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ABSTRACT

Irrigation source is one of factors affecting physical properties of paddy soil. This research was aimed to determine the impact of polluted irrigation on soil physical properties of rice field. The study site was located in Koto Nan IV (00o 54' 21.9" S and 100o 23'52.2" E), Dharmasraya Regency, West Sumatra, Indonesia. The rice field over there was irrigated with water from Momongan river in which people did gold mining illegally. For comparison, rice field receiving irrigation from non-polluted source nearby was also anaysed for the physical properties. The result showed that there was a change in physical properties of paddy soil after 7 years of getting irrigation from the river. Based on laboratory analyses, the total suspended solid (TSS) in the tailing reached 10,736 mg/L. The texture of paddy soil was dominated by sand (>50% at the top 100 cm soil depth), and it tended to linearly decrease (R2=0.65) by depth. Likewise, the sand particles also linearly decreased (R2=0.83) but clay particles linearly increased (R2=0.74) as the distance from the water input (terrace-1) became further. This sandy textured soil increased the hydraulic conductivity rate (by up to 19.1 times), soil bulk density (by 38%), and sharply decreased SOM (by 88.5 %), as well as soil total pore (by 22.1%) compared to the paddy soil receiving non-polluted irrigation at the top 20 cm soil. The rice field was suggested to be reclaimed before reusing it, otherwise the soil characteristics requirement, especially soil water retention, for rice field could not be fulfilled.

Keywords: Illegal gold mining, Paddy soil, Polluted irrigation, Soil physical properties

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1. INTRODUCTION

Gold mine tailing contributes to environmental degradation, due to the soil particles and the minerals contatined in it (Hu et al., 2014; Sahara and Puryanti, 2015; Abdul-Wahab and Marikar, 2012, Yassir and Alain, 2016). Some of the minerals, especially heavy metals such as Hg, Pb, Cu, As, Ag, Pt, Cd. Cr, Ni, Co, dan Zn are considered as toxic elements (Keskin, 2010; KLH, 1990). Even the micro essential elements, Fe and Mn, can be toxic to plants if the concentration is quite high (Alghobar and Suresha, 2016; KLH, 1990). Most of the tailing was dumped into rivers nearby, where the water was used for farming lands as well as for domestic use (Sahara and Puryanti, 2015; Uktiani et al, 2014; etc.).

Sujatha et al (2016) found that polluted water near Johnson's industry in Autonagar India was above maximum desirable limits due to industrial waste from the site itself, as well as from the agricultural and antropogenic waste in the surrounding area. Yulnafatmawita et al (2017) reported that soil erosion from agricultural land did not only distributed soil particles to the environment, but it also brought some nutrients especially N, P, K to the water source causing eutrophication. Furthermore, Hakami (2015) reported that soil and water pollution due to agrochemical application had caused serious impact on food safety and people health in arid dryland area.

If the mining is located in a river, the water will be more polluted due to more soil particles and the chemicals used to process the minerals are dispersed and distributed in the river water. As water of the river used for rice field irrigation, the particles dissolved and suspended will be accumulated in rice field. Rice fields getting water directly from the river were so much affected than those receiving through tertiary canal. Some heavy metals accumulated in rice field due to mine tailings were Cu, Zn, and Cd in China (Hu et al, 2014), As, Cr, Cu, Hg, Mn, Ni, Zn, Pb, Cd in Cam Pha, Vietnam (Martinez et al., 2013); As and Fe in Annum Valley of Ghana (Adomako et al, 2014), Cu and Zn in Guangdong, China (Yang, 2008), Zn, Mn, Fe, Cu, and Pb in Gazipur, Bangladesh (Begum et al, 2011).

Other farming lands could be also contaminated by mine tailings. The amount of heavy metals accumulated in plants reported by Khan et al (2008) had exceeded the permissible limits by WHO. Some of the toxic elements determined were As, Co, Cd,Cr, Sn, Pb, Sb, Hg, Se, and Ni, in grazing cattle at Kidston Gold Mine, Queensland Australia (Bruce et al., 2003), Cu, Pb, and Zn in Vietnam (Khai et al., 2008) and Zn at Kolar Gold Field in India (Roy et al., 2012), etc. All were found to be yield reduction.

