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COMPARATIVE ANALYSIS OF INFILTRATION AREA REGULATIONS: A STUDY OF MINISTERIAL REGULATION NO. 10/2015 ON PUBLIC WORKS AND PUBLIC HOUSING VERSUS MINISTERIAL REGULATION NO. 10/2022 ON ENVIRONMENT AND FORESTRY WITH A FOCUS ON RUPAT ISLAND, INDONESIA

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ABSTRACT
Groundwater sustainability on small islands depends heavily on effective infiltration zones that support natural recharge. Rupat Island in Indonesia faces declining groundwater levels and seawater intrusion, raising the need for accurate infiltration mapping. This study aims to compare the suitability and sensitivity of two national regulatory frameworks—Ministerial Regulation No. 10/2015 (Public Works and Public Housing) and Ministerial Regulation No. 10/2022 (Environment and Forestry)—in delineating infiltration areas. A GIS-based weighted overlay analysis was applied using rainfall, slope, land use, and soil type parameters, following the classification standards of each regulation. The results show substantial discrepancies: the 2022 framework identifies 5.86% of the island as critical infiltration areas, while the 2015 framework identifies only 0.001%. These differences are statistically confirmed through a two-way ANOVA ($p < 0.05$), indicating that the ecological emphasis of the 2022 regulation produces more conservative classifications. The findings imply that regulatory interpretation significantly influences groundwater zoning, especially on ecologically sensitive small islands. The study contributes theoretically by demonstrating how policy frameworks shape spatial hydrological assessments, and practically by providing evidence-based guidance for local authorities to improve infiltration protection, land-use planning, and groundwater management strategies.
Keywords: *Infiltration Area, GIS, Groundwater Management, Small Islands, Spatial Analysis*

1. Introduction

Water scarcity has become a pressing environmental issue globally, particularly on small islands where freshwater resources are limited (Holding et al., 2016) (Briggs et al., 2021), highly dependent on rainfall, and vulnerable to seawater intrusion. Unlike continental regions, where water supply can be diversified, small islands rely predominantly on groundwater stored within fragile freshwater lenses formed through rainfall infiltration. This reliance makes infiltration processes fundamental for sustaining groundwater recharge, especially under conditions of rising water demand, land-use conversion, and intensifying climate extremes. Groundwater is often the primary water source, yet its sustainability relies on adequate infiltration zones that support natural recharge. In many island environments, land-use change and canal development disrupt infiltration processes, increasing the risk of seawater intrusion and groundwater depletion. These problems have been highlighted in recent global and regional studies emphasizing the importance of strengthening groundwater governance through integrated and spatially explicit approaches (J. O. Aquino et al., 2023). Recent studies emphasize that disruptions to infiltration—whether due to vegetation loss, soil compaction, or drainage alterations—can directly accelerate groundwater depletion and seawater intrusion in similar island environments (Abdullateef et al., 2021) (Alrawi et al., 2022). Integrated Water Resources Management (IWRM) has been recognized internationally as a key strategy to achieve sustainable water governance (Imig et al., 2025). In Indonesia, the 2024 World Water Forum highlighted the urgency of strengthening IWRM implementation across small islands to ensure water security, resilience, and environmental sustainability.

Rupat Island in Riau Province, Indonesia, exemplifies these vulnerabilities. Rapid land-use changes, peatland degradation, settlement expansion, and drainage canal development have altered natural infiltration pathways, contributing to declining groundwater levels and increasing risks of saltwater intrusion. Rupat Island located in Bengkalis Regency, Riau Province, is one of Indonesia's small islands bordered by the Strait of Malacca, covering approximately 1,500 km². The island's communities rely primarily on groundwater as their main water source. However, the increasing construction of canals, urban development, and land-use change have disrupted natural infiltration processes, leading to groundwater depletion and potential seawater intrusion (J. Aquino et al., 2023). The declining groundwater table reduces hydrostatic pressure, allowing saline water to seep into aquifers, which threatens freshwater quality and availability. Although previous research in Indonesia has examined groundwater potential, recharge estimation, or land-use impacts, these studies predominantly focus on physical or hydrological aspects without considering the influence of regulatory frameworks. This represents a significant issue because groundwater and infiltration assessments in Indonesia often follow standardized ministerial regulations, each prescribing different parameters, weighting schemes, and classification thresholds. As a result, regulatory differences-not hydrological conditions alone-may substantially shape the delineation of infiltration zones on small islands, yet this issue remains largely unexplored in scientific literature.

