic imagery from field reconnaissance that highlighted zones of apparent soil heterogeneity warranting targeted laboratory verification. Points coinciding with impervious surfaces or road infrastructure, where undisturbed sample retrieval was physically infeasible, were relocated to the nearest accessible position within a 50-meter radius to preserve spatial representativeness. The resulting distribution is presented in Table 2 (Figures 8-11).

Table 2. Determining the points for taking samples

Location	Number of Points
Pontianak City District Maximum Longitudinal Distance: 1.368 km Maximum Transverse Distance: 0.886 km	13
Southeast Pontianak District Maximum Longitudinal Distance: 1.722 km Maximum Transverse Distance: 2.298 km	18
East Pontianak District Maximum Longitudinal Distance: 1.298 km Maximum Transverse Distance: 1.258 km	14
North Pontianak District Maximum Longitudinal Distance: 1.992 km Maximum Transverse Distance: 1.395 km	23

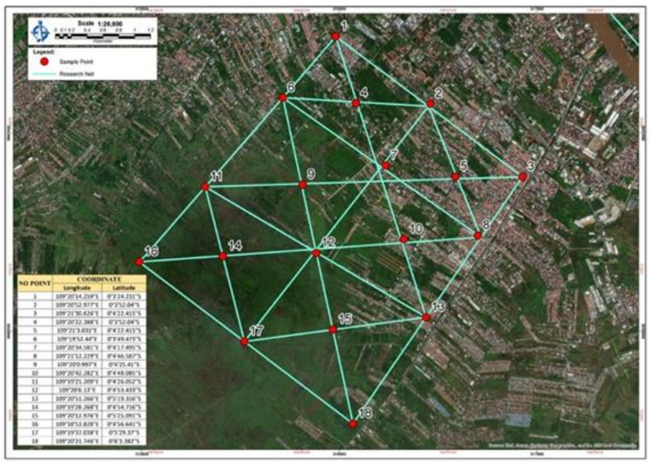

Figure 8. Position of soil sample collection points, Pontianak City District

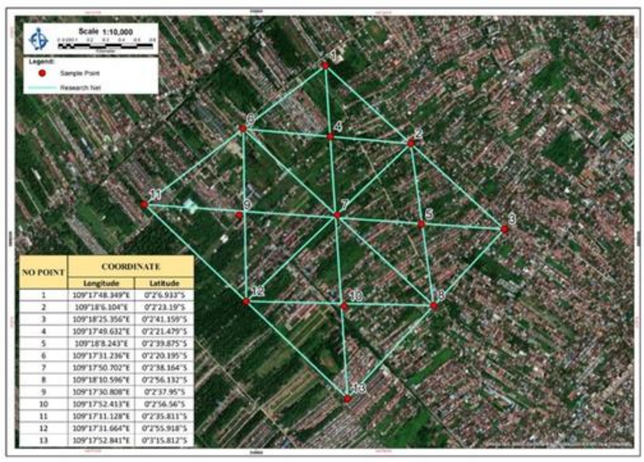

Figure 9. Position of soil sample collection points, Southeast Pontianak District

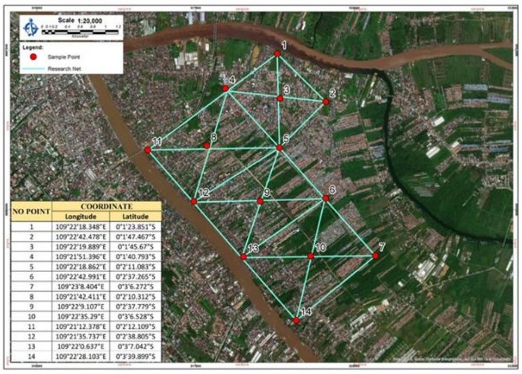

Figure 10. Position of soil sample collection points, East Pontianak District

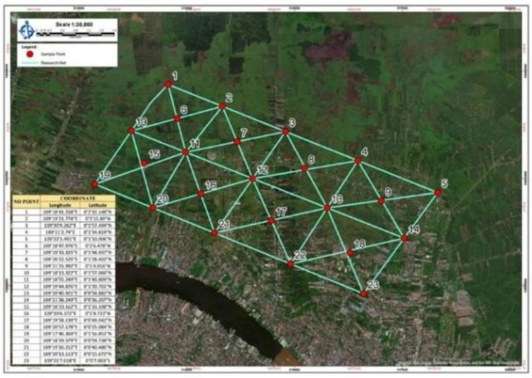

Figure 11. Position of soil sample collection points, North Pontianak District

2.3.2 Field sampling procedures

Field sampling operations were conducted for four specific purposes: (1) determining profile and depth of peat soil layers at observation locations to establish stratigraphic characteristics; and (2) collecting undisturbed samples to test peat soil classification parameters for geotechnical demarcation verification. Peat soil depth inspection utilized Peat Soil Handbor equipment capable of investigating depths up to 10.00 meters, consisting of handlebars, stem, and hand drill components, enabling layer-specific profile characterization at predetermined depth intervals. Undisturbed samples were obtained using PVC pipes at depths ranging from 0.50 to 1.00 meters below ground surface, with sampling depth adjusted according to site-specific conditions, and samples were covered with rubber and plastic layers to maintain soil structure authenticity for immediate laboratory testing to prevent decomposition or moisture content alteration (Figure 12).

Figure 12. Peat soil samples in the field

2.4 Organic content and ash content testing

Laboratory testing protocols focused on determining organic content and ash content parameters essential for peat soil classification and IMDGNP boundary verification, following standardized procedures established by the American Society for Testing and Materials (ASTM). Loss on Ignition (LOI) testing conforming to ASTM D2974 specifications was conducted to quantify organic matter content through controlled combustion procedures, with peat soil samples subjected to high-temperature oxidation to determine the proportion of organic constituents versus mineral components. Organic content determination following ASTM D4427 specifications provided the fundamental classification criterion distinguishing peat soil from organic soil material, with peat defined as soil material containing less than 25% ash content on a dry weight basis (equivalent to greater than 75% organic content), while organic soils exhibit ash content exceeding 25% but containing sufficient organic matter to influence engineering behavior. These standardized classification procedures enabled systematic verification of IMDGNP preliminary peatland boundary estimations through empirical field and laboratory data, supporting the refinement of spatial demarcation from coarse-resolution cartographic products (1:250,000 scale) to detailed engineering-scale mapping (1:50,000 scale) based on quantitative geotechnical classification parameters rather than preliminary visual assessments.

2.5 Geographic Information System analysis

2.5.1 Spatial data components

GIS analysis employed spatial data characterized as geographically referenced information distinguished by coordinate system frameworks and comprising two key components: (1) location information, including geographic and three-dimensional coordinates with associated datum and projection specifications, and (2) descriptive non-spatial information associated with specific geographic locations encompassing details about vegetation, population, area, and administrative classifications. Three primary base maps were utilized to determine spatial positioning and support demarcation verification procedures: (1) topographic base map of Pontianak City at 1:50,000 scale obtained from the Geospatial Information Agency of Indonesia, depicting administrative boundaries as of 2019 provided by Pontianak Regional Development Planning Agency; (2) land use map based on the City Spatial Plan for Pontianak District City (2013) provided by Pontianak City Public Works Department; and (3) indicative map depicting locations of new permit granting delays at 1:250,000 scale, revised in 2021 and attached to governmental decree issued February 15, 2021, by the Indonesia Minister of Environment and Forestry.

