Study of Tidal and Water Quality in Acid Sulphate Soil of Unit Tamban Lowland Irrigation Area Central Kalimantan

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ABSTRACT
Unit Tamban is one of the reclaimed lowlands in the tidal irrigation area, which is included in the food estate program located in Block D, Central Kalimantan. The water system used in the area is a fork-type with a settling pond at the end of each primary canal. Most of the soils are acid sulfate type with a pyrite depth of more than 50cm. Sedimentation of the canal causes the water supply and drainage processes to slow down, which compromises the water quality. At high tide, there is a process of acid water dilution, while at low tide, acid water will be evacuated out of agricultural land through a network of canals. The study was conducted of examining the effect of tides on water quality as indicated by the characteristics of pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC). Measurements were done at four points along the primary canal during spring tide and neap tide in the wet season. Water level and water quality were measured simultaneously for 27 hours. The results showed that water level fluctuations had a significant influence on the water quality in the canal. When it comes to peak tide during spring tide, the pH of the water increases while the EC and TDS values decrease. Rainfall at high tide also affects the quality of the canal surface water, which raises the pH.

Keywords: *Lowland irrigation area, water quality, tides, acid sulfate soil, land productivity*

1. INTRODUCTION

The government's efforts in overcoming the food crisis due to warnings from the Food and Agriculture Organization (FAO) related to the COVID-19 pandemic are to implement a strategy for developing large-scale cultivation or food estates. The development of food estates aims to meet the needs of national food stocks through increasing agricultural productivity by cultivating existing land and expanding agricultural land [1]. Increasing food production requires the availability of extensive agricultural land. The increasing conversion of agricultural land impacts reducing productive land so the government is looking for alternatives to marginal land use, one of which is swampland, including peat land. Indonesia has a swampland of about 34.12 million ha, consisting of 8.92 million ha of tidal swamps and 25.20 million ha of non-tidal swamps [2].

The Unit Tamban tidal irrigation area is in the working area of the former one million hectares peatland project (Ex-PLG), namely in block D. Administratively, the Unit Tamban is located in Kapuas Regency, precisely located in two districts, namely Bataguh District and Tamban Catur District. Unit Tamban has a soil type of pyrite mineral and non-pyrite mineral [3]. The soils of tidal swamps contain acid sulfate or pyrite substances at various depths of the soil. Submerged pyrite is not dangerous for the plants on it [4]. Reclamation of swamps with drainage causes the groundwater level to fall and pyrite to undergo oxidation. Pyrite oxidation releases acidic substances, toxic iron (Fe^{2+}), and aluminum harmful to plant growth. The shallower depth of pyrite will affect the decrease in pH, K, Ca, Mg, Cu, and Zn [5].

The agricultural productivity of the Unit Tamban is very low, with only one harvest every year (IP100) using local rice, which can survive in extreme conditions where

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the soil pH is classified as acidic and poor in nutrients. Currently, irrigation water sources only rely on rainfall because the water in the canal has a relatively low pH. Canal rehabilitation is constrained by social problems where the communities around the primary canal refuse to be moved. As a result, the canal gradually undergoes sedimentation. Sedimentation forms dead spots in the canal disrupts water traffic and decreases water quality. Proper water management of the swamp irrigation network must meet at least three goals. The first goal is to provide enough water for washing and diluting acid. The second can drain excess moisture during the wet season, and the third is to maintain the potential of acidic sulfate soils in a reduced state to avoid excessive oxidation [6].

Water quality on the canal and tidal swamp irrigation is influenced by a season or rainfall, high or low tide conditions, and distance location irrigation from the estuary [7]. Tides are divided into spring tides and neap tides. Spring tide will produce the highest tide and lowest ebb, while neap tide will produce the lowest tide and highest ebb [8]. The energy at high tide is used to supply irrigation water from the river to the canal. At low tide, it will evacuate acid water out of the canal, resulting in washing water in the canal. An intensive water washing process can improve water quality and increase agricultural productivity.