Accumulated soil particles and some heavy metals in rice fields change properties and fertility of paddy soil, either the physical, chemical, or biological fertility of the soil. Physical properties are the main factors considered in rice field formation. Arunachalam et al (2004) reported that fine gold mine tailings from Boddington Mine, Western Australia caused extreme soil physical and chemical properties such as massive clay structure, desiccation cracks, high penetration resistance when dry, low hydraulic conductivity, high pH and salinity. Furthermore they also found that there was a linear relationship between penetration resistance and size of the roots and water content.

Polluted irrigation source gives bad impact to the plant growth. As reported by Alia et al (2015) that root length of rice crops decreased and could be damage with increasing Al and/or Fe concentration in soil. However, at higher soil pH, organic acids such as oxalic and citric secreted by rice roots were able to chelate the Al and Fe ions causing they were unavailable to rice crops. Dong et al (2012) determined that high heavy metals (Cd and Cr) concentration was found within wheat grains growing in mining area in Xuzhou China exceeded the national food hygiene standard. The following impact will be on people health. Alia et al (2015) determined that as soil pH increases into 6.0, rice could protect itself against Fe toxicity by secreting organic acids from the roots which can chelate Fe ions. Even treated waste water did not improve rice yield in Vidyaranyapuran due to increase of micronutrients in soil and plant crops (Alghobar and Suresha, 2016).

Illegal gold mining in Koto Nan IV Dharmasraya regency since 2004 has caused in situ land degradation and polluted main water resource. The gold mine tailing resulted caused the soil particles and all of elements contained polluting the water river (Sahara and Puryanti, 2015). This was indicated by the color of the river water which had turned yellowish-brown. Meanwhile, the river water was used by people for domestic purposes and also for rice field irrigation. Sahara and Puryanti (2015) found that the Batang Hari river contained high Hg and Pb concentration, which was above the standard limit stated by Indonesian Ministry of Environment No. 82 year 2001, especially in Batu Bakauik, Dharmasraya.

2. MATERIALS & EXPERIMENTAL PROCEDURES

Illegal gold mining was conducted in Momongan river in Subdistrict IX Koto Dibauah, Dharmasraya Regency, Indonesia since 2007. It was still going on during this research time in 2016. The mining and the processing of the gold ore took place in the river. The tailing was directly dumped into the river. Therefore, the water color along the river turned yellowish brown until it met the Batang Hari river. The water from the Momongan river was used to utilize by people as an irrigation source for the rice field along the river sides. One location in the river bank using the river water as the irrigation source was Nagari Koto Nan IV. People directly took water from the river using water mill for the rice field irrigation. The rice field receiving the polluted water was said as polluted rice field (PRF) and that which did not receive polluted water was said as non polluted rice field (NPRF).

Soil samples were taken from PRF at 101°24’0.61” E and 01°00’0.52” S, and NPRF at 101°24’16.4” E and 01°00’44.1” S, in Nagari Koto Nan IV, Subdistrict IX Koto Dibauah, Dharmasraya Regency, Indonesia. For each rice field, soil samples were taken from dry and wet condition. Dry rice field (at PRF) was rice field that was not reclaimed since receiving polluted irrigation from the gold mining started. At the sampling time, the rice field had been fallowed for 2 years. This soil was sampled from the top to 100 cm depth with 20 cm increment to look at the vertical variation of the physical properties. The dry NPRF was sampled at the top 20 cm depth. At wet PRF, soil was horizontally sampled from the terrace in which polluted irrigation water was directly received from the river (terrace-1) until the farthest terrace (terrace-5) to determine horizontal variation of the soil physical properties

The gold mine tailing was also sampled for 5 days to determine the total suspended solid (TSS) discarded into the river. Parameters analyzed for these samples were soil texture (using sieve and pipette method based on Gee and Bauder, 1986), heavy metal content (using XRF method), SOM content (using wet oxidation method), total-N using digestion method), soil bulk density (BD) and total pore (TP) (using gravimetry method), and then hydraulic conductivity (HC) (using constant head method based on Darcy's low). Soil color was determined using Munsell Soil Color Chart.

3. RESULTS AND DISCUSSION

Rice field in research location was irrigated by water from Momongan river, in which people did gold mining (Fig. 1). The river water was directly uptake and poured into the rice field through traditional watermills (Fig 2). After a long time, the use of the waste water from the polluted river to the rice field caused significant effect on the paddy soil. Among the effect was at the soil physical properties of the rice field.