2.5.2 Geographic Information System development and processing

GIS development encompassed five systematic stages for comprehensive peatland demarcation verification: (1) Planning and Preparation defining GIS objectives for presenting data on identification and determination of Pontianak peatland boundaries utilizing QGIS software; (2) Data Collection assembling spatial data from analog sources, remote sensing imagery, field measurements, and GPS data, with attribute data obtained from Pontianak City Government, Ministry of Environment and Forestry, and open-source internet resources (Figure 13); (3) Data Processing executing input data entry, correction, transformation, digitization, and raster-to-vector data conversion procedures; (4) Data Analysis implementing spatial analysis techniques including zone buffer creation on specified objects and multi-layer overlay operations for examining relationships between data, distance calculations, area determinations, and network analysis; and (5) Data Visualization and Presentation developing cartographic products with attributes and symbols supplemented by supporting information. The database management system procedures incorporated four systematic components applied uniformly to peatland demarcation objectives: collection, input and correction for system data selection through manual digitization and database integration; storage and retrieval for data preparation facility control and memory capacity management; manipulation and analysis employing digital model transformation techniques with mathematical algorithms; and output reporting generating new spatial data visualizations integrated into comprehensive mapping products depicting verified peatland boundaries and land use classifications, peat soil layer depth distributions.

Figure 13. Navigation for points on the study site (adapted from Google Earth)

2.6 Research flowchart

The structured flowchart (Figure 14) illustrates the procedures for demarcation, spanning from initial data collection and analysis to final cartographic visualization, integrating standardized database management system protocols while preserving clear distinctions among input, process, analysis, and output stages. The delineation flowchart necessitates two primary data inputs: (1) Peat soil layer profile and classification data, including the depth of the peat layer as determined through Peat Soil Handbor investigations, field testing, and classification procedures; undisturbed soil sampling utilizing PVC pipes at specified depths; and laboratory analysis of organic and ash content in accordance with ASTM D4427 standards to confirm peat classification criteria (ash content less than 25% on a dry weight basis). (2) Demarcation control source data, comprising an administrative map of Pontianak City at a 1:50,000 scale; peat area data derived from the Indonesian IMDGNP at a 1:250,000 scale requiring verification; and the City Spatial Plan for Pontianak District City (2013), which provides land use regulatory frameworks. Following established database management protocols—including data collection and entry with validation, storage and retrieval, manipulation and analysis, as well as output and reporting—the investigation produces four primary mapping outputs: (1) Mapping and delineation of verified peatland regions in Pontianak City to rectify IMDGNP preliminary assessments, (2) mapping and documentation of peatland land use classifications in accordance with the 2013 Pontianak spatial planning regulations, (3) mapping of the depth distribution of peat soil layers to support functional classification, and (4) mapping of Pontianak peat soil classifications based on organic content.

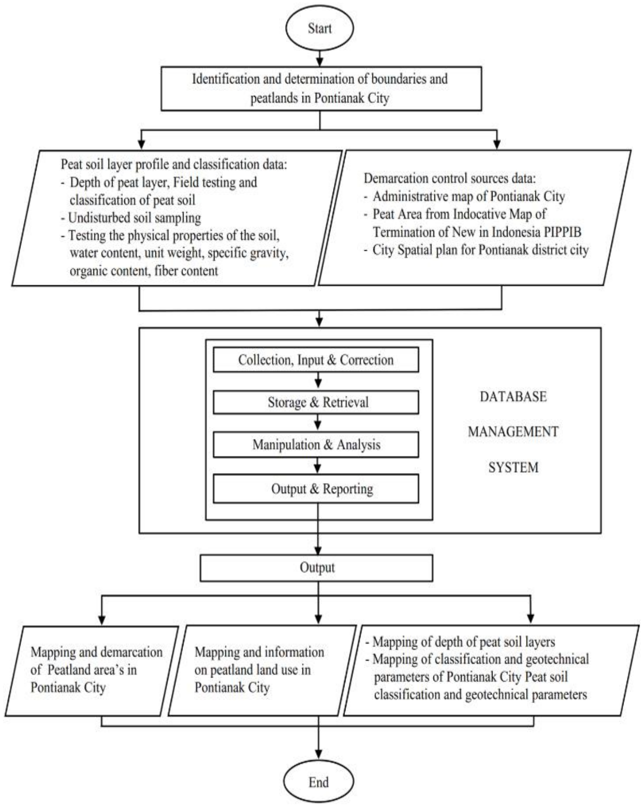

Figure 14. Flowchart diagram for demarcation of Pontianak peat soil

3. RESULTS AND ANALYSIS

This investigation presents comprehensive findings addressing the primary research objective of verifying and refining peatland demarcation boundaries in Pontianak City through systematic field observation, laboratory testing, and spatial analysis. Results and analysis comprise four principal components: (1) field investigation results encompassing land use observations at 614 systematically distributed points and preliminary peatland distribution assessment across four initially detected districts; (2) laboratory investigation outcomes focusing exclusively on organic content and ash content determinations following ASTM D4427 and ASTM D2974 standardized procedures for definitive peat soil classification; (3) systematic data analysis and evaluation incorporating land use assessment, peatland demarcation refinement based on classification results, and peat soil layer depth characterization; and (4) geospatial mapping utilizing GIS presenting refined spatial distributions of verified peatland boundaries. The investigation systematically integrates field reconnaissance data, laboratory classification results, and GIS-based spatial visualization techniques to address documented deficiencies in preliminary IMDGNP map estimations at 1:250,000 scale, providing refined demarcation boundaries suitable for engineering applications and urban infrastructure planning.

3.1 Field investigation results

3.1.1 Preliminary peatland distribution from Indicative Map of Delay in Granting New Permits map

Field investigation protocols were implemented to achieve peatland demarcation objectives through systematic spatial identification and verification of preliminary IMDGNP estimations across Pontianak City boundaries. Quantitative assessment results derived from initial peatland distribution maps identified four administrative districts containing preliminary peatland designations with varying spatial extents: Pontianak City District (0.9072 km²), Southeast Pontianak District (6.7569 km²), East Pontianak District (3.4325 km²), and North Pontianak District (12.7683 km²), collectively accounting for approximately 23.8649 km² or 20.15% of Pontianak City's total area. North Pontianak District exhibited the largest absolute preliminary peatland extent at 12.7683 km² within its 41.097 km² total area, representing approximately 53.5% of the city's aggregate preliminary peatland distribution, while Southeast Pontianak District demonstrated the highest proportional coverage at 41.90% despite smaller absolute extent; detailed distribution of estimated peatland area in Pontianak City is presented in Table 3. Comprehensive field observations were conducted across 614 systematically distributed observation points established at 250-meter intervals in orthogonal directions, employing integrated documentation protocols and drone-based remote sensing, utilizing drone for orthophotography processing, producing geometrically corrected aerial photographs ensuring precise correspondence between photographic representation and cartographic position for subsequent spatial analysis. The systematic observation framework facilitated comprehensive verification of preliminary peatland designations through visual field assessment and precise GPS coordinate documentation, establishing foundational spatial data for laboratory classification procedures and refined boundary demarcation.

