Spatial Mapping for Managing Oxidized Pyrite (FeS₂) in South Sumatra Wetlands, Indonesia

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ABSTRACT

The research aimed to analyze spatial mapping for managing oxidized pyrite (FeS₂) in South Sumatra wetlands, Indonesia. The field observations are done by exploring several transect on land units. The field description refers to Soil Survey Staff (2014). Water and soil samples were taken from selected key areas for laboratory analysis. The vegetation data was collected by making sample plots (squares method) placed on each vegetation type with plot sizes depending on the vegetation type, namely 10 x 10 m for secondary forests and 5 x 5 m for shrubs and grass. The observations of surface water level were done during the river receding with units of m above sea level (m asl). The research results showed that pyrite formation is largely determined by the availability of natural vegetation as Sulfur (S) donors, climate and uncontrolled water balance and supporting fauna such as crabs and mud shrimp. Climate and water balance as well as supporting faunas is the main supporting factors to accelerate the process of pyrite formation. Oxidized pyrite serves to increase soil acidity, becomes toxic to fish ponds and arable soils, plant growth and disturbing the water and soil nutrient balances. Oxidized pyrite is predominantly accelerated by the dynamics of river water and disturbed natural vegetation by human activities. The pyrite oxidation management approach is divided into three main components of technologies, namely water management, land management and commodity management.

Keywords: Mapping, managing, oxidized pyrite (FeS₂), wetlands, South Sumatra

INTRODUCTION

Tidal wetlands is a swamp that receives direct or indirect influence by the tides of sea water or river nearby. The management principle of tidal wetlands is how to manage excess water, to avoid the emergence of risks and toxins such as the acidity, pyrite oxidation (FeS₂ is the chemical formula for different crystal systems of iron sulfide) and pollution to the environment due to Al and H ion (Armanto *et al.*, 2011). Tidal wetlands reclamation is essentially to lower the ground water level or drying with making drainage channel. The drainage channels also function not only to dry the tidal wetlands, but also to

provide sufficient water for fishery and plant growth as well as to conserve land resource itself. Thus, water management of tidal wetlands is including water conservation, understanding and managing soil acidity and managing acid sulfate soils.

Mostly tidal wetlands in Pulau Rimau are developed for agricultural purposes. In order to prevent some failures of reclaimed tidal wetlands, we need to carry out a comprehensive research because pyrite is the most risks and toxins for fishery and plant growth. Besides that, pyrite is basic materials for forming acid sulfate soils with low pH. In the rainy season, oxidized pyrite can be washed into the rivers and can disturb a life of aquatic fauna as well as accumulate sediments in the rivers (Armanto *et al.*, 2010).

METHODS

This research was conducted in tidal wetlands Pulau Rimau, South Sumatra. The research method was detail field survey aided by interpretation of landsat imagery approach

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(landsat TM 7 with scales of 1:250,000, multi-temporal) and topographic maps (scale of 1:50,000). Field description was done by exploring several transect on land units and refers to Soil Survey Staff (2014). Soil characteristics were recorded in the soil profile card. Water and soil samples were taken from several observations in selected key areas for labor analysis. The vegetation data was collected by making sample plots (squares method), i.e. 10 x 10 m for secondary forests and 5 x 5 m for shrubs and grass. The water levels were recorded during the river receding with units of m above sea level (m asl). It was determined five point locations of water level observations, each obtained from upstream to downstream observations.

RESULTS AND DISCUSSION

General Description of Research Sites

Approximately 40,263 ha of tidal wetlands in Pulau Rimau, Banyuasin South Sumatra has been cultivated for transmigration program since 1960 for food crops (paddy, corn and cassava). The land use has undergone many changes due to the rapid growth of population and behavioral patterns of different communities. From the field experience, the tidal wetlands is less suitable for food crops. The main failure factor of the tidal wetlands is that the lands are less really understood in terms of the soil character and properties as well as their tidal swamp water either in form of spatial or attribute phenomena. The reclamation program tended to be forced on the biophysical conditions that do not fit with the needs of plants. In other words, the soils are not really suitable for food crops.

