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Research Article

Cadmium mapping and contamination potential on different paddy field managements in Sragen Regency, Indonesia

Pungky Ferina, M.M.A. Retno Rosariastuti, Widyatmansi Sih Dewi*

Master of Soil Science Department, Agriculture Faculty, Sebelas Maret University, Jl. Ir. Sutami No. 36A, Surakarta 57126, Indonesia

*corresponding author: widyatmanisih@staff.uns.ac.id

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Abstract: Cadmium (Cd) is a harmful metal for paddy soil that is affected by inorganic fertilizer, pesticides, and industrialization. This study aimed to investigate the Cd contents in paddy soil, plant tissue, and grain, as well as the spatial distribution of potential Cd contamination. This study was conducted in Sragen Regency on paddy fields with different management, i.e., organic paddy fields, conventional paddy fields (Alfisols, Entisols, Inceptisols, and Vertisols), and paddy fields that often use wastewater (textiles, batik, and sugar factories) for irrigation. Forest land was used as a control. This study used descriptive explorative methods based on overlay land use, soil type, and industrial distribution map of Sragen Regency. The results showed that paddy soils with different management had higher Cd content than the forest soil. Organic paddy field had the lowest Cd content in soil (0.019 ppm) and rice grain (0.0006 ppm). Approximately 1,914.4 ha (3%) of paddy field in Sragen Regency that uses sugarcane industry wastewater as irrigation had the highest soil Cd content (0.16 ppm). In contrast, the highest Cd content in rice grain (0.046 ppm) was observed in conventional paddy field. The management of paddy field and rice cultivation significantly affected Cd contamination in soil and rice grain; therefore, environmentally friendly paddy field management needs to be encouraged.

Keywords: *heavy metal, pollution, remediation, spatial distribution, toxic*

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Introduction

In the recent era of the 4.0 Industrial Revolution, industrialization and urbanization activities are rapidly expanding. It should be balanced with good environmental management practices. The population of Indonesia about 271 million people, and half of the total demographic (152 million people) are on Java Island (BPS, 2020), causing high demand for goods through industrialization. More industrial factories will produce side products is a waste. One of the harmful waste is Cadmium (Cd) (Zhang et al., 2015). Cadmium is a heavy metal with atomic number 48 and includes transition metals, harmful to humans, animals, microorganisms, and easily absorbed by plants (Qin et al., 2020). In agricultural land, Cd can come from various industrial wastes, mining, household waste, the use of excess pesticides and fertilizers, especially phosphate fertilizers (María et al., 2020). Cd can absorb the human body through the food chain, and it can affect kidney damage, liver disease, cancer, bone development disorders, and 'Itai-itai' disease like occurs in Japan (WHO, 2003). Rice consumption in Indonesia in 2020 is estimated to reach 22.28 million tons (the Ministry of Agriculture, 2020). The Cadmium damage makes the Indonesian government concern about providing healthy food and free of pollutants. The Indonesian Government, through the Agency for Drug and Food Control (BPOM), has limited the maximum concentration of the Cd in the rice is 0.05 ppm, while the maximum tolerance of the Cd input in the human body is below 1 µg/kg body weight/day (the BPOM Republic of Indonesia, 2017). The Indonesian Government's effort to suppress the Cd content in the soil through regulations by lowering the value of the Cd threshold in the soil is 0.15 ppm (PP RI No. 101, 2014). Cd has accumulative properties in the soil and potentially causes Cd contamination in agriculture land (Guo et al., 2019). Sragen Regency is one of the rice centres in Central Java, Indonesia. About 68.753 ha (73.02 %) of total agriculture land in Sragen Regency is a paddy field (BPS, 2018). Cd content in the paddy field in Karanganyar village, Sambungmacan Sub-district, Sragen Regency was 1.18 ppm, it has exceeded the Cd threshold value (Sa'ad et al., 2009). In contrast, that site of the research was not an industrial area.

In August 2019, thousand hectares of agriculture land in Sragen Regency suffered drought; thus, farmers in some areas used wastewater for agricultural land irrigation. We suspected that the soil used wastewater as irrigation that potentially contains Cd larger than the paddy field never uses industrial wastewater. Pradika et al. (2019) reported that paddy field in Bedoro village, Sambungmacan Sub-district, Sragen Regency contained 0.28 ppm Cd that exceeded the threshold value. However, studies conducted by Sa'ad et al. (2009) and Pradika et al. (2019) in the Sambungmacan Sub-district, Sragen Regency focused only on a small and local scale. Yet, there are 19 other districts in Sragen Regency with different ways of managing paddy fields, some organically, conventionally, and some even use industrial wastewater as irrigation. Do all rice fields in Sragen Regency contaminated with Cd exceed the threshold value? What about Cd in rice plants? These questions are the focus of this research. Cadmium mapping on a large scale is very important to identify the production of rice that originated from the Cd contaminated area and to reduce the risk.

This study aimed to explore the Cd content of paddy soil, plant tissue, and rice grain with different paddy field managements, evaluate the relationship Cd in the soil, paddy tissue, and rice grain, and create a spatial distribution map of potential Cd contamination in Sragen Regency. Understanding the Cd relationship between soil - plant - and grain is very important to determine the direction of a healthy rice culture policy.

