Abstracts of the

13th ICID International Drainage Workshop

Ahwaz, Iran, 4 - 7 March 2017

Drainage and Environmental Sustainability

ICID.CIID

International Commission on Irrigation and Drainage
Iranian National Committee on Irrigation and Drainage

IRNCID

Abstracts of Papers

13th ICID International Drainage Workshop

Ahwaz, Iran, 4-7 March 2017

Drainage and Environmental Sustainability

International Commission on Irrigation and Drainage (ICID)
Iranian National Committee on Irrigation and Drainage (IRNCID)

Organized by:

International Commission on Irrigation and Drainage

Iranian National Committee on Irrigation & Drainage

Khuzestan Regional Committee on Irrigation & Drainage

Khuzestan Water and Power Authority

Iran water Resources Management Company

Islamic Republic of Iran Ministry of Energy

Hosted by:

Khuzestan Water and Power Authority

The International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). ICID, through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework.

ISBN:976-600-96875-1-0

Table of Contents

Keynotes

Topic 1: Measures to Lower Volume of Drainage Water

Topic 2: Measures to Improve Drainage Water Quality

Topic 3: Adaption of New Design Criteria in Favor of the Environment

Topic 4: Application of Alternative Drainage Methods

Topic 5: Irrigation and Drainage Management

Topic 6: Drainage Special Issues

COMPARISON OF THE BENEFIT FOR APPLYING SHALLOW DRAINAGE METHOD OF FOOD CROPS AND DEEP DRAINAGE OF TREE AT THE RECLAIMED LOWLANDS IN JAMBI-INDONESIA

Aswandi1), R. H. Susanto2), I. Iskandar3), E. Saleh4), A. Sudirman5), and M. R. Abdillah6)
1Inacid Jambi/ University of Jambi
2, 3,4Inacid South Sumatera/ Sriwijaya University
5 Inacid Jambi/ The Head of BWS Jambi, DG Water Resources, Jambi
6 Tohoku University, Sendai, Japan
Corresponding Author: aswandi.unja@gmail.com

Abstract

This research focuses on the projection of an irrigated tidal peat-swamp in the Rantau Makmur village, Jambi, Indonesia, particularly to assess the impact of peat losses due to drainage system. Several drainages scenarios were considered carefully to find the best scenario suitable for the region. In order to quantify the impact of drainage, we develop 3-D (x,y,t) EmSub model. The model can be used to estimate the CO_2 emission due to the peat oxidation, as well as to estimate the subsidence based on soil consolidation and peat losses. Short-term simulation for 4 years shows good agreement between simulated subsidence and the observational data. Therefore, the utilization of this model for a long-term projection may be promising. The impacts from various scenarios are investigated using 100 years simulation. The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. Every plant has different drainage depth. Two groups of plants are introduced: 1) Tree crops (industry and forestry) which live on deep water table (acacia and palm oil); 2) Food crops which live on shallow water table (paddy). The simulations show that tree crops release abundant CO_2 emission and strong subsidence which lead to not-usable soils due to inundation. Therefore, profit/loss ratio of food crops drop significantly and smaller than tree crops. In general, the model has shown that the tree crops group (acacia, palm oil, rubber, jelutong) contributes largely to the CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit significantly. In particular, the highest rate of the CO_2 emission and subsidence is triggered by acacia, which needs very deep water table. Detail results and discussions of every plant are shown in this paper. This will help users and decision makers to choose the best scenarios for long-term land management planning in the study area.

