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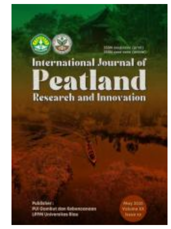

Comparative Analysis of Peat Soil Hydraulic Conductivity Determined by Slug Test and Falling Head Method in Tanjung Leban, Indonesia

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ABSTRACT

Peat soil has unique hydraulic characteristics that affect water movement, infiltration, and storage. Understanding its hydraulic conductivity is essential for effective peatland restoration and sustainable water management. This study compares the hydraulic conductivity values obtained from field and laboratory measurements in the Tanjung Leban Landscape, Bengkalis, Indonesia. Field data were collected using the Slug Test method, while laboratory tests used the Falling Head method on the same peat samples. Results show that the Slug Test produced higher conductivity values, ranging from 0.011 to 0.741 m/day, whereas the Falling Head test yielded lower values between 2.57×10^{-8} and 1.33×10^{-7} m/s. The difference reflects natural macro-pores and root channels influencing field flow, while laboratory conditions represent intrinsic permeability. These findings indicate that field measurements describe effective hydraulic conductivity, whereas laboratory tests capture intrinsic hydraulic behavior, offering valuable insights for peatland hydrological modeling and water management.

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1. Introduction

Peat soils are unique natural formations consisting of decomposed organic materials that accumulate under water-saturated and anaerobic conditions. They play an essential role in global ecosystems by storing carbon, regulating groundwater, and maintaining biodiversity [9], [7]. In Southeast Asia, particularly Indonesia and Malaysia, tropical peatlands cover extensive lowland areas and serve as critical regulators of hydrological processes and climate balance [13]. However, anthropogenic activities such as drainage development, land clearing for oil palm plantations, and unregulated canal systems have significantly altered peatland hydrology, leading to subsidence, high fire susceptibility, and loss of ecological function [10], [12].

A fundamental hydrological property in understanding peatland processes is hydraulic conductivity (K), which describes the soil's ability to transmit water through its pore network. Accurate estimation of hydraulic conductivity is essential for evaluating groundwater recharge, designing drainage and restoration systems, and modeling water table dynamics [2], [6]. The measurement of hydraulic conductivity can be performed using both field tests and laboratory tests. Field methods, such as the Slug Test, provide in-situ representations of hydraulic behavior, including the effects of natural heterogeneity and macropores. Laboratory methods, such as the Falling Head Test, provide intrinsic soil properties under controlled conditions, isolating the influence of structure and boundary variability [1], [3].

Recent studies in Indonesia have contributed to understanding these differences. Idris *et al.* [4] measured hydraulic conductivity of peat soil in the field using the Slug Test at the Tanjung Leban Landscape, Bengkalis Regency, Riau Province, and found values ranging between 0.011 and 0.741 m/day, with higher values in restoration areas compared to oil palm plantations. Conversely, Idris *et al.* [5] conducted laboratory Falling Head tests on peat samples from the same area, revealing lower values ranging from 2.57×10^{-8} to 1.33×10^{-7} m/s, representing the intrinsic hydraulic properties of the peat matrix.

Despite the wide application of both techniques, comparative studies between field and laboratory measurements of peat soil hydraulic conductivity remain limited, particularly in tropical regions. Understanding this relationship is crucial for improving hydrological modeling and validating laboratory results against natural field conditions [11], [8]. Therefore, the objective of this study is to compare the hydraulic conductivity of tropical peat soil obtained from field (Slug Test) and laboratory (Falling Head) methods, and to evaluate the implications of these results for peatland water management and restoration strategies in the Tanjung Leban Landscape.

2. Research Significance

The present study is significant in advancing the understanding of hydraulic behavior in tropical peat soils, particularly in the context of comparing field- and laboratory-based measurement methods. Previous studies have generally focused on either laboratory or field testing independently, resulting in limited interpretation of how the two sets of data relate to one another in tropical environments. By analyzing and comparing Slug Test and Falling Head results from the same site, this research provides empirical evidence that links the intrinsic permeability of peat measured under controlled laboratory conditions with its effective hydraulic performance observed in situ.

The outcomes of this study are expected to benefit several groups. Researchers and hydrologists may use the comparative results to calibrate and validate hydrological models that predict water movement in peatlands. Government agencies and environmental planners can apply the findings to design more accurate drainage and water management systems that support peatland restoration and fire-prevention programs. In addition, local communities and land managers will gain improved strategies for maintaining groundwater levels to prevent peat subsidence and degradation.

Ultimately, this study contributes to the growing body of knowledge on sustainable peatland management and provides a methodological reference for future assessments of soil hydraulic properties in tropical regions.