The scientific literature increasingly emphasizes that infiltration potential is influenced by multiple biophysical factors—including rainfall intensity, slope gradient, soil texture, and land-cover characteristics—whose interactions vary across landscapes (Guerrón-Orejuela et al., 2023) (He et al., 2020) (Lei et al., 2020). These factors are frequently integrated using GIS-based multi-criteria decision analysis (MCDA) or weighted overlay techniques, which have become standard approaches for groundwater recharge and infiltration mapping (Mensah et al., 2022). However, despite the widespread use of these tools, no previous research has evaluated how different government regulations in Indonesia—specifically Ministerial Regulation No. 10/2015 (Public Works and Public Housing) and No. 10/2022 (Environment and Forestry)—produce different infiltration zonation outcomes when applied to the same island environment. This represents a critical research gap, particularly important for small islands, where more ecologically conservative approaches may provide greater protection against groundwater stress. At the same time, global literature shows that GIS-based multi-criteria analysis (MCDA), weighted overlay techniques, and remote sensing data have become standard tools for delineating groundwater recharge or infiltration zones in hydrologically sensitive environments.

From a theoretical perspective, infiltration capacity is influenced by a combination of hydrological, geomorphological, and land-use factors (Lubis et al., 2025). The interaction between rainfall intensity, slope gradient, soil texture, and vegetation cover determine groundwater recharge potential (He et al., 2020) (Lei et al., 2020). Soil texture, porosity, organic matter, and moisture content are primary hydrological drivers of infiltration. Higher porosity and organic matter generally increase infiltration, while high bulk density and compaction reduce it (Jia et al., 2024) (Zhu et al., 2023) (Sun et al., 2018). However, regulatory classifications often simplify these relationships, which may not adequately reflect field realities. Therefore, assessing how different regulatory models interpret these parameters provides valuable insight into the balance between environmental policy and scientific validity.

This study aims to fill this gap by conducting a comparative analysis of infiltration zoning on Rupat Island using the two ministerial regulations. The proposed contribution of this research is twofold. Scientifically, it evaluates how regulatory frameworks influence spatial hydrological assessments, providing insight into the relationship between policy assumptions and infiltration mapping outcomes. Practically, it offers evidence-based guidance for local governments and water managers to select regulatory standards that better reflect the ecological realities of small islands. By integrating GIS-based weighted overlay analysis with a regulatory comparison approach, this study provides a novel interdisciplinary lens—bridging hydrology, spatial analysis, and environmental policy—to support sustainable groundwater management in small island settings.

2. Literature Review

Infiltration is a fundamental hydrological process governing groundwater recharge, flood regulation, and soil moisture balance. It depends on several interacting factors such as soil type, rainfall intensity, land slope, and land use characteristics (Abdo et al., 2024). Low rainfall intensity allows more water to infiltrate, while high intensity often exceeds the soil's infiltration capacity, leading to runoff (He et al., 2020) (Simelane et al., 2024) (Morbidelli et al., 2018) (Ramos et al., 2019). Infiltration is a dynamic process essential for water resource management and ecosystem health. Its capacity is shaped by soil characteristics, rainfall patterns, topography, and especially land use. Sustainable land management and vegetation cover are crucial for maintaining high infiltration rates and mitigating flood and drought risks (Zhu et al., 2023) (Mongil-Manso et al., 2025). Numerous GIS-based studies have applied multi-criteria evaluation (MCE) and weighted overlay analysis to identify suitable infiltration zones, particularly in areas facing groundwater depletion or land-use change (Ghosh et al., 2022). Studies typically combine thematic layers such as rainfall, soil type, slope, geology, land use/land cover, drainage density, lineament density, and topography. Each layer is assigned a weight based on its relative influence on infiltration or groundwater potential, often using the Analytic Hierarchy Process (AHP) or similar MCDA techniques (Mouhoumed et al., 2024) (Mengistu et al., 2022) (Chen et al., 2025). The weighted layers are overlaid in GIS to produce maps that classify areas into zones of low to high infiltration or recharge potential. These maps are validated using field data such as well yields, groundwater levels, or ROC curve analysis, with reported accuracies often exceeding 75% (Wijesinghe et al., 2023) (Singh et al., 2018). These studies highlight the necessity of adopting a holistic and spatially explicit approach to determine potential infiltration zones.