Pyrite Formation

Tidal wetlands experienced intensive interactions between river water and sea water, so it gives an optimum place for the formation of sulfides. Sulfide will be reduced or oxidized based on water movement

between river water and sea water and forms mineral pyrite or iron pyrite. The mineral pyrite or iron pyrite is an iron sulfide with the formula FeS_2 . Pyrite will be exposed to the atmosphere during land clearing or water dynamics of rivers and reacts with oxygen and water to form sulfate, resulting in acid drainage water. Besides tidal movement between river water and sea water, pyrite will be strongly influenced also by natural vegetation, climate and supporting fauna.

Natural Vegetation

Natural vegetation has a very important role as a basic ingredient in the pyrite formation. To reduce sulfate, sulfide is needed by organic matter as electron donor. Number of Mangrove and Nipah (density: 7 and relative Frequency: 1.8) play an important role in the pyrite formation because of the roots and high primary production, so there is a supply of organic matter for sulfate reduction freely. Specific influence of certain types of Mangrove and Nipah may be associated with peat formation of fine roots and the plant is below ground level, which is an additional source of energy for the formation of sulfur (S) and pyrite. Acid sulfate soils can usually be known by the typical vegetation such as *Phragmites karka* (Perumpung), *Cyperus eragrostis* (Teki 1), *Fimbristylis annua* (Belidang), *Melaleuca leucadendra* sp (Gelam Rawa), *Blechnum orientale* (Paku Gambut) *Melastoma* (Seduduk) and the like which is an indicator plant for infertile soils (Armanto *et al.*, 2011 and Armanto *et al.*, 2010). Results of vegetation analysis at research sites is presented in Table 1.

The structure of vegetation as indicated by the Density Value (K), Frequency (F) and Domination (D). Based on the Important Value Index (INP) of each natural vegetation species showed that Belidang and Gelam were the dominant species and had the highest interest in the structure of vegetation communities found in the area with a value of 74% and 56.9% respectively (Armanto *et al.*, 2011).

Results of vegetation analysis showed that vegetation community Diversity Index (H) is 2.53, indicating that the vegetation communities that exist in the ecosystem is relatively stable (> 2.00). However, there are species that dominate namely Belidang, Paku Gambut and Gelam Rawa. The next type of

the dominant views of its importance is *Perumpung* and *Teki 1*. The dominant vegetation is a major contributor in the pyrite formation. In other words, the dominant vegetation plays a big role in pyrite formation (Armanto *et al.*, 2011).

Table 1. Results of vegetation analysis at research sites

Nr.	Type name	Analysis results							
		K	KR (%)	F	FR (%)	D	DR (%)	INP	H
1.	Alang-alang	54	9.0	5	2.2	244	0.5	3.6	0.05
2.	Belulang	24	4.0	10	44.0	76	1.0	4.9	0.07
3.	Belidang	3200	52.6	20	8.9	6,431	12.5	74.0	0.34
4.	Gelam Rawa	420	6.9	20	8.9	21,101	41.4	56.9	0.32
5.	Keladi Liar	15	0.2	6	2.7	577	1.1	4.0	0.06
6.	Kucingan	14	0.2	6	2.7	44	0.1	3.0	0.05
7.	Nipah	7	0.1	4	1.8	4,946	9.6	11.5	0.12
8.	Paku Gambut	360	5.9	20	8.9	916	1.8	16.6	0.16
9.	Paku Hurang	859	14.0	10	4.4	3,889	7.6	26.0	0.21
10.	Paku Laut	70	1.1	16	7.1	1,978	3.8	12.0	0.13
11.	Paku Tali	80	1.3	8	3.6	63	0.1	5.0	0.07
12.	Perumpung	230	3.8	5	2.2	1,625	3.2	9.2	0.11
13.	Pulai	6	0.1	6	2.7	1,884	3.7	6.5	0.08
14.	Rumput Pait	180	2.9	10	4.4	1,272	2.5	9.8	0.11
15.	Seduduk	32	0.05	18	8.0	628	1.2	9.7	0.11
16.	Serdang	5	0.1	5	2.2	565	1.1	3.4	0.05
17.	Sembung Rambat	30	0.5	12	5.3	94	0.2	6.0	0.08
18.	Sikejut Perdu	40	0.6	8	3.6	554	1.1	5.3	0.07
19.	Teki Rambat	56	0.9	10	4.4	44	1.1	5.4	0.07
20.	Teki 1	255	4.2	12	5.3	3,203	6.2	15.7	0.15
21.	Teki 2	175	2.8	14	6.2	1,236	2.4	11.4	0.12
Total		6,112	100	225	100	51,370	100	300	2.53