Materials and Methods

Study area and data collection

The study area was a paddy field with different management, located in Sragen Regency, Central Java Province, Indonesia. The geographic positions of the study sites are spread over at 110º45′-111º10′ E, and 7º15′-7º30′ S, with a total area of 941.55 km^2. Sragen Regency consists of 20 sub-districts, with an average rainfall of 3,082 mm per year. Land uses in Sragen Regency consists of 25,402 ha (26.98 %) of non-farmland, and 68,753 ha (73.02 %) of agricultural land, dominated by intensive management of paddy field (BPS, 2018). There is only one village that implements organic paddy management in Sukorejo village, Sambirejo Sub-district. According to the USDA Soil Taxonomy Classification System, the soils in Sragen Regency can be grouped into Alfisols, Entisols, Inceptisols, and Vertisols, or Mediteran, Litosol, Regosol, Grumusol, and Alluvial based on Indonesian Soil Research Center System 1978-1982. The method used in this study was descriptive, an explorative method based on survey. The site sample was determined through purposive sampling based on the similarity of the soil mapping unit resulted from overlay soil type map, land uses, and industrial map. There were three paddy field managements, i.e., organic paddy (T2), conventional paddy [Alfisols (T3), Entisols (T4), Inceptisols (T5), and Vertisols (T6) soil type], and conventional paddy with wastewater irrigation [textile wastewater (T7), batik wastewater (T8), and sugar factory wastewater (T8) wastewater], and forest soil (T1) as a control. Each was replicated three times with a distance at least to 100 m. Organic paddy means no synthetic inputs, while conventional paddy uses synthetic inputs. Soil, rice root, shoot, and grain samples were taken at each sampling point. Composite soil samples were collected from the depth of 0-20 cm. The site sampling spatial distribution is shown in Figure 1.

Soil sample and plant tissue analysis

Soil samples were dried at room temperature and sieved to pass through a 2 mm mesh sieve. Rice plant tissues (root, stem, and grain) were dried in an oven at 70ºC for 24 hours, ground and sieved for chemical analysis. Soil samples analyzed were total Cd, cation exchange capacity (CEC) (NH_4OAc), organic matter (Walkley and Black method), and pH (potentiometric method). Soil analysis was performed following the protocol established by the Indonesian Soil Research (Balittanah, 2009). The Cd content in soil, root, stem, and grain was analyzed using the wet destruction method and read by Atomic Absorption Spectrophotometer (AAS).

Cd distribution mapping

After obtaining data of Cd concentrations in soil, roots, stems, and grains from each location, a Cd distribution map was based on the level of Cd content.

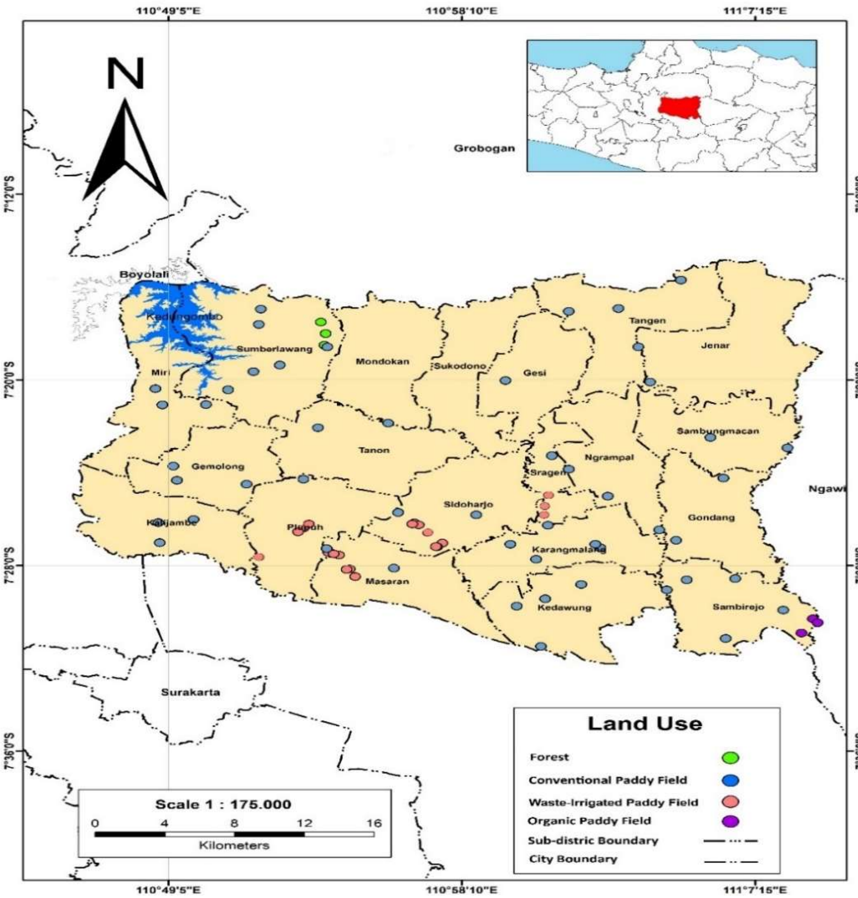


Figure 1. Spatial distribution of sampling location in the paddy field, Sragen Regency.

Cd data were extracted and inserted into the map through a spatial distribution using ArcGIS version 10.4 (Figures 2 and 3).

Statistical analysis

The normality data was analyzed using the Kolmogorov Smirnov test. The statistical analysis of the Cd content of different paddy soil management used One Way Analysis of Variance (ANOVA) with IBM SPSS Statistics version 22. The significant differences between average data of Cd content in the soil, rice root, stem, and grain were analyzed using a post hoc Tukey's test. A correlation analysis was performed using the Pearson test.

