SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Groundwater Level Fluctuations in Cultivated Land on Peatlands in Pontianak City, West Kalimantan

Nurhayati[1,*], Rizki Purnaini[1], Kiki Prio Utomo[1], Slamet Widodo[1], Rosmina Ahmad Bustami[2], Darrien Yau Seng Mah[2], Yoke Seng Wong[3], Sartika Ananta Hanun[1]

[1] Fakultas Teknik, Universitas Tanjungpura, Pontianak, 78124, Kalimantan Barat, Indonesia
[2] UNIMAS Water Centre (UWC), Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[3] Faculty of Computing and Meta-Technology, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia

ARTICLE INFO

Article history:
Received 27 February 2025
Received in revised form 12 June 2025
Accepted 23 June 2025
Available online 10 July 2025

Keywords:
Cultivation; fluctuation; groundwater; peatland; Pontianak

ABSTRACT

The depth of the groundwater table is significant for the sustainability of the peatland environment. One indicator of peatland degradation is the depth of the groundwater table. The decline in groundwater levels is connected to peat fires, where the reduced water levels expose the organic matter on the peatland surface, rendering it dry and flammable. The Government of the Republic of Indonesia regulates peatland ecosystems, and the function of cultivation is declared damaged if the depth of the groundwater table in peatlands is more than 40 cm below the peat surface. Peat is a hydrological regulator and climate controller because it can absorb and store carbon, biodiversity conservation, energy sources, and cultivation sites. This study aims to analyze the hydrological dynamics of cultivated land in the peri-urban areas of Pontianak City by measuring groundwater levels, rainfall, air temperature, water levels in drainage channels, peat depth, and peat physical properties. The findings are expected to provide deeper insights into the interaction between hydrometeorological factors, peat characteristics, and land hydrology conditions, supporting sustainable water management and peatland conservation efforts. The research was conducted in Siantan Hulu Village and Siantan Hilir Village, North Pontianak District, Pontianak City, West Kalimantan Province, Indonesia. Peatlands in the North Pontianak District are included in protected peat indicatives. The groundwater table depth was measured on three community-owned lands planted with aloe vera, papaya, and oil palm, and one location was on secondary forest land. One piezometer was installed within 50 m of the canal at each research site. Groundwater level measurements are carried out daily at 07.00 AM and 4.00 PM for seven days. The physical properties of peat measured in this study are peat depth, content weight, particle-specific gravity, porosity, permeability, gravimetric moisture content, and volumetric moisture content. Rainfall and temperature measurements were conducted daily at 07.00 AM and 4.00 PM for seven days. The results showed that groundwater level fluctuations varied based on the water table in the canal, rain, air temperature, and physical properties of peatlands.

[*] *Corresponding author.*
E-mail address: nurhayati@civil.untan.ac.id

https://doi.org/10.37934/arfmts.133.1.169183

1. Introduction

Pontianak City is the capital of West Kalimantan Province, Indonesia. It is located in the lowlands; part of the area is peatland with varying depths. Pontianak City is included in the Peat Hydrological Unit of the Punggur Besar River-Kapuas River. Peatlands in Pontianak City are spread across Southeast Pontianak District, South Pontianak District, Pontianak Kota District, West Pontianak District, North Pontianak District, and East Pontianak District.

Peat is an organic material formed naturally from imperfectly decomposed plants, which remains with a thickness of 50 cm or more and accumulates in swamps [1-12]. Peat is known as a hydrological regulator and climate controller for its ability to absorb and store carbon, conserve biodiversity, mitigate climate change, as energy sources, and cultivation sites [3-32].

In response to Pontianak City's expanding population, the scarcity of available land has driven the conversion of peatlands, primarily for agricultural purposes. This transformation aims to support food security and accommodate the construction of office buildings, shopping centers, schools, housing, and other essential city facilities and infrastructure in non-agricultural areas.

Peatland reclamation causes peat to shrink, subside, become compact and dense, and become oxidative [2,4,5,13,23,28-30,33-48]. In an aerobic atmosphere, peat mineralization causes peat emission in the form of CO_2 to take place dominantly, so peat quickly thins and runs out [49-51]. With a long dry season, peat is flammable and challenging to extinguish [3,16,39,52-55]. Large peat fires can deplete peat layers over large areas, lasting a long time, and the resulting smoke causes air pollution.

Information on groundwater levels is needed to manage water resources in peatlands. The groundwater level in agricultural land must be controlled so that plants grow and maintain peatland moisture so that it does not dry out and is prone to fire in the dry season and subsidence.

The groundwater management in Pontianak's cultivated peatlands represents a critical challenge at the intersection of food security, climate change mitigation, and environmental sustainability. Groundwater level position is the master variable controlling peat preservation, carbon emissions, agricultural productivity, and landscape-scale hydrological functions. Research on understanding and managing these groundwater fluctuations provides an essential foundation for developing sustainable approaches to peatland use in West Kalimantan and similar tropical peatland regions globally.

2. Methodology

2.1 Location

The research was conducted in Siantan Hulu Village and Siantan Hilir Village, North Pontianak District, Pontianak City, West Kalimantan Province as shown in Figure 1. Peatlands in the North Pontianak District are included in protected peat indicatives. The groundwater table depth was measured on three community-owned lands planted with aloe vera, papaya, and oil palm, and one location was on secondary forest land. The canal near the measurement site on the land planted with aloe vera and papaya has a width of 1 m, and the canal near the measurement site on the land planted with oil palm has a width of 5 m. The canal near the measurement site in the secondary forest has a width of 4 m.