3. Methods

3.1 Study Area

This study was conducted at the Tanjung Leban Landscape, Bengkalis Regency, Riau Province, Indonesia, located within the Peat Hydrological Unit (*Kesatuan Hidrologis Gambut*, KHG) of the Rokan–Siak Kecil system. The area is characterized by a tropical climate with high annual rainfall (approximately 2,300–2,800 mm/year) and low topographic gradients. Two dominant land-use types were selected for sampling: restoration area and oil palm plantation area, each representing different hydrological and soil disturbance conditions. The peat thickness in this region ranges from 2 to 6 meters, with water table fluctuations influenced by rainfall, evapotranspiration, and canal drainage.

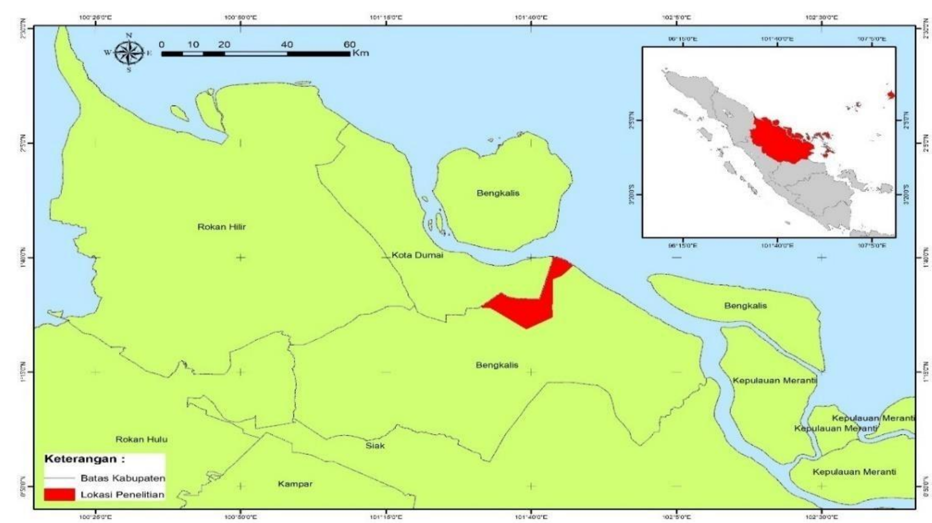

Fig 1. Location of the study area in Tanjung Leban, Bengkalis Regency, Riau Province, Indonesia.

3.2 Field Measurement: Slug Test

The **Slug Test** was performed in the field to determine *in situ* hydraulic conductivity using the **Hvorslev (1951)** method, which is suitable for unconfined and partially penetrating wells. Eight observation wells were installed at representative points across the study area (four in restoration sites and four in oil palm plantations).

Each well was constructed from 2.5-inch PVC pipe with a perforated section in the lower part and an impermeable section at the top. A water-level data logger was placed inside the well to record changes in water level over time at 1-second intervals. During the test, a known volume of water was added to or removed from the well to create an instantaneous change in water level, and the recovery of the water level back to equilibrium was recorded.

The hydraulic conductivity (K) was computed using the **Hvorslev equation**:

$$K = \frac{r_c^2 \ln \frac{L}{r_w}}{2LT_{0.37}} \tag{1}$$

where:
K= hydraulic conductivity (m/s);
r_c= radius of casing (m);
r_w= radius of well screen (m);
L= length of the well screen (m);
$T_{0.37}$= time required for the water level to fall to 37% of its initial head difference (s).

The test was repeated at each well, and data from the loggers were processed using spreadsheet-based analysis to calculate K for each observation point.

3.3 Laboratory Measurement: Falling Head Test

The Falling Head test was performed on peat samples obtained from the same eight sites used in the field experiment. Sampling was conducted carefully using a stainless-steel core sampler to preserve the natural structure and water content of the peat. The samples were stored in sealed containers to minimize disturbance before testing.

The test was carried out using a standard permeameter apparatus with a transparent standpipe connected to the top of the sample. The soil specimen had a length (L) of 11.5 cm and a diameter of 10.1 cm. The standpipe had a cross-sectional area (a) of 0.316 cm², and the soil specimen had a cross-sectional area (A) of 173.093 cm². Water was allowed to flow through the sample, and the decrease in head (h) was recorded at time intervals of 5, 10, 15, 30, and 60 minutes.

