Chapter 9
Water Management for Integrated Peatland Restoration in Pulau Tebing Tinggi PHU, Riau

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Abstract Water management is an important aspect for hydrological restoration in the tropical peatland because the availability of water is not evenly distributed in the dry and rainy seasons. The aim of this study was to conduct action research focusing on water management for integrated peatland restoration at Pulau Tebing Tinggi Peatland Hydrological Unit (PHU), Riau, Indonesia. The actions were to implement some research results and findings by developing demo-plots for a pilot project and analyzing their impact. The pilot project for water management was developed at Pulau Tebing Tinggi PHU not only for the purpose of peat rewetting, but also to support revegetation efforts and revitalization of livelihood. Pulau Tebing Tinggi PHU, located in Kepulauan Meranti Regency, Riau Province, is susceptible to peat fires. In 2014, big peat fires occurred in Pulau Tebing Tinggi PHU and several peatland areas in Riau, causing a haze disaster that lasted for about 2 months. The

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disaster produced a sickening and deadly cloud of smoky pollution that not only threatened Indonesia but also neighboring countries.

The Thornthwaite-Mather water balance (TMWB) model was applied for water balance analysis as a basis for water management in the research site. A masterplan for water management was developed which was integrated with revegetation and revitalization of livelihood approaches. Canal block constructions, paludiculture, and aquaculture were the integrated activities carried out to support peatland restoration. Two types of canal blocks, whose main materials were wood and vinyl sheet pile, were introduced in this pilot project. Four key parameters of peatland restoration progress were monitored periodically, namely water table, land subsidence, CO_2 emissions, and vegetation growth. This research found that by applying water management properly, the water table can be maintained at a stable and high level in wet peatlands. Water management by applying canal blocking has a good impact for keeping groundwater elevation and keeping peatland in a wet condition for a distance of 400 m upstream from the canal block.

Keywords Water management · Hydrological restoration · Tropical peatland

9.1 Introduction

Peatlands are wetland ecosystems that are characterized by the accumulation of organic matter called “peat,” which is derived from dead and decaying plant material under high water saturation conditions (Parish et al. 2008). Peatland ecosystems are the most efficient carbon sinks on the planet because peatland plants capture the CO_2 naturally released from the peat, maintaining a balance. It was found that peatland only covers 3% of the area of the world, but they store about 15–30% of the world’s carbon in the form of peat or organic matter (Hugron et al. 2013). Peatlands are a type of wetland that are one of the most valuable ecosystems on Earth. They are critical to conserve global biodiversity, provide safe drinking water, minimize flood risk, and help address climate change. Peatlands are adapted to the extreme conditions of high water and low oxygen content, of toxic elements, and low availability of plant nutrients (Joosten and Clarke 2002). Peatlands have today become a global topic in relation to a raft of environmental issues that include land fires, declining massive ecosystem functions, and increasing carbon emissions (Sabiham et al. 2016). Peatland fires are hard to extinguish because these occur below the surface, and thus can only be put out by rain or artificial rain using weather modification technology (Sandhyavitri et al. 2018; Sutikno et al. 2020b).

Indonesia holds the largest tropical peatland area, comprising approximately 50% of world’s total tropical peatlands. The tropical peatland area in Indonesia is estimated at about 14.91 million ha, spread over Sumatra Island, 6.44 million ha (43%); Kalimantan Island, 4.78 million ha (32%); and 3.69 million ha (25%) in Papua Island (Osaki et al. 2016). Recently, most of those peatlands have already been cleared and drained for food crops and cash crops such as palm oil and other plantations. However, large-scale drainage of peatlands for those purposes has often generated major problems of subsidence, fire, flooding, and deterioration in soil quality (Adesiji et al. 2015; Putra et al. 2016; Ritzema 2008). The Indonesian government, through the Peatland and Mangrove Restoration Agency (Badan Restorasi Gambut dan Mangrove, BRGM) and stakeholders, has been continuously undertaking restoration and fire prevention efforts on those degraded peatlands.

A key factor in tropical peatland restoration is always keeping the peat wet (Giesen and Sari 2018). Hence water management is an important aspect for hydrological restoration in tropical peatlands because the availability of water is not evenly distributed in the dry and rainy seasons. The aim of this study was to conduct action research focusing on water management for integrated peatland restoration at Pulau Tebing Tinggi Peatland Hydrological Unit (PHU), Riau, Indonesia. Action research in this study means that the research was followed by some actions to implement research results and findings by developing some demo-plots for a pilot project. The pilot project for water management at Pulau Tebing Tinggi PHU was aimed not just at peat rewetting but also at supporting revegetation and livelihood revitalization. Pulau Tebing Tinggi PHU, located in Kepulauan Meranti Regency, Riau Province, is at high risk from peat fires.

Canal block constructions, paludiculture, and aquaculture were the integrated activities carried out to support the restoration. Two types of canal blocks, made out of wood and vinyl sheet pile, were introduced in this pilot project. To investigate the performance of the canal blocks, some monitoring and measurement activities are underway, i.e., monitoring and measurement of water table elevation and velocity, land subsidence, and vegetation growth surrounding the canal blocks.

9.2 Methodology

9.2.1 Study Area

The study area is in the island of Tebing Tinggi, Kepulauan Meranti Regency, Riau Province, Indonesia. Based on hydrological assessments, this study found three villages on high priority for hydrological restoration at Pulau Tebing Tinggi PHU, Riau Province, namely, the villages of Tanjung Peranap, Lukun, and Tanjung Sari, as shown in Fig. 9.1. Those villages and many peatland areas in Riau suffered big peat fires in 2014, which caused a haze disaster that lasted nearly 2 months and affected not just Indonesia but neighboring countries as well. Figure 9.1 shows the several hotspots in those villages. This disaster produced a sickening and deadly cloud of smoky pollution which not only threatened the nation but also neighboring countries. Therefore, this action research picked two villages, Lukun and Tanjung Sari, as pilot project areas for the water management model in the tropical peatlands. These villages have different sources of livelihood: the villagers of Tanjung Sari mostly cultivate coconut plantations, while Lukun's economy is mostly based on sago and rubber plantations. This difference will certainly affect the water management system for peatland restoration associated with the dominant land uses in both

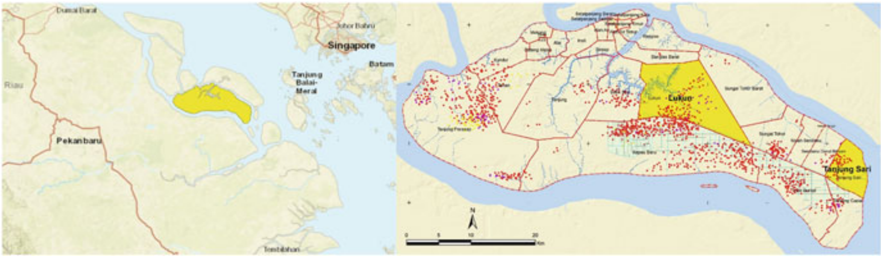

Fig. 9.1 The study area of this action research and the historical fires

villages. Lukun's sago-dominant land use is excellent for a wet environment so there is synergy with the rewetting aspect of peatland restoration. On the other hand, Tanjung Sari, with a coconut-dominant land use, should be cautious with water management because the groundwater elevation should be optimally positioned.