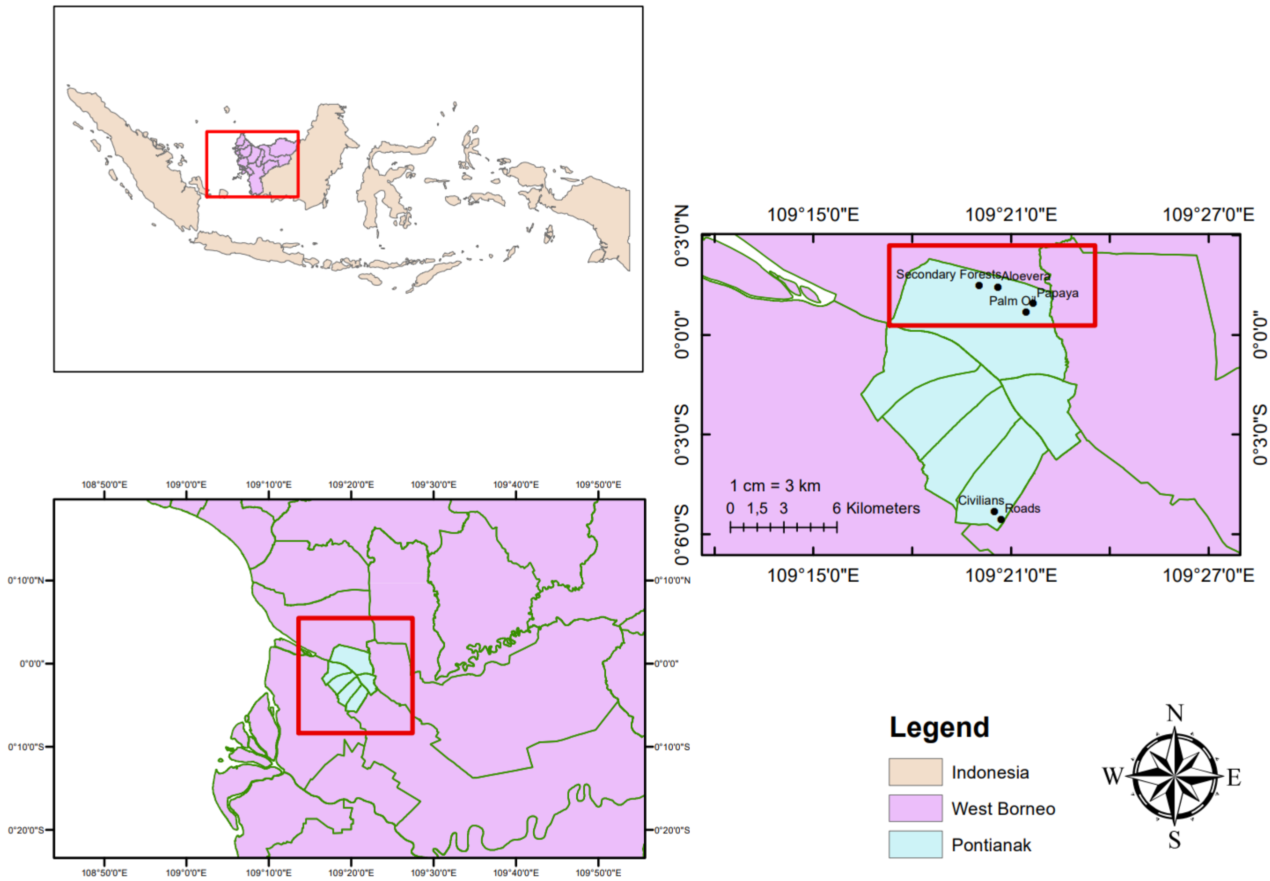


Fig. 1. The research location is in Pontianak City, West Kalimantan, Indonesia

2.2 Method

2.2.1 Groundwater level monitoring

Groundwater level monitoring is done by monitoring wells from PVC pipes 2.5 inches in diameter and 2 m long, where 1.5 pipes are hollowed out around them. The perforated part of the pipe is immersed in the ground, and the non-perforated end is above ground level. One piezometer is installed on each site within 50 m of the canal. Groundwater level measurements are carried out daily at 07.00 AM and 4.00 PM. The location of the groundwater level monitoring is shown in Figure 2.

