Water chemistry of Sebangau River and Kahayan River in Central Kalimantan, Indonesia

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ABSTRACT Water chemistry of two rivers in Central Kalimantan, Indonesia was surveyed in September 2003. Effects from sea salt on the surface water chemistry of the river appeared 94 km upstream from the mouth of the Sebangau River, although little effect from sea salt appeared 45 km upstream from the mouth of the Kahayan River. Water discharged from canals (Paduran, Pangkoh and Pulangpisau) into the mainstream of the Sebangau River and the Kahayan River showed lower pH compared to the mainstream water of the rivers, implying sulfuric acid loading from the canal to the mainstream of the rivers. The ratio of $\text{SO}_4^{2-}/\text{Cl}^-$, which was used as a parameter for estimating the contribution of pyritic sulfate to the river water chemistry, showed that the sulfuric acid loading from pyrite oxidation appeared from the river mouth up to 145–179 km upstream in both the rivers.

Key words: basin, canal, peat, pyrite, sea salt, sulfate

INTRODUCTION

Peat consists of the accumulated organic remains of dead plants, and peat lands are regarded as important carbon pools which regulate the green-house gases in the atmosphere (Moore et al. 1994; Martikainen et al. 1995; Hadi et al. 2000; Haraguchi et al. 2000; Shimada et al. 2001; Nakagawa et al. 2002). Tropical areas have large expanses of peat lands (Anderson, 1983) and the tropical peat especially in Kalimantan makes up a large carbon pool (RePPProT, 1990). Maltby and Immirzi (1993) estimated that 3–4% of global peat and carbon (329–525 Pg) is in Indonesian peat swamp forest. Recent agricultural utilization of peat swamp forest in Kalimantan has led to the disappearance of peat in huge areas of the district. The basin of the Sebangau River and Kahayan

River, Central Kalimantan, Indonesia, belongs to the tropical forest zone and has very high precipitation in the rainy season, which impedes plant decomposition as a result of the high water table and the consequent anoxicity in the peat layer.

Destruction of tropical peat land due to agricultural land use leads not only to global warming by emission of green house gases but also to various serious regional environmental problems. One of the regional environmental problems caused by the destruction of tropical peat is the oxidation of pyrite within the sediment underneath the peat layer in the coastal area of the tropical region, an effect much like sulfuric acid pollution in coal mining areas of Europe (Monterroso and Macías, 1998; Balkenhol et al. 2001). After destruction of the peat layer over pyrite-containing sediment, pyrite is biologically oxidized by atmospheric oxygen and sulfuric acid is produced. Then the sulfuric acid concentration increases in the soil, and a large proportion of nutrients will be lost. Discharged sulfuric acid from the soil causes the acidification of river water and subsequent effects on the littoral zone. Haraguchi et al. (2006) studied the vertical profile of the chemical properties of peat in the basin of the Sebangau River and clarified that the peat in the lower basin of the river was affected by the pyrite in the mineral layer underneath the peat layer. However, insufficient data are available for clarifying the range of pyrite distribution and the extent to which peat soil and discharged water are polluted by the sulfuric acid after pyrite oxidation.

The objective of this study is to estimate the area of the basin which is chemically affected by the sulfate produced by pyrite oxidation under the peat layer. In this study we accumulated the fundamental chemical data on river water in the two basins in Central Kalimantan, Sebangau River and Kahayan River. We collected surface water from the river including discharged water from canals at 1–3 km intervals and analyzed the chemical components in the water. The surveyed area ranged from

the river mouth to the uppermost stream of the Sebangau River (ca. 176 km from the river mouth). In the Kahayan River, we surveyed the range between 45 km and 262 km from the river mouth including Rungan tributary (from 224 km to 246 km from the river mouth). From the analytical data for dissolved dominant cations and anions, we estimated the range over which the river water is affected by sulfuric acid produced by pyrite oxidation.