9.2.2 The Peatland of Pulau Tebing Tinggi PHU

Tebing Tinggi Island is dominated by peatlands, whose area is estimated at more than 80% of the island. The peat thickness varies from 1 m to 11 m and forms several peat domes. Based on a field survey, it was found that there are three main peat domes at Pulau Tebing Tinggi PHU as shown in Fig. 9.2 (Nasrul et al. 2020). This study found that the topography of the peat landscape does not reflect peat thickness at Pulau Tebing Tinggi PHU. At this location, high-thickness peat can be found at the edges of the peat dome if it is above a basin or valley in the substratum, while thinner peat can be found in the center if there are mounds in the substratum. Another important finding from this study is that the shape of the peat surface and the substrate surface is not the same; a flat peatland surface may have an undulating substrate and vice versa.

The Ministry of Environment and Forestry has divided the peat domes on the island into three zones, namely, Zone-1, which is located in the Tebing Tinggi Barat Sub-District; and Zone-2 and Zone-3 in the Tebing Tinggi Timur Sub-District, in the middle and east areas, respectively (KLHK 2017). For more detailed hydrological analysis, this study divided Pulau Tebing Tinggi PHU into five sub-PHU which have separate hydrological systems (Fig. 9.3). The sub-PHU division was based on spatial analysis of topographic data, canal networks, and peat depth. Those sub-PHUs are Sub-PHU-1, Sub-PHU-2, Sub-PHU-3, Sub-PHU-4, and Sub-PHU-5, with the area about 41,294 ha (35.8%), 21,840 ha (18.9%), 4230 ha (3.7%), 34,099 ha (29.6%), and 13,864 ha (12%), respectively (Sutikno et al. 2020a).

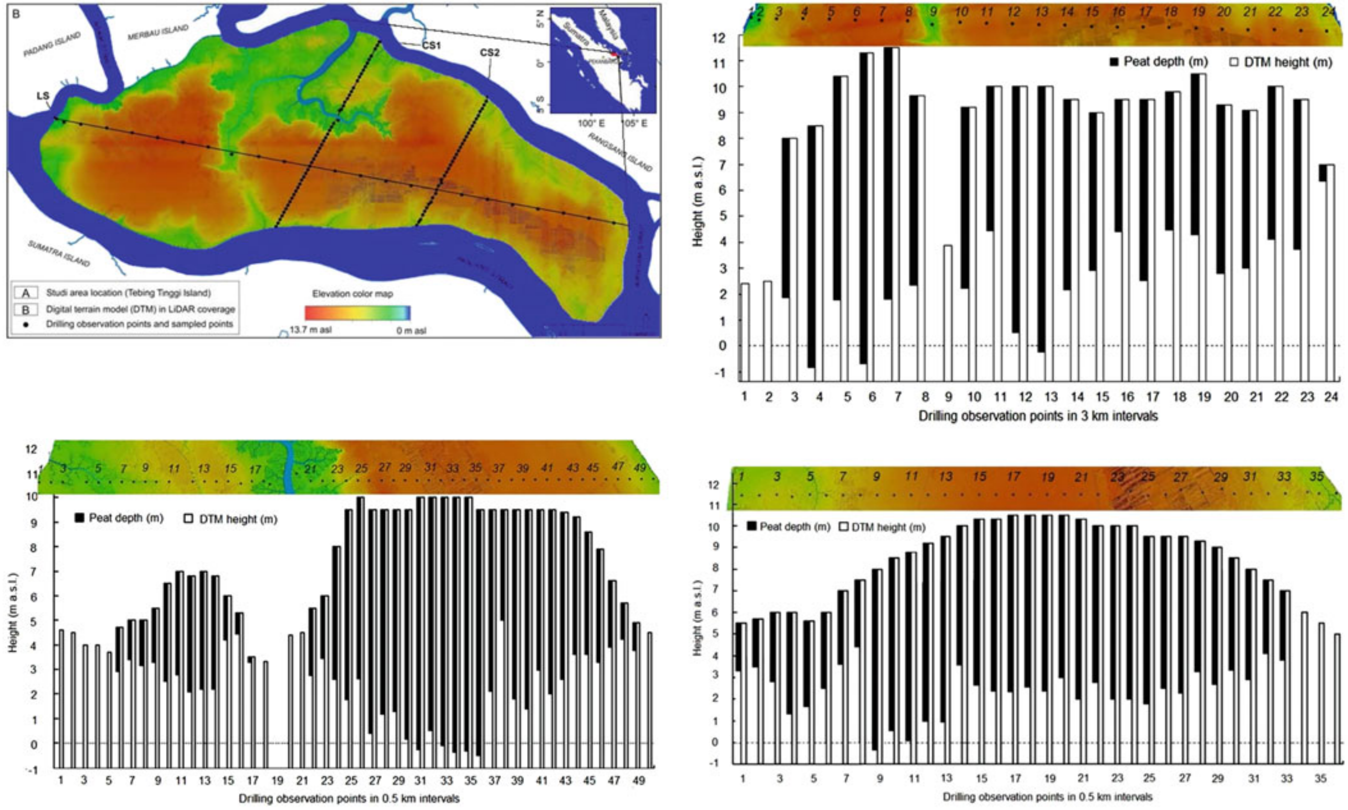

Fig. 9.2 The spatial distribution of peatland thickness in Pulau Tebing Tinggi PHU, and its correlation with the topography of the peat landscape (Reprinted from Nasrul et al. 2020)

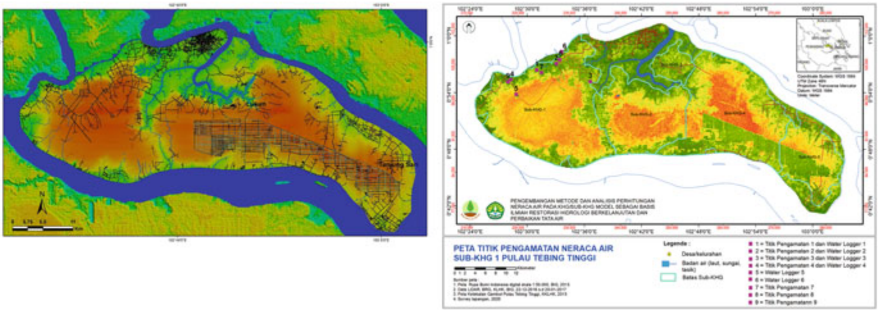

Fig. 9.3 Peat dome zones and the sub-PHU division at Pulau Tebing Tinggi PHU (Gunawan and Budi Triadi 2020)

9.2.3 Peatland Degradation Status

Most of the peatlands in Pulau Tebing Tinggi PHU have been degraded because of the loss of water—which has been directed to plantations—and fires in the last several years. The peatland degradation status in Pulau Tebing Tinggi PHU was analyzed using Landsat Satellite Imagery 8 Operational Land Imager (acquisition date, 26 June 2016), which consists of 11 bands. Figure 9.4 shows the result of the peatland degradation analysis of Pulau Tebing Tinggi PHU. The remaining primary peat swamp forest is only 31% of the original forest area, while the rest of the original forest has been used and degraded as burn scars, disturbed/regrowth peat swamp forest, and agriculture mosaic as shown in Table 9.1 (Sutikno et al. 2020a).

9.2.4 Thornthwaite Water Balance Model for Water Management

This study applied the Thornthwaite-Mather water balance (TMWB) model in Pulau Tebing Tinggi Peatland Hydrological Unit (PHU), Riau Province, Indonesia to analyze the water balance for water management on degraded peatlands. The data required for analysis were monthly rainfall and temperature, land use, degree of peat decomposition, and the latitude of the location. Using the estimated day length based on latitude and month, as well as temperature, the monthly potential evapotranspiration (PET) was estimated. Actual evapotranspiration (ET) will be equal to PET if there is sufficient rainfall (P) and soil moisture, otherwise, Hamon's method is used to estimate ET from PET. When the quantity of P exceeds PET, then the water will enter the soil moisture storage. After the field capacity of the soil is exceeded, the excess becomes runoff. The remaining water in soil moisture storage at the end of the month is carried over to the following month. The general formula of the water balance for the peatland is as follows.