GIS-based infiltration mapping combines spatial datasets to evaluate the contribution of physical parameters. Methods such as Analytical Hierarchy Process (AHP), Weighted Linear Combination (WLC), and Overlay Analysis are widely used to assign scores and weights to each parameter (rainfall, soil, slope, land use). Key physical parameters influencing infiltration (e.g., rainfall, soil, slope, land use/land cover, geology, drainage density, lineament density) are selected based on their relevance to groundwater recharge and local conditions (Abdekareem et al., 2022) (Jothibasu & Anbazhagan, 2016). AHP is widely used to assign relative weights to each parameter through pairwise comparisons, often based on expert judgment or literature review. WLC and overlay analysis then combine these weighted layers to produce infiltration or groundwater potential maps (Melese & Belay, 2021) (Rajesh et al., 2021). These techniques enable comparison across regions and regulations by quantifying spatial suitability for groundwater recharge. Sensitivity and validation tests, including field infiltration measurements and statistical comparison, are crucial to ensure data reliability. These classification criteria are consistent with earlier studies that associate gentle slopes and sandy soils with higher infiltration potential (He et al., 2020) (Lei et al., 2020). However, the regulatory framework simplifies these natural relationships by assigning fixed weights.

Groundwater systems in small islands are especially vulnerable to overextraction, sea-level rise, and reduced recharge capacity. Many small islands already experience water stress, with 44% in a state of water stress due to high demand and limited aquifer capacity. Over-abstraction leads to saltwater intrusion, degrading groundwater quality and increasing salinity (De Biase et al., 2021) (Sharan et al., 2023) (Solihuddin et al., 2024). Climate change is projected to decrease rainfall and net recharge on many islands, further shrinking freshwater lenses and exacerbating water scarcity. For example, recharge is projected to decrease by up to 58% on 31 out of 43 studied islands, and a 27% reduction in recharge was observed on Norfolk Island over 50 years (Hughes et al., 2022). Research (J. Aquino et al., 2023) emphasized that groundwater management on small islands must integrate hydrological data with land-use planning and environmental policies. Successful case studies from Malta (Sapiano, 2020) and the Azores (Cruz et al., 2017) demonstrate how integrated spatial analysis can guide sustainable groundwater zoning and community-based water management. However, in Indonesia, studies that systematically link groundwater recharge mapping with national regulatory frameworks remain limited.

Many previous studies approaching infiltration mapping from a purely scientific or hydrological perspective, without examining how regulatory frameworks influence parameter weighting and classification. Theoretical perspectives on eco-hydrology and integrated water resources management emphasize that groundwater recharge assessments should reflect both physical conditions and environmental policy objectives. Future infiltration mapping should systematically incorporate regulatory frameworks and environmental objectives to ensure that groundwater management aligns with both physical realities and societal goals (Meng et al., 2024) (Elshall et al., 2020). Two Indonesian regulations provide standardized classification systems—Ministerial Regulation No. 10/2015 (Public Works and Public Housing) and Ministerial Regulation No. 10/2022 (Environment and Forestry)—but the conceptual basis behind their scoring schemes differs significantly. The Public Works and Public Housing regulation adopts engineering considerations emphasizing slope stability and soil drainage, while the Environment and Forestry regulation integrates ecological degradation risk, land-cover condition, and watershed rehabilitation priorities. These conceptual differences imply that spatial outcomes could vary substantially.

A comparative understanding of these frameworks is critical for small island hydrology. The Public Works and Public Housing regulation uses coarser rainfall and slope intervals, suitable for mainland hydrological planning, whereas the Environment and Forestry regulation applies finer classification ranges and broader land-use categories aligned with ecosystem-based management (Ministry of Public Works and Housing, 2015) (Ministry of Environment & Forestry, 2022). This divergence implies potential variation in infiltration area mapping, which can significantly affect groundwater zoning decisions. However, academic evaluation of these two frameworks' performance—particularly through spatial and statistical analysis—has not yet been conducted, representing the key research gap addressed in this study. Infiltration potential mapping depends on integrating regulatory, hydrological, and spatial dimensions. This integration supports the evaluation of how different policy approaches influence the scientific interpretation of infiltration potential across small island ecosystems.