The study was conducted of examining the influence of tides on water quality with specific indicators on the primary canal. The results of tidal studies on water quality are needed to be an input for technical considerations in increasing agricultural productivity.

2. METHOD

2.1. Study Area

The research is located in the Ex-PLG area, in Block D at the Unit Tamban, Kapuas Regency, Central Kalimantan. The source of irrigation water comes from the Kapuas Murung River. The distance of the Kapuas Murung River estuary to the Main Primary Canal is about ± 26km.

The water management system in the Unit Tamban is a fork-type with a settling pond at the end of each primary canal. The lengths of the middle primary canal, the left primary canal, and the right primary canal are respectively 6.4 km, 6 km, and 6.8 km. The settling pond has a size of 400x400 m. The settling pond was malfunctioning and full of shrubs due to sedimentation. Unit Tamban scheme can be seen in Figure 1.

The soil of the Unit Tamban is acid sulfate soil with a pyrite depth of more than 50cm from the soil surface with a reaction level category that is weak to strong. Pyrite is a FeS_2 soil mineral often found in swamplands, especially tidal swamps. The pyrite reaction can be found when there is foam when mixed using Hydrogen Peroxide (H_2O_2). Weak pyrite has the characteristics of being slightly bubbly, slightly smoky, and slightly smelly. Strong pyrite has the characteristics of being heavily bubbly, smoky, and smelly. The variation in pyrite depth affects rice productivity because with the more profound presence of pyrite the roots of plants can grow better. If pyrite is near the soil surface, it will be easily oxidized, which is toxic to plants due to increased soil acidification [9].

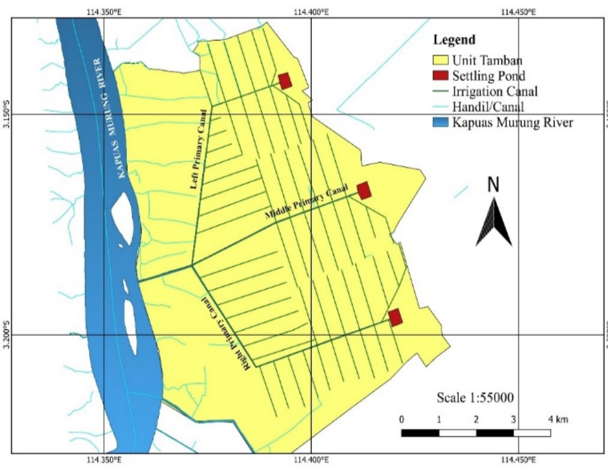


Figure 1 Scheme of Unit Tamban Lowland Irrigation Area (Modified) [10]

2.2. Tide Observation

The tides on the Unit Tamban belong to the single daily tidal (diurnal tides). Tides are natural phenomena in the form of up and down movements of sea levels regularly and repeatedly caused by a combination of gravity and attractive forces by the sun, earth and moon. Gravity varies with mass but inversely with distance [11]. Therefore, the moon's attraction is greater than the effect of the sun's gravitational force because it is closer to the earth even though the moon's mass is much smaller than the sun's mass. The type of tide is not always the same in every place. Tidal characteristics in waters are influenced by geographical location, coastal morphology, and water bathymetry [12]. A tidal cycle can be interpreted as sea-level fluctuations that change periodically in a specific time interval. The sea tides are grouped into 3 (three) types, namely:

1. Half-day tides, meaning that there is one tide and one ebb every half-day (12 hours) in a particular place. Hence, there are two tides and two ebbs (semi-diurnal tide) in a day (24 hours).
2. Daily tides occur when within one day (24 hours), there is only one tide and one ebb (diurnal tide).
3. Mixed tides (mixed), in one day (24 hours), irregular tides and ebbs occur. These mixed ups and downs are divided into two groups, namely:
    a. Mixed semi-diurnal tide.

b. Mixed tide leans towards the daily form (mixed diurnal tide).

