Water management for increase rice production in the tidal swampland of Kalimantan, Indonesia: constraints, limitedness and opportunities

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Abstract. Water management is a key factor in the development of swampland for agriculture, especially rice. Naturally, swampland is affected by water tide from the sea or river during spring and neap tide. Micro water management greatly influences the success of farming in swampland. The functions of micro water management: improvement of land quality, leaching out of ions and toxic compounds, controlling of certain weeds and pests, plant growth and yield, and mitigating of climate change and greenhouse gas emissions. There are many factors influence the increasing rice production in swampland through improved water management. For example, the implementation of a one-way water flow system or a dam overflow system is restricted by tide strength, canal dimensions, and construction and operational of water gate. Support of water supply network infrastructure is important and influences land productivity and cropping intensity. In poor swamp irrigation areas (SIA), most farmers can only plant once a year (Cropping Index, CI= 100) with productivity 2-3 t ha-1. But in a good SIA, the yield reaches 6-7 t ha-1 and 2-3 planting times a year (CI 180-200). The implementation of water management in agriculture in swampland also requires the participation of farmers and solid institutional of water administrator. This paper is a review of several research results on the implementation of water management in tidal swampland that have been carried out by Indonesian Swampland Agricultural Research Institute (ISARI). This paper will address the constraints, limitations and opportunities of water management including an effort to mitigate and adapt to climate change through water management in tidal swampland of Kalimantan, Indonesia.

1. Introduction
Tidal swampland is the land where its water regime is affected by water tide from the sea or river. Based on the influence of the tides, tidal swampland can be divided into four types. Area with tidal type A is flooded by water tide during spring and neap tide, while area with tidal type B is flooded by water tide only during spring tide. These two types also known as direct tidal area. Area with tidal type C is not flooded by water tide but its ground water table is less than 50 cm depth, while area with tidal type D is not affected by water tide but its ground water table is more than 50 cm depth. Tidal types C and D are also called indirect tidal area and are often identified with freshwater swampland or rainfed rice field.

Based on the authority area and its infrastructure, water management as the key successes of swampland development is differentiated between macro and micro water management system [1]. Macro water management is under the authority of the Ministry of Public of Works and Housing which is mostly related to civil engineering. This water management includes management from primary, secondary to tertiary canals. Meanwhile, micro water management is mostly related to farming activities
such as rice field, which under the authority of the Ministry of Agriculture. Rice is a commodity that is widely cultivated in swampland because its growth requirements are in accordance with the potential of swampland.

Macro and micro water management should be implemented in an integrated management system because they are interconnected. If macro water management is poor, for example uncontrolled, water circulation does not work so that the soil and water conditions are acidic, micro water management will be affected, meaning that the acidic water is supplied into rice fields, then the rice production is less than optimal or even fails. However, if macro water management is good, but not properly regulated at micro level, for example inundated rice, then the yield will also not be optimal.

Therefore, the success of farming in swampland is greatly influenced by the micro water management. In concern to the production system, the objectives of micro water management include (1) improving land quality, (2) leaching out ions and toxic compounds, (3) controlling certain weeds and plant pests, (4) plant growth and yields, and (5) climate and greenhouse gas emissions control. Increasing rice production in swampland can be expected through improved water management. However, there are some important notes that need be considered in designing a water management system in swampland, including tidal capacity, construction and operation of water gates, and dimensions of the canals. Supporting water system network infrastructure in swampland is very important and affects land productivity and planting intensity.

In poor swamp irrigation area (SIA), most farmers can only plant once a year (CI 100) with a productivity of 2.0-3.5 t ha\(^{-1}\), but in a good SIA, farmers can plant twice a year (CI 180-200) or three times a year (CI 300) with yield of 5.0-7.0 t ha\(^{-1}\) using new high yielding varieties. The implementation of water management in agriculture in swampland also requires the participation of farmers and solid institutional of water administrator.

This paper will present a number of results of research and development of water management systems in swampland therewith the constraints, limitedness and opportunities as well as development strategies for increasing rice production in Kalimantan, Indonesia.

2. Swampland water management in perspective

Water management is the key success in converting swampland as a source of growth in rice production [2]. In the history of clearing swampland, the water management system applied by pioneer farmers was very simple and conventional. They make a small canal perpendicular to river (locally called *handil/tatah/ray*). The dimension of *handil* is 2-3 m in width with a depth of 0.5-1.0 m and a length of 2-3 km [3]. It is made by human labor in a mutual help (locally called *gotong royong*). This system, which has worked on with human labor, replaced with heavy equipment with a target area of clearing between 5,000-10,000 hectares as the management unit.