MATERIALS AND METHODS

Study area

We surveyed two rivers in Central Kalimantan, Indonesia during dry season, that is, the lowest precipitation period of the year. Sebangau River originates at Kya, 6 km upstream from Kerengbangkirai (the southern part of Palangkaraya city), and flows west of Palangkaraya city (Fig. 1). Six main tributaries (Bakung, Rasau, Bangah, Ranang, Paduran and Ketimpun) flow into the main stream of the Sebangau River. Six canals have

been constructed and connected to the Sebangau River from the eastern part of the main stream. The Kahayan River originates at Kahukung Mountain area (ca. 200 km upstream from Palangkaraya) and flows east of Palangkaraya city (Fig. 1). Five canals from the western part and five canals from the eastern part have been connected to the main stream of the Kahayan River downstream from Palangkaraya. The Kahayan River is connected to the Kapuas River by the Pulangpisau Canal from Pulangpisau to Kualakapuas. The Rungan River, a tributary that merges 6 km upstream of Palangkaraya, was also studied.

Water sample collection

Water samples were collected from the two rivers in Central Kalimantan in September 2003. Water samples from the Sebangau River were collected on 10 September 2003 from Kerengbangkirai ($2^{\circ} 18' 13''$ S, $113^{\circ} 54' 28''$ E; 170 km from the river mouth) to Rasau ($2^{\circ} 29' 33''$ S, $114^{\circ} 02' 30''$ E; 137 km from the river mouth), on 11

Fig. 1. Study area and sampling points in Sebangau River and Kahayan River in Central Kalimantan, Indonesia. Canals are presented as dotted lines. Number in the parenthesis denotes the distance from the river mouth.

September 2003 from Kerenbangkirai to Kya ($2^{\circ} 18' 25''$ S, $113^{\circ} 52' 47''$ E; 176 km from the river mouth) and on 12 September 2003 from Rasau to the mouth of the river ($3^{\circ} 10' 24''$ S, $113^{\circ} 36' 13''$ E). Kya is at the uppermost stream of the Sebangau River. Five samples from Paduran tributary ranging from the confluence ($2^{\circ} 53' 38''$ S, $113^{\circ} 52' 23''$ E; 48 km from the river mouth) to the location $2^{\circ} 53' 26''$ S, $113^{\circ} 51' 47''$ E (49.5 km from the river mouth) were collected at ca. 200 m intervals on 12 September 2003.

Water samples from the Kahayan River were collected on 11 September 2003 from Palangkaraya ($2^{\circ} 12' 41''$ S, $113^{\circ} 55' 31''$ E; 224 km from the river mouth) ranging from the upper stream to the location $2^{\circ} 00' 42''$ S, $113^{\circ} 55' 53''$ E (262 km from the river mouth) and also from the upper stream of Rungan tributary ranging from the confluence ($2^{\circ} 10' 10''$ S, $113^{\circ} 55' 18''$ E; 124 km from the river mouth) to the point $2^{\circ} 05' 32''$ S, $113^{\circ} 50' 30''$ E (246 km from the river mouth), and on 17 September 2003 from Palangkaraya ranging downstream to the point $3^{\circ} 00' 00''$ S, $114^{\circ} 09' 58''$ E (near Pangkoh; 54 km from the river mouth). One sample from Pangkoh Canal ($2^{\circ} 57' 42''$ S, $114^{\circ} 09' 07''$ E; 59 km from the river mouth and 2.31 km from the confluence) and another sample from Pulangpisau Canal ($2^{\circ} 45' 12''$ S, $114^{\circ} 16' 04''$ E; 81 km from the river mouth and 1.16 km from the confluence) were collected on 17 September 2003.

Water samples were collected at the center of the river at intervals of every 1.0–2.0 km along the rivers. Each water sample was directly collected from a boat by using a ca. 1,000ml plastic tub at each sampling point. The position of each sampling point was determined by GPS (POKE-NAVI 65EX, EMPEX Co. Ltd., Tokyo, Japan).

Chemical analysis

Water temperature and pH of the collected water were measured just after the water sampling by using a pH meter (TOA Model HM-14P, TOA Denpa Co. Ltd, Tokyo Japan). Water samples were filtered within 12 hours after sampling using a 0.45 μ m cellulose acetate membrane filter (Advantec Toyo Dismic25AS045AN, Advantec Co. Ltd., Tokyo, Japan) and stored at room temperature in 2.0 ml plastic tubes before chemical analysis. Major cations and anions (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , NH_4^+ , NO_2^- , NO_3^- , Cl^- , SO_4^{2-} , PO_4^{3-}) were determined by ion chromatograph (Dionex Model DX-120, Japan Dionex Co. Ltd., Tokyo, Japan).