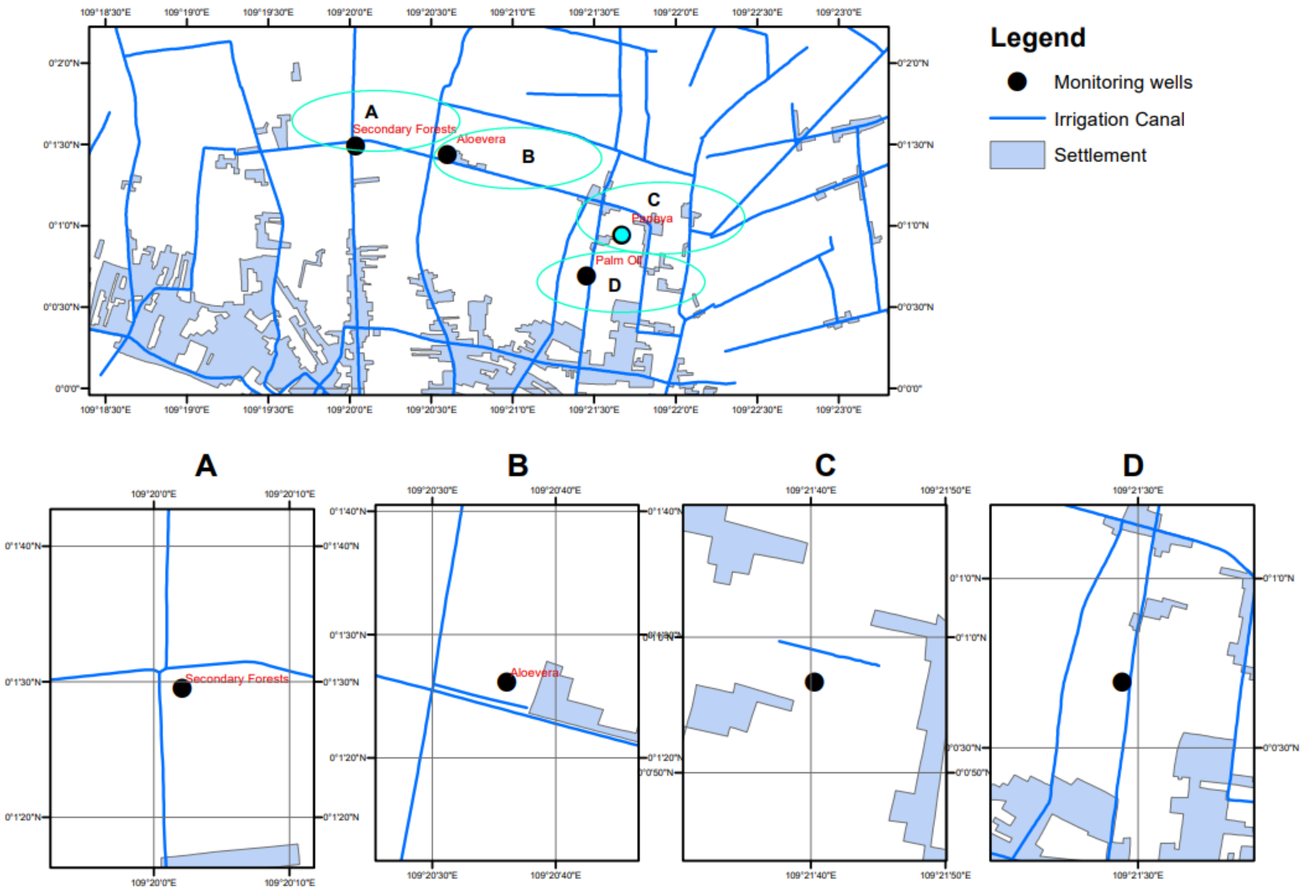


Fig. 2. Groundwater level measurement locations: (A) secondary forests, (B) aloe vera land, (C) papaya land, and (D) oil palm land

2.2.2 Rainfall and temperature monitoring

Rainfall monitoring is carried out with a measuring instrument built from a PVC pipe that is 2.5 inches in diameter, has a length of 1 m, and is given a funnel on top. The temperature is measured using a thermometer. Rainfall and temperature measurements are carried out daily at 07.00 AM and 4.00 PM for seven days.

2.2.3 Peat property measurement

The properties of peat measured in this study are peat depth, content weight, particle-specific gravity, porosity, and permeability. Sampling for measurements of peat properties was carried out at the beginning of the study and at the time of installation of monitoring wells.

3. Results

3.1 Groundwater Level Fluctuation

The groundwater depth observed at 07:00 AM fluctuated from 16 cm to 45 cm below the ground surface, with the average groundwater table depth at 4 locations being 32 cm. The groundwater depth observed at 4:00 PM fluctuated from 10 cm to 45 cm below the ground surface, with the average groundwater table depth at 4 locations being 31 cm. Groundwater level fluctuations from measurements are presented in Figure 3, Figure 4, Figure 5, and Figure 6.

Figure 3 shows that the depth of the groundwater table in the land planted with aloe vera at 7:00 AM and 04:00 PM for seven days of observation was at a depth by the regulations of the Government of the Republic of Indonesia, namely the maximum groundwater depth of 40 cm below the peat surface.

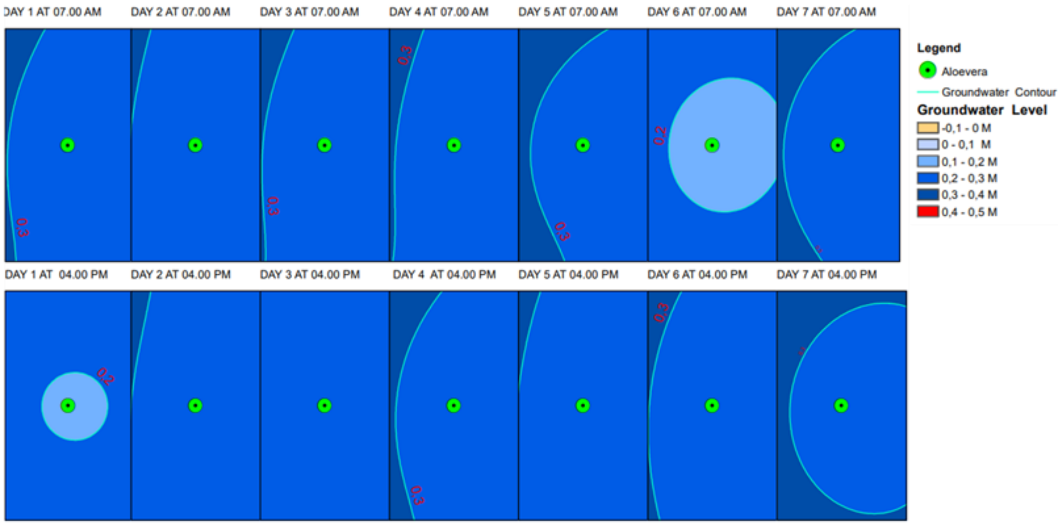


Fig. 3. Fluctuations in groundwater levels in peatlands planted with aloe vera at 07:00 AM and 04:00 PM for seven days

Figure 4 shows that the depth of the groundwater table in the land planted with papaya at 7:00 AM and 04:00 PM for seven days of observation was at a depth by the regulations of the Government of the Republic of Indonesia, namely the maximum groundwater depth of 40 cm below the peat surface.