Hydraulic conductivity was calculated using the **Falling Head equation**:

$$K = \frac{aL}{At} \ln\left(\frac{h1}{h2}\right) \tag{2}$$

where:
K= hydraulic conductivity (cm/s);
a= cross-sectional area of standpipe (cm²);
A= cross-sectional area of soil specimen (cm²);
L= specimen length (cm);
t= elapsed time (s);
h_1, h_2= initial and final head (cm).

The results from all samples were averaged to determine the representative laboratory hydraulic conductivity for both land-use types.

3.4 Data Comparison and Analysis

After both tests were completed, the resulting **hydraulic conductivity values** from field and laboratory experiments were converted to consistent SI units for comparison. Statistical and graphical analyses were performed to assess the relationship between the two datasets, identify differences between land uses, and evaluate the influence of natural field heterogeneity on measured conductivity.

4. Results and Discussion

4.1 Hydraulic Conductivity from Field and Laboratory Test

Table 1 presents the summary of hydraulic conductivity values obtained from both the Falling Head laboratory test and the Slug Test field measurements for peat soil at eight observation points in the Tanjung Leban Landscape. The values have been converted to SI units (m/s) for direct comparison.

Table 1. Summary of Hydraulic Conductivity Values from Laboratory and Field Tests

No	Sample ID	Land Use	Laboratory (cm/s)	Field (m/s)
1	Slug Test 1	Restoration	2.569×10^{-6}	2.569×10^{-8}
2	Slug Test 2	Restoration	1.364×10^{-5}	1.364×10^{-7}
3	Slug Test 3	Oil Palm	5.167×10^{-6}	5.167×10^{-8}
4	Slug Test 4	Restoration	8.922×10^{-6}	8.922×10^{-8}
5	Slug Test 5	Restoration	5.247×10^{-6}	5.247×10^{-8}
6	Slug Test 6	Restoration	8.017×10^{-6}	8.017×10^{-8}
7	Slug Test 7	Oil Palm	1.331×10^{-5}	1.330×10^{-7}
8	Slug Test 8	Oil Palm	1.301×10^{-5}	1.301×10^{-7}

The results show that laboratory tests yielded higher hydraulic conductivity values, ranging between 2.57×10^{-6} and 1.36×10^{-5} cm/s, while the field measurements ranged between 2.57 ×

10^{-8} and 1.36×10^{-7} m/s. Both sets of data follow the same order of magnitude across sites, but the laboratory results are consistently one to two orders higher than those obtained in the field.

4.2 Interpretation of Field and Laboratory Difference

The higher conductivity observed in laboratory tests may be attributed to sample disturbance and compaction effects during sampling and preparation. During the *Falling Head* test, peat samples are placed within a permeameter that can slightly alter pore structure and increase flow along artificial boundaries, particularly when peat fibers are oriented vertically [2], [11]. Additionally, the laboratory test maintains constant head gradients and ideal flow conditions that may enhance vertical flow compared to natural *in situ* conditions.

In contrast, the *Slug Test* represents the actual field environment where the peat layer interacts with variable saturation, root channels, and surrounding hydraulic resistance. In field conditions, partial clogging of borehole screens and the presence of anisotropy or air entrapment within pores may reduce effective flow rates, producing lower K values [1], [3].

These differences indicate that the laboratory *Falling Head* test measures apparent or disturbed hydraulic conductivity, while the *Slug Test* captures effective field conductivity, reflecting actual groundwater movement in peatland systems. This is consistent with findings from Idris *et al.* [4], [5], where the magnitude of K was influenced by water table depth, vegetation roots, and microstructure of peat.

4.3 Land Use Influence

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5. Conclusions

This study compared the hydraulic conductivity of tropical peat soil in the Tanjung Leban Landscape obtained from field (Slug Test) and laboratory (Falling Head) methods. The results revealed that the hydraulic conductivity measured in the laboratory ranged between 2.57×10^{-6} and 1.36×10^{-5} cm/s, while the field values ranged between 2.57×10^{-8} and 1.36×10^{-7} m/s. Laboratory measurements consistently produced higher values than field tests, indicating that laboratory conditions may enhance flow along artificial boundaries or disturbed peat structures, whereas field tests reflect effective conductivity under natural conditions.

These findings demonstrate that both testing methods are reliable but represent different hydrological scales: laboratory tests describe the intrinsic hydraulic properties, while field tests measure the effective hydraulic behavior influenced by site-specific factors such as pore connectivity, saturation, and land use. The comparison provides valuable insights for improving hydrological modeling, groundwater management, and restoration strategies in tropical peatlands.

Future research should expand the dataset to different peat depths and land-use systems, incorporating seasonal water table fluctuations to better understand the spatial and temporal variability of peat hydraulic conductivity.

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