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Unveiling Heavy Metal Pollution in Soils and Rice Crops (*Oryza sativa* L.) Cultivation

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ABSTRACT

*The landscape changes through the increasing built-up areas (settlements and industrial) have a potential impact on reducing the quality of agricultural land. Waste from anthropogenic activities (industrial and domestic) is the main source of heavy metals that can affect rice production in the fields. This study examines the quality changes of paddy fields (*Oryza sativa *L.) polluted by wastewater in Muara Bakti Village, Bekasi Regency. Wastewater's impact on paddy fields is known through heavy metal contamination analysis in soil and rice plants. Chemical analysis of soil, water and plants was completed by the Balai Penelitian Tanaman Sayuran (Balitsa) Laboratory, West Bandung. The results showed that heavy metal levels such as lead (Pb) and cadmium (Cd) in the paddy soil samples were above the threshold in soil, respectively more than 25 mg/l and 0.01 mg/l. In contrast, the rice plant samples, it was identified as containing heavy metals such as Cd and chromium (Cr). Pb content was not detected in the rice plants. Soil in Muara Bakti Village contained optimal nutrients that are still suitable for agriculture. However, heavy metal content detected in soil samples and rice plants requires special handling to prevent endangering the agroecosystem and human health.*

1. INTRODUCTION

Water is a key factor in agriculture, especially in irrigation the provision for various food crops. Irrigation is used to provide additional water and meet the plants' needs, as well as to saturate soils to obtain a good structure for growth (Paudel *et al*., 2016). Surface water sources are the main source of supplying irrigation, especially during the dry season (Dede *et al*., 2022a). However, irrigation provisions depend on water sources, thus we must ensure that there are any contaminants that could affect the water quality for agricultural purposes (Chen *et al*., 2013).

Criteria for water quality in agricultural uses are highly dependent on the plant types, source quality, and mineral content in the soil (Dinasia *et al*., 2022; Piranti *et al*., 2018). In Indonesia, the Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning Water Quality Management and Water Pollution Control contains criteria for water quality based on its classes for various uses. For agricultural irrigation, water must meet class II, class III, and class IV with many fulfilled parameters (Sunardi *et al*., 2022). However, the water need for agriculture is very large and increasing as the human population continues, and also faces challenges because river water quality is decreasing and exposed to many pollutants (Dede *et al*., 2023). Efforts to meet the large demand for water with good quality are difficult to fulfill many human needs in modern era.

Polluted water is a threat to plant cultivation, especially in those areas that act as food providers (Rai *et al*., 2023). Some plants known as hyperaccumulators absorb high levels of pollutants without poisoning themselves (Sytar *et al*., 2020). Hyperaccumulator plants take up toxins in soil or water – including heavy metals or radioactive contaminants, this process is called phytoremediation (Singh *et al*., 2022). On the other hand, water polluted by waste is an alternative for irrigation in food crop production, especially for prone to water scarcity areas (Singh *et al*., 2012). Even so, it still requires an in-depth study to determine the best treatment and to protect the agroecosystem.

In West Java, Indonesia, rice farms face the threat of wastewater contamination from industrial and residential activities. For irrigation utilization, we need to pay more attention to dissolved oxygen (DO) which is used as an indicator of the water freshness level (Elbana *et al*., 2012). DO plays a role in the oxidation and reduction processes of organic and inorganic materials, and even determines the biological activities carried out by aerobic and anaerobic organisms (Pang *et al*., 2023). Therefore, it is important to the irrigation water quality because it can affect the field's fertility through which the flows. However, the research aims to identify and analyze the contamination levels from heavy metals, especially the chemical content of soil and rice plants in Bekasi Regency, West Java.