RESULTS

Water chemistry of the Sebangau River

We described the tendencies of water chemistry evident in each river from the upstream areas to those areas downstream.

In the Sebangau River, the pH of the river water decreased from the 176 km point to the 143 km point, then decreased abruptly from the 143 km point to the 133 km point (pH=3.51), and then the pH abruptly increased to 4.08 at the 133 km point (Fig. 2). Then the pH gradually decreased from the 133 km point to the 83 km point and again it increased downstream from the 83 km point. The pH in the Paduran canal was lower than in the main stream of the Sebangau River and it changed by 0.52 units within 1.48 km. Ammonium ion concentration fluctuated between the 48 km point and the 176 km point, and the value was constantly under the detection limit downstream from the 47 km point (Fig. 2). Ammonium ion concentration in the Paduran canal was as high as in the main stream of the Sebangau River. Sodium ion concentration increased from the 176 km point to the 94 km point, abruptly decreased to the minimum at the 92 km point (1.31 mg l^{-1}), and then increased to $6,846 \text{ mg l}^{-1}$ at the river mouth (Fig. 2). Sodium ion concentration in the Paduran canal was lower than in the main stream of the Sebangau River. Potassium, magnesium and calcium ion concentrations were almost constant from the 176 km point to the 63–67 km point, and then increased to 30 mg l^{-1} , 108 mg l^{-1} , and 31 mg l^{-1} , respectively, from these points to the river mouth (Fig. 2). Potassium, magnesium and calcium ion concentrations in the Paduran canal were higher than in the main stream of the Sebangau River. Chloride ion concentration was rather constant from the 176 km point to the 105 km point, and then increased to $23,325 \text{ mg l}^{-1}$ from the 105 km point to the river mouth (Fig. 2). Nitrate ion concentration gradually increased from the 176 km point downstream to the 46 km point and fluctuated under 0.6 mg l^{-1} (Fig. 2). Nitrate concentration downstream from the 46 km point was lower than in the upper stream from the 46 km point. Chloride and nitrate ion concentrations in the Paduran canal were as high as in the main stream of the Sebangau River. Sulfate ion concentration was rather constant from the 176 km point to 145 km point, and then increased to $2,877 \text{ mg l}^{-1}$ from the 145 km point to the river mouth (Fig. 2). Sulfate ion concentration in the Paduran canal was higher than in the main stream of the Sebangau River.

Water chemistry of the Kahayan River

In the Kahayan River, the pH decreased from the 262 km point to the 224 km point and the pH showed a minimum (5.50) at the 186 km point from the river mouth (Fig.

Fig. 2. Water chemistry of surface water of Sebangau River on 11–13 September 2003 in Central Kalimantan, Indonesia. Data from the main stream of Sebangau River (closed circle) and from the Paduran Canal (open circle) are presented.

3). The pH increased from the 224 km point to 152 km point, and then fluctuated around 7.1 to the 45 km point. The pH of the tributary Rungan decreased from the 246 km point from the river mouth to the confluence with the main stream of the Kahayan (230 km from the river mouth). Water in the Pangkoh Canal and Pulangpisau Canal showed lower pH than that of the main stream of the Kahayan. Ammonium ion concentration fluctuated under 0.3 mg l^{-1} , although values of $1.0\text{--}1.8 \text{ mg l}^{-1}$ appeared upstream from the 226 km point. Ammonium ion concentration in the water of the Rungan as well as in the two canals was the same level as that for the main stream. Sodium ion concentration fluctuated from $3.0\text{--}5.5 \text{ mg l}^{-1}$ between the 167 and 262 km points, decreased from the 167 km to the 262 km point, and then fluctuated around 2.0 mg l^{-1} from the 163 km to the 45 km point (Fig. 3). Sodium ion concentration of the tributary Rungan did not differ from that of the main stream of the Kahayan River. Sodium ion concentration of the two canals was a little higher than that found in the main stream. Potassium ion concentration fluctuated between 0.5 and 0.8 mg l^{-1} and the concentration of the tributary Rungan did not show any difference from that of the main stream of the Kahayan River (Fig. 3). Potassium ion