3. Research Methods

This study was conducted on Rupat Island. Geographically, it borders the Strait of Malacca to the north and east, Dumai City to the south, and Rokan Hilir Regency to the west. The island's climate is classified as tropical humid, with annual rainfall ranging from 2,000 to 3,000 mm, concentrated during the monsoon season from October to March. Land use on the island is dominated by peatlands, mixed dryland farming, mangrove forests, and settlements, which directly affect groundwater recharge capacity. Four key spatial parameters were used in this study: rainfall, land slope, land use, and soil type.

This study applies a GIS-based multi-criteria overlay analysis to assess infiltration potential on Rupat Island under two regulatory frameworks: the Public Works and Public Housing Regulation and the Environment and Forestry Regulation. The rationale for choosing this method is its ability to integrate multiple spatial factors—rainfall, slope, land use, and soil type—and reflect the regulatory scoring schemes exactly, ensuring comparability between frameworks and transparency in assumptions. The analysis followed a weighted overlay method using a Geographic Information System (GIS). For each parameter, classification and weight values strictly follow those defined in the relevant regulation. This approach avoids arbitrary weighting and ensures the analysis directly compares the regulatory frameworks rather than researcher-subjective scoring. Each regulation provided different weight and score criteria for the four parameters. The weight values for each infiltration parameter were adopted from the ministerial regulations and are summarized in Table 1.

Table 1 - Weight value of infiltraion parameters

No.	Parameter	Weight Value
1	Soil Type	5
2	Rainfall	4
3	Land Use	3
4	Slope	2

According to Ministerial Regulation No. 10/2015 (Public Works and Public Housing), infiltration zones are determined by several key parameters including rainfall, slope, soil type, and land use. The following table summarizes the weighting system used under this regulation (table 2).

Table 2 - Weighting of Infiltration Area Parameters

Parameter	Spatial Classification	Infiltration	Weight	Score
Soil Type	Sand	Very High	5	5
	Clay Sand	High	5	4
	Sandy Loam	Medium	5	3
	Fine Sandy Loam	Low	5	2
	Clay	Very Low	5	1
Rainfall	>3000 mm/year	Very High	4	5
	2000-3000 mm/year	High	4	4
	1000-2000 mm/year	Medium	4	3
	500-1000 mm/year	Low	4	2
	<500 mm/year	Very Low	4	1
Land Use	Forest	Very High	3	5
	Shrubs	High	3	4
	Mixed Farmland	Medium	3	3
	Rice Land-Pond-Swamp	Low	3	2
	Settlement	Very Low	3	1
Slope	<5 %	Very High	2	5
	5-20 %	High	2	4
	20-40 %	Medium	2	3
	40-60 %	Low	2	2
	>60 %	Very Low	2	1

The Regulation Number 10/2022 (Minister of Environment and Forestry) adopts a more ecologically oriented weighting scheme, reflecting a shift toward watershed rehabilitation principles (table 3).

Table 3 - Weighting of Infiltration Area Parameters

Parameter	Spatial Classification	Infiltration	Weight	Score
Soil Type	Regosol	Very High	5	5
	Aluvial and andosol	High	5	4
	Latosol	Medium	5	3
	Litosol Mediteran	Low	5	2
	Grumusol	Very Low	5	1
Rainfall	>5550 mm/year	Very High	4	5
	4500-5500 mm/year	High	4	4
	3500-4500 mm/year	Medium	4	3
	2500-3500 mm/year	Low	4	2
	<2500 mm/year	Very Low	4	1
Land Use	Primary dryland forest, secondary dryland forest	Very High	3	5
	Production forest, plantation, forest plantation	High	3	4
	Shrubs, grasslands	Medium	3	3
	Horticulture, dryland farming, mixed dryland farming	Low	3	2
	Settlement, rice field, airport, swamp scrub, natural mangrove forest, secondary mangrove forest, natural swamp forest, secondary swamp forest, extractive industry, wetland, pond, open land, resettlement area, water body.	Very Low	3	1
Slope	<8 %	Very High	2	5
	8-15 %	High	2	4
	16-25 %	Medium	2	3
	26-40 %	Low	2	2
	>40 %	Very Low	2	1

As field infiltration measurements were not available, validation consisted of cross-checking mapped infiltration zones with known land-use and topographic conditions (e.g., peat areas, settlement zones). Limitations include reliance on secondary spatial data, absence of soil hydraulic tests, and no hydrological simulation — which are acknowledged and recommended for future studies. To evaluate consistency between the two regulatory results, a two-way ANOVA test was applied. This statistical test examined whether the spatial classification differences between Regulation 10/2015 and Regulation 10/2022 were significant. The analysis used total infiltration scores as dependent variables and regulatory framework as independent factors. In addition, the resulting maps were visually validated through comparison with field observations and previous infiltration mapping studies conducted in similar small island environments.

