Post reclamation of acid sulphate soil due to extended tidal irrigation area in Palingkau, Central Kalimantan, Indonesia

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Abstract. The Palingkau Swamp Irrigation Scheme SP1 SP2 SP3 extends tidal irrigation between Kapuas Murung River and Kapuas River, which local peoples developed. The development of the new agricultural land behind the old tidal irrigation system creates oxidation of potential acid sulphate (FeS2) soil. The result of the leaching process polluted local's agricultural area causes the decrease land productivity. The field observation recorded the water pH ranges between 3.9 - 5.3; 3.7 - 4.31 at the handil; 2.5 - 4 at the collector channels; and 2.8 - 3.6 at the primary channels. Good water management is needed to overcome these problems, both at the new irrigation system and handil. The HECRAS mathematical model is used to evaluate water circulation in the system and its reliability. The efforts to normalize the handil impact increasing the amount of water entering the handil although it is not significant. Moreover, it still cannot meet the water demand for the leaching process in the network system by 2.06 million m³/day. It is necessary to increase the capacity of the channel to allow freshwater flow from the river for the leaching process in the network system.

Keywords: acid sulphate, mathematical model, reclamation, water management

1. Introduction

The Swamp Irrigation Area Palingkau SP1 SP2 SP3 Scheme is part of the former Peatland Development Project (PLG) in block A, developed in the 90s [1,2,3]. This swamp irrigation area located in Kapuas Regency, Central Kalimantan Province, has an area of approximately 9,000 hectares. The water source for this irrigation area comes from the tides of the Kapuas River on the left and the Kapuas Murung river on the right, which enters through the existing handil. In the beginning, the local community made a drainage channel (handil) to dispose of excess water in their agricultural area and a source for the entry of tidal water from the Kapuas Murung river. The Palingkau SP1 SP2 SP3 Scheme extends the local community's agricultural area with a handil system and an irrigation network system behind the handil. The government developed a new swamp irrigation system of collector, primary, secondary, and tertiary channels behind the old tidal irrigation system. This network system simultaneously connects handil on the left side (Kapuas River) and handil on the right side (Kapuas Murung River). It is hoping that the tides from the river can enter the network system.

The swamp reclamation process by creating a new network system behind the handil causes a decrease in the groundwater level on the mainland. It triggers the pyrite (FeS2) oxidation process. At the beginning of the rainy season, the toxic material then flows into the channel. The water in the channel
becomes very acidic and harmful for plants [4,5,6,7]. After more than 20 years, the Palingkau Unit SP1 SP2 SP3 was opened; from the results of the studies conducted, it was found that the reclamation process had not yet been fully completed. It means that the problem of acid sulphate soils still occurs and must be resolved. In the Palingkau SP1 SP2 SP3 Scheme, water in the network system containing toxic materials flows into agricultural land at low tide. It causes a decrease in agricultural productivity in handil. Water management is needed to overcome the problem of diluting toxic materials in the water system and the handil. The location of the Palingkau SP1 SP2 SP3 Scheme is shown in Figure 1 below.

![Figure 1. Location of Palingkau SP1 SP2 SP3 Scheme](image)

2. Material and methods
In the existing condition, the handils on the right side of the system, which originate from the Kapuas Murung river, consist of 13 handils varying in length between 3.9 ~ 4.1 km and width between 4 ~ 8 meters. From the survey results, the pH value in the handil ranged from 3.7 ~ 5.34. Six of the 13 handils are directly connected to the collector channel, while the rest are not connected due to a large amount of vegetation. In general, all of these handils experienced much sedimentation. There was much vegetation that hindered the flow of water. Ten handils are on the left side of the system and discharged to the Kapuas River. The length of the handil varies from about 2.2 ~ 2.9 km, with a width ranging from 7 ~ 14 m. The two handles are directly connected to the collector line. The pH value in the handil varies between 3.85 ~ 5.08. The handils on the left side are the same as the handils on the right side, experiencing much sedimentation and being covered by vegetation. Two handils are currently used as a means of public transportation. Both handils are in better condition than other handils.

The collector channel on the Unit Palingkau SP1 SP2 SP3 surrounds the area that is the boundary between the handils and the primary channel and the secondary and tertiary channels within the unit. The dimensions of the collector channels at the upper and lower ends ranged from 4.2 ~ 4.5 km, and those associated with handils ranged from 9.6 ~ 9.8 km. The total length of the collector channels was about 28 km. The condition of the collector channel associated with the handil on the right side is generally better than the collector channel on the left and the collector channel parallel to the primary
channel. The width of the collector channel on the right side varies between 6 ~ 11 m; for the left side, it ranges from 3 ~ 10 m, while the upstream and downstream sides are covered with vegetation and dead ends. The pH value in the collector channel varied between 2.58 ~ 3.84, with the lowest pH value obtained in the clogged upstream and downstream side of the collector channel, and there was no flow.