3.1. Total Suspended Solid

Based on laboratory analyses, total suspended solid in tailing of gold mine conducted in the river was very high. For several days of sample collected, it was found that the average of the TSS was about 10,376±970 mg/L. Compared to the tolerated value of TSS in irrigation water (≤ 600 mg/L), total suspended solid in the gold mine tailing was much higher. The average of suspended soil in the tailing was > 17 times of the tolerated concentration.

This suspended solid seemed to be derived from soil particles, especially sand, silt, and clay during gold mining and the processing. Since the gold mining activity was conducted within the Momongan river, the river where the irrigation source for the rice field, the amount of particles dispersed within the water body and then went to rice field was quite large. This number was much higher than that found by Sahara and Puryanti (2015) in Batu Bakawuik, at different river in the same regency. They reported that the value of TDS reached 3090 mg/L.

Figure 1 Gold mining and processing activities at Momongan river in Dharmasraya Regency, Indonesia (*yf-doc.2016*)

Figure 2 Traditional watermills to bring water up from Momongan river into rice field in IX Koto Dibauah, Dharmasraya Regency,(*yf-doc.2016*)

3.2. Heavy Metal Accumulation

In general, the concentration of heavy metals found in rice field receiving polluted irrigation was higher than that found in rice field receiving non-polluted irrigation (Table 1). Polluted rice field contained iron as much as 171%, Ag was uncomperable, Mn was 391%, Zn was 195%, Cr was 153%, Pb was 148%, and Ni was 200%, and Cu was 95% of those in non-polluted rice field. These heavy metals have been proved to affect rice growth and production (Begum *et al*., 2011; Alia *et al*., 2015, Dong *et al*., 2012).

Sahara and Puryanti (2015) found that the Pb content was 1.259 mg/L, and Hg was 5.198 mg/L in Batang Hari river in Batu Bakawuik, Dharmasraya. Based on 3 years evaluation by Dhramasraya Environment Control Division (2016), Momongan river in the down stream (in Sungai Kambut, Pulau Punjung) was categorized as heavy polluted river and classified as class 2 of water quality standard by using Storet method and Water Pollution Index by Indonesian Environmental Rule No.115, year 2003.

Tabel 1 Heavy metal content in rice field receiving polluted and non-polluted irrigation in Koto Nan IV, Dharmasraya Regency, West Sumatra, Indonesia

Rice Field	**Fe**	**Ag**	**Mn**	**Zn**	**Cr**	**Cu**	**Pb**	**Ni**
	mg/kg							
PRF	74036	7200	900	332	138	133	74	60
NPRF	43410	um	230	170	90	140	50	30

Note: um=unmeasureable

Concentration of Fe, Ag, and Mn in PRF tended to increase linearly (R^2=0.82, R^2=0.69, R^2=0.71, respectively) by depth in soil profile (Figure 3). This probably due to the particle density of the heavy metal (>5 Mg m^{-3}) which is considered much higher than that of soil particles (± 2.65 Mg m^{-3}), they accumulate in lower depth. Iron content in NPRF even though it was only about half of the PRF, but it was still considered higher than average in general rice field, this seems to be affected by the parent materials of the soil itself. High density (>5 Mg m^{-3}) of heavy metals, also affected the bulk density of the soils as well as total and distributed soil pores.

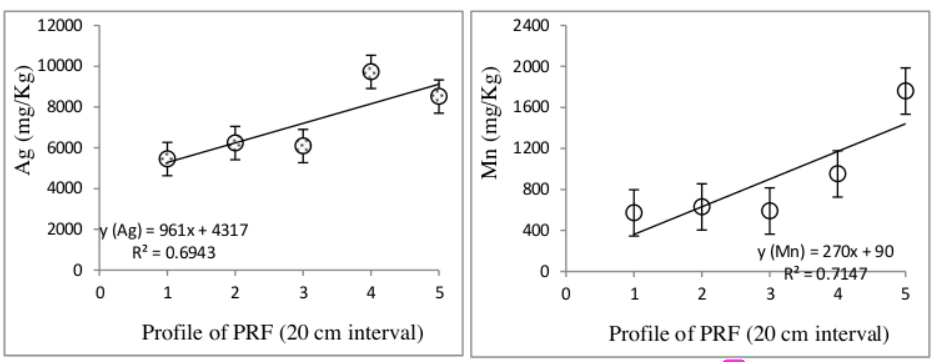

Figure 3 Heavy metals concentration in the profile of polluted rice field (PRF) in Koto Nan IV, Dharmasraya Regency, Indonesia.