![Figure 1. Classification of tidal swampland based on the influence of tides](image-url)
Based on the coverage area and infrastructure, there are two water management systems, namely macro and micro water management systems. These two systems should be in one integrated management system. Micro water management system is based on four tidal types A, B, C and D (Figure 1). The following description describes water management, along with constraints, limitedness and opportunities in increasing land productivity and commodities, in this case is rice.

2.1. Constraints
Utilization of tidal swamp areas for agricultural development requires opening or reclamation in the form of making drainage canals to remove water from inundated or waterlogged swamp areas so that it can be used for planting. The purpose of this reclamation or drainage is in addition to making the soil moist or slightly dry, it is also to accelerate the ripening of the soil so that it is suitable for cultivation and operational requirements of agricultural machinery so that it does not collapse or sink. Furthermore, after the reclamation, the clearing and preparation of the land, as well as the forming of a rice fields, are carried out using heavy equipment such as excavators and tractor [3][4].

Beside its fragile or prone environment, agrophysical conditions including the physics, chemistry and biology of the soil properties of the swampland are the constraints in clearing and preparation of tidal swampland for agriculture. Since the physical properties of the soil are soft or mud soil, it is difficult for the agricultural machinery to operate and causing buildings to easily shift or collapse because some of the sand at the bottom can easily pass water. Soil chemical properties include high degree of acidity (pH 3-4); the presence of a layer of pyrite (FeS$_2$) and sand on the substratum which is a source of acidity; low status of macro nutrients such as N, P, K, Mg, Ca and micro nutrients as Cu, Zn, Mo, B; high salinity in areas infiltrated by sea water; thick peat layer (> 3 m) which is less fertile [3]. Therefore, farming in swampland requires proper water management technology and inputs such as fertilizers and ameliorants as needed.

2.2. Limitedness
In the development of swampland, the Ministry of Public of Works and Housing is the planner and manager of the macro water management system. This ministry has an authority to provide the construction of primary, secondary and tertiary canals, water gates, embankments and main roads. In reclamation, it known the phasing term. In Phase I, water-building structures are constructed simply, low cost construction and takes 7-14 years. Phase II, water-building structures made with permanent construction and other buildings built with temporary construction for 3-5 years. Whereas, phase III, all water-building structures built permanent. Overall, the time required for reclamation is 20-25 years from the initial conditions to the end with the increase in the standard of living of farmers [4].

In the new paradigm, swamp areas were opened to be irrigated and conserved, in contrast to the old paradigm which tended to be drained [5]. The principle that needs to be considered is to prevent over-drainage which causes irreversible drying and subsidence [5]. In practice, it is difficult to avoid it to keep swamplands always wet/fresh or inundated without gates or dam overflow at the respective secondary and/or tertiary canal estuaries. Moreover, for peatlands, drainage can change the nature of the peat, which initially hydrophilic turn into hydrophobic when it is dry. According to Furukawa [6] to maintain reductive conditions so that the soil is always wet/fresh, it is necessary to construct water gates and dam overflow before digging the canals.

Based on the description above, it can be concluded that the reclamation system and its water network system both in terms of time and management system need to be improved so that swampland can actually be developed into a source of future rice production or food barn. Supporting water infrastructure in water management is the key to the successful development of food crop cultivation, particularly rice in swampland.

2.3. Opportunity
Utilization of tidal swampland by local communities for agriculture that had been done previously since a long time is a long history that proves the potential and opportunities of tidal swampland as potential
production land. The capacity and ability of farmers in dealing with tidal swampland constraints is an interesting experience, especially in the cultivation of food crops and horticulture. Based on experience, local wisdom and the success of this community, the government cleared up tidal swampland for wider agricultural development for the community, including transmigrants. Recently, the Government has launched a food estate area in the swampland of Central Kalimantan to anticipate the food crisis due to the impact of the Covid 19 pandemic, which cannot be predicted when it will end. Meanwhile world food-supply countries will prioritize meeting their domestic needs rather than exports [7]. Subagio et al. [2] and Sulaiman et al. [8] showed that in the future swampland will become a food security and opportunity as a source of growth for new world food production.