Results and Discussion

Spatial distribution of Cd in the soil

Spatial distribution is a way to determine a sample spread on a particular space (Guo et al., 2020). Based on data analysis, this study revealed that the difference in the way of managing paddy land had a significant effect ($p < 0.05$) on the level of Cd content in the soil. The agricultural land in Sragen Regency is 68,753 ha or 73.02 % of the total area. Forest land with a total area of 370 ha (0.56 %) has an unpolluted degree with an average Cd content of < 0.007 ppm (Table 1). This value is the lowest and significantly different ($p<0.05$) compared to other land use managements because the forest land remains original and undisturbed. Cd content in the forest is not due to deposits of human activities, but it is derived from the parent rock material. The main geological type of forest land is a young quarter volcano derived from volcanic activity. Based on data from BAPEDA Sragen Regency, geology consist of 4 types, there are a) Young quarter volcano, b) Pliocene facies sediment, c) Miocene facies sediment, and d) Pleistocene facies volcano. Volcano geology produces minerals; one of them is Cadmium (Za and Varma, 2018). Cd is found in various rock, such as basalt, granite, lime sand, and especially rock phosphate, approximately 100 ppm (Zaozheng et al., 2010).

On the other hand, organic paddy field management (T2) in the second level with the pollution status is lightly polluted, with a total area of 388 ha (0.61 %) consisting of one village in Sukorejo, Sambirejo Sub-district, Sragen Regency (Table 1). The Cd content in organic paddy soils was not significantly different ($p > 0.05$) from Cd in forest soils, but was significantly different ($p < 0.05$) from Cd in conventional paddy soils. Although the organic paddy field was managed organically or did not use inorganic fertilizer and pesticides, the soil still contained 0.019 ppm Cd that might be caused by land management inputs such as organic fertilizer. Manure fertilizer and compost are organic fertilizers, but manure fertilizer contains 0.1 to 0.8 ppm Cd. In comparison, the compost contains 0.01 to 100 ppm Cd (Kurnia et al., 2007); thus, the use of those organic fertilizers affect Cd deposit into an organic paddy field.

The conventional paddy field (T3 to T6) has a medium polluted degree level with Cd content in the soil ranged from 0.053 to 0.069 ppm, with the largest total area of 61,151.4 ha (95.83%) (Table 1). The conventional paddy field management that does not use industrial wastewater as a source of irrigation water is significantly different ($p < 0.05$) from the paddy field management using industrial wastewater (Table 1). The differences in soil types [Alfisols (T3), Entisols (T4), Inceptisols (T5), and Vertisols (T6)] did not indicate a significant difference in the total Cd content in the soil. The initial Cd content in the paddy soil derived from parent material, however, is very low. The average value of Cd in the soil in China is 0.097 ppm (Du et al., 2013). The presence of Cd in paddy soil in Sragen Regency is suspected to be due to the long period, frequent and overdose use of P fertilizers and pesticides.

Farmers in Sragen Regency always apply N, P, and K fertilization using inorganic fertilizers such as TSP, SP-36, NPK, Phonska. This practice has been carried out from generation to generation during rice cultivation. The practice of using pesticides by farmers in Sragen has been carried out for a very long period to control pests, diseases, and weeds, even with excessive doses. The Cd content in paddy soil in most areas of Sragen Regency was lower than that of a study conducted in a small area in the Sambungmacan sub-district, Sragen Regency by Sa'ad et al. (2009) and Pradika et al. (2019). The results of this study also showed that the soil Cd was lower than the agricultural land around the former mining area in Korea, with the average soil Cd content of 10.6 ppm (Yang et al., 2020). The increase of Cd accumulation in paddy soil can be affected by the frequent application of high doses of chemical fertilizers (Rodríguez-Eugenio et al., 2018). Cd is often an impurity element in phosphate fertilizer (Du et al., 2013). Pesticides often contain heavy metals, including Cd. The use of pesticides in the long term affects the accumulation of Cd in paddy soil (Mishra and Mishra, 2018; Yu et al., 2019).

Waste-irrigated paddy field had the highest pollution degree levels, which were moderate to heavily polluted of 1,667.7 ha (2.61%) and heavily polluted of 246.7 ha (0.39 %), as shown in Table 1. In the future, more industrialization will produce more pollution. It is not only the textile industry but also the food industry that produces heavy metals (Massoud et al., 2019); thus, the good paddy filed management become the main key to reduce the Cd content and the expansion of Cd pollution.

The spatial distribution of Cd contamination of paddy soil in Sragen Regency is demonstrated in Figure 2. The lowest Cd concentration (<0.01 ppm) was in the forest land of the Sumberlawang region (approximately 0.56% of total area), which is shown in blue colour. Forest land has the lowest Cd contamination because it is undisturbed land, and it does not get Cd input derived from anthropogenic sources. The lightly polluted soils that ranged from 0.01-0.06 ppm Cd in the soil were observed in the organic paddy field of one village in the Gondang Sub-district (approximately 0.56% of total area), which is shown in green colour. The Cd content in organic paddy soil is thought to have come from the use of organic fertilizers. Based on the map, Cd contamination of paddy soil in the Sragen district is dominated by a moderately polluted degree, ranging from 0.06 to 0.11 ppm, distributed at 95% of the total area, as shown by yellow colour (Figure 2). Cd contamination in conventional paddy soil with moderately pollution levels is suspected because paddy soil gets input from anthropogenic sources, such as phosphate fertilizers and pesticides, in long periods. Phosphate fertilizer and Nitrogen fertilizer contains about 0.1 to 170 ppm and 0.05 to 8.5 ppm Cd, respectively. SP-36 fertilizer, commonly used by farmers, contains about 11 ppm Cd (Erfandi and Juarsah). Cd from anthropogenic sources is harmful to agricultural land because it can be absorbed by plants to enter the food chain.