Although the GIS-based overlay technique effectively identifies potential infiltration zones, certain limitations exist. First, the accuracy of results depends on the spatial resolution of the input data (30 m DEM and land use maps). Second, the weighting system in each regulation is policy-driven rather than empirically calibrated, potentially introducing bias in the infiltration classification. Third, no direct field infiltration measurements were available for Rupat Island; hence, the analysis relied on secondary data and regulatory parameters. Future research should incorporate field infiltration tests and hydrological modeling for validation.

4. Results and Discussions

The GIS-based analysis of infiltration potential on Rupat Island produced two distinct spatial outcomes depending on the applied regulatory framework: Ministerial Regulation No. 10/2015 (Public Works and Public Housing) and Ministerial Regulation No. 10/2022 (Environment and Forestry). Both regulations consider the same physical parameters—rainfall, slope, land use, and soil type—but differ in weighting schemes and classification thresholds. This divergence reflects the contrasting policy objectives of the two frameworks: engineering stability versus ecological sensitivity.

According to the 2015 Public Works and Public Housing Regulation, infiltration zones classified as critical start conditions accounted for only 0.01 km² (0.001%), while natural-normal conditions covered 1,000.70 km² (65.64%), and good conditions reached 523.90 km² (34.36%). In contrast, the Regulation of Environment and Forestry yielded 89.42 km² (5.86%) of critical start conditions, 1,090.08 km² (71.50%) of natural-normal conditions, and 345.11 km² (22.64%) of good conditions. The notable increase in "critical" zones under the Environment and Forestry framework indicates that this newer regulation adopts stricter ecological parameters, especially by assigning lower weights to disturbed land uses such as settlements and plantations. Similar findings were reported by, who observed that stricter environmental classification criteria tend to reduce the proportion of high-infiltration areas while improving ecological realism. The comparative GIS analysis reveals marked differences between infiltration zoning outcomes under the two regulatory frameworks. When applying the 2015 (Public Works and Public Housing) criteria, the majority of Rupat Island is classified under "normal" infiltration potential, with only a negligible area falling into the "critical-start" category. Conversely, the 2022 (Environment and Forestry) criteria yield a substantially larger portion of the island as "critical," reflecting the regulation's ecological sensitivity and conservative classification approach. This divergence underscores how regulatory interpretation alone—not differences in input data—can lead to vastly different spatial outcomes.

The two regulations therefore represent different epistemological paradigms: Public Works and Public Housing focuses on engineering hydrology, while Environment and Forestry integrates eco-hydrology and landscape management. Such divergence in interpretation is consistent with recent studies emphasizing that regulatory definitions of recharge zones strongly depend on the management philosophy adopted (Ghosh et al., 2022).