Keywords: *spatial model, drainage, peat swamp, subsidence, CO_2 emission.*

Introduction

Previous study has shown that drained peat swamp could release significant CO_2 emission and cause rapid land subsidence due to peat oxidation (Hooijer et al., 2001). However, the method used for calculating the CO_2 emission is still under debate. This study, therefore, propose a numerical method to simulate groundwater flow in peat swamp and estimate the impact of various drainage scenarios. Aswandi et al [2015] have developed a groundwater model for a tidal peat swamp, which was coupled with open-canal system in 3-dimensional (x,y,t) frame. They named the model as Groundwater-Canal Flow (GCFlow) model. Based on their model, this study introduces a model for simulating CO_2 emission and land subsidence, so-called the Emission-Subsidence (EmSub) model. The EmSub model uses predefined water table map calculated by GCFlow model to estimate the amount of CO_2 loss and subsidence in various drainage scenarios. Based on estimated CO_2 emission and land subsidence, we evaluate the impact of drainage on food crops and various forest scenarios.

Methodology

Research site is located in an irrigated block in Berbak Delta, Jambi, Indonesia, with an area of ±100 ha bounded by two primary canals and two secondary canals (Figure 1). It is B/C typology class land where always inundated during high tide, or where the water will come only during high tide.

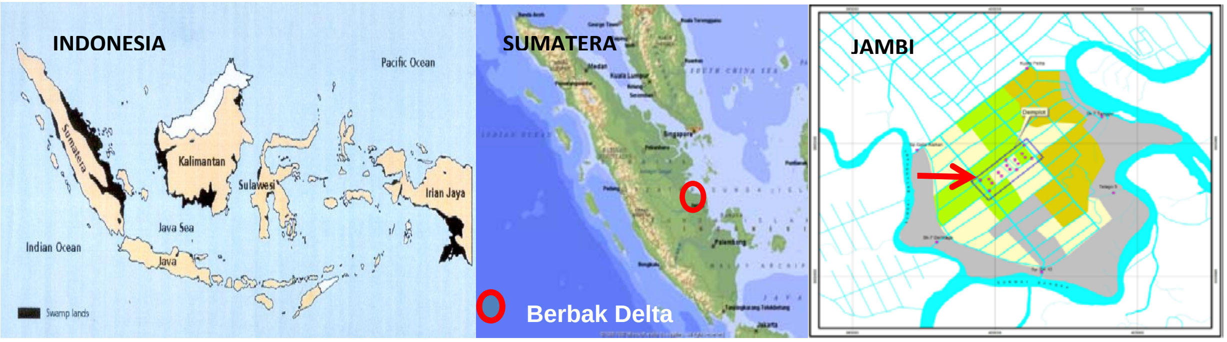

Figure 1: Research Site in the Berbak Delta, Jambi-Sumatera, Indonesia

In this research, two main models were developed. The first model is the GCFlow model, which has been developed in our previous study [Aswandi *et al.*, 2015]. The second model is the EmSub model, which simulates CO_2 emission and land subsidence. Firstly, the GCFlow model is run for 365 days to get 1-year averaged water table. Outputs from the GCFlow model were used as input for 100-years simulation of the EmSub model. As the land subsides, drainability limit of the land is calculated which is used to reveal“age of usable land” and percentage of land condition in each year. Finally, we calculated the profit/lost ratio by comparing the crop productions and profit with CO_2 losses.

Model design

There two main components in the EmSub model, those are the CO_2 emission and the land subsidence. Note that the CO_2 emissions come from peat decomposition To calculate CO_2 emission, we use a proxy that relates annual average of CO_2 emissions rate per one meter of water table depth. Thus, this component uses the annual average of ground water table as the input. While the component of land subsidence (*hereafter* subsidence – S) consists of two sub-components; (a) subsidence due to oxidation of peat mass loss (S_E) and (b) physical compaction (also called consolidation) as a result of changes in effective stress in Terzaghi model (S_C). Therefore, total Subsidence (S) is sum of these two: $S = S_E + S_C$.

Subsidence due to the loss of peat mass is converted from annual CO_2 emission rate based on the content of C and bulk density of peat. It uses annual CO_2 emissions as input. While the consolidation component uses the lowest ground water level as input.