The Northeast Area at Gesi, Tangen, and Jenar Sub-districts (2.61% of total area) dominates the moderate to heavily polluted degree level of Cd contamination, shown by orange colour (Figure 2). The irrigation of textile waste causes Cd pollution. Based on this study, conventional paddy soil with wastewater irrigation derived from the textile industry contains 0.11 ppm Cd (Table 1). If the wastewater is used continuously, Cd can be accumulated in the soil and causes moderate to heavily polluted status increased become heavily polluted status; thus, countermeasures to alleviate Cd contamination are required. The highest Cd contamination was observed in Plupuh, Sidoharjo, and Sragen Sub-districts with heavily polluted ranged more than 0.15 ppm Cd in the soil (Table 1), demonstrated by red colour (Figure 2). Highest Cd accumulation due to textile and sugarcane industrial waste. Cd concentration of more than 0.15 ppm exceeds the threshold value by the Indonesian Government Regulation (PP RI No 101, 2014). The distribution of Cd contamination map of paddy soil in Sragen Regency (Figure 2) shows that almost all areas have been lightly to heavily contaminated by Cd. Therefore, efforts are needed to prevent the increase of Cd residue in the soil through management strategies; it can be preventive or recovery. Prevention can be done through counselling efforts on environmentally friendly rice cultivation practices, while recovery efforts can be through bioremediation.

Table 1. Soil Cd content, degree level of its contamination, and the total area of distribution in various paddy fields management in Sragen Regency.

Point	Land Use	Cd in soil (ppm)	Total area (ha)	Percentage (%)	Pollution Degree*
T1	Forest	0.007 d	370	0.56	Unpolluted
T2	Organic Paddy Field	0.019 d	388	0.61	Lightly polluted
T3	Conventional Paddy Field (Alfisols)	0.054 c	13,461.8	21.09	Moderatly polluted
T4	Conventional Paddy Field (Entisol)	0.069 c	24,443.4	38.31	Moderatly polluted
T5	Conventional Paddy Field (Inceptisol)	0.053 c	12,577.7	19.71	Moderatly polluted
T6	Conventional Paddy Field (Vertisol)	0.057 c	10,668.5	16.72	Moderatly polluted
T7	Paddy Field Irrigated by Textile Industry	0.112 b	471.2	0.74	Moderate to heavily polluted
T8	Paddy Field Irrigated by Batik Industry	0.115 b	1,196.5	1.87	Moderate to heavily polluted
T9	Paddy Field Irrigated by Sugarcane Industry	0.164 a	246.7	0.39	Heavily polluted

* The pollution degree level is based on modified PP RI No 101, 2014.

Cadmium exposure and uptake in rice

Available Cd in the soil is potentially taken up by rice plant root and translocated into the rice plant tissues and deposited in rice grain. It is a serious problem because, in the Indonesia population, rice is a major consuming as a staple food. In Sragen Regency, paddy soil is dominated by the moderately polluted status of Cd due to the long history of excessive use of fertilizers, pesticides, and industrial wastewater as water irrigation. Uptake of Cd by the root from soil solution is the first step in rice plant Cd accumulation. Cadmium content in rice plant tissue harvested from the same site of soil sampling is presented in Figure 3. The management of paddy field in Sragen Regency had a significant effect ($p<0.05$) on the content of Cd in the root, shoot, and grain rice (Figure 3). Point T1 is forest land with no data because it is in uncultivated (Figure 3). The lowest Cd content in root was in point T2 (organic paddy management) of 0.0015 ppm, significantly different ($p<0.05$) from other paddy field management. The highest Cd content in root was found in T9 (conventional paddy field irrigated by sugar cane wastewater), but it was not significantly different ($p>0.05$) from T3, T4 and T5. Plant root cell wall interacts directly with heavy metals dissolved in soil solution, and it is the outermost layer of the protoplast protection against Cd toxicity (Li et al., 2017). Thus, Cd can be suppressed to stabilization in the root and not translocated in the stem tissue. The lowest Cd content in the shoot was consistently observed in point T2 (organic paddy management) of about 0.0012 ppm, and it was significantly different ($p<0.05$) from conventionally paddy with or without wastewater irrigation (Figure 3).

The highest Cd content in a shoot (0.094 ppm) found in conventional paddy irrigated using sugarcane wastewater, and it was significantly different ($p<0.05$) from another conventional paddy management. The Cd content of paddy shoots of point T2 was lower than that in paddy root. OsHMA2 gene is responsible for localizing root to shoot translocation of Cd in the membrane plasma; that gene decreases Cd concentration in a shoot (Zhang et al., 2020). Besides, paddy can tolerate Cd by sequestering it in root and decreasing its translocation to stem by binding it to cell wall and vacuoles and combining it with different compounds such as organic acid, protein, and polysaccharide (Rizwan et al., 2016). If Cd is not phytostabilized in the root, it is transferred into the shoot by xylem to the phloem (Li et al., 2017). The higher Cd content in shoot almost in all sites allegedly because overspray of pesticides containing Cd. Thus, excessive applying of pesticides become anthropogenic sources of Cd input in rice shoot and grain. The average Cd content in rice grain was harvested from paddy soil in the Sragen district between 0.0006 to 0.046 ppm (Figure 3). The lowest Cd content in rice grain of 0.0006 ppm was consistently found in point T2 (organic paddy management), and it was significantly different ($p<0.05$) from another paddy management (Figure 3).