3.3. Soil Properties

3.3.1. Particle Size Distribution and Soil Texture

In general, soil texture of paddy soil under PRF both vertically within the soil profile and horizontally within 5 terraces showed higher percentage of sand particles than that in NPRF (Table 2). In 100 cm depth of soil profile of PRF, sand particles decreased by depth for approximately 11% from the top 20 cm into the lowest 100 cm. This might be due to the original texture of the PRF had higher clay percentage which then mixed with incoming sand particles within the irrigation. On the other hand, the clay particles tended to increase by depth within the profile of PRF. This was caused by accumulation of sand particles brought by irrigation water that prefer to be on the top of the soil profile.

Tabel 2 Particle size distribution and texture class of dry soil profile at polluted rice field (PRF) after seven years receiving polluted irrigation as well as cultivated PRF and NPRF in Koto Nan IV, Dharmasraya Regency, West Sumatra, Indonesia

	Particle size (%)			**Texture Class**
Profile of PRF	Sand	Silt	Clay	
0-20 cm	62	24	14	sandy loam
20-40 cm	66	21	14	sandy loam
40-60 cm	63	20	18	sandy loam
60-80 cm	56	20	25	sandy clay loam
80-100 cm	55	24	22	sandy clay loam
Position of PRF				
Terrace-1	88	7	9	loamy sand
Terrace-2	55	24	21	sandy clay loam
Terrace-3	52	25	23	sandy clay loam
Terrace-4	40	36	24	Loam
Terrace-5	39	36	26	clay loam
NPRF	32	2	66	Clay

Furthermore, based on the terrace position of the PRF, the percentage of sand particles on the top 20 cm soil depth of the rice field linearly decreased (R^2=0.83) as the position of the terrace was farther from the incoming water at Terrace-1 (Figure 4). The sand particles decreased into 62.5%, 59.1%, 45.5%, 44.3% of the terrace-1, respectively at the terrace-2, terrace-3, terrace-4, terrace-5. The sand content of the farthest terrace position (Terrace-5) of PRF was 28% higher than that at NPRF. It is found to be true since the sand particles are larger and heavier than those of other soil particles, silts and clays, they will deposit faster than the others. Therefore, more sand particles determined at the first terrace and less at the last terrace. As reported by Abbasi (2014) that velocity of particles was determined by the BD and the size.

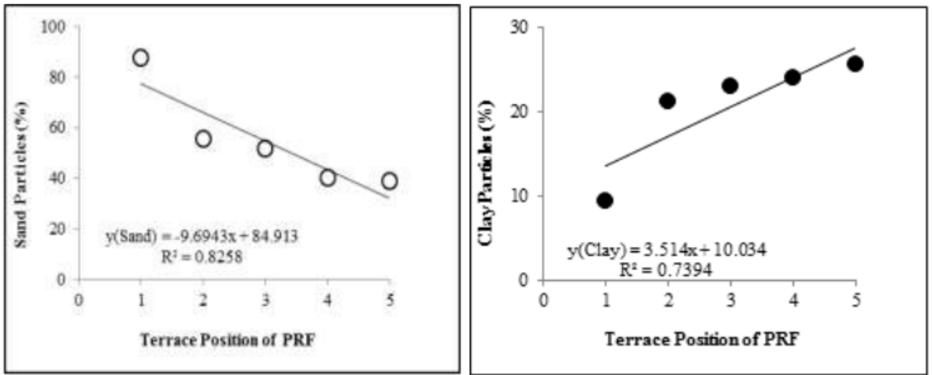

Figure 4 Sand and clay content of polluted rice field (PRF) in Koto Nan IV, Dharmasraya Regency, Indonesia.

In contrast, percentage of clay particles linearly increased (R^2=0.74) by farther position of terrace from the incoming water. It became 133%, 256%, 267%, and 289% of the that at terrace-2, -3, -4, and -5 respectively compared to terrace-1. However, if it was compared to the NPRF, the terrace-5 of PRF had 18% higher of the sand content and 61% lower of the clay content than those at NPRF. Spatial variation of heavy metals distribution was also reported at rice field in China (Zhao *et al*., 2015).