The CO_2 emission and subsidence scheme

The model uses horizontal partitions on *X-Y* axis with an annual time-step. The CO_2 emission using the annual groundwater level as a proxy can be formulated as follows.

$$E_{i,j,k} = c\left(H_{top,i,jk} - H_{i,jk}\right),$$

$$H_{top,i,j,k} = H_{top,i,j,k-1} - S_{i,j,k-1},$$

where E is the rate of annual CO_2 emissions due to peat oxidation, H_{top} is the elevation of the land surface relative to the averaged sea level (L) and S is the subsidence (L). In addition, the coefficient of CO_2 emissions rate in the peat land is defined as c ($ML^{-3}T^{-1}$) (M, L, and T are unit for mass, length, and time, respectively). *i, j, k* are the indices representing the column, row, and layer, respectively. Hooijer proxy explains that for each depth of the ground water level of 1 m, the rate of CO_2 emissions amount to 90 ton ha^{-1} per year, or 9 kgm^{-3} per year. The CO_2 emissions can be converted into components of subsidence (S_E) with the following equation,

$$S_{E,i,j,k} = \frac{E_{i,j,k}\left(\dfrac{M_C}{M_C + 2M_O}\right)}{\rho_{b,i,j,k} N_C},$$

where M_C and M_O are the atomic weight of carbon and oxygen (kg/mol), respectively. Meanwhile, ρ_b and N_C are bulk density (L^3M^{-3}) and fraction carbon content of peat (MM^{-1}), respectively On the other hand, subsidence due to compaction (S_C) consists of primary and secondary consolidation components, which can be calculated with the following equation,

$$S_{C,i,j,k} = L_{0,i,j,k} \frac{C_c}{1 + e_{0,j,j,k}} log\left(\frac{P_{0,i,j,k} + \Delta P_{i,j,k}}{P_{0,i,j,k}}\right) + L_{0,i,j,k} \frac{C_\alpha}{1 + e_0} log\left(\frac{t}{t_0}\right),$$

where L_0 is the initial thickness of the peat layer, C_c and C_α are the indices for primary and secondary compression (no units), e_0 is the initial void ratio (LL^{-1}), while P_0 and ΔP respectively represent the initial effective stress and change in effective stress due to decrease in ground water level ($ML^{-1}T^{-2}$). Meanwhile, t and t_0 respectively represent the time parameter and the time at the beginning of secondary consolidation. The first term in the right hand side of represents primary consolidation, while the second term represents secondary consolidation. Primary consolidation takes place very quickly (in a few days or weeks), while the secondary consolidation is lasting longer over years. In our simulation, the primary consolidation is defined to zero because the first drainage was done in past years.

Effective stress is assumed as weight of peat mass minus buoyancy of groundwater. Effective stress increases when the water level decreases (deeper water table). Effective stress during pre-drainage (or pre-dredging) is calculated based on the lowest ground water level before the drainage, and it is written as

$$P_0 = \rho_b g L_0 - \frac{\rho_b}{\rho_s}\rho_w g H_0 ,$$

whereP_0 is the largest effective stress at initial pre-drainage or pre-dredging ($ML^{-1}T^{-2}$). g is the gravitational acceleration constant (LT^{-2}). ρ_b, ρ_s and ρ_w are respectively the bulk density of peat, the density of peat particles, and the density of water (ML^{-3}). H_0 is ground water level calculated from the water table to the bottom of peat (L).

During drainage, effective stress can increase due to lowering of water table and can be calculated as follows,

$$P = \rho_b g L - \frac{\rho_b}{\rho_s}\rho_w g\left(H_0 - \Delta H\right).$$

P is the largest effective stress after drainage ($ML^{-1}T^{-2}$) and ΔH is the change in ground water level depth (L). By calculating the subsidence, the surface elevation can be simulated dynamically. Note that the simulated subsidence is used for estimating the surface elevation, the peat depth and the ground water level of the next year. Therefore, we may say that our model can simulate the spatial and dynamical process of the water table.