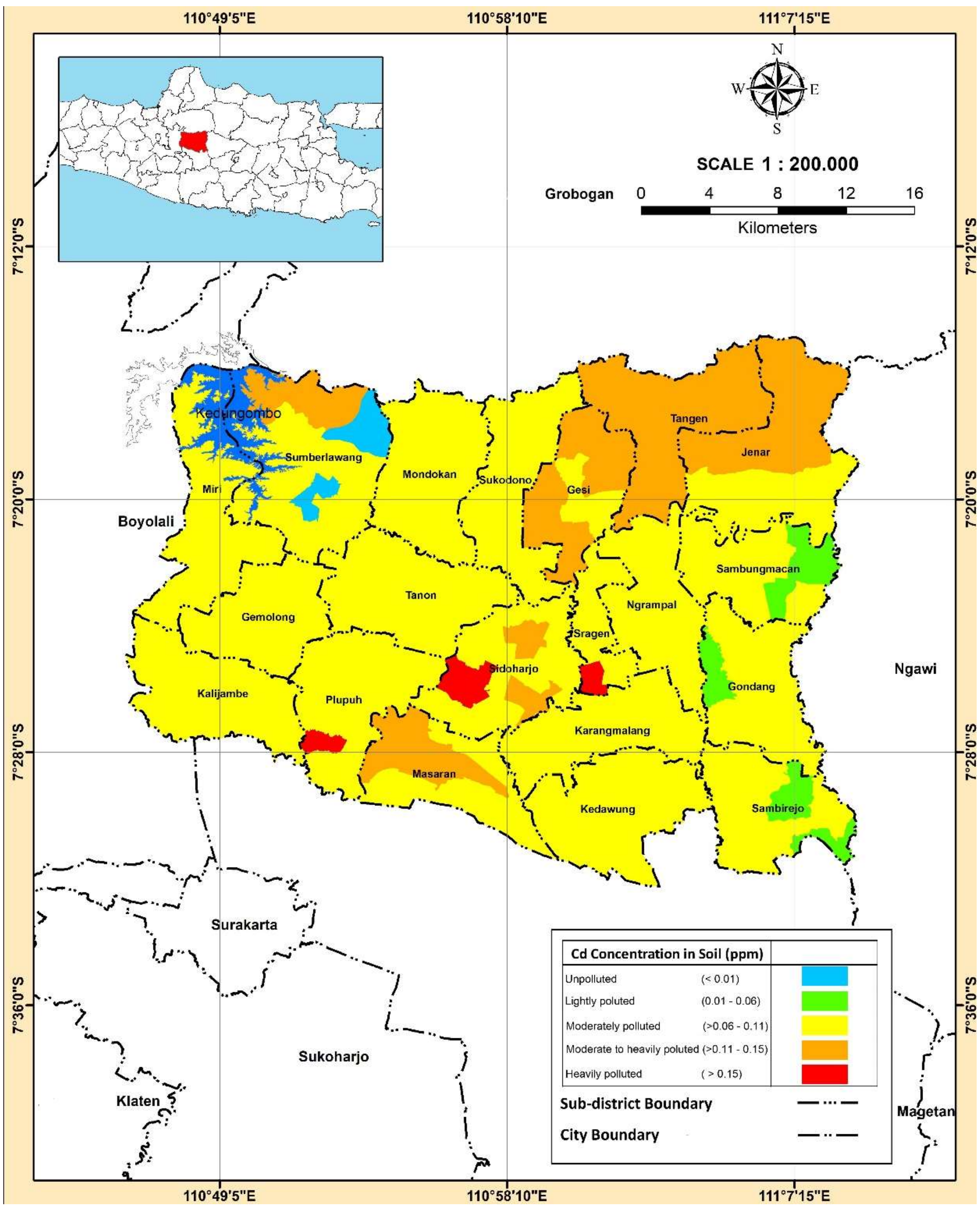
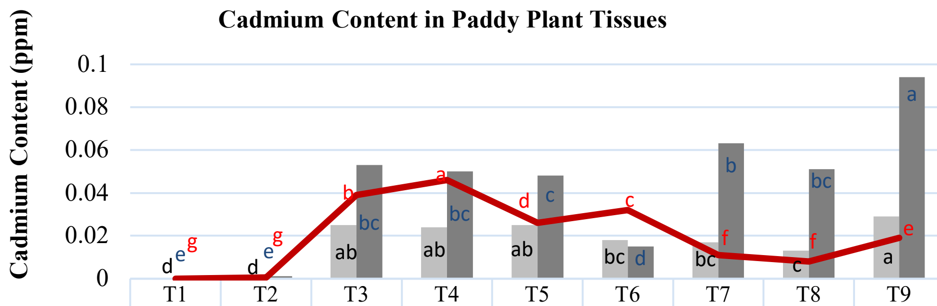


Figure 2. Spatial distribution of Cd contamination in paddy soil of Sragen Regency.