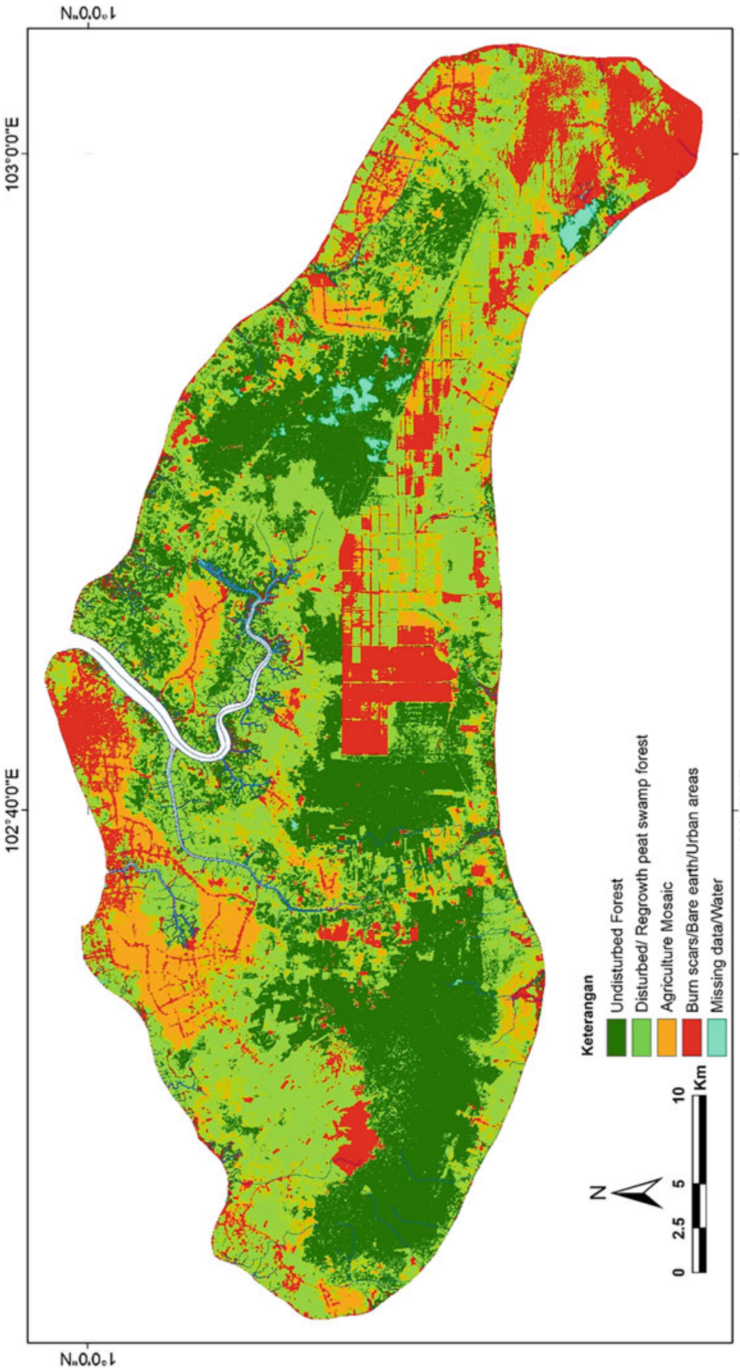

Fig. 9.4 Peatland degradation area in Pulau Tebing Tinggi PHU (Sutikno et al. 2020a)

Table 9.1 The status of peatland degradation in Pulau Tebing Tinggi PHU (Sutikno et al. 2020a)

No	Land cover type	Area (ha)	Percentage (%)
1	Primary peat swamp forest (PSF)	41,378	31
2	Disturbed/regrowth PSF	56,889	43
3	Agriculture mosaic	14,554	11
4	Burn scars	18,091	14
5	Missing data/water	1286	1
Total		132,198	

$$\pm \Delta \mathrm{S} = \mathrm{Input} - \mathrm{Output} \tag{9.1}$$

where, ΔS is an addition or reduction to the existing storage in the peat dome.

Analysis of water balance spatially and temporally in peatlands is important to determine the water quantity in spatial and time series. With the water balance analysis, the time (months) and the amount (volume) of surplus or deficit of water in a study area can be understood. The status of “surplus” and “deficit” in a peatland area as a result of water balance analysis is very important to know in order to design the water management program.

9.3 Results and Discussion

9.3.1 The Basic Concept of Water Management

Always keeping the peat wet in tropical degraded peatland requires the proper application of a water management system that is developed based on the water balance characteristics of the study area. Water balance is an estimation of the amount of water in a system based on the hydrologic cycle which consists of water input from precipitation and output from evapotranspiration, outflow, and seepage. The water balance analysis can determine the time (months) and the amount (volume) of surplus and deficit of water in a study area. Thus, it can be calculated whether the excess water can be used to cover the deficit in the dry season. Alternative methods for storing and managing excess water in the rainy season can be applied to keep peat wet in the dry season by keeping the groundwater level (GWL) high.

Figure 9.5 shows the water balance condition of Sub-PHU-1 Pulau Tebing Tinggi in 2019 as results of the TMWB model simulation. It clearly shows that in the dry season, particularly January–February and June–September, that the rainfall was limited. The water balance in these months was a deficit which means the water input was less than the water output. This condition caused the groundwater level to decrease and made the peatland became dry. On the other hand, in the rainy season, particularly in October–December and March–May, the water balance was a surplus which means the water input was more than the water output. The excess water in the

Fig. 9.5 The monthly water balance in Sub-PHU-1 of Pulau Tebing Tinggi (Gunawan and Budi Triadi 2020)

PHU flows into canals and rivers and eventually empties into the sea. However, in order to mitigate the water deficit in the dry season, that excess water should be managed and stored optimally to wet the peatlands in the dry season.

The basic concept of water management in tropical peatlands is to store as much water as possible and for as long as possible in the peatlands while water from the rains (without any flooding) continues to wet the peatlands in the dry season. The water is expected to be stored in the peat dome, which functions as a peatland reservoir, as presented in Fig. 9.6. Water that flows from the peat dome through canals is stopped by a series of blocks along the canal to reduce its velocity and to store it in the canals. The stored water is supposed to infiltrate horizontally to the peatlands so that they are always kept wet. Finally, excess water is drained into the sea to prevent flooding.