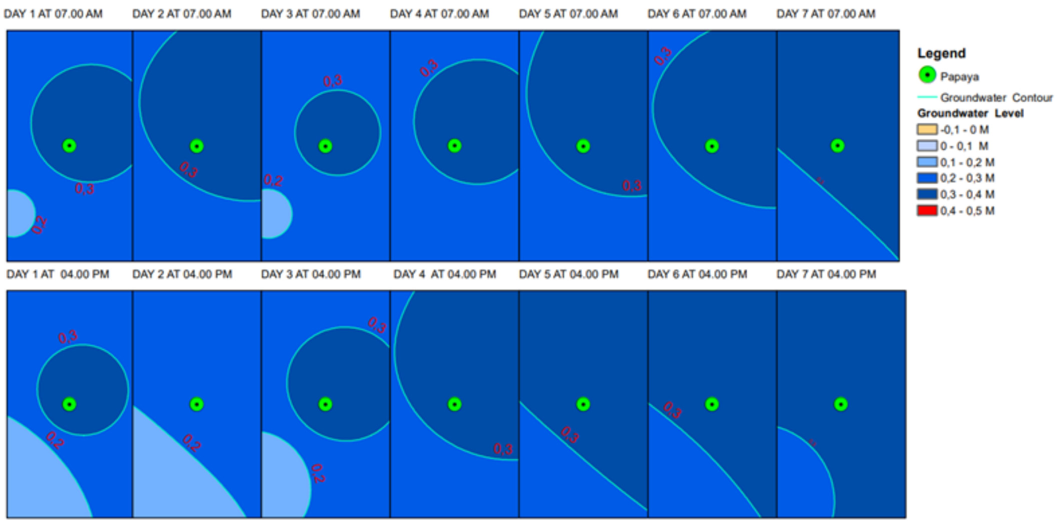


Fig. 4. Fluctuations in groundwater levels in peatlands planted with papaya at 07:00 AM and 04:00 PM for seven days

Figure 5 shows that the depth of the groundwater table in land planted with oil palm at 7:00 AM and 04:00 PM for seven days of observation was at a depth by the regulations of the Government of the Republic of Indonesia, namely the maximum groundwater depth of 40 cm below the peat surface.

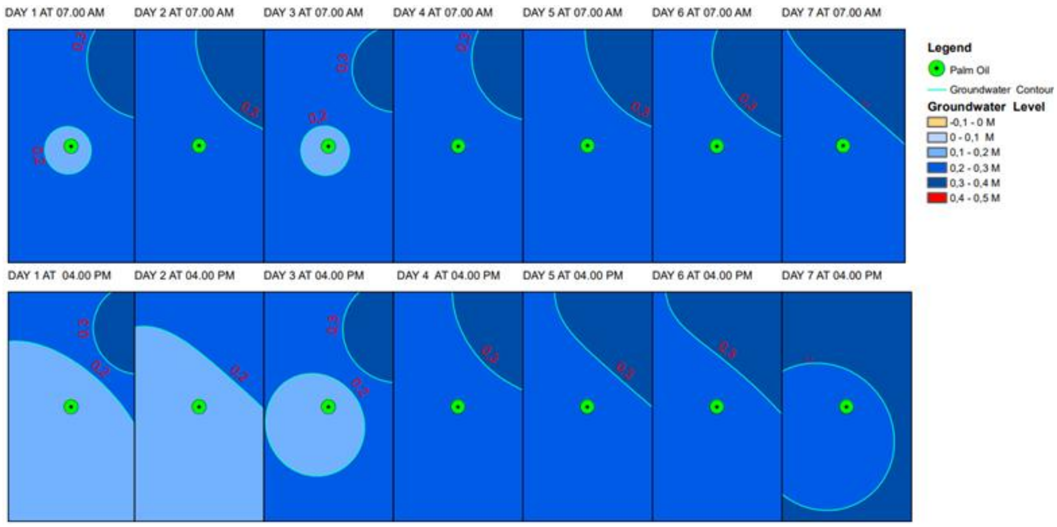


Fig. 5. Fluctuations in groundwater levels in peatlands planted with oil palm at 07:00 AM and 04:00 PM for seven days

Figure 6 shows that the depth of the groundwater table in the secondary forest at 7:00 AM for the first-day observation to the fifth-day observation, and the seventh-day observation was at a depth that is not by the regulations of the Government of the Republic of Indonesia, namely the maximum groundwater depth of 40 cm below the peat surface. However, on the sixth day, the groundwater table depth is based on the regulations of the Government of the Republic of Indonesia, i.e., the maximum groundwater depth of 40 cm below the peat surface. The depth of the groundwater table in the secondary forest at 04:00 pm on the first-day observation and the third-day observation of the groundwater table depth according to the regulations of the Government of the Republic of Indonesia, namely the maximum depth of 40 cm below the peat surface, while on the second-day observation, the observation on the fourth to seventh day was not by the regulations of the Government of the Republic of Indonesia.

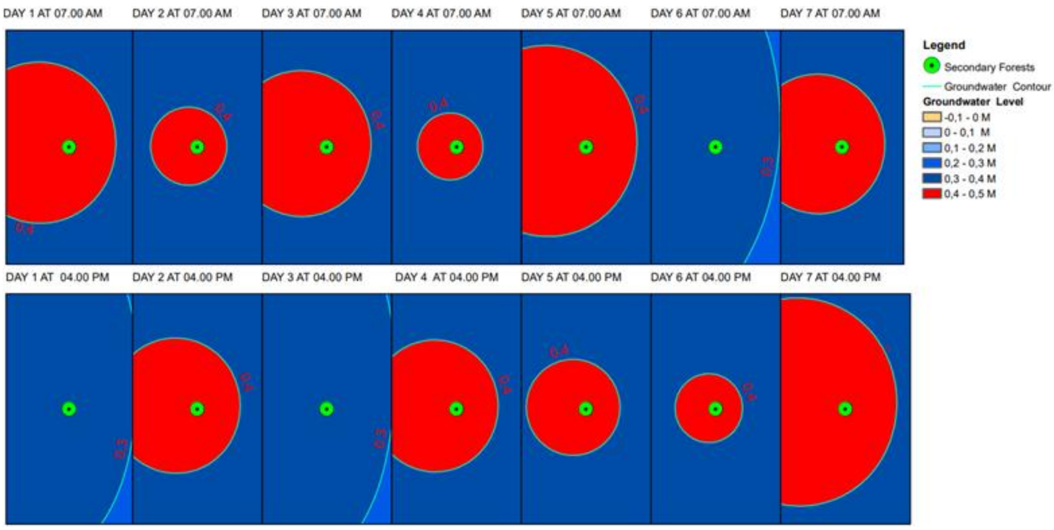


Fig. 6. Fluctuations in groundwater levels in peatlands at a secondary forest at 07:00 AM and 04.00 PM for seven days