	T1	T2	T3	T4	T5	T6	T7	T8	T9
Cd on Root	0	0.0015	0.025	0.024	0.025	0.018	0.017	0.013	0.029
Cd on Stem	0	0.0012	0.053	0.05	0.048	0.015	0.063	0.051	0.094
Cd on Rice	0	0.0006	0.039	0.046	0.026	0.032	0.011	0.008	0.019

Figure 3. Cadmium content in paddy plant tissue.
*Histograms that have the same colour followed by the same letters indicate no different significantly

The highest Cd content in rice grain of 0.046 ppm was in point T4 (conventional paddy field-Entisol). Cd from rice stem is transported to rice grain by OsLCT1 as a Cd transporter expressed at the nodes for transporting Cd (Guo et al., 2019). Besides that, the use of overspray pesticides is also a source of Cd in the rice plant because Cd residue sticks to the rice grain part. Agriculture management significantly influences Cd content in the rice grain ($p < 0.05$), so eco-friendly paddy cultivation management is urgently applied to reduce the Cd content in the rice grain. The spatial distribution of Cd content in the rice grain produced from rice fields in Sragen Regency is presented in Figure 4. Results of this study showed that Cd content in the soil is not correlated with the Cd content in rice stems and rice grain. The high Cd soil content is not always followed by high Cd content in stems or rice grain. Soil types have no significant effect on soil Cd content. It implies that Cd content in rice stem and grain is related to pesticide use during rice plant growth.

The spatial distribution of Cd content in rice grain in Sragen Regency is shown in Figure 4. A higher concentration of Cd in the rice grain was observed in the north-west and south region of the Sragen Regency, and it was significantly different from the north part region (Figure 4). The north area of this study is dominated by green colour with Cd content in the rice grain ranging from 0.001 to 0.016 ppm. The white colour in the map demonstrates no data because the forest land is uncultivated by the rice plant. The lowest Cd content in rice grain from an organic paddy field management, less than 0.0006 ppm, is presented with blue colour (Figure 4). The Government should support the area with low Cd content in the rice grain as a form reward. It is an important strategy to support food security from free pollutants (Koch et al., 2018). The highest Cd content in the rice grain of more than 0.045 ppm presented with red colour was observed in the conventional paddy field that does not use wastewater. The threshold of Cd content in the rice grain by the Indonesian Government is less than 0.05 ppm (BSNI, 2009). The paddy field irrigated by industrial wastewater is dominated by a yellow colour or moderately polluted level with 0.017 to 0.032 ppm Cd content in the rice grain. The enrichment of industrial wastewater to agricultural land potentially increased Cd content in the rice grain. Cd contamination in the paddy field is responsible for rice grain yield and quality. It is detrimental to rice production and the national economy (Liu et al., 2016). The statistical test showed that land use management significantly influenced Cd content in the rice plant. Rice farmers in the red areas on the map need to get early warning priority from the Government to practice rice cultivation by reducing pesticide use. An area with high Cd content in the rice grain should get attention from Government, academicians, and farmers to alleviate Cd content in the rice plant and for decreasing expansion of the distribution of rice containing high Cd.

Soil properties affect to Cd availability

Cadmium availability is mainly controlled by soil pH, soil cation exchange capacity (CEC), and soil organic matter (Ye et al., 2014). In this study, the highest soil pH was in point T1 (forest land) of about 7.48. T1 has a Regosol soil type with a relatively high pH compared with other agriculture management (Table 3). Points T3 to T6 on the conventional paddy field had neutral pH value, while points T7-T9 on the wastewater irrigated-paddy field had low pH values that tended to acidification.