Table 3. Comparison of total area with estimates on preliminary peatland maps in Pontianak City

No.	District	Total Area (km^2)	Estimated Area of Peat Soil (km^2)	Percentage of Peatland Area (%)
1	Pontianak City	16.016	0.9072	5.66
2	Southeast Pontianak	16.127	6.7569	41.90
3	East Pontianak	12.061	3.4325	28.46
4	North Pontianak	41.097	12.7683	31.07

3.1.2 Land use classification results

Land use classification criteria established according to the 2013 Pontianak City Spatial Planning Map encompassed seven primary categories (Figure 15, Table 4): settlements, peatland distribution, agriculture and farm operations, educational facilities, green open space, trade and services, and urban forest designations, providing systematic frameworks for field observation and spatial analysis. Systematic field reconnaissance revealed distinct land use patterns across the four initially detected peatland districts: Pontianak City District, Southeast Pontianak District, East Pontianak District and North Pontianak District, with North Pontianak exhibiting the most diverse land use configuration encompassing six distinct categories. Preliminary spatial analysis based on visual field assessment indicated that only three districts—Southeast Pontianak, East Pontianak, and North Pontianak—contained areas warranting detailed laboratory investigation for peat soil classification, demonstrating initial discrepancies between preliminary IMDGNP cartographic estimations and empirical field conditions. Drone-based orthophotography utilizing vertical photography techniques provided comprehensive land area representations adjusted to geographic coordinates through photogrammetry procedures, facilitating precise measurement of potential peatland extent and systematic documentation of land use patterns at all 614 observation points to support subsequent laboratory testing and classification verification. The land use assessment established essential baseline data for understanding spatial relationships between urban development patterns, agricultural activities, and organic soil distributions within Pontianak City boundaries, providing contextual frameworks for interpreting laboratory classification results and refined peatland demarcation procedures.

Table 4. Land use criteria for each district based on the 2013 Pontianak City spatial planning map

No.	District	Estimated Peatland Area (km^2)	Land Use Criteria
1	Pontianak City	0.9072	Settlements, Educational Facilities, Green Open Space
2	Southeast Pontianak	6.7569	Settlements, Peatland distribution
3	East Pontianak	3.4325	Settlements, Trade and Services, Educational Facilities
4	North Pontianak	12.7683	Settlements, Peatland Distribution, Agriculture and farm, Landfill, Government Facilities, Green Open Space

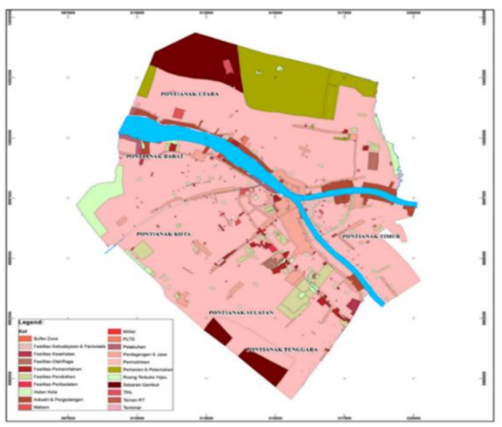

Figure 15. Pontianak City regional spatial planning map 2013

3.2 Laboratory classification results

3.2.1 Organic content testing results

Organic content determination constituted the primary classification parameter for distinguishing peat soil from organic soil formations, with laboratory testing conducted on 68 systematically collected undisturbed samples following ASTM D4427 "Standard Classification of Peat Samples by Laboratory Testing" specifications establishing organic content exceeding 75% on dry weight basis as the definitive threshold for peat soil designation. Comprehensive organic content examination results revealed substantial variations across the four initially detected districts: Pontianak City District exhibited average organic content of 6.41% from 13 sampling points, Southeast Pontianak District demonstrated 63.60% average from 18 points, East Pontianak District showed 13.86% average from 18 points, and North Pontianak District displayed 87.59% average organic content from 23 sampling points, with only North Pontianak District exceeding the 75% classification threshold characteristic of peat soil formations. The organic content values were determined through LOI methodology conforming to ASTM D2974 standardized procedures, whereby organic matter content is calculated by subtracting measured ash content from 100%, yielding percentage organic content values utilized for systematic classification according to established geotechnical standards. Based on comprehensive organic content analysis, Pontianak City District (6.41%), Southeast Pontianak District (63.60%), and East Pontianak District (13.86%) failed to meet the 75% threshold requirement, indicating classification as organic soils rather than peat formations, while North Pontianak District (87.59% average) definitively qualified as peatland area warranting detailed spatial demarcation and further geotechnical characterization. These classification results necessitated substantial revision of preliminary IMDGNP designations and prompted concentrated research efforts on North Pontianak District for comprehensive peatland boundary refinement and spatial analysis at enhanced cartographic scales suitable for engineering applications.

3.2.2 Ash content testing results

Ash content determination following ASTM D2974 standardized procedures provided complementary classification verification through Method C involving ignition of oven-dried soil specimens in muffle furnace at 440 ℃ ± 40 ℃ until constant weight achievement, with the remaining inorganic residue constituting ash content expressed as percentage of oven-dried sample mass and serving as inverse indicator of organic content. Comprehensive ash content testing results for Pontianak City District revealed values ranging from 89.01% to 96.49%, substantially exceeding the 25% threshold and confirming classification as organic soil rather than peat formation, consistent with the measured average organic content of 6.41%. Southeast Pontianak District exhibited substantial heterogeneity with ash content spanning from 3.42% to 96.99%, indicating spatial variability in organic matter content and suggesting mixed soil conditions containing both peat formations (ash content < 25%) and organic soils (ash content > 25%) within district boundaries, consistent with average organic content of 63.60% falling below the 75% peat classification threshold. East Pontianak District demonstrated ash content values ranging from 77.44% to 96.49%, with all observation points exceeding the 25% threshold limit, definitively classifying the entire district as organic soil rather than peat formation and correlating with average organic content of 13.86%. North Pontianak District exhibited ash content ranging from 1.61% to 19.53%, with all 23 observation points demonstrating values below the 25% threshold consistent with peat soil classification according to ASTM D4427 specifications, validating the average organic content measurement of 87.59% and establishing North Pontianak as the dominant peatland formation within Pontianak City requiring comprehensive spatial demarcation. The systematic ash content analysis provided independent verification of organic content determinations, enabling confident classification decisions distinguishing peat formations from organic soils and establishing empirical foundations for refined peatland boundary delineation superseding preliminary IMDGNP estimations with laboratory-verified data.

Comprehensive organic content and ash content testing results are presented in Tables 5 and 6, augmented with standard deviation and coefficient of variation statistics to characterize the degree of spatial heterogeneity across the four initially identified districts. Pontianak City District and East Pontianak District exhibited low internal variability — CV of 29.2% and 28.2% for organic content, respectively — with all sampling points consistently falling well below the 75% peat classification threshold (means: 6.41% and 13.86%), providing high confidence in their uniform classification as organic soils. North Pontianak District similarly demonstrated a moderate CV of 24.9%, yet with a mean organic content of 87.59% and 95.65% of observation points exceeding the 75% threshold, its classification as a dominant peatland formation is unambiguous and statistically robust.