The advantages of developing swampland as a source of growth in food production include: (1) abundant water availability due to its intertwining with rivers and high rainfall; (2) the topography is relatively flat and has a few basins so that the land clearing and forming costs for rice fields are easier and cheaper; its topography allowing rice production in the wet season and moisture retention for dry season crop; (3) it does not require large-scale displacement or eviction of the population such as bedol desa because of the availability of land in the form of stretch and ease of land ownership (4) some areas already have a water system network (SIA) and also have local wisdom for agriculture so that agricultural activities do not starting at zero, but continuing with the existing one; and (5) adaptive to climate change, especially local varieties of rice, because of its harvest time is on July-August so that it fills the supply gap for Java Island, which is generally in short supply.

In addition to the advantages of swampland above, based on the developing socio-culture and politics, Indonesia has an opportunity to become a world food importer because it is supported by strategic conditions, including: (1) tropical climate with rainfall 2000-4000 mm/year so that it allows opportunities for planting seasons 2 up to 3 times a year; (2) swampland area is 34.12 million hectares. An area of 9-10 million hectares has a potential for agriculture. From this area, 1.2 million hectares were recently cleared by the government and 3.0 million hectares by the community for food crops and 5 million hectares for plantation crops. This indicates that there are still land resources can be developed as food crops areas; and (3) as an agricultural country, Indonesia has a strong agrarian culture and local cultural wisdom in agriculture.

However, the success of agricultural development still depends on the availability of improved technology, good interaction of the external supporting system, such as infrastructures or institution and production input, farmers participation and government policy or action program.

3. Implementation of water management system in swampland

The water management system that meant is the water management system at rice field or micro water management system. The water management system at farmer level is still conventional, which called a two-way water flow system. Network infrastructure and water gates are required in the application of a one-way water flow system. Water management system at micro level based on tidal type. A one-way water flow system can be applied in type A and B, while in type C and D with dam overflow system.

In addition to infrastructure support, farmers in swamplands do not fully understand the advantages of a one-way over a two-way water flow system. In this case an extension and demonstration plot in the field needed. Hereinafter, it will described the results of research and implementation of the water management system in tidal swampland.

3.1. One-way versus two-way water flow systems

A one-way water flow system is a development of the two-way water flow system applied by farmers in the handil system. Handil is a small canal made gradually by farmers using human power with a dimension of 2-3 m width and 0.5-1.0 m depth with a position jutting in 2-3 km from the mouth of a large river/tributary/secondary canal. Handil has a function of flowing water when it is high tide and draining it when it is low [3].

Most of farmers used two-way water flow system. Water enters from secondary to tertiary or tertiary to the quarter through the canal (ray) at high tide and returns back to exit in the same tertiary / quaternary
canal at low tide so that water flows back or forth on the canal. The result is the accumulation of toxins such as Fe, H₂S, organic acids in the canal. The quality of water and soil changes to be more acidic and high levels of toxins which results in low rice yields.

**Figure 2.** Sketch of a one-way water flow system in types A and B in Sumatra [9]

In one-way water flow system (Figure 2) there is intensive flashing and leaching resulting in an increase in water pH followed by an increase in rice yield. This suggests that water management with a one-way water flow system is better because it can improve soil and water quality, thereby increasing rice yields (Table 1 and Table 2).

**Table 1.** Effect of flow systems on drainage water quality and rice yield, Tatas Unit, Kapuas regency, Central Kalimantan.

| Water quality and rice yield | One-way flow system | Two-way flow system |
|-----------------------------|---------------------|---------------------|
| pH                          | 3.32-3.66           | 3.63                |
| Fe-dissolved (me l⁻¹)       | 0.40-0.78           | 0.83                |
| SO₄-dissolved (me l⁻¹)      | 0.76-2.18           | 3.60                |
| Al-dissolved (me l⁻¹)       | 0.36-0.58           | 0.94                |
| Mg-dissolved (me l⁻¹)       | 0.25-0.55           | 0.84                |
| Rice yield (t ha⁻¹)⁷)       | 2.80-3.14           | 1.26-1.43           |

⁷) No lime, no puddling, fertilizer: 90 kg N, 60 kg P₂O₅ and 60 K₂O ha⁻¹

Source: [10][11]

**Table 2.** Effect of flow systems on soil chemical properties and rice yield. Karang Agung Tengah Unit, South Sumatra

| Soil chemical properties and rice yield | One-way flow system | Two-way flow system |
|----------------------------------------|---------------------|---------------------|
| pH                                     | 5.59                | 4.33                |
| Fe-dissolved (ppm)                     | 23.67               | 31.00               |
| EC (mmhos cm⁻¹)                        | 159.20              | 231.00              |
| Rice yield (t ha⁻¹)                    | 5.59                | 2.39                |

Source: [9]
3.2. Water management infrastructure support
The implementation of a one-way water flow system in types A and/or B requires infrastructure support, namely connected canals and water gates in the tertiary inlet and outlet, respectively (Figure 3). In addition, a water pump is also needed, especially in a relatively high area, which functions to supply water from the tertiary canal to rice field and drain water from the field if there is an excess water.