Based on the influence of tides, swamps can be distinguished into tidal swamps and non-tidal swamps consisting of 3 zones, as in Figure 2.

1. Tidal swamps (zone I and zone II)

Swamps in the zone I are influenced by daily tides of brackish or saline water overflow, with the main physiography of this land being peat and marine. In contrast, zone II is influenced by daily tides of freshwater overflows, with the main physiography of this land being alluvial/fluviatile, peat, and marine.

2. Non-tidal swamps (zone III)

The marshlands in zone III are not affected by tides, with the main physiography of these lands being alluvial/fluviatile and peat.

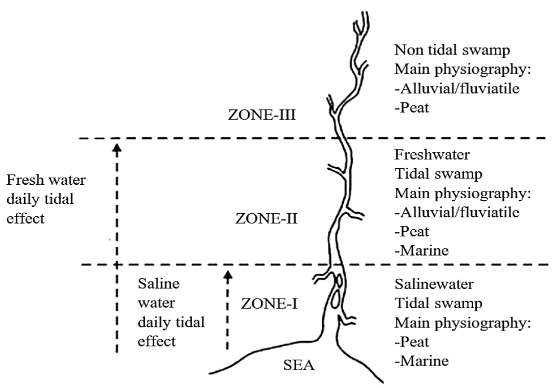


Figure 2 The Division of Swamp Zones Along Watersheds (Modified) [13]

Unit Tamban is in zone II, which is affected by the daily freshwater tides. In this research, water level measurements are carried out to examine the type of tides and determine the elevation of reclaimed land. Water level measurements were carried out simultaneously for 27 hours with an hour interval at four points along the primary canal, namely the main primary canal, the middle primary canal (±5.21km from the estuary), the right primary canal (±7.02km from the estuary) and the left primary canal (±5.47km from the estuary) as shown in Figure 3. Water level measurements are carried out during the wet season of the neap tide (March 21-22, 2022) and spring tide (March 28-29, 2022).

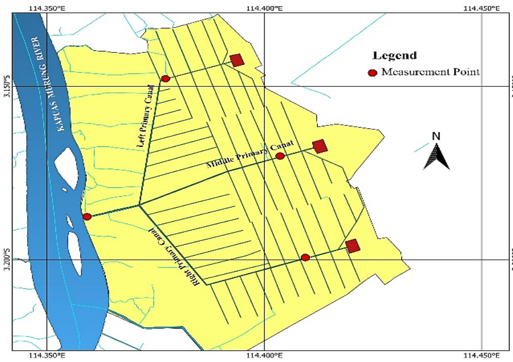


Figure 3 Water Level and Water Quality Measurement Point (Modified) [10]

2.3. Water Quality Observation

The property of water which can dissolve compounds and solid objects can affect its quality. Agricultural productivity cannot be separated from water quality. Water quality can be judged by its physical and chemical properties [14]. The main irrigation water quality parameters that must be known are the degree of water acidity (pH), salinity, and the content of organic and inorganic materials in the water. Changes in water pH greatly affect fluctuations in other water quality parameters. A decrease in water pH can increase ionization in water which increases the value of Electrical Conductivity (EC), affecting plant metabolic processes [15]. The content of organic and inorganic materials due to waste pollution can be seen from the Total Dissolved Solids (TDS) parameter.

Instantaneous water and soil quality measurements were carried out at several points of the irrigation area to determine the initial condition of the Unit Tamban. Water quality parameters are acidity (pH), Total Dissolved Solid (TDS), and Electrical Conductivity (EC). These parameters were measured using *a Digital Water Quality Tester* (Figure 4). The water quality test in this research is direct testing on the water surface of the canal that is carried out simultaneously for 27 hours with an hour interval.

Figure 4 Digital Water Quality Tester

2.4. Hydro-topography Classification

Hydro-topography is the relationship between high tide water levels and land elevations, where water levels higher than land elevations can inundate the land (Figure 5). Tides and the tidal dampening effect on rivers and canals determine tidal levels. The hydro-topography classification of tidal swamps is divided into categories A to category D [16].