There are about 9 primary channels in the Palingkau SP1 SP2 SP3 Scheme with varying lengths between 4.2 ~ 4.5 km with varying widths between 6 ~ 11 m. The primary canal is generally sedimented and covered with vegetation, with pH values ranging from 2.8 ~ 3.6. There are 2 primary channels with better conditions than the others. The primary channel is connected to handil, which is also in better condition and is used as a means of transportation for local people. Secondary canals are generally sedimented and covered with vegetation. The siltation interferes with drainage during the rainy season and causes land inundation. The existing condition of the collector channel on the right and handil on the left area is shown in Figure 2. Existing conditions at primary and secondary channels are shown in Figure 3.

![Collector channel on the right area](a) ![Handil on the left area](b)

Figure 2. Collector channel on the right area (a) and handil on the left area (b)

Most of the agricultural areas in the Palingkau SP1 SP2 SP3 Scheme are in the right handil area irrigated from the Kapuas Murung River. In the unit itself, the rice field area is only about 124.06 ha out of a total area of 4,124.45 ha, while in the left handil area it is a mixture of plantations and shrubs. The existing paddy fields in the network system are mostly located in the SP1 area and a little in the SP2 area, while in the SP3 area it is dominated by mixed plantations, shrubs, secondary crops, and oil palm. In the SP3 area, it was found that the productivity of watermelons was quite good. The local community's cropping pattern is once per year and uses local rice with average productivity of 1.145 tons/ha. It is related to the availability and quality of water because the influence of river tides on the network system is very small and rainfed rice fields. While in the agricultural area in handil, the effect of river tidal fluctuation still reaches the rice fields but is affected by toxic water drained from the network system behind it. The land use map in the Palingkau SP1 SP2 SP3 Scheme is shown in Figure 4.
Figure 4. Land use of Palingkau SP1, SP2, dan SP3 Scheme [2]

Figure 5. Depth of pyrit [2]
The survey results on the Palingkau SP1 SP2 SP3 Scheme [2] stated that most of the pyrite was found at a depth of less than 25 cm (63.82%) and a depth of 25 cm - 50 cm (32.61%) or can be categorized as shallow and moderate. At the same time, the rest are at deep depths (between 51 cm -100 cm) and very deep (more than 100 cm), with a percentage of 2.54% and 1.03%, respectively. The pyrite depth map of the Palingkau SP1 SP2 SP3 Scheme can be seen in Figure 5.

The peat soil depth survey stated that most of the area has shallow peat soil with a depth of less than 25 cm that is 77.06% of the total area in the scheme. It is classified in 19.89% of the medium category with a peat depth of 25 cm ~ 50 cm, 0.90% in the deep category (between 51 cm ~ 100 cm) and 2.15% in very deep (between 100 cm ~ 200 cm). Figure 6 shows the peat depth map in the Palingkau SP1 SP2 SP3 Scheme.

![Figure 6. Depth of peat.][2]

The pyrite depth and water quality data in the canal indicate that the reclamation of sulfuric acid soil has not been completed. It is a problem for irrigating rice fields on agricultural land.

2.1 Proposed Improvement

The process of reclamation of acid sulphate land can be carried out using chemicals, such as lime. However, it is expensive to do in large areas because it requires a large amount of lime. The use of organic soil amendments can improve soft soil in rice cultivation areas formed on sulfuric acid soil. That are by improving soil quality such as soil strength, organic matter content, hydraulic conductivity, pH, electrical conductivity, exchanged Ca2+, Mg2+, K+, and cation exchange capacity to a high range of soil stability index and productivity for rice cultivation [8]. Other possible and feasible efforts include groundwater level regulation, surface water flow regulation, and leaching [9]. Dent also said water management and regulation are the keys to managing acid sulphate soils [10]. The leaching of acidity and aluminium to rivers can be reduced by modern, controlled farmland drainage techniques [11]. They are keeping a reasonably high groundwater level or re-flooding a.s. soils have been shown to reduce
acidity and immobilize aluminium and other potentially toxic metals [12]. Rainfall is the only source of water for leaching; otherwise, irrigation is not available. It is used to improve the drainage system [13].

The leaching process is essential in managing acid sulphate soils, including the Palingkau SP1 SP2 SP3 Scheme problems. A good quality freshwater source with a pH value above 5 and sufficient quantity is needed to support the acid dilution process covering the area in the network system. The efficiency of reclamation measures is determined based on water management balances, including maximum pollution coefficients estimation [14]. In addition, rainwater is also another source of water that can be used in the leaching process. The amount of water required for leaching is about 1000 cm in 200 days or equivalent to 50 cm per day [9]. The need for water in this large area is quite tricky if only rely on rainwater, especially during the dry season. To overcome this problem, fresh water supply from the Kapuas River and Kapuas Murung River through existing handils to support the leaching process in the network system is needed. The Palingkau SP1 SP2 SP3 Scheme has an area of about 4,124.45 Ha, with a leaching water requirement of around 500 m3/Ha/day [9]. A water supply of approximately 2.06 million m3/day is required to support the leaching process. An improvement of the capacity of handils is probably one of the solutions. The effect of leaching can be significantly enhanced by land preparation and sun-drying [15]. Toxicities were removed faster, and water was used more efficiently.