2. MATERIALS AND METHODS

The research methodology for this study involved sample collection and analysis conducted at the Balai Penelitian Tanaman Sayuran (Balitsa) laboratory. Samples of soil and paddy rice were obtained from Muara Bakti Village, located in the Babelan Sub-District of Bekasi Regency, West Java, Indonesia (Figure 1 and 2). Three samples of inceptisol soil and rice plants were selected using purposive sampling, taking into account the degree of pollution in the irrigation water from point sources, as indicated by previous studies (Arum *et al*., 2019; Gupta & Singh, 2016; Zubaidah *et al*., 2019). The sampling location was chosen near the tertiary II irrigation canal, which extends approximately 5.5 km in Muara Bakti.

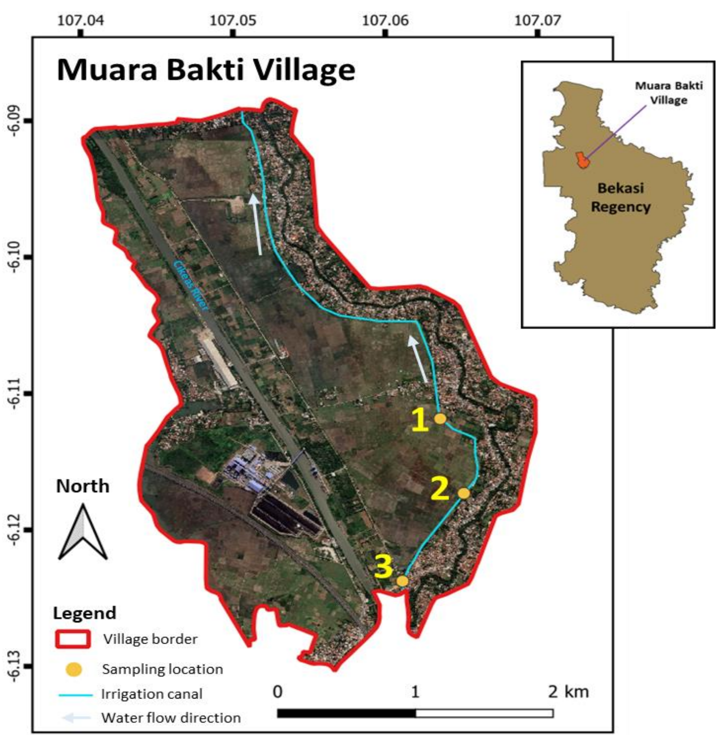

Figure 1. Sampling locations in Muara Bakti, Bekasi Regency, West Java.

Figure 2. The difference between growing rice plants in locations polluted by heavy metals and minimal exposure to those contaminants.

These sampling points are situated on agricultural land irrigated by a separate route from the main river. The primary water source for this irrigation route is the Cikeas River. However, the area also receives untreated industrial and domestic wastewater discharges from the surrounding vicinity. Consequently, it is assumed that heavy metal contamination is already present in the soil and water utilized for agricultural purposes at these locations. This selection of samples was based on considerations of resource availability, time efficiency, and field logistics (Dede *et al*., 2023). The measurements were conducted in triplicates to determine the content in water, soil, and plant samples from each sampling point.

Furthermore, the water quality of the irrigation canal in the Babelan Sub-District was assessed prior to sample collection. Water samples were collected from canals that irrigate agricultural land near the study area to observe soil and rice crops. The distance between each sampling point is approximately 500–1000 m to detect differences in contaminant levels that may vary, thereby affecting flow dynamics. Water quality tests indicated that the canal water was polluted, with DO, BOD, and COD values exceeding quality standards. Dissolved oxygen levels were measured using a DO meter, while BOD and COD values were determined using Oxidirect systems according to SNI 6989.73-2009 (Fadzry *et al*., 2020). According to regulatory standards, water intended for irrigating rice fields should exhibit characteristics of DO levels of at least 3 mg/L, BOD levels of 6 mg/L, and COD levels of 40 mg/L.