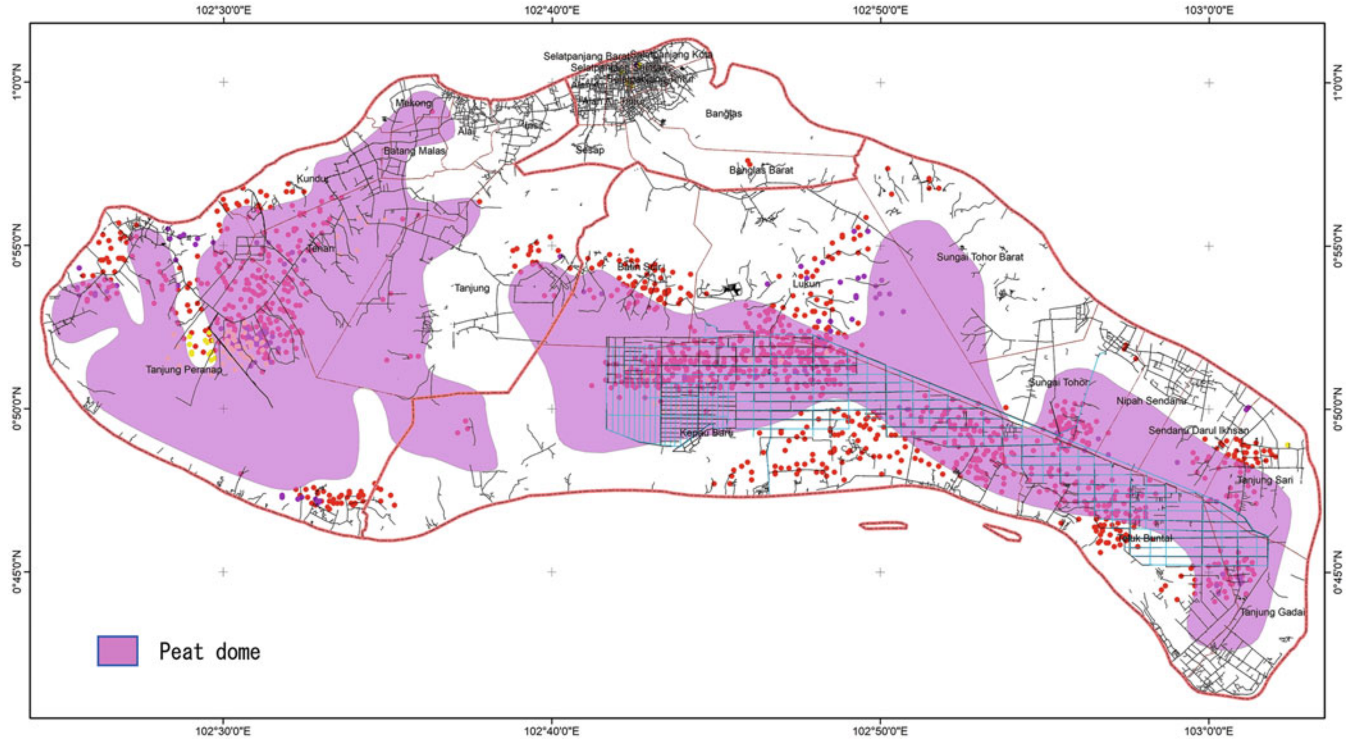

Fig. 9.6 Peat dome as a water reservoir in Pulau Tebing Tinggi PHU (KLHK 2017)

9.3.2 Masterplan for Water Management

A masterplan for water management in Lukun was developed based on a participatory approach together with the local community using spatial data and water balance of the study site. Generally, the masterplan was divided into two zones (Fig. 9.7), i.e., (a) Zone I, where the area is prioritized for peat rewetting and for supporting paludiculture and fishing ponds cultivated by local residents; and (b) Zone II, where the area is prioritized for peat rewetting and fire prevention.

Zone I has been utilized for various economic activities by the local community of Lukun, e.g., developing fishponds in the peat swamp, paludiculture, and other economic activities. Zone II, where much of the fire occurred in 2014, was prioritized for peat rewetting and peatland fire prevention. However, there is a possibility that this zone could be developed for economic activities, such as aquaculture along the canal when the canal block is built.

The masterplan for water management of Tanjung Sari was also developed based on a participatory approach together with the local community. Water management through the construction of a canal block in Tanjung Sari was prioritized to control water allocation for paddy field activities in downstream areas as well as for peat rewetting in upstream areas, as presented in Fig. 9.8. At the moment, paddy fields are being planted in the first phase of planting since these had been developed on the back of water availability. Overall, the masterplan for water management in Tanjung Sari consists of six canal blocks, which are made of vinyl sheet pile, and three areas for paludiculture.

9.3.3 Implementation of Water Management

Peatland restoration efforts in Indonesia involve local communities because these are the main actors in both protecting and damaging peatlands. In addition, peatland restoration efforts are not carried out overnight; rather, it is a continuous process with a long view. As such, local communities play a very important role in the success of peatland restoration efforts. Based on these considerations, the canal blocks for water management should be designed as simply as possible so they could be built by the local community as needed. Also, the material for the canal block model should be locally available. However, the canal block model must function optimally in order to ensure the availability of water to wet the peatlands even in the dry season, to irrigate fishponds and ricefields, and to prevent flooding. For those purposes, the canal block designed for Lukun used wood as shown in Fig. 9.9, and one using vinyl sheet pile was designed for Tanjung Sari as shown in Fig. 9.10.

The canal block model in Lukun uses locally sourced wood that is lightweight, easily available, and inexpensive. The model as designed and as built is presented in Fig. 9.9. The model is equipped with a sluice gate for flexibility and to maintain water levels in the canal during both the rainy and dry seasons. In the rainy season,