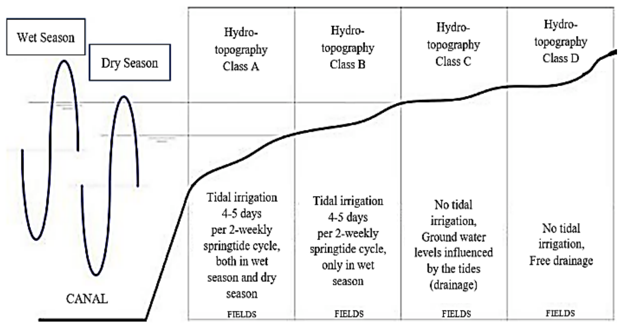


Figure 5 Tidal Swamp Hydro-topography [17]

The higher topography causes a decrease in the thrust of the tides, resulting in differences in the potential for tidal overflow. The hydro-topography of the Unit Tamban is type A (1,214 ha), type B (2,117 ha), and type C (1,993 ha) [3]. Water level results in spring tide at the four measurement points compared to the land elevation showing the classification of hydro-topography around the area.

3. RESULTS AND DISCUSSION

3.1. Existing Condition

The existing condition of the Unit Tamban is no longer functioning correctly, such as sedimentation of the canals, settlements around the primary canal, damaged water buildings, and settling ponds that have undergone sedimentation (Figure 6). The results of instantaneous water quality measurements at several points in the Unit Tamban still found a low pH ranging from 3 to 5.

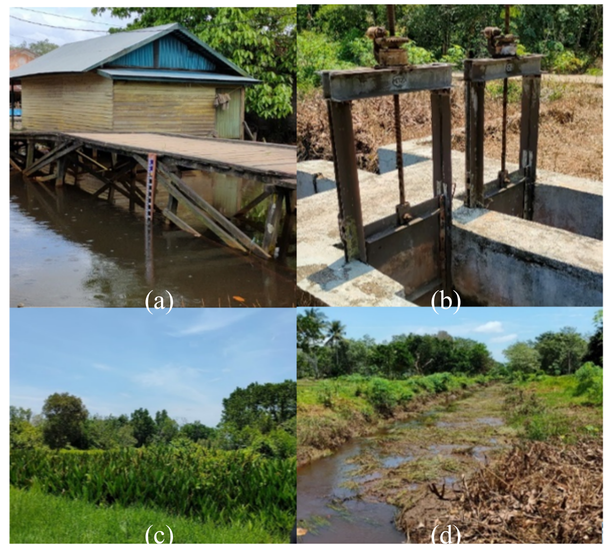


Figure 6 Existing Condition of the Unit Tamban such as (a) settlements around the primary canal, (b) damaged water buildings, (c) settling pond full of shrubs, and (d) sedimentation of the canals

Soil pH measurements were carried out at various points in the Unit Tamban, as in Figure 7. The results of the soil quality test obtained pH range from 4.5 to 6. The soil of Unit Tamban is classified as acid sulfate soil. If the pH conditions in the plant's growing media are acidic, the absorption of nutrients and water by the roots of the plant will be inhibited, which causes the plant's growth to be slow and stunted [18]. The ideal soil pH for rice growth is about 5 to 6.5 [19]. Only local rice can withstand a pH ranging from 4 to 5.