3.2 Groundwater Table and Peat Properties

Peat characteristics in land planted with aloe vera, papaya, oil palm, and secondary forests are presented in Table 1. From Table 1, the peat depth, Bulk density, porosity, and permeability at the four sites have different values. The nature of peat on land planted with papaya and oil palm plantations tends to indicate peat conditions that experience more disturbances in the form of human activities in cultivation, characterized by increased content weight and reduced porosity. Peat soil with low bulk density has more pores, making it prone to water loss.

Table 1
Peat characteristics at the research site

Description	Aloe Vera	Papaya	Oil palm	Secondary Forest
Peat Depth (m)	460	175	75	452
Dry Bulk Density (g cm^{-3})	0.14	0.41	0.32	0.15
Porosity (%)	91.63	77.04	81.24	90.77
Permeability (cm/hour)	16	1.41	5.65	11.3

The table presents the key physical properties of peat under different land cover types: aloe vera, papaya, oil palm, and secondary forest. The deepest peat is found under aloe vera (460 cm) and secondary forest (452 cm), while papaya (175 cm) and oil palm (75 cm) have significantly shallower peat layers. Papaya has the highest dry bulk density (0.41 g/cm^3), followed by oil palm (0.32 g/cm^3). Aloe vera (0.14 g/cm^3) and the secondary forest (0.15 g/cm^3) exhibit lower values, indicating less compacted peat. Aloe vera (91.63%) and secondary forest (90.77%) have the highest porosity, suggesting greater water retention capacity, whereas oil palm (81.24%) and papaya (77.04%) have lower porosity. Aloe vera has the highest permeability (16 cm/hour), followed by secondary forest (11.3 cm/hour), oil palm (5.65 cm/hour), and papaya (1.41 cm/hour), indicating differences in water movement through the peat. These variations highlight how different land cover types influence peat characteristics, affecting water retention, drainage, and groundwater dynamics.

3.3 Rainfall, Groundwater Level, and Temperature

Figure 7 presents rainfall during the measurement period and its relation to groundwater table depth at 7:00 AM. Figure 7 shows a tendency for rainfall to affect the depth of the groundwater table. The figure presents the relationship between rainfall and groundwater table depth in different land cover types over seven days. Rainfall varies significantly, with peaks on Day 3 and Day 6 exceeding 50 mm. On other days, rainfall is relatively low. The groundwater table depth fluctuates differently across land cover types in response to rainfall variations. The secondary forest shows the highest groundwater table depth (lowest water level), indicating better water retention. Papaya maintains relatively stable groundwater levels with a slight increasing trend. Palm oil (red line) gradually rises in groundwater table depth. Aloe vera shows a more dynamic response, with a noticeable drop on Day 6, which coincides with high rainfall, followed by a rise on Day 7. These trends suggest that vegetation type influences groundwater table fluctuations, with secondary forests providing the most stable water table conditions. The effect of rainfall on groundwater levels is also evident, particularly in aloe vera cultivation, which shows the most pronounced response. The temperature during the measurement period and its relationship to the depth of the groundwater table at 7:00 AM are presented in Figure 8.

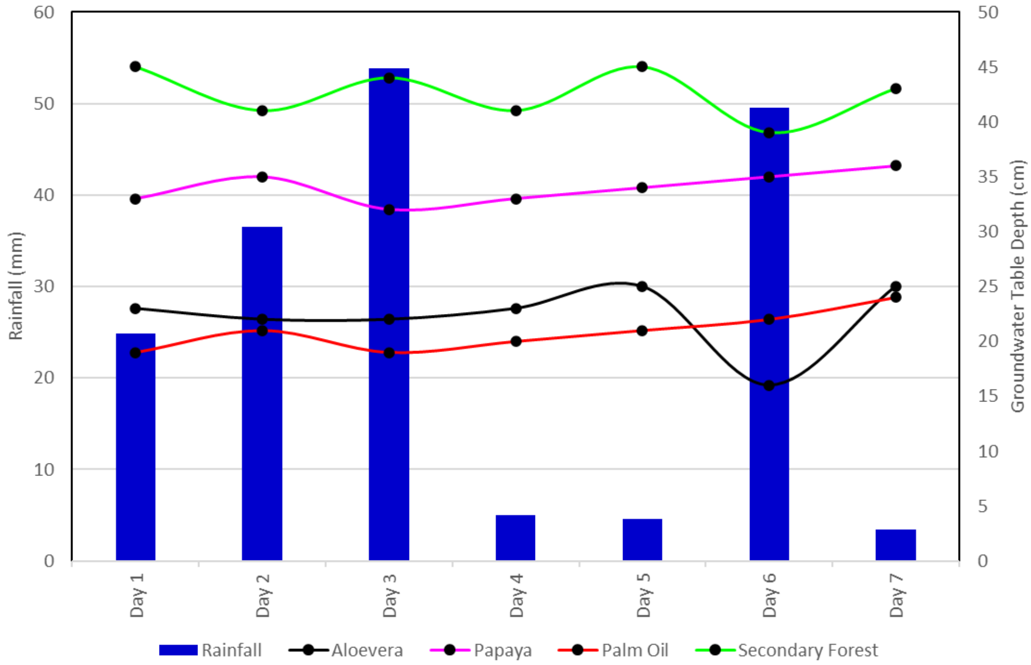


Fig. 7. Rainfall and depth of groundwater table during seven days of observations in aloe vera, papaya, oil palm, and secondary forest fields at 07:00 am

Figure 8 shows that temperature affects the depth of the groundwater table. It presents the relationship between temperature and groundwater table depth across different land cover types over seven days. Figure 9 presents the temperature during the measurement period and its relationship to the depth of the groundwater table at 4:00 PM.