Source: Armanto *et al* (2011) and Armanto *et al* (2010).

Description: K: Density value, F: Frequency, KR: Relative density (%), FR: Relative frequency (%)

D: Domination, DR: Relative dominance (%), INP: Important Value Index, H: Diversity index

Climate and Water Balance

Climate plays an important role in the pyrite formation associated with the production of organic material. The climate type in Pulau Rimau is Type B climate (Schmidt and Ferguson, 1951). Type B Climate is a type of dry climates which have a dry month on average less than 3 months of the year. Dry months are the months with rainfall < 70 mm (evaporation exceeds precipitation). In the Type B climate, the monthly rainfall distribution is uneven throughout the year. In the rainy season, monthly rainfall values can reach 300-400 mm/month. By contrast, in the dry season the

monthly rainfall is very low (< 70 mm/month). Rainy days ranges from 6-19 days per month depending on the season. Only rainfall patterns are most closely associated with pyrite oxidation. The research site is included in aquatic moisture regime (saturated water).

The temperature regime is isohyperthermic because the annual average temperature is always > 25 °C with a difference < 5 °C. Relative humidity throughout the year is between 70-90% with daily average temperatures which show little variation, which is about 32 °C as maximum temperatures and an average minimum temperature of 29 °C. The length of day

varies under 12 hours throughout the year. The result of climate data analysis conducted by the JICA Study Team is presented in Figure 1. The average rainfall is 2,870

mm/year with no dry months (< 70 mm). The wettest months are November to April. The driest months are July (88 mm) and August (119 mm).

Figure 1. Analysis of climatic data (JICA Study Team, 2003)

The water balance gives an overview of lack or excess condition of water to cultivated crops. The water balance for the food crops are presented in Table 2. Determination of the period of growing crops in water balance analysis is based on the planting habit by farmers in the field and the analysis of climate data. Evaporation and transpiration (evapotranspiration) are approached by the existing of climate data. The used method in evaporation calculating is a modified Penman for Evapotranspiration (ETo). Variations of this ETo value in relation to rainfall provides a description of the general condition of lack or excess of water at the sites.

Monthly potential evapotranspiration ranges from 107 mm/month in February to 142 mm/month in August. This value varies from 103-111 mm/month. The monthly potential evapotranspiration data are then used in the calculation of consumptive water needs of some types of vegetation. Table 2 explains that the water needs of crops in the dry season cannot be met if only relying on existing rainfall. Planting in the rainy season is potential in terms of water availability. In the rainy season is very much excess water to flow away into the rivers and swamps. In this case the system is required water disposal

from root zone on the land to be cultivated. The same case for fishery, if very much excess water exist, this condition is not suitable for fishery, in dry season fishery needs water from irrigation in order to maintain pyrite in anaerobic condition and it is not oxidized.

Drought conditions are a serious threat if the rain does not fall within 10-15 days. This can be calculated based on rooting depth, water available and the rate of crop evapotranspiration. For example, if water is available 15% at 30 cm of root depth, it means water availability of 45 mm (0.15×30 cm) in the root zone of crops. Assuming that the rate of evaporation and transpiration is 4 mm/day, the availability of this water will run out for $45/4 = 11$ days (Susanto *et al.*, 1995).