The age of usable land

The spatial-map of age of usable land can be calculated based on the output of elevation that has been simulated. First, we calculate gravity-drainability limit with Euclidian distance method which is controlled by the nearest boundaries of the river or the sea. Drainability limit (E_{dr}) is calculated as: $E_{dr} = E_b + 0.00002D$ where E_b is the elevation of the nearest river or sea, D is the shortest distance to the boundary of the river or the sea, and the constant of 0.00002 is the gravity-drainability slope coefficient, which means 2 cm/km. If the elevation is lower than E_{dr}, then the land is no longer used and thus reduces the productivity of the crop. This map will be created in a grid format with a unit cell size of 10 m. Size of the usable zone tends to decrease due to subsidence. Agricultural cultivation can only be done on a drainable zone (i.e gravity-drainable zone), by assuming that there is no mechanical pumping performed gravity-drainability when the limit is reached.

Profit/loss ratio of crops production

This is a simple model that aims to calculate the ratio of profit/loss of a crop scenario. The model takes into account the potential revenue from the sales profits and potential losses due to emission and/or subsidence, and then calculates their ratio. Calculation period is divided into per-life of each plant and per 100 years. In this model, we assumed that 1 ton CO_2 loss costs about USD 5.5 or equivalent to IDR (Indonesian Rupiah) 77,000.

Model resolutions and assumptions

The spatial models run with 10 × 10 m spatial resolution. *EmSub* model uses 1-year time step for calculation. In profit/loss model, it is assumed that the crop prices and expenses are constant. For each crop scenario, the harvest time is only once a year. The drainage values for combined-plants scenarios are weighted based on the age of the plant. For example, plant A has life time of 3 months with 0.3 m drainage depth, while plant B has life time 5 months with 0.5 m drainage depth. Scenario for combined plant A and B has annual drainage depth of $(0.3 \times 3/8) + (0.5 \times 5/8) = 0.425$ m.

Results and discussion

Data preparation and model evaluation

The main data for the *GCFlow* consists of hydraulic conductivity, storage coefficient, DEM, daily rainfall, channel structure and manning roughness coefficient (see *Aswandi et al*., 2015). We used daily rainfall data for a period of April 1st, 2012 to March 31st, 2013. Note that we assumed the daily rainfall data for that period also applies to other years on the same date. The output is daily water table (WT), which is, then, annually averaged. For *EmSub* models, data and parameters are shown in Table 1. In particular, it uses annual WT from *GCFlow* and peat thickness as the input. Dataset of peat, DEM, and hydraulic conductivity vary spatially. The CO_2 content parameter is based on several findings from similar areas in Indonesia. We use *Couwenberg*'s CO_2 emission coefficient for every 1 meter of drainage depth based on Hooijer *et al*. in [8, 9, 10]. The primary and secondary compression indices are obtained by following previous study [4]. Other soil characteristic data are based on *in-situ* observation. Meanwhile, data for crop prices in the market and crop expenses are obtained through direct observation and interview with the farmers.

Table 1: Data for *EmSub* model

No	Name	Value and unit
1	Annual water table elevation (from *GCFlow* model)	m
2	Peat thickness	m
3	Surface elevation (DEM)	m
4	Soil characteristics (general)	
	• Hydraulic conductivity	$m\,day^{-1}$
	• Storage coefficient	$0.3\ m^3\ m^{-3}$
5	Soil characteristics (CO_2 emission)	
	• CO_2 content	$0.58\ kg\ kg^{-1}$
	• Couwenberg coefficient	$9\ kg\ m^{-2}\ year^{-1}\ m^{-1}$

6	Soil characteristics (consolidation)	
	- Bulk density	200 kg m^{-3}
	- Particle density	1200 kg m^{-3}
	- Primary compression index	2.2
	- Secondary compression index	0.06
7	Time step output	1 year
8	Drainability limit	
	- Gravity-drainability coefficient	0.00002 km km^{-1}
	- Distance to the river	3 km
	- Elevation of the nearest river	5 m