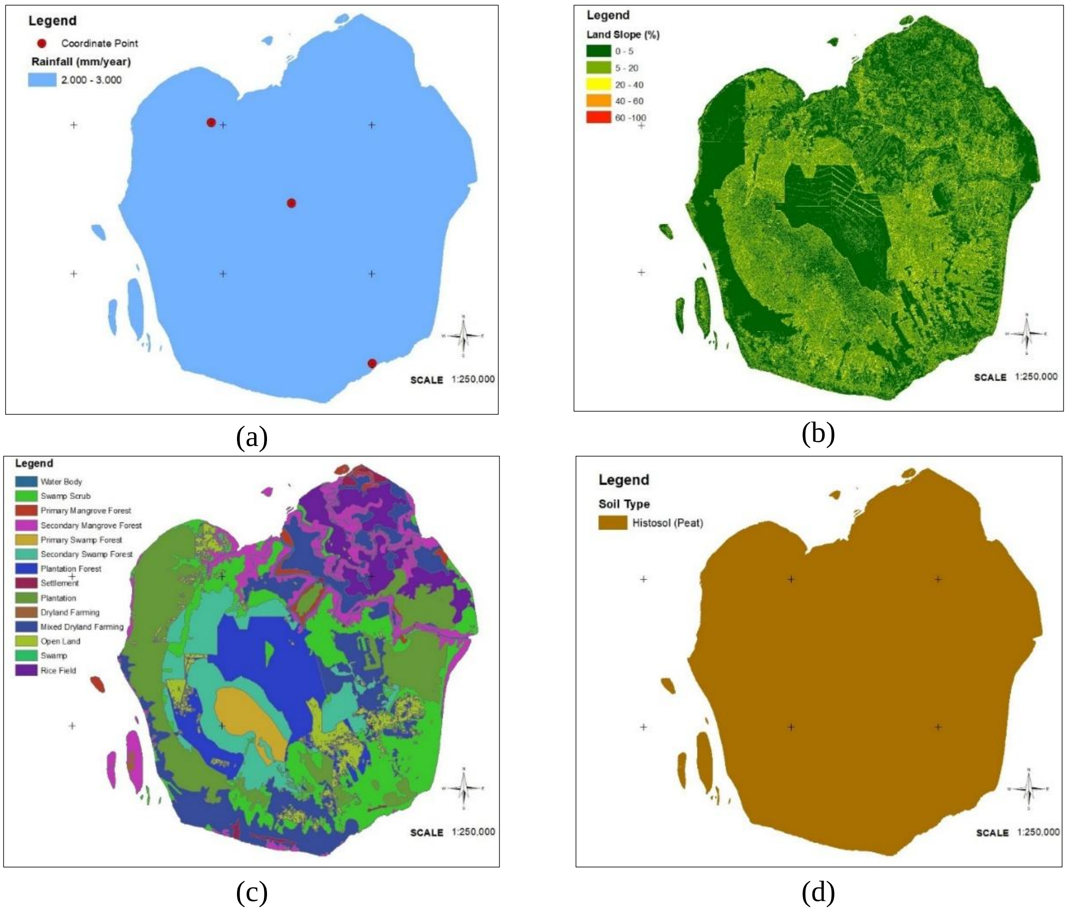
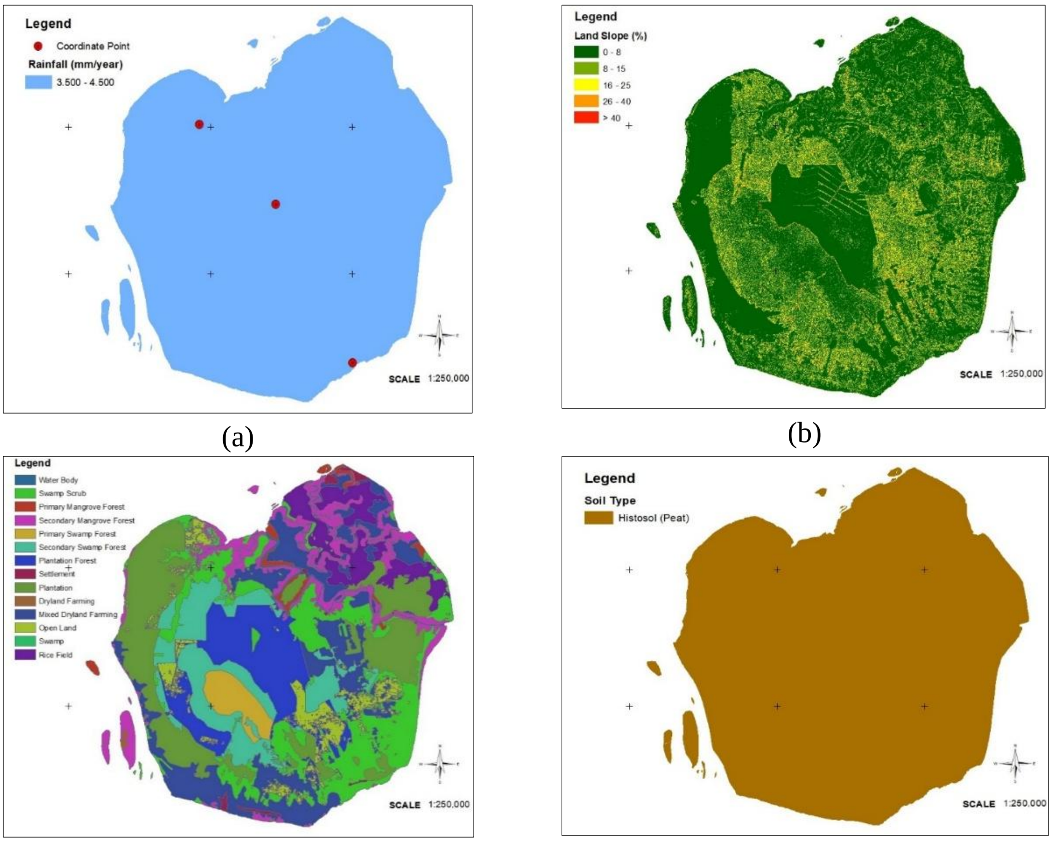