3.3.2. Other Soil Properties

Besides affecting particle size distribution and class of soil texture, polluted irrigation also affected SOM content, total nitrogen, bulk density, total pores and hydraulic conductivity of the soil in polluted rice field. If it was compared to non polluted rice field (Table 3) the SOM content decreased into 16.5%, total N into 23.5%, total pore into 77.9%, but BD increased into138%, and hydraulic conductivity into 19.1 times at polluted rice field.

Low SOM content at PRF was due to low OM content but high suspended solid in irrigation water. Because dispersed particles of soil within the rivers was derived from deep soil layers having very low or no SOM, since SOM derived from plant and animal residues mainly comes from above soil surface. Low SOM content of the soil caused high heavy metals accumulation in the soil. As reported by Liu *et al* (2016), that SOM was one of the important factors controlling the accumulation of Cd, Pb and Cr in soil and rice. The SOM content was positively correlated with the Cd concentrations in soil samples.

Tabel 3 Soil characteristics of in ricefield receiving polluted (PRF) and non-polluted (NPRF) irrigation in Koto Nan IV, Dharmasraya Regency, West Sumatra, Indonesia

Rice Field	SOM	Tot-N	C/N Ratio	Sand	Clay	BD	TP	Hydr. Cond
	%			%		Mg m-3	%	cm h-1
PRF	1.26	0.08	8.73	88	9	1.34	49.29	112.96
NPRF	7.80	0.34	13.49	32	66	0.97	63.29	5.91

Within soil profile, the percentage of SOM of PRF linearly decreased (R^2=0.65) by depth, while on the rice field landscape, the SOM content of PRF linearly increased (R^2=0.95) as the terrace became farther from the incoming water (Figure 5). This probably due to the characteristics of OM which has low density, therefore, it was not leached into deeper depth, but it moved horizontally on soil surface following water movement, instead.

Naturally, total N in soils is positively affected by the SOM, since N is generally derived from OM content of the soil. The total-N content of NPRF was 4.25 times higher than that in PRF. Low SOM and total-N were followed by low of C/N ratio at PRF, it decreased into 65% of that at NPRF. This meant that the SOM at the PRF was further decomposed. This is found to be true, since the PRF dominated by coarse particles having high macropores and good aeration when it is dried during harvest time. That condition gives favorable condition for microorganisms to decompose SOM.

Low SOM as well as high percentage of sand particles in PRF affected soil bulk density, total pores, and hydraulic conductivity. Soil BD increased by 138% compared to that of NPRF on the top 20 cm soil. This was probably contributed by sand particles and heavy metals having high density accumulated in the soil. On the other hand, the percentage of the total pores decreased into 77.9% of the NPRF (Fig. 6). There was an inverse relationship between bulk density (BD) and total pore (TP) of the soils. As reported by Yulnafatmawita *et al* (2014) that soil BD values of Ultisol under corn cultivation in Limau Manis inversely related to soil TP.

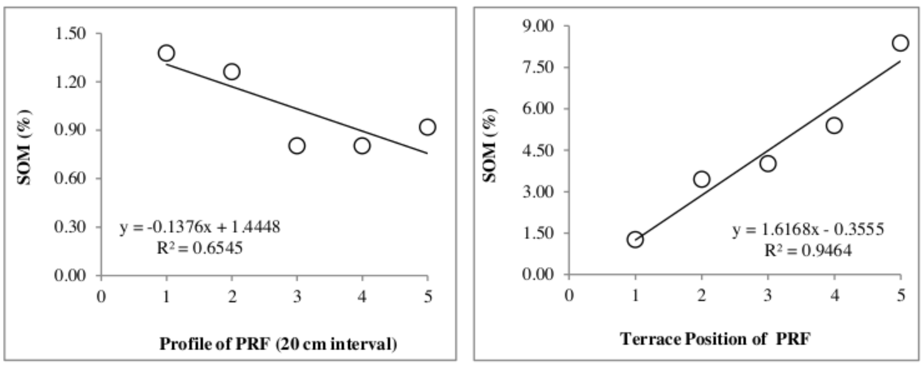

Figure 5 Relationship between depth of soil profile as well as terrace position and SOM at polluted rice field (PRF) in Koto Nan IV, Dharmasraya Regency, Indonesia.

Horizontally, on PRF landscape (Fig. 6), soil BD tended to linearly increase (R^2=0.52) and total pores linearly decreased (R^2=0.44) as the percentage of sand particles increased. High soil pores of PRF having high sand a particle was dominated by macropores which easily transmit water. Chaudhari *et al* (2013) reported that there was high positive correlation (R^2=0.91) between soil bulk density and sand particles content. Salarashayeri and Siosemarde (2012) as well as Urumovic and Urumovic Sr (2014) proved that hydraulic conductivity of a soil could be predicted by the particle size distribution.