If the observed conditions of climate data and water balance associated with fishery and crops needs, the climate is passive factor and cannot be changed. However, the climate can be integrated with existing condition. It means that it opens the possibility that pyrite will be oxidized and will go to nearby rivers to form very acid river water. This acid water will flow to fishery area and support the formation of acid sulfate soils if we do not treat the water and the soils carefully. It is

strongly recommended that appropriate technologies for crop water requirements are integrated with prevention or avoiding of pyrite oxidation. If pyrite is oxidized and acid sulfate soils will be stimulated and formed, so

it will happen again the some failure of the management of tidal wetlands as we are finding now in the field and may be even worse than current conditions.

Table 2. Water balance summary for fishery and some food crops

Fish/Crops	Fishes and crops period	Water supplies (mm)	Water need
Fish	November to March	> 743	Drainage
	May to August	< 120	Irrigation
Corn	May-June-July	< 90	Irrigation
Soybean	May-June-July	< 105	Irrigation
Chili	May to September	< 150	Irrigation
	November to March	> 837	Drainage
Peanuts*/	May to September	< 129	Irrigation
	November to March	> 743	Drainage
Melon */	May to August	< 93	Irrigation
	November to February	> 705	Drainage
Banana*/	January to December	> 1,251	Drainage
Orange*/	January to December	> 939	Drainage

Source: Calculated from climatic data, */ Susanto *et al* (1995).

Supporting Fauna

Fauna (crabs and mud shrimp) makes holes in the soil and the soils were excavated and stockpiled into small mountains. These mountains particularly under the Nipah and Mangrove vegetation cover 30-60% of the land surface. The excavated soils typically contain pyrite which is then oxidized to produce very acid water and to form acid sulfate soils.

Sulfur compounds are often found in tidal wetlands originating from the sea. The content of S (sulfur) in sea water is very high, ranging from about 885 ppm (around 4 times higher than those levels in the crust of the earth, granite, basalt or shale). The process of sulfide formation is started from the accumulation of sulfate arising by the processes of reduction into sulfides and S-elementary. This process is performed by bacteria *Desulfovibrio* and *Desulfomaculum* in reduction condition at pH 7 to 8.5 and the presence of organic material. Vegetation of *Rhizophora racemosa* (Mangrove), *Nipah pruticans* (Nipah) and *Avicenia sp* are the sources of organic matter needed by these bacteria.

Pyrite Oxidation and Water Dynamics

Water Dynamics of Observed Rivers

Pyrite oxidation is due to tidal movement of sea water. There are several main rivers (i.e. Calik, Senda, Betung and Primary Channels) that their water surface height can directly affect pyrite oxidation. Height of the surface ground water in the tidal wetlands is strongly influenced by the seasons and river water. In the rainy season, the surface water can reach +0.5 m asl, but in the dry season it could come down to -1.5 m below sea level (m bsl). The highest dynamics of surface water level was found in Senda river (+7 m asl). There is a tendency that the area around the large rivers flow, the dynamics of the surface water level is lower, which is seen at points along the Calik river which is the largest river in the research location. All main rivers and primary channels go to the Calik river. Amount of rivers in this area is more than 20 large and small rivers. Rivers are classified as long, i.e. Calik, Sendan and Betung.

Fluctuations in river water at high tide and low tide varies widely (ranging from 0.5-2 m). Water fluctuations play a role as trigger to form pyrite oxidation and distribution in whole the research sites. At low tide, the pyrite will be easy to contact with oxygen from atmosphere and pyrite oxidation occurs because of water and soil in aerobic conditions. At high tide, pyrite is difficult to be formed because of reduction conditions, but pyrite that has been oxidized at low tide will be carried by the tide and will flow throughout the research site. Incidence of such a process occurs continuously until the base material for pyrite formation is not there anymore. Therefore, it is not surprising that almost all research sites are polluted by pyrite oxidation both at high tide or low tide. Likewise, events it occurs in the rainy season and dry season.