Table 5. Organic content examination results

No.	District	Organic Content		SD
		Number of Points	Average Value (%)	
1	Pontianak City	13	6.41	1.87
2	Southeast Pontianak	18	63.60	23.39
3	East Pontianak	14	13.86	3.91
4	North Pontianak	23	87.59	21.85

Table 6. Ash content examination results

Location	Ash Content Values (%)		SD
	Minimum	Maximum	
Pontianak City	89.01	96.49	1.87
Southeast Pontianak	3.42	96.99	23.39
East Pontianak	77.44	96.49	4.76
North Pontianak	1.61	19.53	4.48

Southeast Pontianak District, however, exhibited markedly distinct statistical behavior, with organic content ranging from 3.01% to 96.58% (range = 93.57%), an estimated standard deviation of 23.39%, and a coefficient of variation of 36.8%, reflecting extreme spatial heterogeneity characteristic of a transitional peat-to-mineral soil boundary zone. Critically, the district-level mean of 63.60% organic content falls below the ASTM D4427 threshold of 75%, yet this aggregate value masks the fact that 66.67% of individual monitoring stations within the district recorded organic content exceeding 75%, confirming the presence of peat at the point scale. Accordingly, the district-level average was not employed as the sole basis for peatland boundary determination; rather, point-by-point spatial classification integrated within the GIS framework was applied, enabling identification of verified peat zones within Southeast Pontianak that contributed to the 5.798 km² confirmed peatland extent. The high CV of the ash content data for Southeast Pontianak (64.3%, with ash content ranging from 3.42% to 96.99% — spanning the full spectrum from peat to organic soil in a single district) further substantiates the interpretation of this district as a spatially heterogeneous transitional zone where peat and organic soil formations coexist at sub-grid scales, introducing inherent uncertainty in the precise delineation of peat boundaries at the district periphery.

3.3 Data analysis and evaluation

3.3.1 Land use assessment in verified peatland areas

Land use assessment for verified peatland areas focused exclusively on two districts confirmed through laboratory classification procedures (Figure 16): Southeast Pontianak District and North Pontianak District, with quantitative land use distributions systematically documented to support spatial planning and environmental management applications. Southeast Pontianak District land use encompassed three primary categories: settlements occupying 3.9631 km², peatland distribution covering 1.6342 km², and government and educational facilities utilizing 0.1402 km², reflecting relatively limited functional diversity within verified peatland boundaries. North Pontianak District demonstrated substantially more diverse land use configurations encompassing six distinct categories: settlements (4.9522 km²), agriculture and farm operations (7.8000 km² representing the dominant land use), green open space (0.0517 km²), landfill facilities (0.1426 km²), peatland distribution (4.3715 km²), and government and educational facilities (0.0026 km²), indicating complex spatial relationships between urban development, agricultural activities, and peatland ecosystem preservation. Drone-based remote sensing investigations utilizing orthophotography methodology produced comprehensive visual documentation at all observation points within verified peatland districts, creating land area map representations from vertical aerial photography adjusted to geographic coordinates through photogrammetry techniques for precise spatial measurement and land use pattern documentation. The orthophotographic analysis facilitated systematic evaluation of contemporary land utilization patterns, enabling measurement of actual peatland extent and comprehensive documentation of land use transitions, providing essential data for assessing correspondence between documented spatial planning regulations and actual field implementation within Pontianak's verified peatland ecosystems. These land use assessment results established critical baseline information for understanding anthropogenic pressures on peatland formations, informing conservation priorities, and supporting evidence-based spatial planning decisions that balance urban development demands with ecological preservation requirements in tropical peatland environments.

Figure 16. Land use assessment of peatland areas within North Pontianak District

3.3.2 Peatland demarcation refinement and boundary verification

Peatland demarcation boundaries were systematically determined through rigorous application of ASTM D4427 classification procedures, utilizing organic content values obtained from laboratory analysis of 68 undisturbed soil specimens collected at predetermined sampling locations to verify peat soil identification for samples exhibiting organic content exceeding 75% according to established geotechnical standards. Comprehensive organic content assessment results revealed substantial spatial variations across the four initially detected districts (Table 7): Pontianak City District (3.51% to 10.99% organic content, definitively classified as non-peat), Southeast Pontianak District (3.01% to 96.58% organic content, with 66.67% of monitoring stations detecting peat formations indicating heterogeneous soil conditions), East Pontianak District (6.91% to 22.56% organic content, classified as non-peat), and North Pontianak District (11.00% to 98.39% organic content, with 95.65% of observation points detecting peat formations establishing North Pontianak as dominant peatland area). The systematic classification assessment conclusively confined peat soil formations to only two administrative districts within Pontianak City boundaries—Southeast Pontianak and North Pontianak—contrary to preliminary IMDGNP estimations identifying four districts, necessitating substantial revisions to peatland boundaries and reclassification of Pontianak City District and East Pontianak District as containing organic soils rather than peat formations (Figure 17). Spatial demarcation analysis demonstrated significant boundary corrections compared to preliminary cartographic estimations, with refined spatial configurations revealing that Pontianak City District contained zero detected peat points, East Pontianak District similarly exhibited no peat formations, Southeast Pontianak District displayed partial peatland coverage with heterogeneous spatial distribution, and North Pontianak District contained extensive peatland areas exceeding initial IMDGNP estimates while retaining non-peat zones within preliminarily detected boundaries. The corrected peatland boundaries, systematically documented through GIS-based spatial analysis and visualized in comprehensive mapping products at 1:50,000 scale, established verified spatial extents of 0.000 km² (0.000%) for Pontianak City District, 5.798 km² (35.95% of district area) for Southeast Pontianak District, 0.000 km² (0.000%) for East Pontianak District, and 17.320 km² (42.14% of district area) for North Pontianak District (Table 8), providing accurate demarcation data essential for urban planning, infrastructure design, and environmental management applications.

Table 7. Organic content ranges and peat soil classification results by district

District	Organic Content %	Classification
Pontianak City	3.51–10.99	Non-peat
Southeast Pontianak	3.01–96.58	66.67% points detected peat
East Pontianak	6.91–22.56	Non-peat
North Pontianak	11.00–98.39	95.65% points detected peat

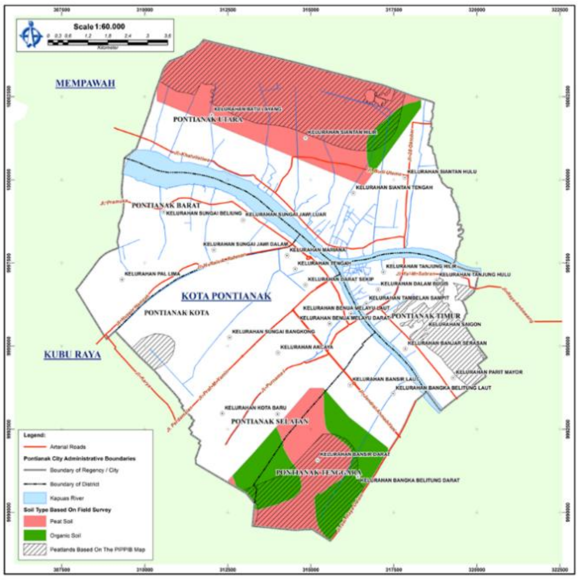

Figure 17. Spatial distribution of Pontianak peat soil areas: Classification

3.3.3 Peat soil layer depth classification

A systematic assessment of peat soil layer depth was undertaken in the North Pontianak District to support land-use identification and the functional classification of peat ecosystems. This assessment adhered to existing regulatory frameworks and employed the classification system developed by Wetlands International (2004). This system categorises peatlands into six classes based on layer thickness: very shallow (< 50 cm), shallow (50–100 cm), moderate (100–200 cm), deep (200–400 cm), very deep (400–800 cm), and extremely deep (800–1200 cm). A comprehensive investigation encompassing 23 observation points within the North Pontianak District was conducted through systematic visual assessment and field inspection. The methodology employed the Peat Soil Handbor apparatus to determine peat layer thickness, with measured depths ranging from a minimum of 1.05 m (moderate peat) to a maximum of 4.30 m (very deep peat).