Source: Aswandi *et al* (2015)

Impact of different drainage scenarios in 100 years simulation

Model output in the 100th year simulation

Depth of water table is proportional to subsidence and thus affects the land cover. Model outputs show that scenario of 0.8 m drainage (current condition) potentially releases about 794,000 ton of CO_2 or equivalent to IDR 61.2 billion (Table 2). In addition, the 0.8 cm drainage scenario causes 52 cm subsidence and leaves 62% of usable land cover. The losses become smaller (bigger) in the shallower (deeper) drainage scenario. For instance, the drainage scenario of 0.1 m has potential CO_2 emission of about 279,500 ton (IDR 21.5 billion), 19.8 cm subsidence, and no damage on the land cover. However, the drainage scenario of 1.5 m can result in 1.4 million ton CO_2 emission (IDR 108 billion), 90.6 cm subsidence, and only 35.9% usable land left.

Table 2: Projection of CO_2 emission and subsidence for different scenarios.

Drainage scenario (m)	**Result for 100 years simulation**			
	CO2 emission (1000 ton)	**CO2 loss (IDR billion)**	**Subsidence (cm)**	**Land condition (%)**
1.5 (*max*)	1407.1	108.3	90.6	35.9%
1.2	1283.8	98.9	82.8	36.3%
1.0	1093.7	84.2	70.9	48.2%
0.8 (*real*)	794.9	61.2	52.1	62.3%
0.6	595.8	45.9	39.6	76.6%
0.4	450.7	34.7	30.5	89.1%
0.3	412.9	31.8	28.1	95.2%
0.2	364.4	28.1	25.1	99.4%
0.1	279.5	21.5	19.8	100%

Spatial features

One advantage of the *EmSub* model is its capability in spatially simulating the land subsidence, emission, and profit/loss ratio. We reveal spatial distributions of the projected DEM, cumulative CO_2 emissions, peat thickness, and age of usable land in 100 years (Figures not shown). Since the subsidence is large, the emission is very high and the lifetime of usable land is very short. We found that the soils near to canal's boundary will suffer most subsidence and emission. This is probably due to deeper water table in this location than the water table in the center of block (curvature effect of water table surface). DEM data shows that the lowest elevation area resides in the middle block (tertiary block), which is vulnerable to inundation.

Time-series

Figure 2 shows the time-series of simulated peat thickness, cumulative subsidence, DEM, cumulative emissions, and rate of emission per year in several WT scenarios. We can clearly see that peat amount is decreased which results in increasing subsidence, lowering DEM, and increasing CO_2 emission (Fig. 2a-b). Shallow WT table scenarios are seen to have small impact, while deep WT scenarios show large impact (20-60 cm). In the early years, their values increase or decrease rapidly. After long simulation, their impacts are reduced logarithmically, especially for deep WT scenarios (1-1.5 m). Therefore, its rate is reduced and stopped in particular year (Fig. 2d). For 1.5 m and 1.2 m scenarios, the peat is predicted to disappear around 90th year and 120th year (Fig. 2a), respectively. However, the shallower WT simulations show that the peat still exists, at least until 200th year in the future. These results clearly show that deeper WT scenarios release more CO_2 rapidly, which directly contributes to the speed of global warming.