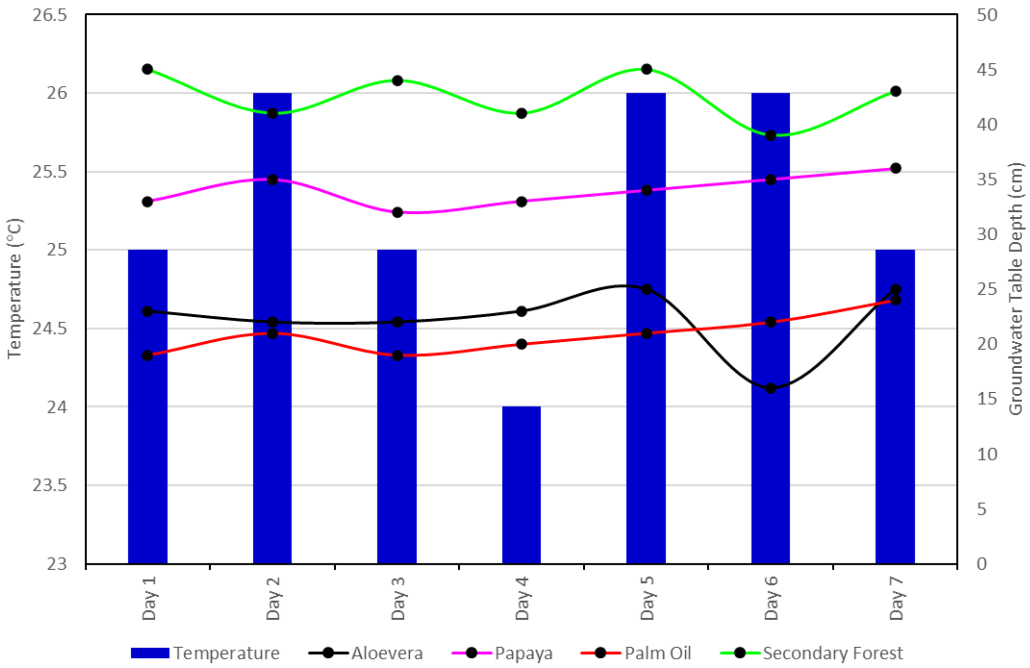


Fig. 8. Temperature and depth of groundwater table during seven days of observations in aloe vera, papaya, oil palm, and secondary forest fields at 07:00 AM

Figure 9 shows that temperature affects the depth of the groundwater table. The data reveal that temperature variations correspond to fluctuations in groundwater table depth. Among the land cover types, the secondary forest consistently exhibits the most significant groundwater table depth, followed by papaya, aloe vera, and palm oil. Notably, the groundwater level under palm oil and aloe vera tends to rise gradually, while secondary forest and papaya maintain relatively stable trends. Higher temperatures are generally associated with increased groundwater depth, suggesting a potential influence of temperature on groundwater fluctuations. These patterns highlight the role of different vegetation types in regulating groundwater dynamics in peatland environments.

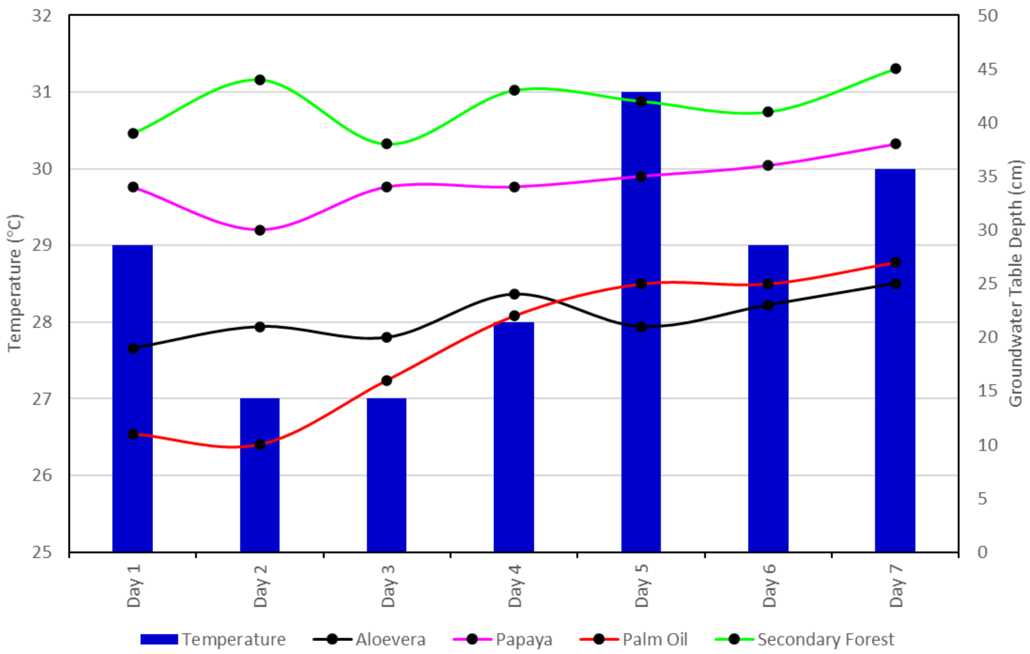
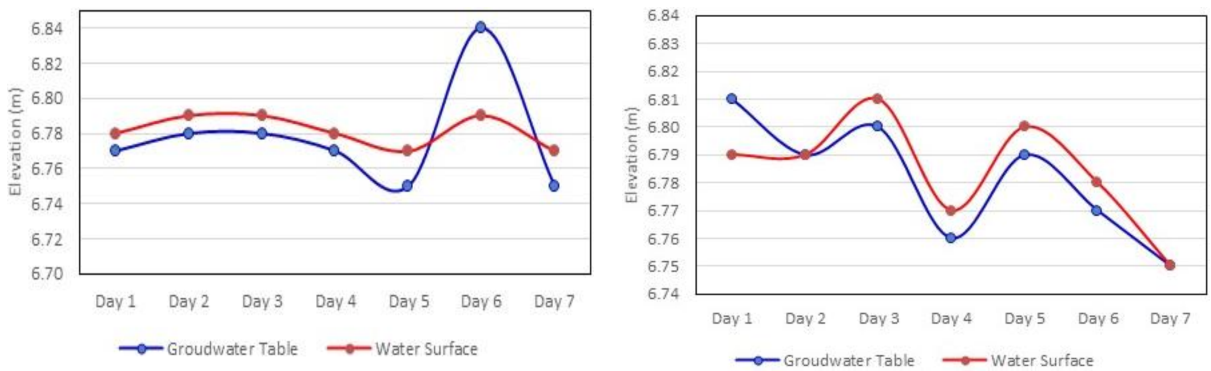