Fig. 1. Rainfall map (a), land slope map (b), land use map (c), soil type map (d) Based on the Minister of Public Works and Public Housing Regulation

Table 4 - Weighting of Infiltration Area Parameters Based on the Minister of Public Works and Public Housing Regulation

Parameter	Spatial Classification	Area (km^2)	Infiltration
Rainfall	2000-3000 mm/year	1.524,61	High
Land Use	Water body	16,90	Very Low
	Swamp scrub	258,52	Low
	Primary mangrove forest	17,95	Low
	Secondary mangrove forest	132,26	Low
	Primary swamp forest	41,55	Low
	Secondary swamp forest	170,53	Low
	Plantation forest	165,15	Very High
	Settlement	8,68	Low
	Plantation	278,03	Medium
	Dryland farming	1,55	Medium
	Mixed dryland farming	258,52	Medium
	Swamp	1,39	Low
	Rice fields	96,65	Low
	Open land	78,59	High
Slope	<5 %	784,67	Very High
	5-20 %	670,92	High
	20-40 %	63,20	Medium
	40-60 %	2,97	Low
	>60 %	0,17	Very Low
Soil Type	Clay	1.524,61	Very High



(a) (b)

(c) (d)

Fig. 2. Rainfall map (a), land slope map (b), land use map (c), soil type map (d) Based on the Minister of Environment and Forestry Regulation

Table 5 - Weighting of Infiltration Area Parameters Based on the Minister of Environment and Forestry Regulation

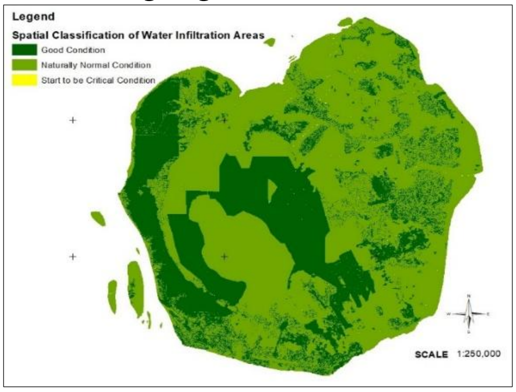
Parameter	Spatial Classification	Area (km^2)	Infiltration
Rainfall	3500-4500 mm/year	1.524,61	Medium
Slope	<8 %	1.058,93	Very High
	8-15%	307,59	High
	16-25 %	125,12	Medium
	26-40 %	27,07	Low
	40-100 %	3,24	Very Low
Land Use	Water body	16,90	Very Low
	Swamp scrub	258,52	Very Low
	Primary mangrove forest	17,95	Very Low
	Secondary mangrove forest	132,26	Very Low
	Primary swamp forest	41,55	Very Low
	Secondary swamp forest	170,53	Very Low
	Plantation forest	165,15	High
	Settlement	8,68	Very Low
	Plantation	278,03	High
	Dryland farming	1,55	Low
	Mixed dryland farming	258,52	Low
	Swamp	1,39	Very Low
	Rice fields	96,65	Very Low
	Open land	78,59	Very Low
Soil Type	Litosol	1.524,61	Very High

After merging the maps into a single representation, the weight values assigned to each parameter—such as rainfall, land slope, land use, and soil type—are summed to categorize the water catchment areas. The classification is determined based on the total sum of these values, using the highest and lowest possible values as reference points. The maximum possible value for classifying water catchment conditions is 70, while the minimum possible value is 14. Table 6 presents the classification of water catchment areas across Rupat Island based on these values.

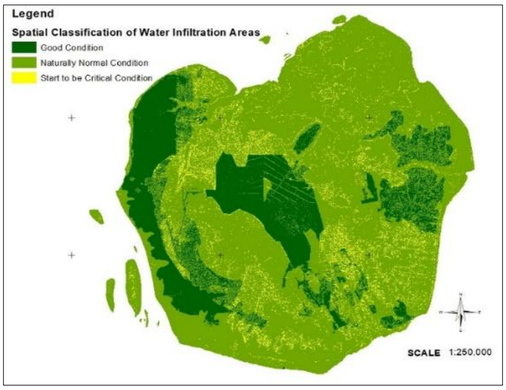
Table 6 - Classification of Infiltration Area on Rupat Island.