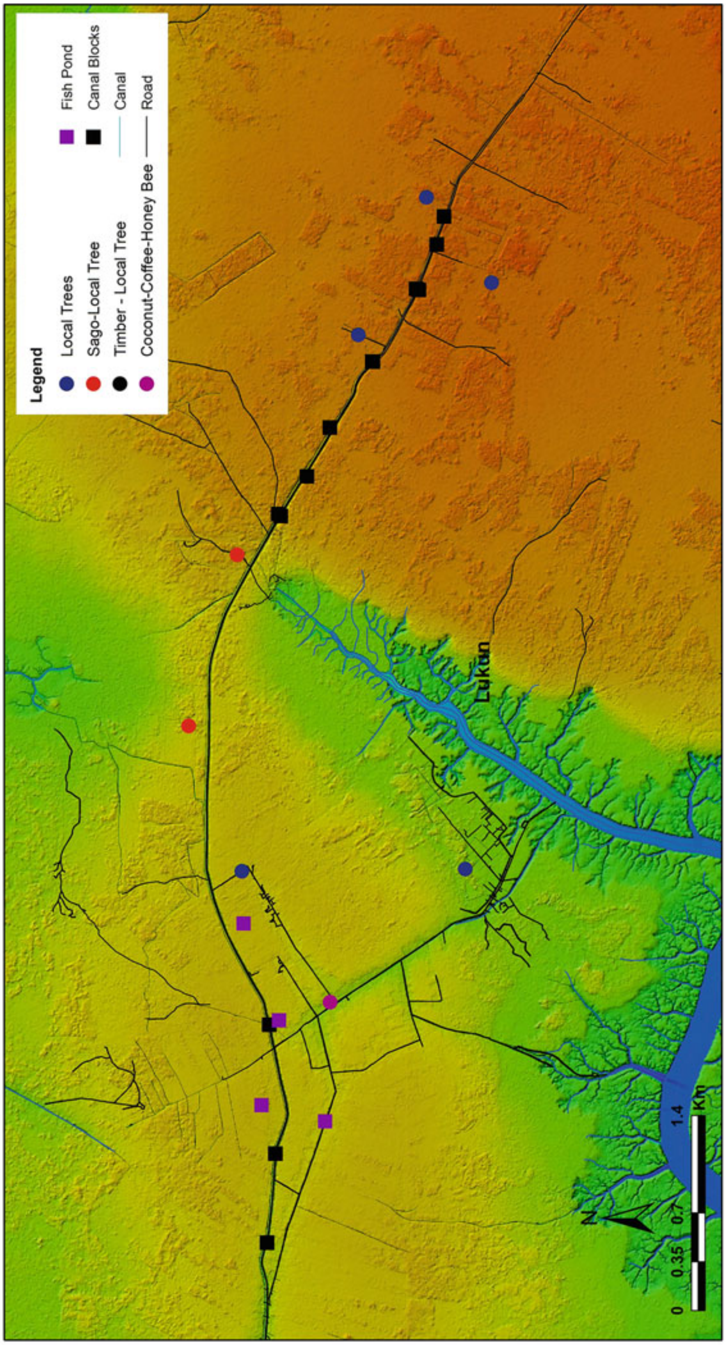

Fig. 9.7 Masterplan for water management in Lukun

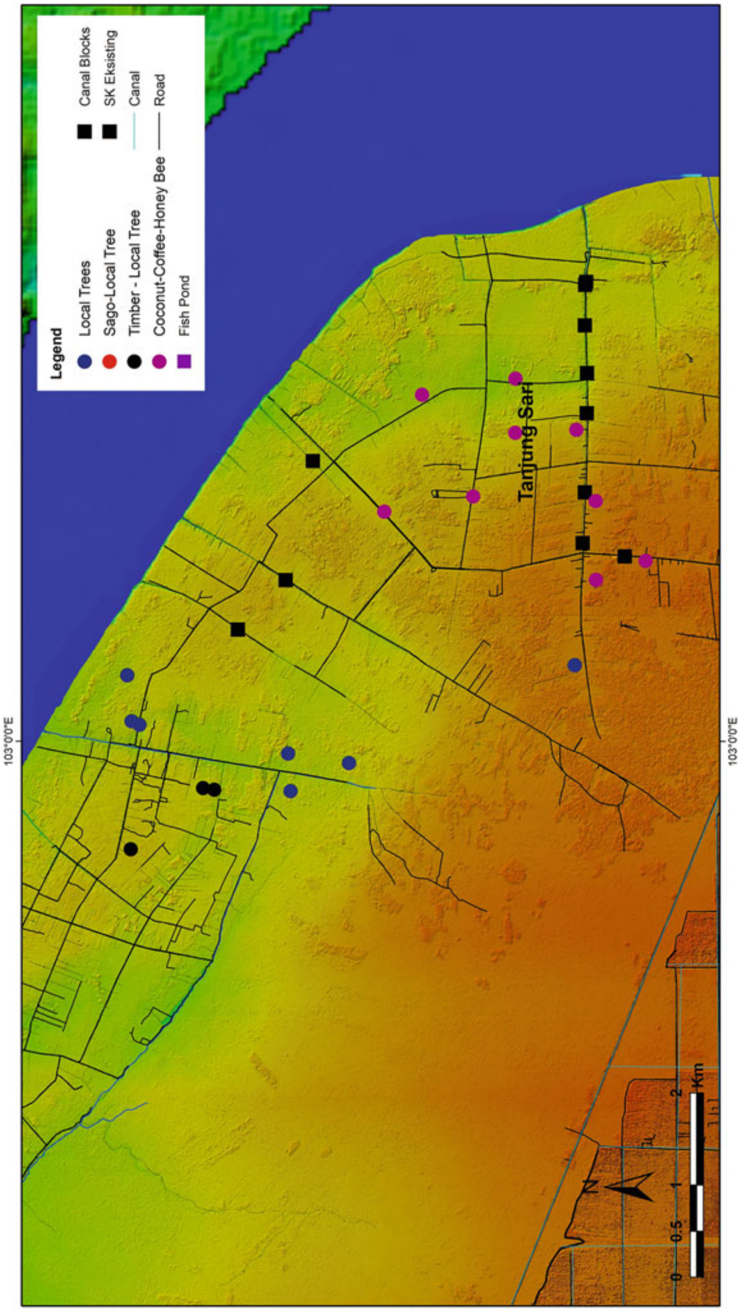

Fig. 9.8 Masterplan for water management in Tanjung Sari

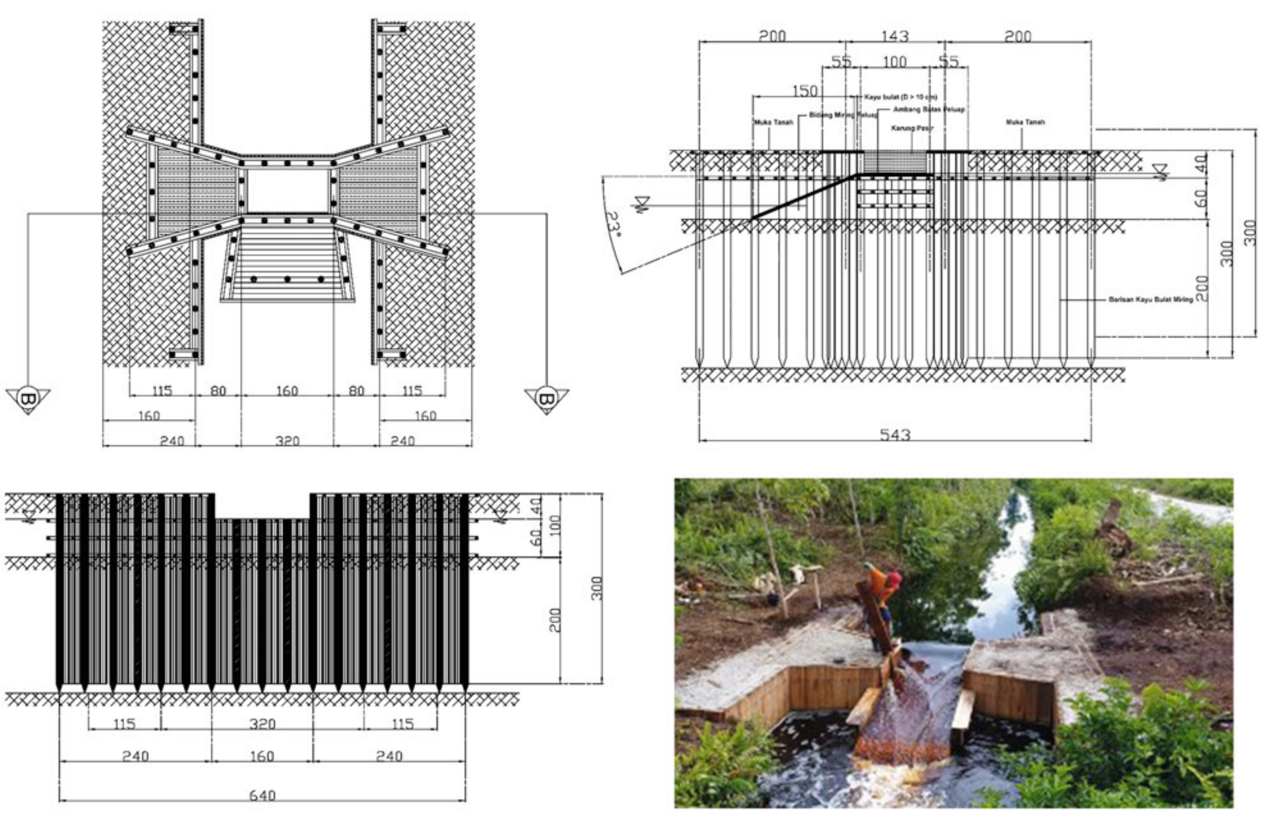

Fig. 9.9 Canal block model for water management in Lukun

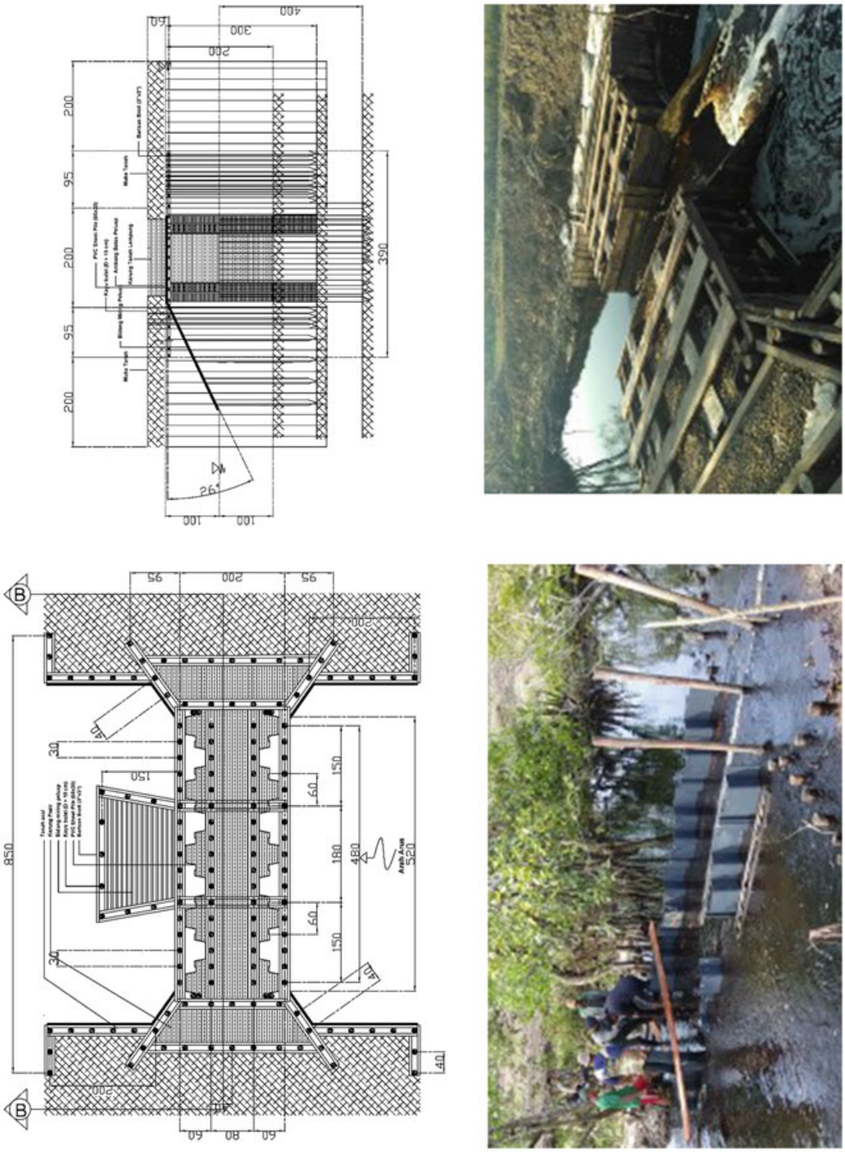

Fig. 9.10 Canal block model for water management in Tanjung Sari

the canal blocks are opened to prevent flooding, and in the dry season the canal blocks are closed to keep the peatlands wet. The canal block is also built with a spillway to prevent turbulence that could cause erosion and affect its structural stability. The local community has adopted the masterplan, building seven canal blocks since 2017.

The canal block model in Tanjung Sari uses vinyl sheet pile, as shown in Fig. 9.10. This material replaces wood, which is quite limited in the area, and works best with the high tide. The vinyl sheet pile has two layers, with the option for a filler material for greater stability. It is also equipped with a sluice gate for flexibility and to maintain water levels in the canal during both the rainy and dry seasons. This canal block model has been constructed in Tanjung Sari.

9.3.4 Monitoring the Progress of Restoration Efforts

Efforts to restore peatlands to their near-natural conditions require a long-term process. Therefore, the progress of the peatland restoration should be monitored periodically. We applied four methods to monitor the four key parameters of the peatland restoration efforts, namely, water table, land subsidence, CO_2 emissions, and vegetation growth. The water table has