concentration showed its maximum at the 224 km point. Potassium ion concentration of the two canals was a little higher than that seen in the main stream. Magnesium and calcium ion concentrations decreased from the 262 km point to the 226 km and 224 km points, respectively, and then increased from these points to the 154 km point, then decreased from the 152 km point to the 45 km point (Fig. 3). Magnesium and calcium concentrations of the tributary Rungan were lower than that of the main stream of the Kahayan River and the values were almost under the detection limit. Magnesium and calcium ion concentrations of the two canals showed the same levels as the main stream. Chloride ion concentration fluctuated between 0.4 and 0.9 mg l^{-1} and the concentration of the tributary Rungan did not show any difference from that found in the main stream of the Kahayan River (Fig. 3). Chloride ion concentration of the two canals was a little higher than that in the mainstream. Nitrate ion concentration fluctuated between 0.5 and 1.5 mg l^{-1} , although the concentration downstream from the 169 km point was rather higher than that upstream from the 169 km point (Fig. 3). Nitrate ion concentrations of the water in the Rungan as well as the two canals did not show differences from results for the main stream of the

Fig. 3. Water chemistry of surface water of Kahayan River (closed circle) and the tributary Rungan (open circle) on 11 and 17 September 2003 in Central Kalimantan, Indonesia. Data from the two canals, Pangkoh and Pulangpisau, are also presented identifying by arrows and the extreme data are presented by the concentration inside each figure.

Kahayan River. Sulfate ion concentration in the Kahayan River fluctuated between 1.3 and 2.0 mg l⁻¹, showing local peaks at the 101 km, 162 km and 224 km points (Fig. 3). Sulfate ion concentration of the main stream showed a minimum (1.03 mg l⁻¹) at the 133 km point. Sulfate ion concentration in the Rungan tributary was lower than that in the main stream of the Kahayan River. Sulfate ion concentration of the two canals was much higher than that found in the main stream.

DISCUSSION

The effects of sea salt on the water chemistry of surface river water

In order to estimate the effects of sea water on the water chemistry of the river water, we used the Cl⁻/Na⁺ ratio and estimated how the sea water affects the water chemistry of the river water at various distances.

In the Sebangau River, chloride and sodium ion concentrations increased downstream from the 92 km point and 105 km points, respectively, from the river mouth. This implies that the effect of sea water on the water chemistry of the Sebangau River appeared from the river mouth to an area 92–105 km upstream (Fig. 2).

Potassium, magnesium and calcium ion concentrations and the pH also increased downstream from the 63–83 km point from the river mouth. The Cl⁻/Na⁺ ratio in the Sebangau River upstream from the 94 km point from the coastline was 0.3 and it increased downstream from the 94 km point (Fig. 4). At the 67 km from the coastline, the ratio showed a partial minimum and then it increased downstream from the 67 km point. The Cl⁻/Na⁺ ratio at the 54 km point was equal to the ratio in sea water (1.8), and the ratio showed its maximum at the 22 km point (4.2). The ratio was ca. 3.0–3.5 downstream from the 22 km point to the river mouth, and the ratio was higher than the ratio in sea water. Sodium ions were adsorbed to the fomic substances by exchanging protons from the fomic substances, whereas chloride ions showed little exchange with anions in organic materials. High concentrations of dissolved organic substances in river water outflows from peat swamps in the basin would cause cation exchange in sea salts, and so the Cl⁻/Na⁺ ratio showed higher values than in sea water in the downstream portion of the Sebangau River. The Cl⁻/Na⁺ ratio downstream from the 94 km point was higher than that in the stream above the 94 km point, and so the effect of the sea water appeared from the river mouth to the 94 km point from the river

Fig. 4. Ratio of chloride and sodium ions (weight ratio) of the surface water of the Sebangau River (upper) and Kahayan River (lower) in Central Kalimantan, Indonesia. Closed circle (upper and lower): main stream of the river, open circle (upper): Paduran canal, open circle (lower): tributary Rungan. Data from the two canals in Kahayan River are presented identifying by arrows.

mouth.