Fig. 9. Temperature and depth of groundwater table during seven days of observations in aloe vera, papaya, oil palm, and secondary forest fields at 04:00 PM

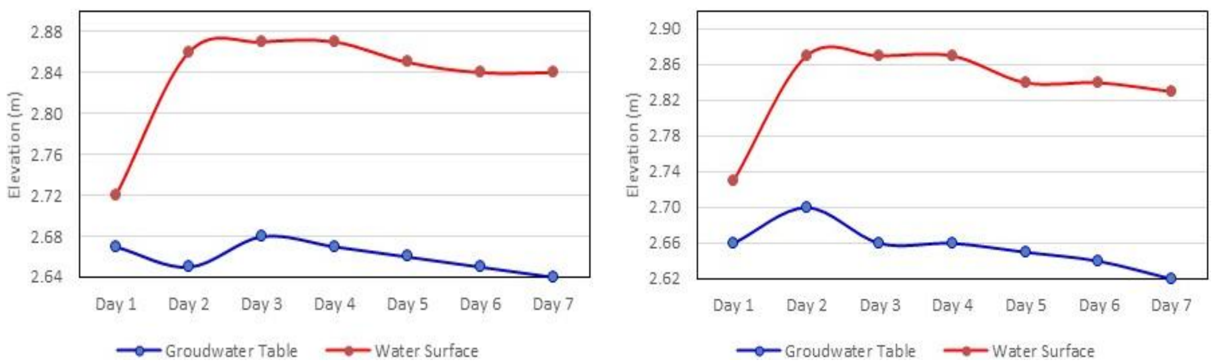
Figure 10 presents the groundwater and canal water levels on land planted with aloe vera, measured at two different times: (a) 07:00 AM and (b) 04:00 PM. The groundwater table and water surface in the canal exhibit variations throughout the seven-day observation period. The groundwater level shows relatively stable fluctuations in the morning (07:00 AM), maintaining a close relationship with the canal water level. However, on Day 6, a significant rise in the groundwater table is observed, indicating possible recharge or water retention within the soil. In the afternoon (04:00 PM), the groundwater table demonstrates more dynamic fluctuations, showing a noticeable decline towards Day 7. The canal water level follows a similar pattern but remains consistently higher than the groundwater level. This suggests that daily evapotranspiration and soil permeability influence water movement between the canal and the soil.



(a) (b)

Fig. 10. Groundwater level and canal water level on land planted with aloe vera at (a) 07:00 AM and (b) 04:00 pm

Figure 11 shows the groundwater and canal water levels on land planted with papaya. The observations cover seven days, with measurements at (a) 07:00 AM and (b) 04:00 PM. The groundwater table (blue line) remains relatively stable, with minimal daily fluctuations. A slight decrease is observed on Day 1, followed by small rises on Days 3 and 4, but the overall variation is limited. In contrast, the canal water level (red line) exhibits a sharp increase from Day 1 to Day 2, followed by a stable phase at a higher elevation for the remainder of the period. The elevation difference between the canal water level and the groundwater table remains consistent after the initial rise, indicating that the canal maintains a higher water level than the groundwater table. This suggests that on papaya-planted land, there is limited interaction between the groundwater and canal water levels, with the canal holding water at a higher level, potentially due to factors such as irrigation management or the low permeability of the soil.



(a) (b)

Fig. 11. Groundwater level and canal water level on land planted with papaya at (a) 07:00 am and (b) 04:00 pm

Figure 12 presents the groundwater and canal water levels on land planted with oil palm, measured over seven days at (a) 07:00 AM and (b) 04:00 PM. The groundwater table (blue line) shows a gradual decreasing trend throughout the observation period. There is a slight increase on Day 3, but afterward, the level continues to decline until Day 7. This indicates a continuous reduction in groundwater storage, potentially due to evapotranspiration or drainage. The canal water level exhibits a fluctuating pattern, with noticeable peaks around Days 3 and 4, followed by a decline and subsequent recovery. The periodic rise and fall of the canal water level suggest an external influence, such as tidal effects or water management interventions. The consistent gap between the canal water level and the groundwater table implies that the canal retains water at a higher elevation than the groundwater table, possibly regulating water availability for oil palm growth. This pattern suggests a dynamic interaction between surface water and groundwater, influenced by natural and managed hydrological processes.