Table 8. Spatial area comparison between Pontianak City boundaries and peatland distribution based on systematic evaluation and laboratory analysis

No.	District	Total Area (km^2)	Peat Soil Area Test Results (km^2)	Percentage of Peat Soil Area in Pontianak City (%)
1	Pontianak City	16.016	0.000	0.000
2	Southeast Pontianak	16.127	5.798	35.95
3	East Pontianak	12.061	0.000	0.000
4	North Pontianak	41.097	17.320	42.14

Table 9, therefore, not only provides generic depth categories but is directly applied here to classify each of the 22 measured peat profiles into moderate, deep, and very deep peat classes. Based on the peat thickness classification system proposed by Wetlands International (2004) and summarized in Table 9, the 22 observation points in North Pontianak District (Figure 18) can be grouped into three primary depth classes: one location (4.55%) falls within the moderate peat category (1.0–2.0 m), seven locations (31.82%) are classified as deep peat (2.0–4.0 m), and fourteen locations (63.64%) correspond to very deep peat (> 4.0 m). Consequently, a total of 95.45% of the surveyed soil profiles are categorized as deep to very deep peat, indicating that the subsurface conditions in the verified peatland areas of North Pontianak are overwhelmingly dominated by thick peat accumulations rather than marginal or shallow deposits. This depth distribution strongly supports the designation of North Pontianak as a structurally critical peatland zone for urban development, as the predominance of deep and very deep peat layers implies substantial long-term consolidation potential and elevated geotechnical risk for heavy infrastructure, particularly where foundation systems are not specifically engineered to accommodate significant compressibility and low bearing capacity.

Table 9. Peat soil classification based on layer thickness parameters

No.	Category	Classification	Explanation
1	< 50 cm	Very shallow	Shallow peat is formed by organic matter mixed with mineral soil that lies just below the peat layer. Shallow peat tends to have more decomposed organic material and is more fertile.
2	50–100 cm	Shallow	
3	100–200 cm	Moderate	The organic matter content in medium peat is higher than that in shallow peat. This is because there is more plant material growing on the surface, which will then die and undergo a weathering process to form a new layer of peat.
4	200–400 cm	Deep	Deep peat is dominated by organic matter, with even less influence from mineral soil. Deep peat also has low levels of Phosphorus (P) and mineral elements, making it infertile.
5	400–800 cm	Very deep	This type of peat has the highest organic matter content.
6	800–1200 cm	Extremely deep	

Source: Wetlands International, 2004.

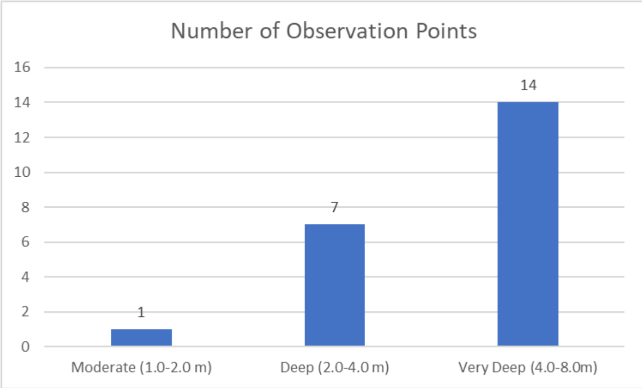

Figure 18. Distribution of peat thickness classes at 22 observation points in North Pontianak District based on Wetlands International (2004)

These depth classification parameters are essential for functional designation, as stipulated by the Indonesian Government Regulation. This regulation establishes two primary classifications: (1) ecosystem protection, for peat soil formations exceeding 3.00 m in depth, intended to maintain environmental stability and ecological preservation; and (2) agricultural productivity, for peatland systems with a depth less than 3.00 m, which supports ecosystem productivity through cultivation. The existing regulatory framework acknowledges a correlation between increased peat layer thickness and enhanced ecological protection, as well as heightened environmental vulnerability to land conversion. Conversely, thinner peat formations are more suitable for agricultural use and entail lower risks of environmental degradation. This understanding provides a scientific basis for sustainable land-use planning and conservation zoning in the peatlands of North Pontianak District. Subsurface profile visualisation, delineating organic–mineral soil stratigraphic boundaries, offered a comprehensive understanding of vertical soil structure (Figure 19). This knowledge facilitated informed decision-making for infrastructure development, agricultural management, and environmental conservation strategies within the verified peatland formations of Pontianak City.

Figure 19. Subsurface profile showing organic-mineral soil stratigraphic boundaries

A field investigation was carried out at 22 sampling locations within the study area, spanning longitudes from approximately 109°17'46"E to 109°22'3"E and latitudes from 0°0'7"S to 0°2'32"N. The measurements of the peat layer depth demonstrate significant spatial variability, ranging from 1.05 m to 4.30 m below the ground surface. According to the established classification criteria, most sampling sites (14 locations, accounting for 63.6% of the total samples) displayed intense peat layers ($\geq$ 4.00 m), primarily concentrated in the northern and eastern regions of the survey area. Deep peat conditions (2.00–3.70 m) were observed at 7 locations (31.8%) and exhibited a transitional pattern across the central regions of the study site. Only a single sampling site (site 5) exhibited a medium depth classification at 1.05 m, indicating possible soil heterogeneity or localised geological differences. The spatial distribution pattern indicates that peat thickness increases predominantly towards the northeastern quadrant of the study area, with important implications for foundation design and ground development strategies. This initial subsurface characterisation offers vital baseline data for future geotechnical assessments and sustainable infrastructure development planning within peatland regions.

Figure 18 presents the distribution of the 22 observation points across the peat thickness classes defined by Wetlands International (2004), demonstrating that only a single profile is classified as moderate peat (1.0–2.0 m), whereas the remaining locations are dominated by thicker deposits. Specifically, seven observation points fall within the deep peat class (2.0–4.0 m), and fourteen points correspond to very deep peat (> 4.0 m), indicating that 95.45% of the surveyed profiles consist of deep to very deep peat formations. This visualisation complements the numerical summary in Table 9 by providing an intuitive depiction of the pronounced skew towards thick peat deposits in North Pontianak, highlighting the predominance of peat layers with substantial thickness that are critical from a geotechnical perspective. The observed depth structure underscores the need for careful foundation design and stringent development control in these areas, as the dominance of deep and very deep peat implies elevated risks of long-term consolidation and differential settlement if conventional shallow foundation solutions are applied without appropriate mitigation.

3.4 Geospatial mapping and GIS assessment

3.4.1 Comparative analysis: IMDGNP vs verified boundaries

Comparative spatial analysis utilizing GIS frameworks facilitated systematic evaluation of discrepancies between preliminary IMDGNP peatland designations and verified boundaries derived from comprehensive field investigation and laboratory classification procedures (Figure 20). The land use mapping approach involved systematic comparison between predicted peatland area designations from the 2013 Pontianak City Spatial Planning Map and contemporary land use conditions. Spatial comparison results revealed that verified peatland extent in North Pontianak District (17.320 km²) substantially exceeded preliminary IMDGNP estimates (12.7683 km²), representing a 35.76% increase in documented peatland boundaries, while Pontianak City District and East Pontianak District required complete reclassification from preliminary peatland designations to organic soil categories based on definitive laboratory classification results (Figure 21).