In the Kahayan River, sodium and chloride ion concentrations increased downstream from the 66 km point from the river mouth; however, the tendency was not so obvious as in the Sebangau River (Fig. 3). The Cl^-/Na^+ ratio in the upstream portion of the Kahayan River from the 186 km point was 0.1–0.2, and the ratio was almost the same as the value in the Sebangau River (Fig. 4). This implies that the loading of sodium and chloride ions from the upper basin to the river was common between the Sebangau River and the Kahayan River. The Cl^-/Na^+ ratio increased from the 186 km point to the 142 km point and it showed a maximum of 0.6–0.8 at the 142 km point. The value fluctuated between 0.2 and 0.6 downstream from the 142 km point to the 45 km point. Even at the 45 km point from the coast line, the Cl^-/Na^+ ratio showed a lower value than the sea water. Relatively lower concentration of organic substances in the Kahayan River than in the Sebangau River would lead to the lower cation exchange in the Kahayan River, and so the Cl^-/Na^+ ratio did not show a value higher than that for the sea water. Sodium and chloride concentrations were also much lower than those for the sea water, and hence the effect of sea water on the river water chemistry did not appear even at the 45 km point from the river mouth in the Kahayan River. A comparatively high flux of river water in the Kahayan River, compared to the Sebangau River, would be the reason why sea water did not affect

the surface water chemistry at 45 km from the river mouth.

Effects of pyritic sulfate on the water chemistry of the surface river water

We estimated the range over which sulfuric acid originating from pyrite oxidation affects the water chemistry of the river. Sulfate ions come both from sea water and from water discharged from pyrite-containing soil. Sulfate ion concentration in the water discharged from soils in which pyrite oxidation occurs is usually much higher than the chloride concentration, and so the ratio of $\text{SO}_4^{2-}/\text{Cl}^-$ can be used to evaluate the effects of sulfuric acid from pyrite oxidation on the river water chemistry.

Increases of sulfate ion concentration down stream from the 145 km point imply that the effects of sulfate originating from pyrite oxidation appeared 145 km upstream from the coast line in the Sebangau River (Fig. 2). Water in the Paduran Canal showed lower pH and higher sulfate ion concentration, implying an extensive sulfuric acid discharge from the basin of the Paduran Canal. The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio in the Sebangau River decreased from the 176 km point to the 142 km point, and it showed a minimum at the 142 km point and it increased from the 142 km point to the 97 km point (Fig. 5). The ratio decreased from the 97 km point to the 46 km point and it fluctuated around 0.18, the same value found in

Fig. 5. Ratio of sulfate and chloride ions (weight ratio) of the surface water of the Sebangau River (upper) and Kahayan River (lower) in Central Kalimantan, Indonesia. Closed circle (upper and lower): main stream of the river, open circle (upper): Paduran canal, open circle (lower): tributary Rungan. Data from the two canals in Kahayan River are presented identifying by arrows.

the sea water, from the 46 km point to the river mouth. Increases of $\text{SO}_4^{2-}/\text{Cl}^-$ ratio downstream from the 142 km point implied that the effect of pyrite on the river water chemistry appeared downstream from the 142 km point from the river mouth.

Sulfate concentration of the main stream of the Kahayan showed a local minimum at the 133 km, 174 km and 226 km points (Fig. 3). This implies that the effects of sulfate ions from the pyrite oxidation on the water chemistry appeared at the 133 km or 174 km or 226 km points. The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio in the Kahayan River was consistently much higher than the ratio in sea water. The ratio in the tributary Rungan was ca. 1.0–2.0, lower than the main stream of the Kahayan (Fig. 5). The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio decreased from the 262 km point to the 179 km point, and then the ratio increased from the 179 km point to the 160 km point, and again it decreased from the 160 km point to the 142 km point. The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio increased downstream from the 142 km point, and it decreased downstream from the 72 km point. The $\text{SO}_4^{2-}/\text{Cl}^-$ ratio showed local minima at the 142 km and 179 km points. This implies that the effects of sulfuric acid from pyrite on the surface river water chemistry would appear at the 142 km or the 179 km points from the river mouth in the Kahayan River. The water in the two canals directly connected to the Kahayan River showed extremely high values (Pangkoh: 6.9 and Pulangpisau: 3.5) for the $\text{SO}_4^{2-}/\text{Cl}^-$ ratio, implying that the canal water contained greater

amounts of pyritic sulfate than the main stream of the Kahayan River.

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