been monitored periodically using SP-MATRIKLAGA (Monitoring Dipwell for Groundwater Table and Fire Risk at Peatland), equipment developed by the University of Riau which uses water loggers. The equipment also uses a floating system that can determine the groundwater depth and the level of fire risk directly from the instrument as presented in Fig. 9.11a. Through this equipment, the impact of canal blocking on rewetting in the peatland can be analyzed. Land subsidence is monitored periodically every year using a fixed reference fix pole as shown in Fig. 9.11b. Nine subsidence pole were installed in Pulau Tebing Tinggi PHU, which are monitored every year. The CO_2 emissions are measured with an environmental gas monitor (EGM) chamber in a closed dynamic chamber as shown in Fig. 9.11c, and vegetation growth is measured periodically using an Unmanned Aerial Vehicle (UAV) as shown in Fig. 9.11d.

9.3.5 Impact of Water Management

This section presents the impact of implementing the masterplan for water management in the tropical peatlands. To analyze the impact, eight dipwells were made to monitor groundwater fluctuations with the distance of 1 m, 101 m, and 201 m from the canal for each of the three transects as presented in Fig. 9.12. The Canal Block-1 is located about 100 m downstream of the Transect-1, and about 200 m upstream of the Transect-2. The Canal Block-2 is located about 100 m downstream of the Transect-2, and about 100 m upstream of the Transect-3.

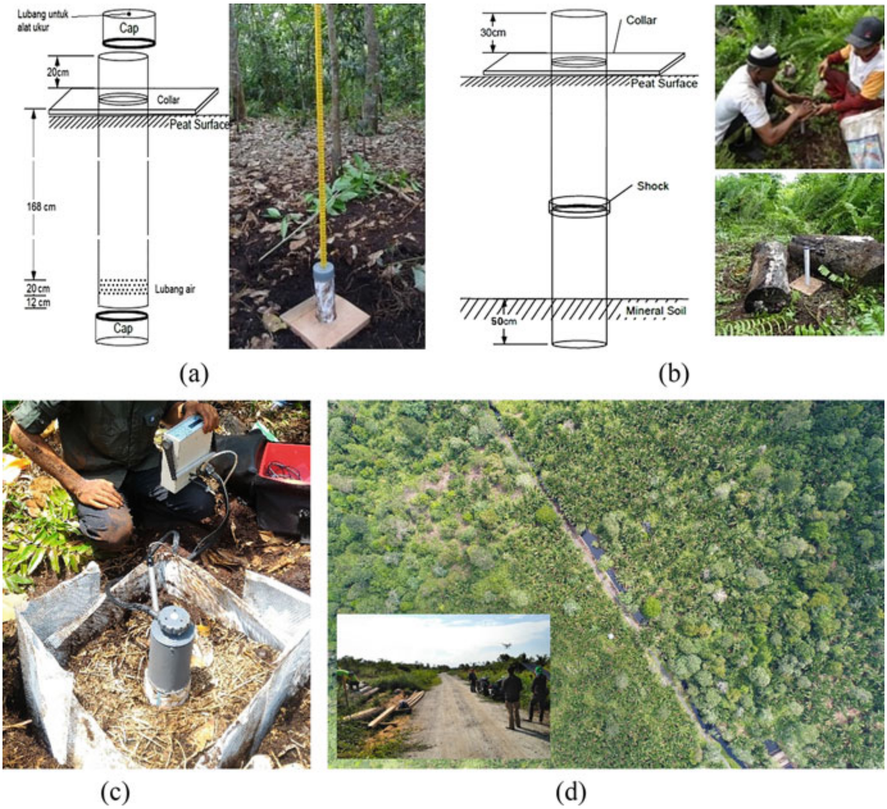

Fig. 9.11 Monitoring of water table (**a**), land subsidence (**b**), CO_2 emissions (**c**), and vegetation growth (**d**)