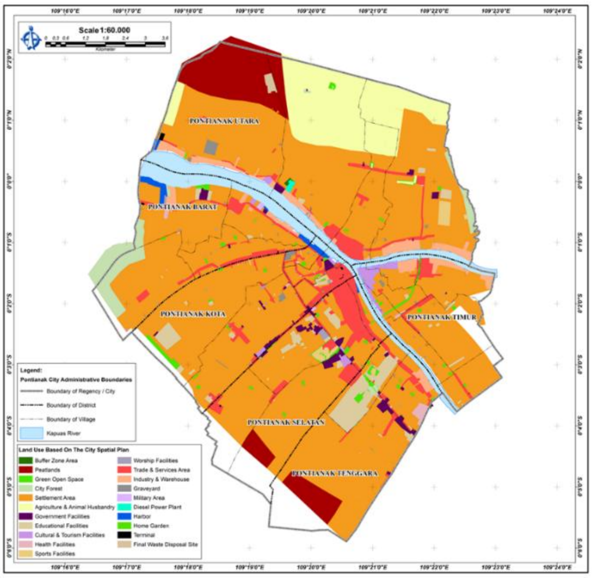

Figure 20. Comparative analysis of land use designations in Pontianak City spatial plan versus empirical observations of peatland areas

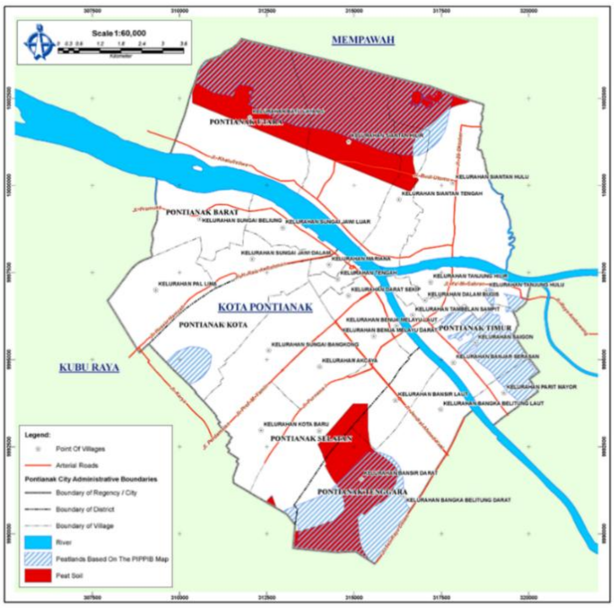

Figure 21. The comparison between the initial identification and the refined demarcation of Pontianak peat soil regions based on comprehensive evaluation and classification results

3.4.2 Final demarcation mapping products

Final demarcation mapping products developed through comprehensive GIS analysis present refined peatland boundaries at 1:50,000 scale suitable for engineering applications, urban infrastructure planning, and environmental management decision-making within Pontianak City. The systematic spatial analysis, integrating field investigation data with laboratory classification results — organic content and ash content determinations according to ASTM D4427 and ASTM D2974 specifications — established definitive peatland extents confined to two administrative districts: Southeast Pontianak District with verified area of 5.798 km² representing 35.95% of district area, and North Pontianak District with verified extent of 17.320 km² representing 42.14% of district area, collectively comprising 23.118 km² of confirmed peatland formations within Pontianak City boundaries. The refined demarcation mapping conclusively reclassified Pontianak City District and East Pontianak District as containing 0.00 km² peatland area, with comprehensive laboratory testing establishing that all observation points in these districts exhibited organic content below 75% and ash content exceeding 25%, definitively classifying formations as organic soils rather than peat according to standardized geotechnical criteria. The GIS database integration incorporated systematic linkage of spatial coordinates with attribute data including organic content percentages, ash content measurements, peat soil classifications, and depth characterizations, facilitating spatial interpolation procedures and enabling generation of comprehensive cartographic products depicting verified peatland distributions with enhanced accuracy compared to preliminary IMDGNP estimations at 1:250,000 scale. The refined demarcation mapping products provide essential geospatial databases suitable for engineering applications including infrastructure routing, foundation design optimization, land use permit evaluation, and conservation area designation according to Government Regulation distinguishing ecosystem protection functions (peat depth > 3.0 meters) from agricultural productivity functions (depth < 3.0 meters), facilitating evidence-based decision-making for sustainable urban planning and environmental management within Pontianak City's tropical peatland ecosystems.

While the two-stage spatial refinement process — integrating topographic overlay, land use classification, and field reconnaissance—substantially improved sampling placement beyond a purely mechanical GRID application, it is acknowledged that fixed-interval systematic sampling carries inherent limitations in complex urban peat boundary delineation. In Pontianak City's densely developed environment, drainage canals, road embankments, and compacted fill layers fragment peat formations at sub-grid spatial scales that neither the 68-point laboratory network nor the 614-point field observation framework can fully resolve, leaving the possibility that localized peat discontinuities narrower than the effective sampling resolution were not captured. Future investigations in comparable tropical urban peatland environments are therefore recommended to consider adaptive or stratified sampling designs that concentrate sampling density at IMDGNP boundary peripheries and zones of rapid land use transition, thereby improving detection of spatially abrupt boundary features that systematic GRID methods may underrepresent.

Figure 22 shows that the verified peatland distribution in Pontianak City does not form a single continuous blanket, but rather a spatially organized system of elongated peat bodies controlled by the low-lying fluvial–deltaic setting. In North Pontianak District, peat soils occupy an extensive belt in the northern and northeastern parts of the city, forming a quasi-continuous band broadly parallel to the Kapuas–Landak river corridor yet shifted landward into backswamp zones away from the natural levees, which indicates preferential accumulation in poorly drained interfluve depressions instead of along the main riverbanks. In Southeast Pontianak District, the verified peat occurrences are more fragmented and discontinuous, appearing as isolated clusters embedded within a finer mosaic of non-peat urban and agricultural land uses, consistent with the effects of drainage canal construction, road embankments, and progressive infilling that have dissected the original peat mass into smaller residual remnants. When

Figures 4-7 are examined alongside Figure 21, peat-dominated areas consistently coincide with the lowest-elevation sectors and zones of persistent surface wetness, whereas districts classified as organic soils are concentrated nearer to fluvial levees and better-drained urban surfaces. Taken together, these patterns indicate that peatland morphology in Pontianak is jointly governed by macro-scale river–delta topography and micro-scale anthropogenic modification, creating a spatial gradient from relatively continuous peat belts in the northern backswamps to highly fragmented peat remnants along the southeastern urban fringe.

Figure 23 illustrates the spatial distribution and variability of organic content within the peat soil of Pontianak City. Organic content values exceeding 75.00% serve as the defining criterion for identifying peat soil presence at specific observation sites. The figure further categorizes organic content into intervals of 10.00%, ranging from 80.47% to 98.39%, thereby providing a detailed representation of organic matter variation across the study area.