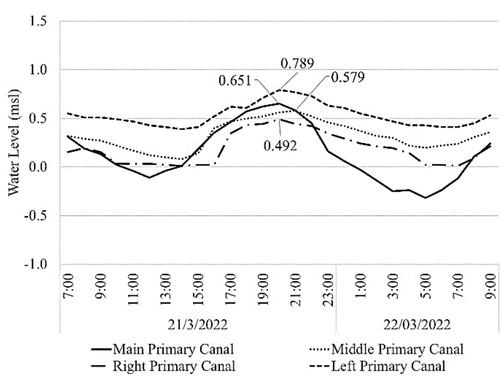
Figure 7 Soil Quality Test Results on March 23rd, 2022

The plant's root zone condition is said to be safe if it can maintain the high water level so that pyrite is always in a flooded condition. Flooded pyrite (FeS_2) is a stable and harmless compound [4]. Water management is needed so that pyrite is not revealed and undergoes oxidation so it can poison the surrounding plants.

3.2. Water Level Analysis

The tidal amplitude at four measurement points in spring tide is more significant than in neap tide (Figure 8). In the main primary canal, duristaff ng spring tide, the tidal amplitude is 2.00 m, while at neap tide is only 0.97 m. At the neap tide, the water level of the left primary canal is higher than the other primary canals. It is caused due to additional upstream discharge due to rain and the small capacity of the canal due to sedimentation. At 14:00-20:00 West Indonesian Time (WIT), water flows from the main primary canal to the other primary canals. The left primary canal only receives incoming water for an hour from 16:00-17:00 WIT. The additional rain discharge from the secondary of the middle primary canal, which is connected to the secondary of the left primary canal, also increases the discharge of water that comes out from upstream towards the main primary canal, which causes the incoming tidal energy to be less and improve the water level.

At spring tide, the water level of the right primary canal is 0.642 m MSL, more minor than another primary canal. It is caused due to the distance of the right primary staff gauge point from the main primary canal is the farthest among other primers, which is ±7.02 km, so the tidal energy is getting smaller. Meanwhile, the left and middle primary canals have water levels of 1.029 m MSL and 0.919 m MSL, with a staff gauge distance from the main primary canal of ±5.47 km and ±5.21 km, respectively. Water level fluctuations are significantly affected by tidal movements of the river and are less likely affected by rainfall [20].



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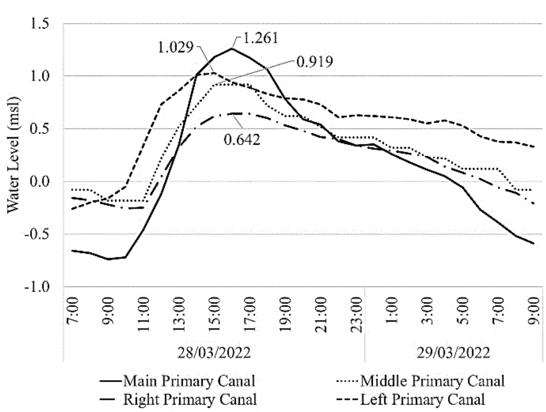


(b)

Figure 8 Results of Tidal Observation in Primary Canal at (a) Neap Tide and (b) Spring Tide

3.3. Water Quality Analysis

3.3.1. Degree of Acidity (pH)

The acidity and alkalinity of water are expressed in pH and are measured on a scale of 0 to 14. The lower pH numbers indicate an acidic solution, whereas a higher number pH indicates an alkaline solution. A low pH value cannot be used to irrigate irrigated land because it will affect the absorption of nutrients by plants [18]. According to Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control [21], the recommended acidity (pH) for irrigation water (class IV) is in the range of 6-9.

The pH values at the four measurement points during spring and neap tides are very volatile. During neap tide, the average pH value in the main primary, right primary, and left primary canals is relatively low, in the range of 2.7 to 4.9. In contrast, the middle primary canal has a fairly good average pH value of 7.18. From the observations, the water current in the middle primary canal always leads towards the main primary canal. This is due to additional rain discharge upstream of the canal and runoff from rice fields. During spring tide, there was an increase in the average pH value in the main primary, the right primary, and the left primary canal ranging from 4.55 to 7.1 while the middle primary canal has decreased, but it can be said that it still has a good pH of 6.9 (no rain). The pH fluctuation in the primary canal is due to the influence of rainwater. The surrounding environment strongly influences the high and low pH, such as the presence of carbon dioxide gas (CO_2) in the water, the concentration of carbonate and bicarbonate salts, the process of decomposition of organic matter, high rainfall, and human activities. The water quality in tidal land is strongly influenced by several factors, namely the amount of rain or seasons, tidal or low tide conditions, and the distance of the location from river estuary or secondary canals [20], [22].