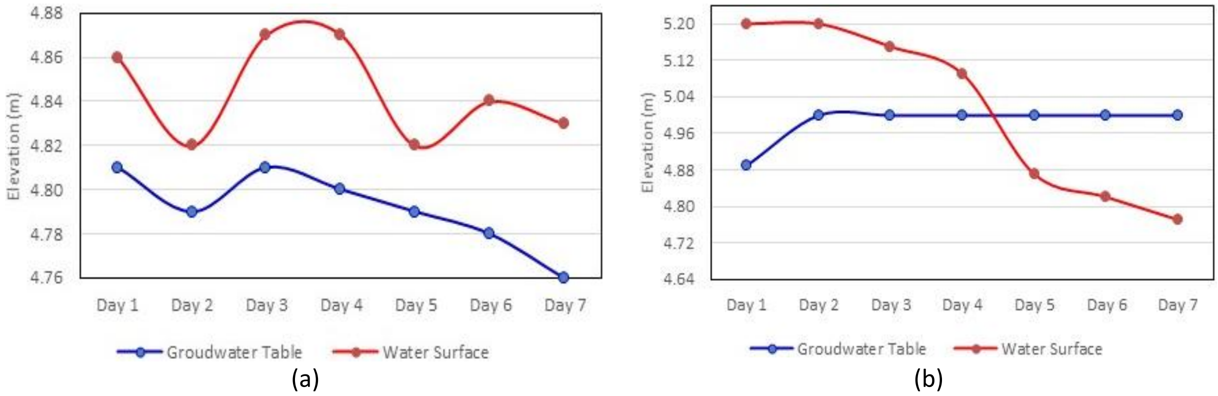


Fig. 12. Groundwater level and canal water level on land planted with palm oil (a) 07:00 am and (b) 04:00 pm

Figure 13 presents the groundwater and canal water levels in the secondary forest, observed over seven days at (a) 07:00 AM and (b) 04:00 PM. The groundwater table exhibits periodic fluctuations, indicating a dynamic interaction between groundwater recharge and discharge. The levels generally remain stable with minor variations, suggesting that the secondary forest has a relatively balanced groundwater condition, likely influenced by high organic matter content and peatland characteristics. The canal water level also shows fluctuations but more pronounced variations than the groundwater table. There are noticeable declines in water surface elevation on certain days, followed by recovery, possibly due to tidal influences or water movement within the canal system. Comparing the two graphs, the morning (07:00 AM) and afternoon (04:00 PM) measurements display similar trends but with variations in magnitude. The differences between the groundwater table and canal water level suggest an interaction between surface and subsurface hydrology, where canal water dynamics may influence groundwater fluctuations in the secondary forest.

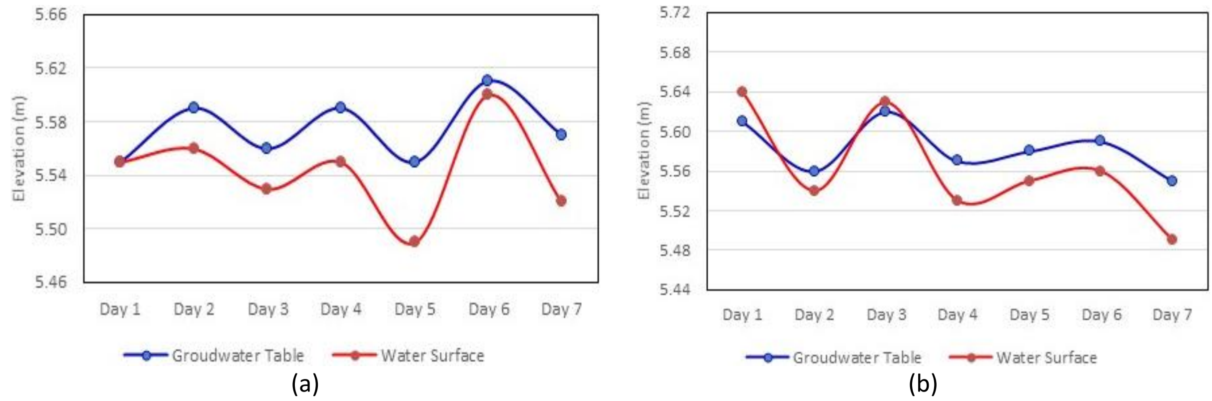


Fig. 13. Groundwater level and canal water level in the secondary forest (a) 07:00 am (b) 04:00 pm

The groundwater level recorded in this study can reflect the condition of peatland management at the study site. The depth of the groundwater table in fields planted with aloe vera and papaya varies within the recommended depth range, which is a maximum of 40 cm from the peat surface. The depth of the groundwater table in secondary forests tends to be more than 40 cm, indicating that the land is vulnerable to peat degradation. According to the government's regulations of the

Republic of Indonesia, a depth of groundwater that exceeds 40 cm is one indicator of peat damage. The condition of peatlands with the groundwater table's depth can increase the fire risk [56].

The depth of the groundwater table can be used as an indicator of the amount of carbon emissions released through peat decomposition [16,49,57,58].

Fluctuations in groundwater levels in lands planted with aloe vera (Figure 10), papaya (Figure 11), oil palm (Figure 12), and secondary forests (Figure 13) correspond to fluctuations in water levels in canals close to these lands. Conditions at the study site indicate that the canal is not equipped with a flow control building. Maintaining the groundwater level of peatlands is one of the efforts to control the negative impacts of peatland use.

4. Conclusions

The groundwater level in cultivated peatlands in Pontianak City fluctuates in response to rainfall, temperature, peat physical properties, and the proximity of drainage canals. The study reveals that rainfall significantly influences groundwater recharge, while higher temperatures accelerate water loss through evapotranspiration.

The physical characteristics of peat, such as permeability and decomposition level, affect water retention, and nearby canals facilitate drainage, leading to groundwater fluctuations. These findings provide insights into the hydrological dynamics of cultivated peatlands, contributing to improved water management strategies in the region.

Acknowledgment
The authors acknowledge the International Matching Grant of Universitas Tanjungpura (UNTAN), Universiti Malaysia Sarawak (UNIMAS), and Universiti Pendidikan Sultan Idris (UPSI). They would also like to thank the Faculty of Engineering, UNTAN, the Pontianak City Government, and the land-owning community for granting permission to carry out this research activity.

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