Meanwhile, the soil for heavy metal testing was obtained using the disturbed soil sample approach, where soil is collected with a hoe, shovel, or soil auger from a certain depth, in quantities ranging from 0.5 to 2 kg (Clayton *et al*., 1995; Simons *et al*., 2002). The observed heavy metals included only three elements: Pb, Cd, and Cr. These three elements were chosen due to their toxicity and their frequent interaction with crops (Wan *et al*., 2019). For the rice plants, we also focused on these three heavy metals. Grind the dried plant sample into a fine powder for analysis, we used the entire plant to determine the overall heavy metal content. This testing procedure was similar to that used to assess nutrient uptake in plants. For heavy metal analysis, we used the wet digestion and the atomic absorption spectrophotometry (AAS) (Liem & Herawati, 2021; Ramanda *et al*., 2024; Shintawati *et al*., 2017).

3. RESULTS AND DISCUSSION

3.1. Irrigation Water Quality

The water quality in Muara Bakti Village is mostly within safe limits for irrigation, except for DO, BOD, and COD, which indicate significant organic or chemical pollution. This can negatively impact aquatic organisms and soil health in the long term. Remedial actions such as aeration, bioremediation, nano-remediation or pollution management might be necessary to improve the water quality, ensuring it remains viable for agricultural use and other purposes (Hussain *et al*., 2022; Saha *et al*., 2017). Poor quality water from irrigation exacerbated this condition, it could not provide regulating and supporting services for rice plants and exceeded the standard threshold as shown in Table 1. On average, there is no significant difference in water quality between the different sampling points.

Inadequate water quality negatively impacts soil health and the growth and development of rice plants. Contaminated water can lead to heavy metals settling in paddy fields and being absorbed by crops, livestock, fish, and other organisms beneficial as human food resources. Additionally, water pollution increases costs as it necessitates treatments to reduce or eliminate pollutants (Mohd, 2022; Simon & Joshi, 2021). This situation might even require sourcing safer water, such as using pump wells, which can lead to competition for groundwater (Mulyadi *et al*., 2020).

Table 1. Water quality in irrigation canals at Babelan, Bekasi Regency

Parameter	Method	Unit	Value				QS
			ID-1	ID-2	ID-3	Mean	
Electrical conductivity	Conductivity meter	µs/cm	770	780	778	776	-
Total dissolved solids (TDS)	TDS meter	mg/L	430	440	441	437	1000
pH	pH meter	-	7.20	7.28	7.30	7.26	6-9
Dissolved iron	Colorimetric	mg/L Fe	0.32	0.34	0.36	0.34	-
Dissolved manganese	Colorimetric	mg/L Mn	0.37	0.33	0.35	0.35	-
Sulphates	Ion chromatography	mg/L SO_4	54	55	56	55	300
Nitrates	Ion chromatography	mg/L NO_3^-N	1.25	1.35	1.30	1.30	20
Chlorides	Ion chromatography	mg/L Fe Cl^-	90	95	92.5	92.50	300
Dissolved oxygen (DO)	DO meter	mg/L O_2	0	0	0	0	≥ 3
Biochemical oxygen demand (BOD)	5-day BOD test	mg/L	25	26	24.6	25.20	6
Chemical oxygen demand (COD)	Dichromate test	mg/L	59	61	60	60	40

Note: QS is the quality standards.

3.2. Heavy Metal in Soil

The heavy metal test found that only a soil sample (ID-3) met the quality standard with Pb content (21 mg/L). Meanwhile, other soil samples (ID-1 and ID-2) contained very high levels of the heavy metal Pb, (34 mg/L and 28 mg/L), these values clearly exceeded the quality standards of 15-25 mg/L. If we used another quality standard, these values are still above the threshold for Pb based on (Kabata-Pendias & Mukherjee, 2007), who stated the safe limit is 20 ppm. In micro quantities, the presence of certain elements belonging to metals such as iron, copper, zinc, boron, manganese and molybdenum, are still needed by plants for their physiological processes (Inaya *et al*., 2021).