3.3.2. Total Dissolved Solid (TDS)

TDS is a term to signify the number of dissolved solids or the concentration of the number of cation ions (positively charged) and anions (negatively charged) in water. TDS is one of the indicators of polluted water. Organic or non-organic compounds can cause TDS, but in peat, water TDS comes from organic matter, namely, peat contaminated with water. TDS has a size of less than one nanometer with units of ppm or mg/l. According to Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control, a good TDS value is less than 2000 mg/l [21]. The TDS value in the Unit Tamban during spring and neap tide meets the requirement in the range of values of 14-196 ppm.

3.3.3. Electrical Conductivity (EC)

EC is the number of ions or salts dissolved in water affecting the ability of water as an electrical conductor. The more salt dissolved in water, the higher the electrical conductivity was produced. EC is an indirect measurement of salt concentrations that can be used to determine the suitability of water for plant cultivation and to monitor nutrient solution concentrations [23]. Conductivity is usually measured in micro or millisiemens per centimeter (µs/cm or mS/cm). Water quality criteria can be determined based on EC values as in Table 1. The EC value in the Unit Tamban when the spring and neap tides are in the range of 29-393 µs/cm which are in the good category for Colorado Irrigation Water and Scofield, while in Oklahoma Irrigation Water is in the very good category. A summary of the average values of water quality results can be seen in the following Table 2.

At spring tide, pH, TDS, and EC changes are noticeable in the main primary canal. The pH increases when heading towards the top of the tide at 14.00-19.00 WIT, while the TDS and EC values decrease, as in Figure 9 (1). These relationships of pH, TDS, and EC are due to the ions released from acid (pH). In electrolyte conductors, flowing electrons are carried by ions, while those that can produce ions include acids, bases, and salts. Strong acids (low pH) will produce higher ions resulting in EC and TDS values going up, while weak acids (high pH) ions only have a few so that the EC values and TDS go down [25].

The increase and decrease in the EC value will be linear to the TDS value. TDS is closely related to inorganic materials containing ions where the number of ions in the water will affect the ability of the water to conduct electricity. Therefore, the more ions contained in the water, the higher the EC value.

Table 1. Water Quality Criteria for Electrical Conductivity (EC) [24]

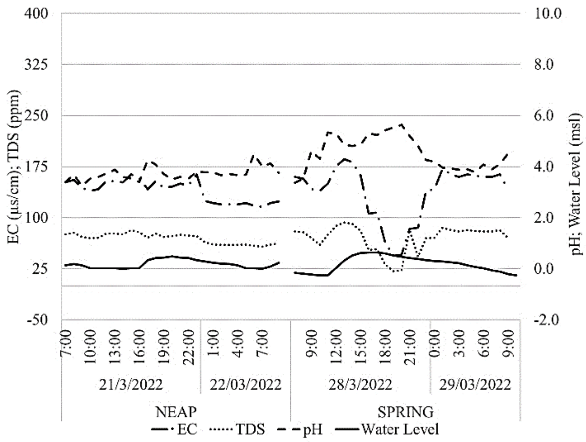
Colorado Irrigation Water		Scofield (1936)		Oklahoma Irrigation Water	
Very good	< 250	Very good	< 250	Very good	500
Good	250 – 750	Good	250 – 750	Good	500-1500
Enough	760 – 1500	Enough	750 – 2000	Enough	1500-3000
Not good	1510 – 3000	Not good	2000 – 3000	Not good	3000-5000
Not feasible	>3000	Not feasible	>3000	Bad	5000-6000
				Not feasible	>6000