No	Total Score Value	Spatial Classification of Infiltration Areas
1	59 – 70	Good condition
2	48 – 58	Natural normal condition
3	37 – 47	Critical start condition
4	26 – 36	Critical condition
5	14 – 25	Very critical condition

Based on the classification (table 6), the map of infiltration areas can be seen in Figure 3. The map overlay was conducted following the guidelines set by the Minister of Public Works and Public Housing Regulation.



(a)



(b)

Fig. 3. Map overlay based on the minister of public works and public housing regulation (a) and map overlay based on the minister of public works and public housing regulation

Spatially, critical and very critical infiltration zones are concentrated in the northern and eastern coastal regions of Rupat Island, where land use is dominated by settlements, oil palm plantations, and open scrub areas. In contrast, central and southern regions, which consist largely of peat forests and mixed dryland farming, show higher infiltration potential. This spatial pattern follows natural topography and land-cover gradients—coastal lowlands with compacted soils restrict infiltration, while inland peatlands and mixed forests enhance groundwater recharge. Comparable trends were reported by (Simelane et al., 2024) in subtropical regions, where vegetation density strongly correlates with infiltration capacity.

Table 7 - Two-way ANOVA Calculation Results.

Source of variation	SS	df	MS	F	P-value	F crit
Rows	77.236	23	3358	130,66	2,71 x 10^{-19}	2,01
Colomns	130,44	1	130	5,08	0,03	4,28
Error	591,13	23	26			
Total	77.985	47				

The two-way ANOVA test confirmed a significant difference between the two regulatory approaches ($F = 5.08$, $p < 0.05$), indicating that the variance in infiltration classification is statistically meaningful. The 2022 regulation produced a higher sensitivity index (i.e., greater differentiation among land-use classes), suggesting stronger alignment with ecological conditions. The statistical result supports the hypothesis that the two regulatory frameworks interpret infiltration criteria differently, leading to diverging spatial outcomes. Similar regulatory comparison studies in India and the Philippines (J. Aquino et al., 2023) reported consistent trends where updated environmental regulations yield more conservative and ecologically realistic classifications.

Overall, the comparative results demonstrate that scientific hydrological modeling and regulatory classification can yield complementary insights when integrated. (Ministry of Public Works and Housing, 2015) framework remains useful for engineering applications such as infrastructure development, while the (Ministry of Environment & Forestry, 2022) regulation provides a stronger ecological safeguard for long-term groundwater sustainability. This complementarity supports the notion of hybrid water governance, combining infrastructure-based and ecosystem-based management strategies.

5. Conclusion

This study compared the delineation of infiltration areas on Rupat Island using two ministerial frameworks: (Ministry of Public Works and Housing, 2015) (Ministry of Environment & Forestry, 2022). Although both apply similar physical parameters—rainfall, slope, soil type, and land use—their weighting and classification systems produced significantly different spatial outcomes. The (Ministry of Environment & Forestry, 2022) framework identified a broader critical area (5.86%) than the (Ministry of Public Works and Housing, 2015) framework (0.001%), indicating that (Ministry of Environment & Forestry, 2022) is more sensitive to ecological and land-cover degradation. The comparison demonstrates that regulatory interpretation strongly influences infiltration zoning results, especially on small islands where land-use changes and groundwater pressure are high. (Ministry of Environment & Forestry, 2022) provides an environmentally oriented perspective suitable for watershed conservation, while (Ministry of Public Works and Housing, 2015) remains useful for engineering and hydrological planning. Combining both approaches could support balanced and adaptive groundwater management in island environments. The main contribution of this study lies in showing how policy-based criteria can affect scientific spatial assessments, highlighting the need for harmonized regulatory standards in Indonesia. Practically, the results can assist local governments in designating critical recharge zones, integrating infiltration mapping into spatial plans, and guiding land conversion control. This study has several limitations, particularly the reliance on secondary spatial data and the absence of field validation. Future work should include field infiltration measurements, hydrological modeling, and climate-adaptation analysis to verify and refine the current findings.

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