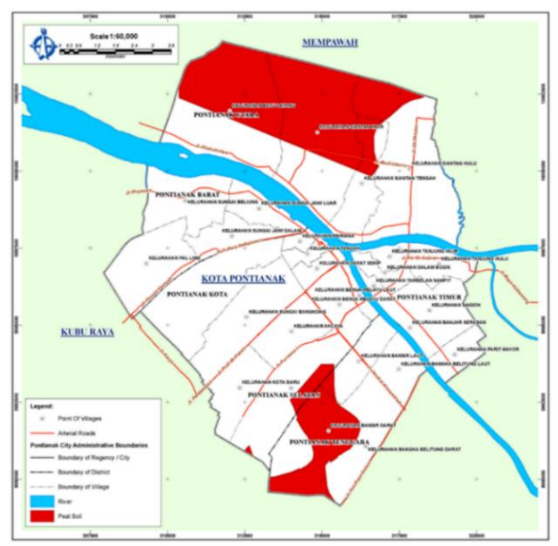

Figure 22. The spatial demarcation of peat soil areas within Pontianak City, derived from comprehensive peat soil evaluation and classification results

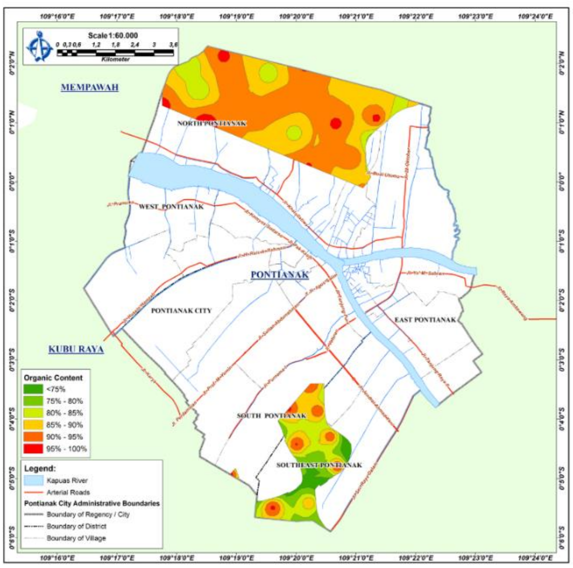

Figure 23. Spatial distribution mapping of organic content in Pontianak City peat soil formation

4. CONCLUSION

This comprehensive investigation successfully achieved the primary research objective of verifying and refining peatland demarcation boundaries in Pontianak City through the integrated application of systematic field reconnaissance, standardized laboratory classification testing, and GIS spatial analysis, thereby addressing critical deficiencies in preliminary Indonesian IMDGNP cartographic estimations at 1:250,000 scale. Laboratory testing of 68 undisturbed soil specimens collected from 614 systematically distributed observation points, using ASTM D4427 organic content determination (> 75% threshold) and ASTM D2974 ash content testing (< 25% threshold), confirmed that peat soil formations are restricted to only two administrative districts—Southeast Pontianak (5.798 km², 35.95% of district area) and North Pontianak (17.320 km², 42.14% of district area)—in contrast to preliminary IMDGNP outputs that identified four districts as containing peatland. Systematic demarcation procedures further demonstrated that verified peatland extent in North Pontianak substantially exceeds the IMDGNP estimate, increasing from 12.7683 km² to a refined boundary of 17.320 km² (a 35.76% increase in documented peatland area), while Pontianak City District and East Pontianak District were reclassified as containing organic soils (ash content > 25%, organic content < 75%) rather than peat formations according to standardized geotechnical criteria. In Southeast Pontianak, the combination of pronounced intra-district variability in organic and ash content with point-by-point GIS-based classification confirmed that peat occurs only in discrete spatial clusters, reinforcing its role as a heterogeneous transitional zone rather than a uniformly extensive peatland. The refined demarcation mapping products developed at 1:50,000 scale—supported by depth assessments showing that the majority of profiles in North Pontianak fall within deep to very deep peat thickness classes—provide essential geospatial databases for engineering applications, including infrastructure routing, foundation design optimization, land use permit evaluation, and conservation zoning in accordance with Government Regulation distinguishing ecosystem protection functions (peat depth > 3.0 m) from agricultural productivity functions (peat depth < 3.0 m), thereby strengthening evidence-based decision-making for sustainable urban planning and environmental management within Pontianak City's tropical peatland ecosystems.

REFERENCES

[1] Raturi, A., Raturi, A., Singh, H. (2024). Climate change impacts on wetland ecosystem functioning with special reference to greenhouse gas emissions. In Forests and Climate Change, pp. 345-364. https://doi.org/10.1007/978-981-97-3905-9_18

[2] Harenda, K.M., Lamentowicz, M., Samson, M., Chojnicki, B.H. (2017). The role of peatlands and their carbon storage function in the context of climate change. In GeoPlanet: Earth and Planetary Sciences, pp. 169-187. https://doi.org/10.1007/978-3-319-71788-3_12

[3] Reed, M.R., Sari, D. (2020). Indonesia's contribution to macro sustainability. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3526758