Table 2. Results of Water Quality Observation

Point	Neap Tides			Spring Tides		
	pH	EC	TDS	pH	EC	TDS
Main Primary Canal	4.90	82	40	7.10	55	26
Middle Primary Canal	7.18	70	34	6.90	86	44
Right Primary Canal	3.74	140	70	4.55	138	70
Left Primary Canal	2.70	310	149	6.78	212	88

3.4. Water Level Analysis on Water Quality Dynamics

Changes in water quality are strongly influenced by fluctuations in water level. Changes in pH, TDS, and EC are visible during spring tide and neap tide in Figure 9. At neap tide, the influence of tides on pH is quite volatile and does not change significantly from its initial state. TDS and EC values indicate linear and inversely proportional to pH. When the pH is low, the TDS and EC will rise, when the pH increases, the TDS and EC tend to fall.



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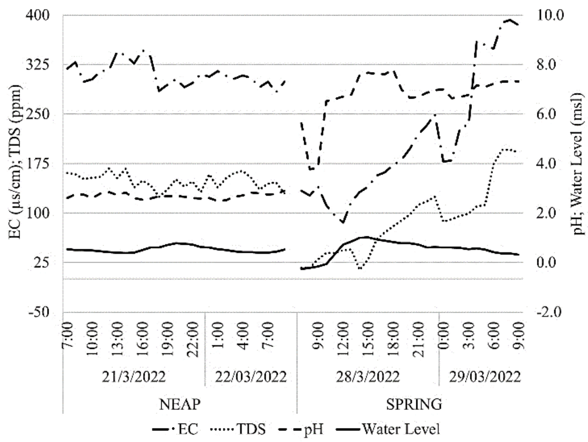
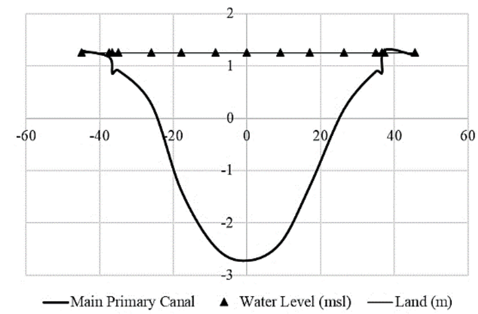


(d)

Figure 9 Relationships of Water Level to pH, EC, and TDS in (a) Main Primary Canal, (b) Middle Primary Canal, (c) Right Primary Canal, and (d) Left Primary Canal

3.5. Hydro-topography Analysis

Tidal swamps utilize tidal energy to supply irrigation water needs because their hydro-topography tends to be flat. Unit Tamban's hydro-topography is type A (1,214 ha), type B (2,117 ha) and type C (1,993 ha) with land elevations between -0.75 m to +2.25 m [3]. Based on the water level measurements at the four measurement points, the highest tide is only +1.261 m MSL. The water level at the highest tide is compared to the land elevation according to the measurement point, the tide cannot flood the land because the land elevation is higher than the water level. Following the hydro-topography map, several locations are not affected by tides where the fulfillment of irrigation water needs using rainwater. Farmers usually plant perennials such as rubber trees in areas not affected by tides. Figure 10 presents a graph of the results of the hydro-topography analysis.



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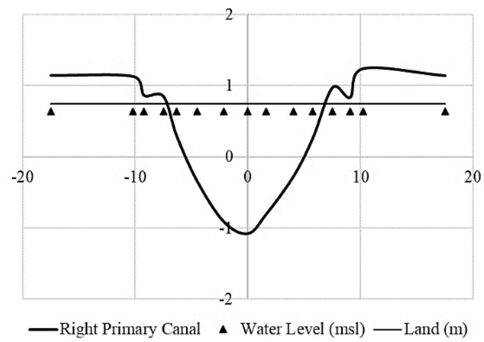