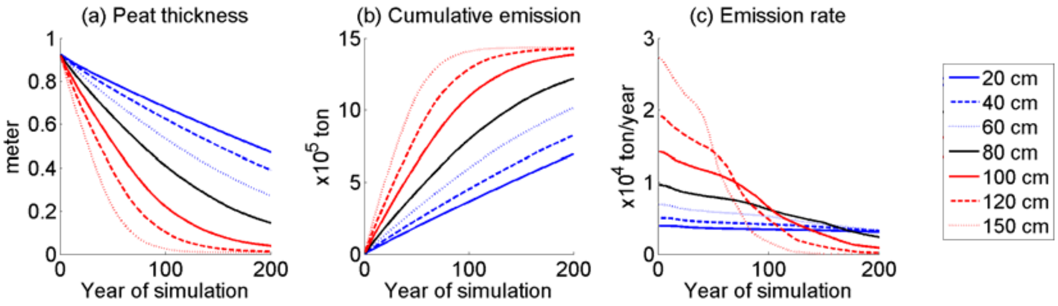

Figure 2: Time-series of model outputs. (a) peat depth, (b) Cumulative emission, and (c) emission rate per year. The model runs are extended to 200 years. Legend is shown in bottom-right of figure.

Profit/loss ratio for several plantations and crops

In order to evaluate the impact of emission and subsidence to the plantations and crops, we run several particular drainage scenarios for each plant, so-called plant scenario. The information of the plants (i.e., typical drainage depth, age, production, price, and expense) is shown in the Table 3. For example, paddy uses drainages of about 0.1 - 0.2 m depth. Then, in the simulation scenario, we run the model twice using both data so that we obtain the approximate impact caused by paddy. The emission released by plant is considered as the losses, which can be converted into money loss. The amount of crop production is affected by land condition (active usable area that can be drainaged).

Table 3: Two group of crop scenarios. It consists of 11 crops and plantation.

No	Plant scenario	Drain Min	Drain Max	Lifetime	Production (kg/ha/year)	Price (IDR/kg)	Expense (IDR)
	Group I						
1	Acacia	80	100	5 year	30000	350	0
3	Oil Palm	60	80	25 year	18000	800	41,000,000.00
2	Rubber	40	60	50 year	2400	5500	3,000,000.00
4	Jelutong	20	40	100 year	3200	5000	3,000,000.00
	Group II						
1	Paddy	10	20	3 month	3000	4500	3,000,000.00
2	Corn	30	40	4 month	5000	3200	2,500,000.00
3	Soybean	30	40	3 month	1500	6000	2,000,000.00
4	Cassava	30	40	5 month	5000	2000	1,000,000.00
5	Red Chilli	20	30	4 month	1000	40000	10,000,000.00
6	Long bean	20	30	2 month	3000	4000	2,500,000.00
7	Peanut	30	40	3 month	1200	10000	3,000,000.00

Figure 3 exhibits model results comparison between plants scenarios. The plants in the first group release high CO_2 emission (Fig. 3a). Among plants in the first group, *acacia* is the highest contributor (795 - 1094 thousand ton), followed by palm oil (596 – 795 thousand ton), rubber (451 – 596 thousand ton), and *jelutong* (364 – 451 thousand ton). The largest subsidence is also caused by *acacia* with averaged subsidence of 52 – 71 cm, while the smallest subsidence is caused by *jelutong* (25 – 31 cm) (Fig. 3b). In case of percentage drainable area due to subsidence, farmers are expected to lose about 50% of area if the *Acacia* would be planted (Fig. 3c). Meanwhile, the *jelutong* scenario could save the drainable area up to 89 – 99%. *Acacia* lives in the deep drained land of about 80 – 100 cm depth. Palm oil and rubber are also considered using deep drainage of about 60 – 80 cm and 40 – 60 cm depth, respectively. We may suggest that the deep drainages are susceptible and inappropriate to the peat swamp because it could affect the peat substantially, release more CO_2 emissions, and trigger strong subsidence. On the other hand, *jelutong* has been shown to contribute be friendly to the environment. *Jelutong* also lives quite long (Table 4, lifetime). In 100 years, farmers need only 1 time planting, compared to *acacia*, palm oil and rubber that need 20 times, 4 times, and 2 times planting in 100 year, respectively. Finally, *jelutong* gives the highest profit/loss ratio among industrial forests, which is very profitable to be applied (Fig. 3d). Otherwise, *acacia*, palm oil and rubber are less appropriate in the study area and should be avoided.