[4] Lestariningsih, S.P., Hamkani, H., Nurwendi, A.F.,

Harahap, R.N. (2024). Karakteristik lahan gambut dan tinggi muka air gambut di Kecamatan Siantan Hilir, Pontianak Utara. Jurnal Lingkungan Hutan Tropis, 3(1): 102-112.
[5] Lesmana, R. (2022). Identifikasi kenampakan fisik tanah gambut (peat soil) di Kelurahan Tanjung Selor Timur Kabupaten Bulungan Provinsi Kalimantan Utara. Jurnal Pendidikan Tambusai, 6(3): 13688-13693. https://doi.org/10.31004/jptam.v6i3.4492
[6] Kolay, P.K., Taib, S.N.L. (2018). Physical and geotechnical properties of tropical peat and its stabilization. In Peat. InTech. https://doi.org/10.5772/intechopen.74173
[7] Mahyan, N., Taib, S., Sa'don, N., Truna, L., John, J. (2023). Correlation of different peat soil index properties. International Journal of Integrated Engineering, 15(6): 21-30. https://doi.org/10.30880/ijie.2023.15.06.003
[8] Amaludin, A.E., Asrah, H., Mohamad, H.M. (2023). A review of advances in peat soil stabilisation technology: Exploring the potential of palm oil fuel ash geopolymer as a soil stabiliser material. Civil Engineering Journal, 9(8): 2085-2104. https://doi.org/10.28991/cej-2023-09-08-017
[9] Xu, J., Morris, P.J., Liu, J., Holden, J. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. CATENA, 160: 134-140. https://doi.org/10.1016/j.catena.2017.09.010
[10] Trappe, J., Kneisel, C. (2019). Geophysical and sedimentological investigations of peatlands for the assessment of lithology and subsurface water pathways. Geosciences, 9(3): 118. https://doi.org/10.3390/geosciences9030118
[11] Agus, F., Wahyunto, Dariah, A., Setyanto, P., Subiksa, I.G.M., Runtunuwu, E., Susanti, E., Supriatna, W. (2010). Carbon budget and management strategies for conserving carbon in peatland: Case study in Kubu Raya and Pontianak districts, West Kalimantan, Indonesia. In Proceedings of the International Workshop on Evaluation and Sustainable Management of Soil Carbon Sequestration in Asian Countries, Bogor, Indonesia, pp. 217-234.
[12] Tunar Özcan, N., Ulusay, R., Işık, N.S. (2020). Geo-engineering characterization and an approach to estimate the in-situ long-term settlement of a peat deposit at an industrial district. Engineering Geology, 265: 105329. https://doi.org/10.1016/j.enggeo.2019.105329
[13] Wahyunto, W., Supriatna, W., Agus, F. (2013). Land use change and recommendation for sustainable development of peatland for agriculture: Case study at Kubu Raya and Pontianak districts, West Kalimantan. Indonesian Journal of Agricultural Science, 11(1): 32. https://doi.org/10.21082/ijas.v11n1.2010.p32-40
[14] Comas, X., Slater, L., Reeve, A. (2004). Geophysical evidence for peat basin morphology and stratigraphic controls on vegetation observed in a northern peatland. Journal of Hydrology, 295(1-4): 173-184. https://doi.org/10.1016/j.jhydrol.2004.03.008
[15] Hooimeijer, F.L., Maring, L. (2018). The significance of the subsurface in urban renewal. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 11(3): 303-328. https://doi.org/10.1080/17549175.2017.1422532
[16] Gunawan, I., Soemardiono, B., Septanti, D. (2022). Typology of settlement development in riverbanks in Pontianak. International Journal of Environment, Architecture, and Societies, 2(2): 73-84. https://doi.org/10.26418/ijeas.2022.2.02.73-84
[17] Affrilyno, A., Gultom, B.J., Jati, D.R., Zhang, A. (2024). Quantifying fire risks in Pontianak for future planning and development. International Journal of Environment, Architecture, and Societies, 4(1): 1-12. https://doi.org/10.26418/ijeas.2024.4.01.1-12
[18] Flood, K., Wilson, D., Renou-Wilson, F. (2025). Evidence synthesis and knowledge integration for sustainable peatland management. Land, 14(7): 1397. https://doi.org/10.3390/land14071397
[19] Taskin, E., Rastorgueva, N., Foley, L., Noto, R., Borruso, L., Cesco, S., Mimmo, T. (2025). Living labs for sustainable soil management: A systematic review of global practices and perspectives. Journal of Soils and Sediments, 25(11): 3342-3359. https://doi.org/10.1007/S11368-025-04100-Z
[20] Evers, S., Yule, C.M., Padfield, R., O'Reilly, P., Varkkey, H. (2016). Keep wetlands wet: The myth of sustainable development of tropical peatlands - Implications for policies and management. Global Change Biology, 23(2): 534-549. https://doi.org/10.1111/gcb.13422
[21] Wahyunto, W., Nugroho, K., Ritung, S., Sulaeman, Y. (2014). Indonesian peatland map: Method, certainty, and uses. In Pengelolaan Berkelanjutan Lahan Gambut Terdegradasi, Jakarta, pp. 81-96. http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/prosiding_gambut_icctf/05.
[22] Pertanian, K., Penelitian, B., Pertanian, P. (2011). Peta lahan gambut Indonesia skala 1:250.000. https://repository.pertanian.go.id/handle/123456789/5840.
[23] Minasny, B., Adetsu, D.V., Aitkenhead, M., Artz, R.R.E., et al. (2023). Mapping and monitoring peatland conditions from global to field scale. Biogeochemistry, 167(4): 383-425. https://doi.org/10.1007/s10533-023-01084-1
[24] Cha, S., Lee, J., Choi, E., Lim, J. (2024). Unveiling the past: Deep-learning-based estimation of historical peatland distribution. Land, 13(3): 328. https://doi.org/10.3390/land13030328
[25] Indrajaya, Y., Yuwati, T.W., Lestari, S., Winarno, B., et al. (2022). Tropical forest landscape restoration in Indonesia: A review. Land, 11(3): 328. https://doi.org/10.3390/land11030328
[26] Leng, S., Lin, J.R., Li, S.W., Hu, Z.Z. (2021). A data integration and simplification framework for improving site planning and building design. IEEE Access, 9: 148845-148861. https://doi.org/10.1109/ACCESS.2021.3124010
[27] Ren, S., Song, C., Ye, S., Cheng, F., Akhmadov, V., Kuzyakov, Y. (2023). Land use evaluation considering soil properties and agricultural infrastructure in black soil region. Land Degradation & Development, 34(17): 5373-5388. https://doi.org/10.1002/ldr.4850
[28] Anda, M., Ritung, S., Suryani, E., Sukarman, Hikmat, M., Yatno, E., Mulyani, A., Subandiono, R.E., Suratman, Husnain. (2021). Revisiting tropical peatlands in Indonesia: Semi-detailed mapping, extent and depth distribution assessment. Geoderma, 402: 115235. https://doi.org/10.1016/j.geoderma.2021.115235
[29] Kunarso, A., Bonner, M.T.L., Blanch, E.W., Grover, S. (2022). Differences in tropical peat soil physical and

chemical properties under different land uses: A systematic review and meta-analysis. Journal of Soil Science and Plant Nutrition, 22(4): 4063-4083. https://doi.org/10.1007/S42729-022-01008-2

[30] Zheng, Y., Li, X., Pang, S., Chen, J. (2025). Evaluation of soft soil consolidation parameters before and after dynamic compaction in port areas. Geotechnical and Geological Engineering, 43(8). https://doi.org/10.1007/S10706-025-03386-7

[31] Carless, D., Kulessa, B., Booth, A.D., Drocourt, Y., Sinnadurai, P., Street-Perrott, F.A., Jansson, P. (2021). An integrated geophysical and GIS based approach improves estimation of peatland carbon stocks. Geoderma, 402: 115176. https://doi.org/10.1016/j.geoderma.2021.115176

[32] Basu, D., Misra, A., Puppala, A.J. (2015). Sustainability and geotechnical engineering: Perspectives and review. Canadian Geotechnical Journal, 52(1): 96-113. https://doi.org/10.1139/CGJ-2013-0120

[33] Raihan, A. (2024). A systematic review of geographic information systems (GIS) in agriculture for evidence-based decision making and sustainability. Global Sustainability Research, 3(1): 1-24. https://doi.org/10.56556/GSSR.V3I1.636

[34] Sutikno, S., Yusa, M., Andy Hendri, Kusairi, M., Ahmad Muhammad, Nurul Qomar. (2025). Mapping peat thickness and groundwater level using a portable electromagnetic instrument in Indragiri Hilir, Riau, Indonesia. Journal of Degraded and Mining Lands Management, 12(3): 7431-7441. https://doi.org/10.15243/jdmlm.2025.123.7431

[35] Stanitsa, A., Hallett, S.H., Jude, S. (2022). The challenges of implementing evidence-based strategies to inform building and urban design decisions: A view from current practice. Journal of Engineering, Design and Technology, 22(4): 1099-1118. https://doi.org/10.1108/JEDT-01-2022-0003

[36] Vernimmen, R., Akmalia, R., Fitranatanegara, N., Artiyan, E., Febrianto, T., Yuherdha, A., Mulyadi, D., Syahrozi, O., Anugrah, I. (2018). Peatland mapping for Kubu Raya, West Kalimantan, using limited LiDAR data and peat thickness field measurements. https://cms.deltares.nl/assets/common/downloads/Peatland-mapping-for-Kubu-Raya-Team-Deltares-1.pdf.

[37] Hirose, K., Takeda, T., Anshari, G., Nuriman, M., Tanimoto, T., Christianto, R., Takahara, S., Kobayashi, H., Hidayat, G.G. (2016). Assessment of tropical peatland map in West Kalimantan, Indonesia. In Proceedings of the 15th International Peat Congress, Kuching, pp. 86-90. https://peatlands.org/assets/uploads/2019/06/ipc16p86-90a392hirose.takeda.etal_.pdf.

[38] FAO & FAOLEX. (2017). Regulation of the Minister of Environment and Forestry of the R.I. No. P.14/MENLHK/SETJEN/KUM.1/2/2017 on procedures for the peat ecosystem inventory functions. https://www.informea.org/en/legislation/regulation-minister-environment-and-forestry-ri-no-p14menlhksetjenkum122017-procedures.