Figure 3. Fiberglass stoplog in the tertiary/quaternary canal (left) and flap gate in the tertiary canal (photos by Edy H./DIR Rawa and M. Noor/Balittra).

In the dry season, the tertiary canal can be used as a long storage, so that dam overflow and a water pump are needed for filling the canal. Elbow systems can be built on relatively high land types C or B to facilitate water conservation during the rainy season for reserves in the dry season (Figure 4). The advantage of the elbow system is that if the elbow pipe is straightened, the water from the inside cannot come out so that the water automatically does not come out as long as the elbow pipe is upright. To lower the water level, the elbow pipe is lowered as needed.

Figure 4. Ironwood dam overflow (left) and concrete with an elbow system on type C (photos by M. Noor/Balittra).

3.3. Participation and institutional of farmer
Most of the water management practices in swampland still rely on the participation of farmers because they are still conventional and manual. The opening and closing of the water gates was still operated with human power. The tide and neap movements take place following the cycle of the moon’s movement so that the spring tide during the full moon on every 13 to 15 or dead moon every 1st to 3rd with unfixed time or hour of the tide. As the reason, sensor and digital-based water gate operations (internet of thing) are required in the practice of water management in the future.
Water management in swampland cannot be carried out partially because of the linkages between locations and other locations so that it can be based on the water management unit. Most of the swampland developed for agriculture are equipped with irrigation systems in the form of secondary, tertiary and quaternary canals, so that water management involves many farmers or farmer groups.

The role of the Water User Farmer Association (P3A) needs to be involved in water management operations such as the farmers group (Poktan) or the farmer group association (Gapoktan). Therefore, strengthening P3A in swampland is very important in order to improve the performance of water management in swampland [12].

3.4. Mitigating and adapting to climate change
Climate change and global warming due to increasing greenhouse gas emissions (GHG), i.e. CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O require prevention. Mitigation and adaptation efforts is needed to control climate change. These efforts are closely related to agricultural development. For example, agricultural development in tidal swampland, in this case peatlands, will be controversial, meaning that it can increase CO\textsubscript{2} emissions by trigger peat decompose. However, on the other hand, the existence of plants covering peatlands becomes a CO\textsubscript{2} sequestration, so caution is needed, for example by adjusting the surface water level and ground water not deeper so as to prevent peat decompose and excessive CO\textsubscript{2} emissions [13]. The deeper the groundwater level (35-80 cm) showed higher CO\textsubscript{2} emission than the shallow groundwater level (10-15 cm) [13].

GHG in the form of CH\textsubscript{4} and N\textsubscript{2}O are mainly generated in an inundation condition such as in rice field. The results of Hadi et al. [14] showed that CH\textsubscript{4} and N\textsubscript{2}O emissions were influenced by the tidal type. Tidal type A showed the highest CH\textsubscript{4} emissions. CH\textsubscript{4} emissions have a positive correlation with groundwater content. Intermittent irrigation in rice field cultivation can reduce CH\textsubscript{4} and N\textsubscript{2}O emission levels [14]. These results indicate that the role of water management is very important in mitigating greenhouse gas emissions.

4. Conclusion
Water management in swampland has an important role, among others, for improving land quality, leaching of ions and toxic compounds, controlling weeds and certain plant pests, increasing crop yields, as well as controlling climate and emission of carbon dioxide or other greenhouse gases emissions. Water management is faced with several constraints, namely the physical properties of soft soil, layers of pyrite and sand on shallow substratum (<50 cm), thick and/or raw peat, and intrusion of sea water. The limitation of water management to apply the new paradigm, namely improved irrigation and conservation, is different from the old paradigm which tends to improve drainage. Swamplands have an opportunity as a source of food growth due to its several advantages in terms of water, costs for opening and forming rice fields, land resources, history and local wisdom.

The one-way water flow system has an advantage over the two-way water flow system because in the one-way water flow system there is intensive flushing and leaching followed by an increase in rice yield. Implementing a management system requires adequate infrastructure support, farmer participation, and good institutions in developing a water management system in swampland.

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