In individual food crops scenarios, corn, soybean, cassava and peanut are the largest contributors of CO_2 emission (413 – 451 thousand ton) (Fig. 3a). The second contributors for CO_2 emission are red chilli and long bean (364 – 413 thousand ton). Corn, soybean, cassava, and peanut cause land subsidence of about 28 – 31 cm (Fig. 3b). The lowest emission is coming from paddy (280 - 364 thousand tons). Land subsidence in paddy is also the smallest (about 20 – 25 cm).

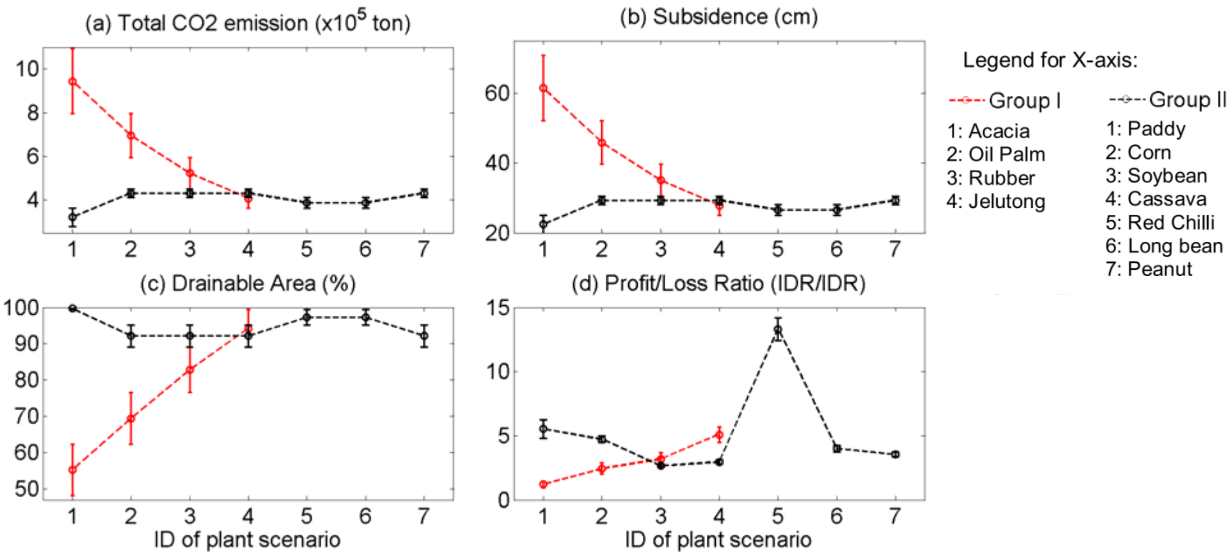

Figure 3: Distribution of impacts on different plantations. (a) and (b) exhibits area average of 100 years CO_2 emission and subsidence, respectively. (c) shows drainable area in the 100th year. (d) shows profit/loss ratio measured by annual selling profit divided with predicted CO_2 loss. Horizontal axis denotes the ID of plant scenario. Legend of scenario ID is shown in the right.

Conclusion

The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. In addition, the lowered soils may cause wide-inundated area which are not suitable for plantation. The effects can be smaller and higher depending on the depth of drainage. In order to evaluate the impact of emission and subsidence to the plantations and crops, sensitivity experiments using selected and combined plantations are conducted. In general, the model has shown that the industrial plantation group (e.g. *acacia*, palm oil, rubber, *jelutong*) contributes largely to the CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit significantly. In particular, the highest rate of the CO_2 emission and subsidence is triggered by *acacia*, which needs very deep water table. The impacts caused by food crops group (paddy, corn, soybean, cassava, red chilli, long bean, peanut) are much smaller. The paddy contributes the smallest CO_2 emission and subsidence. Farmers should consider changing the forest into food crops in order to both save the environment and stabilize the profit.