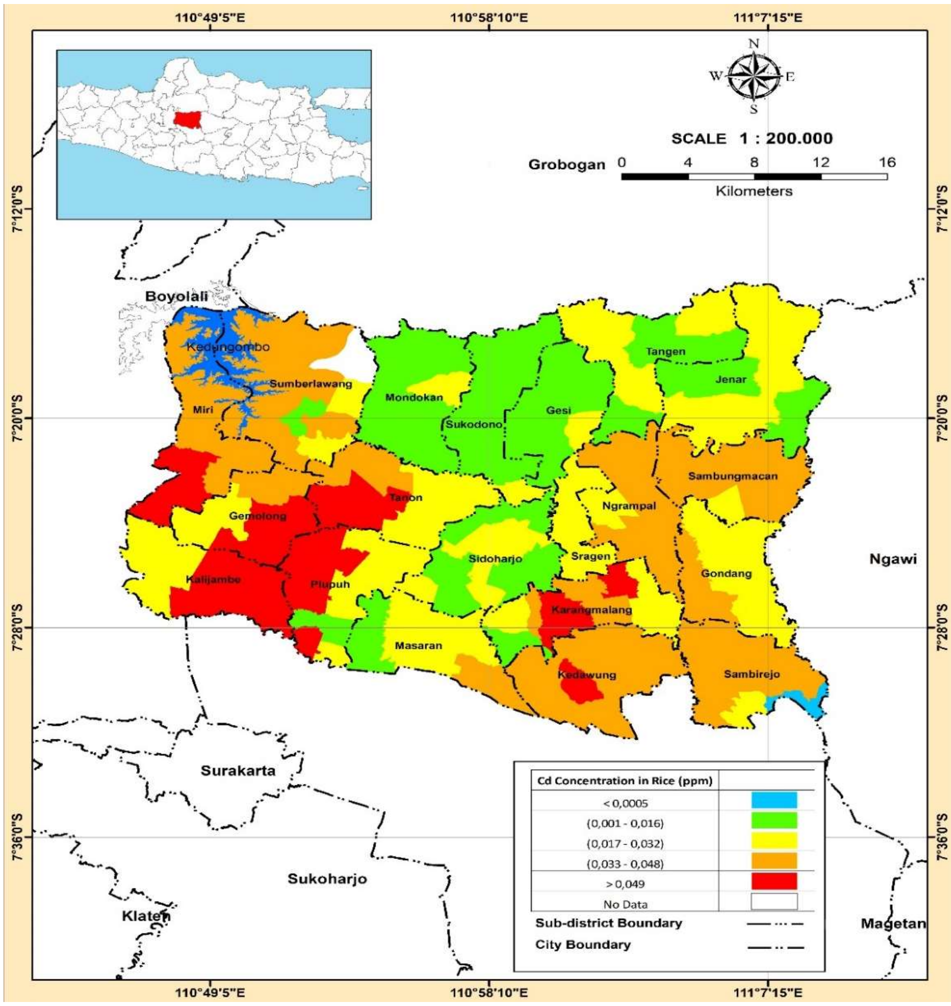


Figure 4. Spatial distribution of Cd contamination in the rice grain.

The research result showed that soil pH had a significantly negative correlation with soil Cd content (r = - 0.72*). It means that the availability of soil Cd increases when the soil pH decreases and otherwise. Decreasing soil pH can enhance the cation mobility in the soil pore water due to the placement of H^+ by the exchangeable cation from the soil and that the solubility of metal bounded by soils of different materials (Elyamine et al., 2018). Based on the statistical test, soil pH on the forest land was significantly different from that of the conventional paddy field and wastewater irrigated-paddy field. Generally, soil pH decreases with increasing water content and sodium chloride (NaCl) concentration. At low soil pH, the solubility of Cd in solid-phase increases, but in higher soil pH, Cd is likely to form Cd $(OH)^+$ by hydrolysis, which resulted in enhancement of Cd adsorption affinity to the soil. Thus, the mobility of Cd will be decreased, and Cd accumulation in rice plants becomes lower. So the soil acidification must be avoided to prevent Cd accumulation (Li et al., 2017).

Soil organic matter (SOM) has a vital role in decreasing Cd availability in the soil through adsorption or forming a stable complex with humic acid. Based on correlation analysis showed that soil Cd content had to correlate negatively significant with soil organic matter content (r = -0.41*). In Figure 5, the highest soil organic matter at the point T1 (forest land) was 5.2%, while the lowest SOM was at the point T5 (conventional paddy field-Inceptisol) of about 1.36%. Fulvic acid, as a fraction of soil organic matter, has a capacity complexation of divalent metal cations. A high proportion of the humification of SOM can reduce the bioavailability of Cd in the soil with adsorption and complex formation stabilized with humic substance. SOM can re-distribute heavy metal from soluble and exchangeable form to fraction associated with SOM or carbonates and a residual fraction (Elyamine et al., 2018). It is in line with research by Ferina et al. (2017a) that high organic carbon content can decrease heavy metal content in the soil. Higher SOM in the soil can decrease or increase Cd concentration in the soil depending on the soil type, soil pH, soil CEC, etc.

Table 3. Soil pH.

Point	Land Use	Soil pH
T1	Forest	7.48 a
T2	Organic Paddy Field	6.53 bcd
T3	Conventional Paddy Field (Alfisols)	6.60 c
T4	Conventional Paddy Field (Entisols)	6.66 bc
T5	Conventional Paddy Field (Inceptisols)	7.06 ab
T6	Conventional Paddy Field (Vertisols)	7.46 a
T7	Paddy Field Irrigated by Textile Industry	6.48 c
T8	Paddy Field Irrigated by Batik Industry	6.39 cd
T9	Paddy Field Irrigated by Sugarcane Industry	5.78 d

This study showed that the point with the highest accumulation Cd was the point T9 (paddy field irrigated by sugarcane waste), which had a high enough soil organic matter of about 3.17 % (Figure 5). It discloses that the higher SOM does not necessarily cause a decline of Cd accumulation in the soil, because organic acid exists as negative anions, thus vigorously with Cd and immobilize Cd in the soil. Organic matter can also supply organic chemical to the soil solution and can chelate and enhance Cd availability in the rice (Li et al., 2017). Decreasing Cd fraction bound to organic matter resulted in increasing the residual Cd fraction. The Cd affinities with the SOM depends on the functional composition and substance (Elyamine et al., 2018). Soil CEC can affect Cd bioavailability and change its impact on soil organisms and plants (Chai et al., 2020). Higher soil CEC will be increasing Cd accumulation in the soil (Ziper et al., 1988), such as in point T9 with soil CEC of 41.86 c_{mol}(+)/kg with the highest Cd accumulation in the soil. Based on Ferina et al. (2017b), a higher soil CEC can increase the possibility of exchanging heavy metals cations with other cations. But, any two types of interaction between metals during their uptake by plants, which is synergistic (the addition of one metal increased the uptake of the other) or antagonistic (the addition of one metal decreased the uptake of the other). This study showed that CEC significantly negatively correlated with Cd content in the root (r = -0.48*) and Cd content in rice grain (r = -0.76*). Cd accumulation in rice plants as affected by soil type and soil texture. Vertisol (T6) has a high CEC value compare to Alfisols (T3), Entisols (T4), and Inceptisols (T5) (Figure 5). The Cd accumulation in the soil with clay texture has a higher Cd accumulation than the sandy clay and sandy loam texture (Rizwan et al., 2016). In this study, the Vertisol soil type tends to have a lower Cd content in shoot and rice grain compared to T3, T4, and T5 (Figure 3).