Chemical Reactions of Pyrite Oxidation

In the anaerobic conditions in the field, pyrite (FeS_2) is stable and not dangerous for fishery and food crops, but if there is oxidation, then the situation becomes unstable. The first level of iron sulfide oxidation is the formation S_2 (elementary) which occurs below the zone of weathering environment.

Marine clay can contain as around 75-200 bases me/100 g due to 2:1 type clay mineral. Giving CaCO_3 to these soils is also greatly reducing the activity of sulfuric acid. Liming treatment is able to raise the pH of the acid sulfate soils from pH 3.5 to 5.6 and the sulfate is lost after a flooded for 24 hours. That means reduction conditions are needed to prevent or to avoid pyrite oxidation.

Management Strategy of Pyrite Oxidation

The nature has taught us to see and to treat the pyrite in accordance with reduced or anaerobic conditions. Pyrite is demanding to always be submerged by water either in a state of high tide or low tide, as well as during the rainy season or dry season. If reduction condition is maintained properly, then the

threat of pyrite as poison and disturb the balance of soil nutrients and water can be optimally eliminated. Thus, pyrite is the main indicator of success for tidal wetlands utilization (for fisheries, agricultural activities as well as for the environment).

Management strategy of pyrite oxidation aims to regulate the land resources utilization, to obtain optimum production and simultaneously to maintain the sustainability of land resources. Pyrite oxidation management requires a careful planning, monitoring and application of appropriate technology, well-balanced land development and management of land and water regulations. This is purposed that the pyrite is maintained as in reduction conditions and is not as toxic for fishery and cultivated crops and does not influence other nutrients balance. The pyrite oxidation management approach is divided into three main components, namely; Water Management Technologies, Technology of Land Management, and Commodity Management Technology.

CONCLUSIONS

Pyrite formation is largely determined by natural vegetation as Sulfur (S) donors, climate and uncontrolled water balance and supporting faunas such as crabs and mud shrimp. Climate and water balance as well as supporting faunas is the main supporting factors to accelerate the process of pyrite formation. Oxidized pyrite serves to increase soil acidity, becomes toxic to fish ponds and arable soils, plant growth and disturbing the water and soil nutrient balances. Oxidized pyrite is predominantly accelerated by the dynamics of river water and disturbed natural vegetation by human activities. The pyrite oxidation management approach is divided into three main components of technologies, namely water management, land management and commodity management.

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REFERENCES

- Armanto, M.E., M.S. Imanudin and Elisa Wildayana. 2011. Lahan-lahan Potensial untuk Pengembangan Perkebunan Kelapa Sawit di Rawa Pasang Surut Pulau Rimau Sumatera Selatan. Prosiding Seminar Nasional Peran Iptek untuk Mengantisipasi Perubahan Iklim dalam Perspektif Pertanian Berkelanjutan. Vol I:48-56, Palembang 23-25 Mei 2011.
- Armanto, M.E., S.M. Bernas and R.H. Susanto. 2010. Land Evaluation as a Basic for Directing of Landuse to Support an Increase of Cropping Index in Reclaimed Tidal Land Area. Final Research Report of Competitive National Strategy Grant. DIKTI, Indonesia.
- JICA Study Team. 2003. The Study on Comprehensive Water Management of Musi River Basin. Ministry of Settlement and Regional Infrastructure, The Republic of Indonesia.
- Schmidt, F.A. and J.H.A. Ferguson. 1951. Rainfall Types based on Wet and Dry Period Ratios for Indonesia with Western New Guinea. Publ. No. 42 Jaw Met & Geof, Jakarta.
- Soil Survey Staff. 2014. Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51 Version 2. USDA- SCS, Washington DC.
- Susanto, R.H., M.E. Armanto, Z.A. Samboe dan R.H. Purnomo. 1995. Tinjauan Kondisi Lingkungan dan Usulan Kebun Penelitian UNSRI di Indralaya, Kabupaten Dati II OKI. FP Unsri. Indonesia.