However, if these elements are present in too high amounts or excessive, they can cause toxicity to plants and even other living organisms that consume the plants (Azeh Engwa *et al*., 2019; Handayanto *et al*., 2017). Only Cr (20-27 mg/L) in Table 2 still meets the quality standards, while the other elements exceed that. All soil samples tested contained Cd (2 mg/L), this result exceeded the quality standard. Several factors such as organic matter content, pH, soil particle size, ion exchangeability and soil temperature can affect Cd absorption (Setyoningrum *et al*., 2014). Shayler *et al*. (2009) stated that soil characteristics, organic matter content, pH, soil particle size, ion exchangeability and temperature can affect contaminants in the field. From Table 3, paddy soil samples have moderate N, C-organic and C/N. Instead, P and K are very high as well as the soil pH is neutral. Although the soil nutrient content indicated that the agricultural fields in Muara Bakti are still suitable for rice cultivation, there are some heavy metals detected in soil and plant samples that pose a health threat.

When paddy fields contain heavy metals above safe limits, several negative impacts can occur. These metals can damage soil structure and fertility, reducing the soil ability to support plant growth. Rice plants and other crops may suffer from toxicity, leading to stunted growth and symptoms like chlorosis or necrosis (Alengebawy *et al*., 2021). In addition, heavy metals affect soil organisms like worms and microorganisms, disrupting the ecological balance and soil functions. Therefore, managing contaminated land requires remediation measures such as phytoremediation, liming, or using binding agents to reduce the availability of heavy metals in the soil (Khalid *et al*., 2017).

Table 2. Heavy metals content in the soil

Sample	Pb (mg/L)		Cd (mg/L)		Cr (mg/L)	
	Actual	**QS**	**Actual**	**QS**	**Actual**	**QS**
Soil field 1 (ID-1)	34		2		20	
Soil field 2 (ID-2)	28	15-25	2	0.01	21	100-300
Soil field 3 (ID-3)	21		2		27	
Detection limit	0.022		0.005		Not applicable	

Note: QS is the quality standards.

Table 3. Characteristics of paddy soil

Parameter	Method	Value				Status
		ID-1	**ID-2**	**ID-3**	**Mean**	
N (ppm)	Kjeldahl	0.24	0.26	0.25	0.25	Moderate
P_2O_5 (ppm)	Olsen	108.5	108.7	108.9	108.7	Very high
K (ppm)	Morgan-Venema	204.0	204.5	204.7	204.4	Very high
C-organic (%)	Kurmies	2.68	2.70	2.69	2.69	Moderate
Ph	H2O	6.90	6.80	7.00	6.90	Netral
C/N	Ratio test	11.0	11.2	10.8	11.0	Moderate

3.3. Heavy Metal in Rice Plant

The rice plant samples analyzed were also identified as containing heavy metals (Cd and Cr), while Pb was not detected (Table 4). The Cd metal exceeds the quality standard limit of 0.02 mg/L. High levels of Cd can have an impact on decreased production and reduced quality of rice seeds (Zhang *et al*., 2019). In addition, the high level of Cd in rice plants can also cause poisoning in animals and humans. In addition to Cd, the Cd content in rice plants has also exceeded the safe limit of 0.02 mg/L (Widyasari *et al*., 2023). Long-term consumption of rice containing Cd above the threshold can lead to kidney damage, increased cancer risk, nervous and immune system disorders, negative effects on reproductive and cardiovascular systems, and bone disorders (Sutrisno & Kuntyastuti, 2015). Potential pollution of agricultural land can be affected by poor management, including excessive use of inorganic fertilizers (Danapriatna *et al*., 2023a). Inorganic fertilizers contain metals that can accumulate in the soil and be absorbed by plants, which can then harm human health (Danapriatna *et al*., 2023b; Shukla *et al*., 2018).