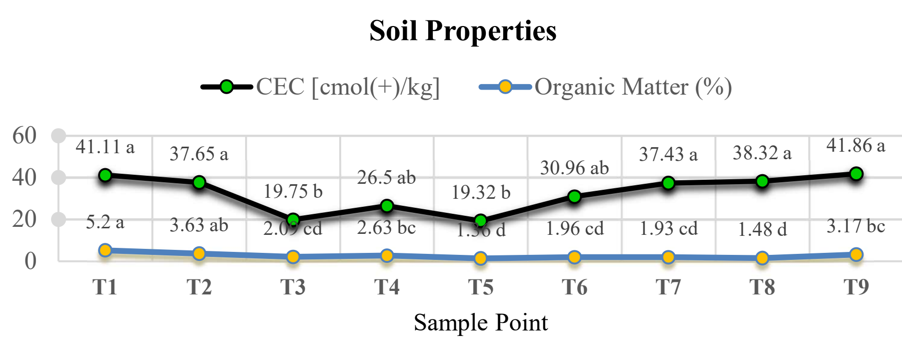


Figure 5. Soil CEC and organic matter content of paddy field in Sragen Regency.

Strategy to minimize Cd accumulation

Efforts to reduce the accumulation of Cd in soil and plants can be made through four main strategies, namely fertilizer management, water management, good agricultural management, and bioremediation. First, good fertilizer management is the use of organic fertilizer such as compost and manure. However, compost and manure also contain Cd but still in a low portion compared with inorganic fertilizer. If the paddy field is forced to be managed semi-organic, inorganic fertilizer should not be excessive. Inorganic fertilizer, especially excessive phosphate fertilizer, can lead the Cd residue accumulation in soil. 60% of farmers do not know that inorganic fertilizer leaves heavy metal residue in the soil (Pradika et al., 2019). The whole amount of the fertilizers applied is not taken up by the crop; some part is lost in volatilization, while some are leached down in irrigation flow or soil profile, which results in the pollution of natural resources (Za and Varma, 2018). Besides, limestone can increase soil pH and, respectively, results in a decrease of Cd in the soil and metal uptake by paddy plant (Rizwan et al., 2016).

Second, water management in the paddy field irrigated by waste significantly influences Cd accumulation in the soil. Besides, the paddy field under flooded conditions can increase the availability of Cd in the rice plant. In contrast, irrigation under aerobic conditions produces rice grain with low Cd but high Cd accumulation in the soil. Thus, the best water management in the paddy field compares water management to aerobic and flooded treatments such as SRI (System Rice Intensification) (Rizwan et al., 2016). Arao et al. (2009) reported that flooding for three weeks before and after heading was most effective in reducing Cd in the rice plant. Third, good agriculture practice implements organic management with low pesticide and low herbicide. The direct impact of pesticides and herbicides is not only human, but also causes poisoning in plants, microorganisms, and animals or insects (Mayer et al., 2020). Crop rotation is also one way to reduce Cd availability because it can reduce 46.80% Cd (Wu et al., 2018). The selection of rice varieties is important because Cd accumulation in the rice plant varies significantly among rice cultivars even under the same growth condition and metal contamination (Luo et al., 2019). Liming on soil with low pH value and applying compost, green fertilizer, and organic fertilizer is an important strategy to control contamination in rice fields in Sragen Regency.

The last strategy to reduce the Cd in soil and plants is with bioremediation. Bioremediation is the process of eco-friendly and sustainable for eliminating heavy metal in the environment (Li et al., 2017). Bioremediation of heavy metal can use biochar, earthworm, metal accumulator plants, microbial community, and mycorrhizae. Biochar can adsorb Cd from their ligands (Quan et al., 2020). Earthworms can accumulate Cd in their body ranging from 0.57 to 22.11 mg/kg (Arifin et al., 2015). Many microbial communities are resistant to heavy metal toxicity and transform into a harmless form. Also, the Cd accumulation can be reduced by using phytoextraction plants and mycorrhizae as reported by Nababan et al. (2017) who used Ketul plants and the addition of mycorrhizal and EDTA in reducing the Cd accumulation.

Conclusion

The conversion of forest land to paddy fields increases the content of Cd. The majority of paddy fields in Sragen Regency (96%) are conventionally managed and show a moderate degree of Cd contamination. Local authorities need to pay serious attention and look for strategies to address this problem. About 3% of paddy fields in the Sragen Regency with heavily polluted status need to prioritize the Local Government in dealing with it. This study revealed in a general pattern of the Cd content from the highest to the lowest is soil Cd content > Cd in shoot > Cd in rice grain > Cd in the root. Paddy field that is managed organically, conventionally, and irrigated by industrial wastewater, potentially increase the content of Cd in the soil. However, the organic paddy field (without chemicals, fertilizers, and pesticides) showed the lowest Cd contents in the soil and rice grains compared to other management practices. Soil pH and soil organic matter become the determinant factors of low Cd content in the soil. Management of organic matter is an important strategy to manage the Cd contaminant in paddy soil in Sragen Regency.

The limitation of this study is the mapping was on a large scale so that it is unable to reveal in detail the factors causing high Cd contents in the soil and rice grain. Further studies are needed to evaluate the relationship between soil pH and soil organic matter management, with Cd contents in soil and rice. Besides, the influence of various rice cultivars and microbial communities on Cd content in rice plants also needs to be studied. Research on farmer behaviour in managing land to overcome Cd contamination in soil and rice plants is also needed.

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