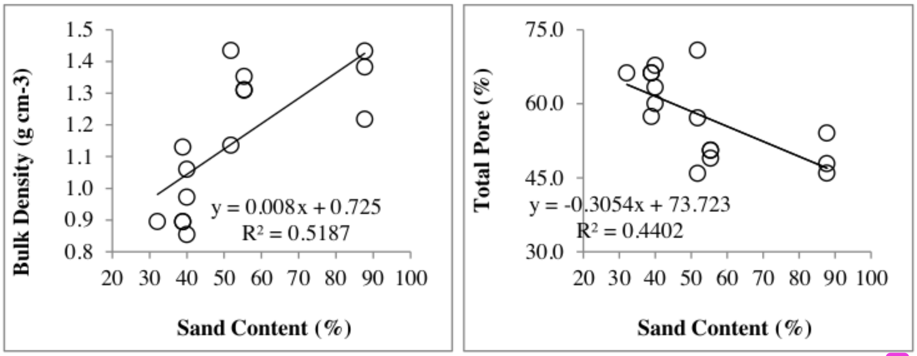

Figure 6 Relationship between sand particles and soil BD as well as TP of polluted rice field (PRF) in Koto Nan IV, Dharmasraya Regency, Indonesia.

Based on Table 4, the hue of the soil color at all terraces was 10 YR (yellowish red). This indicates that the soil minerals were dominated by iron (Fe). As presented at Table 1, the Fe concentration was extremely high, it reached 74,036 µg/kg soil. The value was almost double the Fe concentration of NPRF. This seems to be due to the effect of parent materials of the soil. Based on soil map, Dharmasraya having high temperature and rainfall annually was dominated by Ultisols and Oxisols, highly weathered soils.

Table 4 Soil Color at profile of PRF in Koto Nan IV, Dharmasraya Regency, Indonesia

Rice Field	**Depth (cm)**	**Hue**	**Value / Chroma**	**Color**
Terrace-1	0-15	10 YR	5/4	Dull yellowish Brown
	15-35	10 YR	6/3	Dull Yellowish Orange
	35-60	10 YR	6/2	Dull Yellowish Orange
	>60	10 YR	6/6	Bright yellowish Brown
Terrace-2	0-20	10 YR	4/4	Brown
	20-42	10 YR	6/3	Dull yellowish orange
	42-58	10 YR	6/2	Greyish Yellow Brown
	58-80	10 YR	4/2	Greyish Yellow Brown
	80-110	10 YR	7/2	Brownish Black
	110-120	10 YR	6/2	Greyish Yellow Brown
Terrace-3	0-50	10 YR	7/4	Dull yellowish orange
	50-70	10 YR	7/3	Dull yellowish orange
	70-100	10 YR	6/4	Dull yellowish orange
Terrace-4	0-10	10 YR	6/3	Dull yellowish Brown
	10-17	10 YR	6/2	Greyish Yellow Brown
	17-22	10 YR	6/2	Greyish Yellow Brown
	22-35	10 YR	6/3	Greyish Yellow Brown
	>35	10 YR	7/1	Light Grey
Terrace-5	0-22	10 YR	5/3	Dull yellowish orange
	22-35	10 YR	6/3	Greyish Yellow Brown
	>35	10 YR	7/1	Light Grey

4. CONCLUSION

Based on field survey and laboratory analyses, it can be concluded that polluted water due to gold mine tailing in Momongan river which was used to irrigate rice field changed the soil physical properties. The main change was soil texture, it increased sand particles from 36% to 88% and decreased clay content from 66% to 9%. This was affected by high TSS (10,736 mg/L) in the gold mine tailing. High sand particles and heavy metals accumulation increased soil BD from 0.97 to 1.34 Mg m^{-3}, decreased total pores from 63.29% to 49.29%, as well as increased hydraulic conductivity from 5.91 to 112.96 cm h^{-1}, compared to NPRF. This polluted water also decreased SOM content from 7.80% at NPRF to 1.26% at PRF. Since the rice field must physically have low hydraulic conductivity and high clay content, the rice field in the research site has to be reclaimed to maintain the productivity.

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