Rice in paddy fields that have been polluted by heavy metals grown prematurely because nutrient absorption was uneven. At sampling locations that have low heavy metal content, rice grew optimally and developed together. Higher exposure to heavy metals disrupts plant metabolism, of course, this is detrimental for farmers who want rice to grow optimally and produce abundant grain. The heavy metals toxicity (metalloids) can change the physiological processes of plants which has an impact on stunted growth, reduced biomass, and yield loss (Hasanuzzaman *et al*., 2022). Exposure to heavy metals also inhibits the germination process and initial growth of plants, even causing disturbances in plant-water relations (Hafeez *et al*., 2023; Rumampuk & Warouw, 2015; Siahaan *et al*., 2017).

In the short term, consuming rice from Muara Bakti Village can be considered safe as long as there are no alternative sources from other areas that are free from heavy metals. However, if this continues in the long term, cumulative effects will emerge, potentially burdening local and national healthcare systems due to chronic diseases caused by consuming staple foods contaminated with heavy metals (Windi, 2018). Therefore, further treatment is needed to reduce the heavy metals level in paddy soil and rice plants, this effort is to minimize the contamination of crop yields and guarantee the consumers' health as well as agroecosystems. Water, soil, and rice plants are interconnected components, especially when the growing medium or irrigation is exposed to heavy metals. The use of organic fertilizers, soil washing, reclamation, and phytoremediators plants (bioremediation) can be an option to reduce heavy metal content besides the assessment from pollutant sources (Ashraf *et al*., 2019; DalCorso *et al*., 2019; Ning *et al*., 2017). Tackling heavy metal contamination is a fundamental effort to maintain the sustainability of agricultural land amidst urbanizing landscape (Dede *et al*., 2024), where many productive paddy fields are threatened by spatial policies through built-up areas expansion – settlements, industries and infrastructures (Dede *et al*., 2022a; Dede *et al*., 2022b; Widiawaty *et al*., 2020).

The community also needs comprehensive education on controlling heavy metal pollution and efforts to diversify food sources. However, land remediation efforts are paramount, as heavy metal pollutants are one of the significant issues in Indonesian agriculture, along with farmer regeneration, land conversion, and climate change (Yuniarti, 2020). Conservation and rehabilitation of agricultural land require an integrated approach that combines biogeophysical, social, cultural as well as economic aspects. Additionally, we should understand that land, soil, and water are interconnected biosystems and social systems, necessitating cross-border government, transdisciplinary studies, and cross-sectoral approaches (Setiadi *et al*., 2023).

Table 4. Heavy metals content in the rice plants

Sample	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
Rice plant 1 (ID-1)	0	1	2
Rice plant 2 (ID-2)	0	0	3
Rice plant 3 (ID-3)	0	1	2
Detection limit	0.022	0.005	Not applicable
QS	2	0.02	1.3

Note: QS is the quality standards.

4. CONCLUSION

Based on heavy metal testing on soil samples, only one met the quality standard with Pb content (21 mg/L). Other samples contained very high levels (34 mg/L and 28 mg/L). All soil samples contained a heavy metal (Cd) at 2 mg/L, which exceeded the quality standard. High levels of Cd can have an impact on decreasing the production and quality of rice seeds as well as can cause poisoning in animals and humans. Although the soil nutrient content indicates that agricultural land is still suitable for rice cultivation, there are some heavy metals detected in soil and plant samples that pose a health threat. In the short term, consuming rice with heavy metal content will not have immediate health effects due to its cumulative nature. A comprehensive strategy is needed, ranging from land conservation and rehabilitation to establishing a safe food supply chain for the community. Therefore, further treatment is needed to reduce the heavy metals in paddy soil and rice plants, also we need some efforts to prevent contamination from the sources. Further research is needed to know the use of organic fertilizers, soil washing, reclamation, and phytoremediator (bioremediation) plants to reduce heavy metal content in soil and rice plants. Important to prevent heavy metal pollution based on point-sources management. To assess heavy metal contamination, further research is needed to uncover the interactions between water, soil, and rice plants at the field or regional scale.

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