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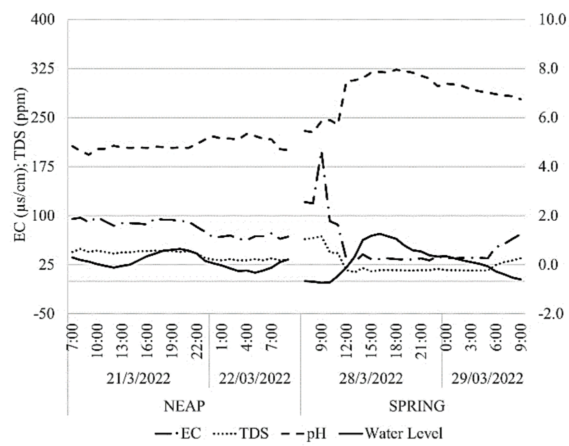

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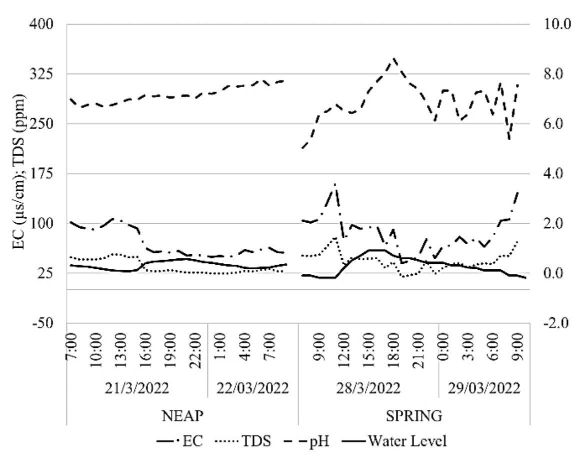

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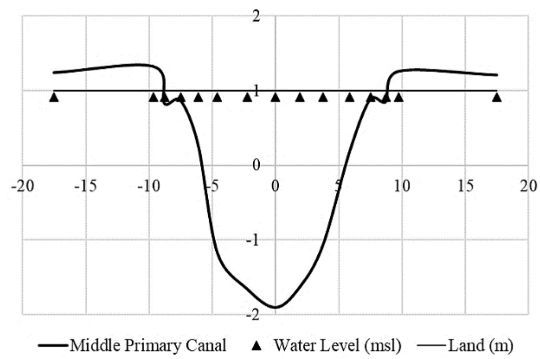

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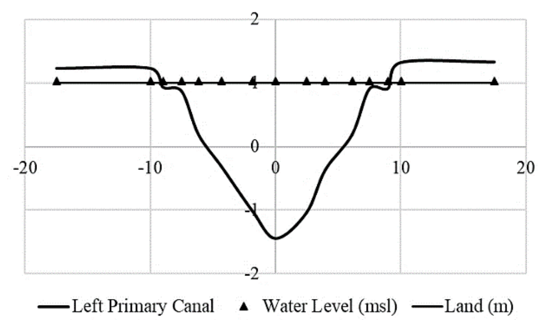

(d)

Figure 10 Variations in the hydro-topography of the land around (a) Main Primary Canal, (b) Right Primary Canal, (c) Middle Primary Canal, and (d) Left Primary Canal

4. CONCLUSION

Simultaneous water level and quality measurements show the highest tides and lowest tides in tidal swamp irrigation areas. The results of the analysis showed that fluctuations in water level had a significant influence on the water quality in the canal. When heading towards the top of the tide during the spring tide, the water's pH increases while the EC and TDS values decrease. The rainfall during neap tide affects the quality of the canal's surface water, which raises the pH. This relationship between the influence of tides on water quality can be used as basic knowledge for technical considerations used in increasing agricultural productivity in the Unit Tamban.

To see how far the tide can bring fresh water into the canal and receding can sense excessive waterlogging in the wet season, it is necessary to conduct studies with unsteady flow modeling 1D or 2D. Further research needs to be done by measuring the water level over a longer period to obtain data on the highest tides and lowest ebbs.

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