2.2 Hydraulic simulation

The channel system is planned for drainage, irrigation, and leaching acid water resulting from the pyrite oxidation process (FeS2). The channel was designed based on extreme rainfall for a specific return period as a drainage network, and it is influenced by the drainage time during periods of low tide. As an irrigation network, the channel capacity must flow fresh water from the river at high tide. As a channel to support the reclamation process, the channel network must discharge acid water into the river at low tide and enter fresh water at high tide. A mathematical model HEC-RAS is used to simulate unsteady flow in designing the channel network. Hydraulic simulation with the HEC-RAS model was carried out to evaluate the ability of the existing network and rehabilitation efforts of the existing network to support the water circulation process in the scheme.

The Palingkau SP1, SP2, and SP3 schemes are swamp areas in the middle between the Kapuas River and the Kapuas Murung River. This swamp area is connected to the two rivers through the existing handil. The ebb and flow of the Kapuas River from one side and the ebb and flow of the Kapuas Murung River on the other side will meet at a dead point in the middle. If this happens, freshwater circulation to support the reclamation process will not occur. This hydraulic simulation examines the flow influenced by river tides at several points at the end of the handil that enters the SP1, SP2, and SP3 areas. Tidal forces that enter the system will affect the volume of water entering and leaving the collector to the river through the handil. It can be used to evaluate the effectiveness of the system to support the leaching process.

3. Results and discussion

Hydraulic simulation with the HEC RAS mathematical model was made based on topographic and hydrometric data from field surveys. Tidal data in the Kapuas and Kapuas Murung rivers were used as boundary conditions. The schematic of the mathematical model used can be seen in Figure 7. The mathematical model calculation shows that the water level in the downstream right handil ranges from -0.87 m to +0.85 m and from +0.1 m to +0.61 m upstream. There is excellent tidal damping, from a tidal difference of 1.60 m to 50 cm. In the upstream part, the water level elevation is strongly influenced by the condition of the existing handil profile, which is sedimented and covered by vegetation. Meanwhile, in the downstream area, which borders the Kapuas Murung river, the existing handil profile is still quite good. The right handil water level curve in the existing condition is shown in Figure 8.
Figure 7. The schematization of a mathematical model of Palingkau SP1 SP2 SP3

Figure 8. Water level fluctuation Right Handil (Existing condition)

From the existing conditions, it is known that there is a tidal damping effect on the handil. The peak tide attenuation in the middle of the handil is about 10 cm, while at the upstream is about 25 cm. This tidal attenuation significantly affects tidal water flow into the Sangatkau SP1 SP2 SP3 scheme's channel network. Efforts to normalize handil are carried out by digging sedimentation at the bottom of the handil. However, the normalization effort did not change the damping in the upstream part of the handil much. The graph of Handil's water level after the normalization effort can be seen in Figure 9.
Figure 9. Water level fluctuation Right Handil after normalization

Figure 10. The volume of water flowing through Right Handil existing condition.

The simulation is continued by calculating the volume of water that enters the handil. At the downstream of the right handil in the Kapuas Murung river, the volume of water flowing into the handil is 473.652 m³, and the water flowing out is 446.436 m³. While in the upstream part of the handil connected to the collector channel, the volume of water flowing in is 158.760 m³, and the water flowing out is 113.328 m³. The water volume curve for the existing handil can be seen in Figure 10. After normalization efforts have been carried out on the handil, the volume of water flowing in is 570.492 m³, and flowing out is 544.932 m³ in downstream. While the upstream, the volume of water flowing in is 194.688 m³, and the water flowing out is 142.992 m³. The curve of the volume of water flowing in the handil after normalization can be seen in Figure 11. The Efforts to normalize handil impact increasing the amount of water entering the handil, although not significantly. Furthermore, still not able to meet the water needs for the leaching process in the network system of 2.06 million m³/day. It is necessary
to increase the capacity of the channel to allow freshwater flow from the river for the leaching process in the network system. However, increasing the capacity by deepening the channel must be avoided, which will increase pyrite oxidation. Therefore, rainwater is the most reliable source of water to support the acid water leaching process.

4. Conclusions
The reclamation process of acid sulphate soil, both in the scheme and handil, requires reasonable water management efforts. The Palingkau SP1 SP2 SP3 scheme recommends remaining as rainfed rice fields with various cultivations, namely rice, secondary crops, or watermelons with good production. It is related to the tidal propagation of the river water as a source of irrigation and leaching that cannot reach into the system, only reaching the end of handils around 4-5 km from the river. The source of irrigation and leaching in that scheme comes from rainwater. It is necessary to rehabilitate the channel that functions as drainage to evacuate the excess water to prevent excessive inundation. In addition, it is necessary to build sluice gates in secondary channels to maintain the groundwater level during the dry season to prevent pyrite oxidation, which produces toxic materials. In the handil area, it is necessary to rehabilitate the channel to facilitate the flow of tidal water to reach upstream of handil. The rehabilitation of the embankments around the handil and the construction of sluice gates in the canals that regulate water for rice fields are efforts to reduce the spread of dissolved toxins at low tide. These efforts should be accompanied by good operation and maintenance because the reclamation process runs very slowly without good operation and maintenance.

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