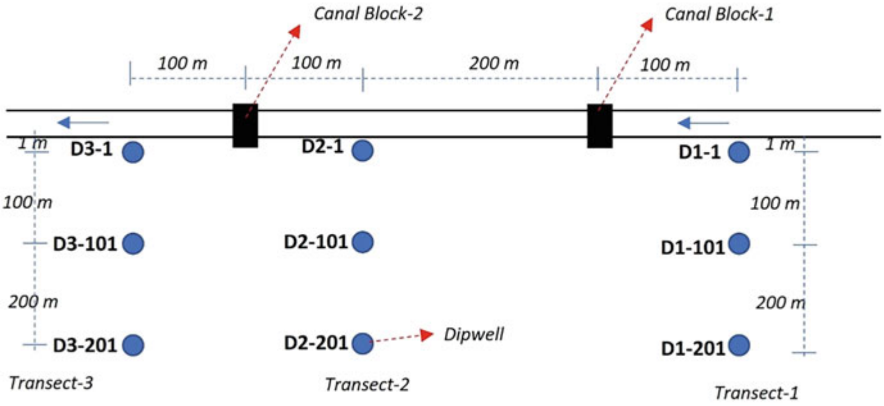

Fig. 9.12 The setting of dipwells for monitoring the impact of water management in the research site

Figure 9.13 shows the daily groundwater level monitoring results before and after water management with canal blocking. The Canal Block-1, which is on the upstream side, was built in mid-November 2018, and the Canal Block-2 was built in early November 2018. When the Canal Block-1 was constructed, the groundwater level at dipwell D1-1, which is about 100 m upstream of the Canal Block-1, increased significantly, but the other two wells did not. This means that canal blocking only affects upstream areas. Groundwater levels at dipwell D1-1 were stable at an elevation of about 8.5 m. This means that the water management with canal blocking worked well to maintain the elevation of the groundwater table and to keep the peatland in a wet condition.

When the Canal Block-2 was constructed, there was an effect on groundwater levels in dipwell D2-1 which is about 100 m upstream. However, this blocking had no impact on dipwell D1-1 which is about 400 m upstream. This means that in this case the canal blocking was successful in wetting an area of no more than 400 m upstream. Groundwater level fluctuations downstream of the canal block were not affected by canal blocking in the upstream part. In the rainy season from October to December 2018, the groundwater level fluctuated dynamically according to rainfall occurrence. In the dry season from January to March 2019, the groundwater level remained stable. There were very few rains, but GWL on dipwell D1-1 and D2-1 was still high because of canal blocking. There was a slight groundwater level decrease in February due to evapotranspiration, but the water table remained high to keep the peatland in the wet condition although in the dry season. It means that the water management by canal blocking had a significant impact on increasing the groundwater levels which can reduce the risk of peatland fire.

To analyze the impact of canal blocking on wetting efforts on peatlands, groundwater level fluctuations were analyzed from three dipwells on each transect with a perpendicular distance of 1 m, 101 m, and 201 m, respectively. Figures 9.14 and 9.15 show the relationship between the increase of water levels in the canal due to canal blocking and the increase of GWL in peatland with a distance of 101 m and 201 m to the canal on Transect-1 and Transect-2 respectively. The increase of GWL in peatland due to canal blocking varied in each location depending on the distance to the canal. The canal blocking does not have an impact on rewetting at a distance of 101 m and 201 m to the canal if the increase in water levels at the canal is less than 0.4 m and 0.45 m in case of Transect-1 (Fig. 9.14) and Transect-2 (Fig. 9.15) respectively. Water levels in the canal with an increase of less than 0.4 m on Transect-1 and 0.45 m on Transec-2 due to rainfall did not affect the increase in groundwater levels in the peatland. The groundwater level in peatlands in these conditions has decreased which is probably due to higher evapotranspiration than rain. The increase of GWL due to canal blocking varied in each location depending on the distance to the canal. The increase of water level at the canal of about 0.58 m on Transect-1 caused the increase of groundwater level of about 0.42 m and 0.34 m for a distance of 101 m and 201 from the canal respectively (Fig. 9.14). The increase of water level at the canal of about 0.57 m on Transect-2 caused the increase of groundwater level of about 0.32 m and 0.30 m for a distance of 101 m and 201 from the canal respectively (Fig. 9.15).

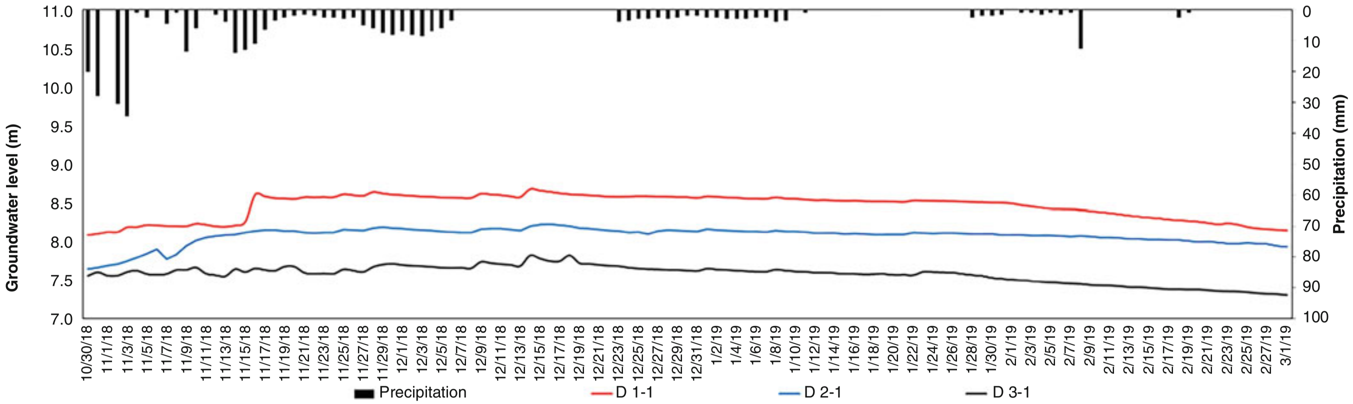

Fig. 9.13 Daily water table fluctuation because of water management of three dipwells along the canal with 1 m distance from the canal, from October 2018 to March 2019