References

1. Aswandi, H. Susanto; E. Saleh, I. Iskandar, and M. R. Abdillah. 2015. *A simulation model for coupled groundwater and open channel flow in reclaimed tidal peatswamp*. The GEOMATE International Society. Tsu City. Mie-Jepang. ISBN Number: 978-4-9905958-5-2 C3051

2. Christian, Aswandi, and D. S. Rais. 2004. *Hydrological Modelling. "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forests" Case study Air Hitam Laut river basin, Jambi Province, Indonesia*. Technical Report. WI-IP Bogor.
3. Rais, D. S. 2011. *Drainage-driven Subsidence and carbon emission in Air Hitam Forest Reserve and its surrounding area, Johor- Malaysia.* Technical Report. WI-IP Bogor.
4. Wosten, H and Aswandi. 2009. *Interdependencies between hydrology and ecology in tropical peat swamps*. Proceeding of Open Science 2005. The Role of Tropical Peatlands in Global Change Processes. Join Working Committee of Indonesia Institute of Science (LIPI) and Netherland Association (INA).
5. Hooijer, A, S. Page, J.Jauhiainen, W.A.Lee, Aswandi, and G. Anshari. 2011. *Subsidence and carbon loss in drained tropical peatlands.* Journal Biogeosciences 9, 1053-1071.
6. Hooijer, A., W. A. Lee, and Aswandi. 2010. *Jambi peatland management knowledge base and training programme focus on water management*. Technical workshop, Part-1. 12-14 August 2009. University of Jambi.
7. Hooijer. A., M. Silvius, H. Wosten, and S. Page. 2006. *Peat-CO2:Assessment of CO2 emission from drained peatlands in SEAsia*, Delft Hydraulics Report Q3943.
8. Jabatan Pengairan dan Saliran. 2001. *Water management guidelines for agricultural development in lowland peatswamps of Sarawak*. Manual, Technical Report. Department of Irrigation and Drainage, Kerajaan Sarawak-Malaysia.
9. Lee. W.A, A.Hooijer, X. Lu, Aswandi., Sugino., and F. Teddy. 2011. *Impact of drainage on peatland subsidence*. Proceeding of International Perspective on Water Resources and the Environment (IPWE). Faculty of Engineering, National University of Singapore.
10. Misra, S, P. Sanjai, and Aswandi. 2013. *Microbial and metabolic profiling reveal strong influence of water table and land-use pattenrs on classification of degraded tropical peatlands*. Journal Biogeosciences.
11. Vries, F.T de. 2003. *Practical use of hydrological model for peatlands in Borneo, Modelling the Sungai Sebangau Cachment in Central Kalimantar, Indonesia*. Alterra-report 797. Wageningen, Netherland.
12. Remson, I., G.M. Hornberger and F.J. Molz. 1971. *Numerical methods in subsurface hydrology with an introduction to the finite element method*. Wiley Inter-science. New York.
13. Susanto, R.H. 1998. *Water status evaluation in tertiary and secondary blocks of South Sumatra reclaimed tidal lowlands using the hidrotopography and SEW-30 concepts*. Proceeding of the Young Professional Forum-International Commision on Irrigation and Drainage Seminar (B3). Bali July 23rd, 1998.
14. Wosten, J.H.M., J.Van Berg, P.Van Eijk, , G.J.M. Gevers, W.B. J.T. Giessen, A.Hooijer, Aswandi, P.H. Leenman, D. S. Rais, C. Siderius, N. Suryadiputra, and I.T. Wibisono. 2006. *Interrelationship hydrology and ecology in fire degraded tropical peat swamp forests*. Journal Water Resources Management, Vol. 22 No. 1, 157-174.

Acknowledgement

The authors appreciatively acknowledge funding from DP$_3$M project, Directorate of High Education, Department of National Education of Republic of Indonesia.