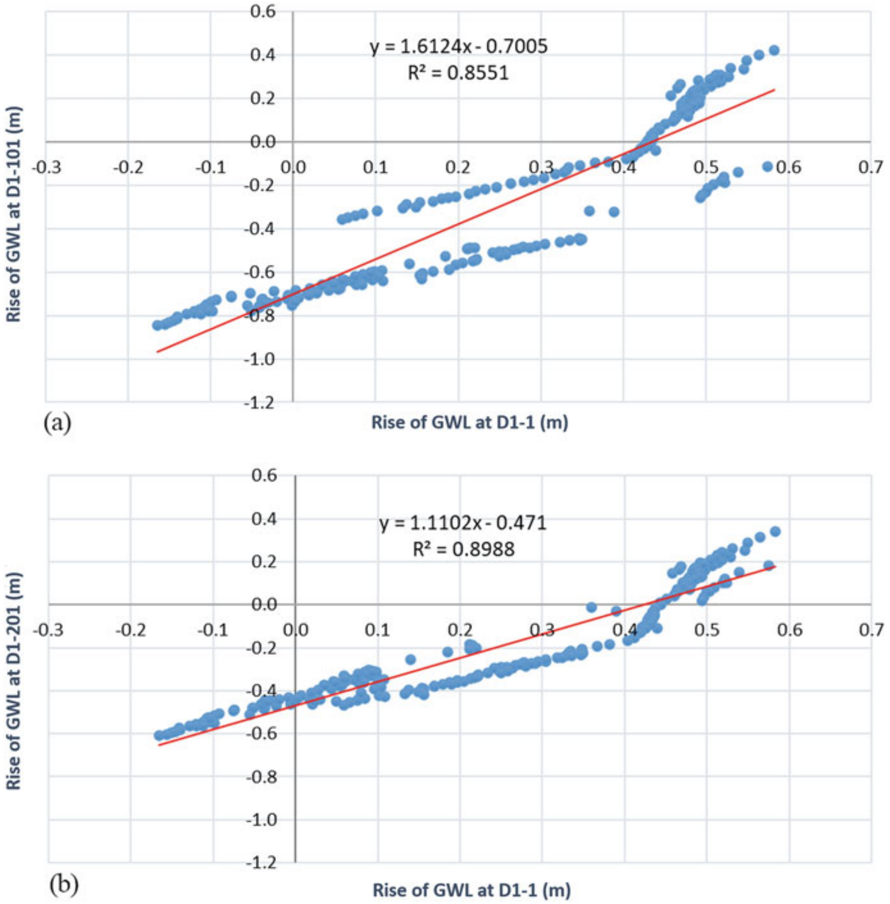

Fig. 9.14 The relationship between the increase in water levels at the canal (D1-1) and the increase of GWL in peatlands with the distance of 100 m (**a**) and 200 m (**b**) to the canal for Transect-1

In comparison with GWL fluctuation because of canal blocking, Fig. 9.16 presents the increase of GWL on the peatlands with a distance of 101 m to the canals without the impact of canal blocking on Transect-3. It shows that there is an increase of GWL on peatlands in line with the increase in the water level in the canal. However, the increase in water level in canals tends to be smaller than the increase of GWL in the peatlands. This shows that water fluctuations in canals and GWL on peatlands are caused by precipitation, without the impact of canal blocking. The increase in water level in the canals is smaller than the increase of GWL in peatlands due to the large water loss due to the absence of canal blocking.

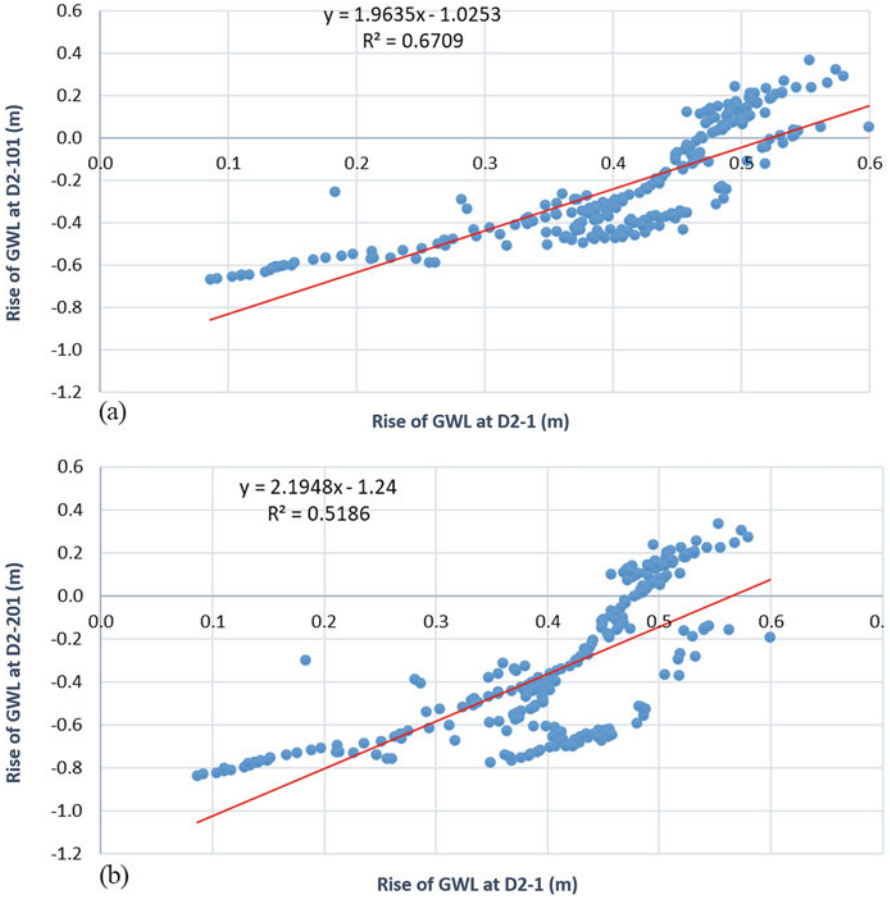

Fig. 9.15 The relationship between the increase in water levels at the canal (D1-1) and the increase of GWL in peatlands with the distance of 100 m (**a**) and 200 m (**b**) to the canal for Transect-2

9.4 Conclusion

This study presented a pilot project for water management not only with the purpose of peat rewetting but also for supporting revegetation efforts and revitalization of livelihood in Pulau Tebing Tinggi Peatland Hydrological Unit (PHU). Two masterplans of water management for both Lukun and Tanjung Sari were developed with the participation of the respective communities. The latter have adopted the masterplans by constructing seven wooden canal blocks in Lukun and a sheet pile canal block in Tanjung Sari. These canal blocks were integrated with other restoration activities, such as paludiculture and aquaculture. This research found that by applying water management properly, the water table can be maintained at a stable

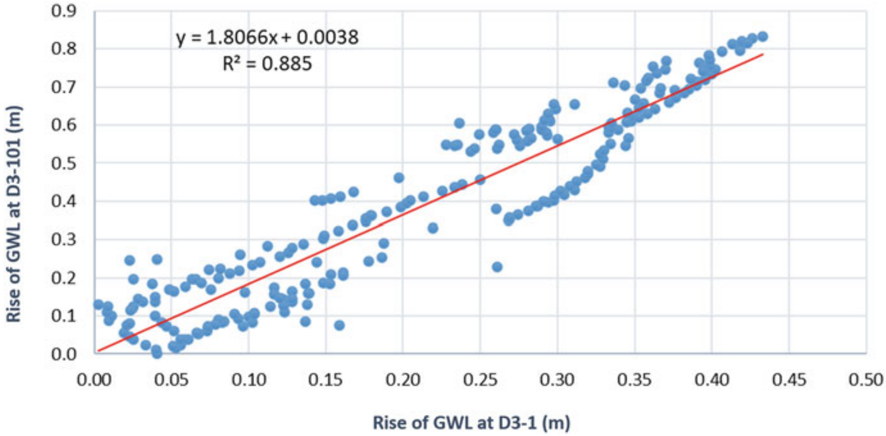

Fig. 9.16 The relationship between the increase in water levels at the canal (D1-1) and the increase of GWL in peatlands with the distance of 100 m to the canal for Transect-3

and high level to wet the peatlands. Water management by applying canal blocking worked well to keep groundwater elevation and keep peatland in a wet condition for an area 400 m upstream from the canal block. Canal blocking will have a good impact on wetting in peatlands up to a distance of 201 m perpendicular to the canal if the water level rise in the canal is more than 0.45 m.

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