Heavy metal pollution assessment in paddy fields and dryland in Bandung District, West Java

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Abstract. Excessive use of fertilizers and pesticides causes the accumulation of heavy metals in intensive agricultural land. Besides, the development of industries around the agricultural area further aggravates the accumulation of heavy metals. This study aimed to assess spatial distribution of heavy metal contamination in agricultural land in Bandung District. In this study, seven concentrations of heavy metals (Cr, Pb, Cd, Co, Cu, Ni, and Zn) in soils were analysed from 273 sampling sites in paddy and horticultural lands in Bandung Regency, Indonesia. The single pollution index (PI) and the Nemerow Integrated Pollution Index (NIPI) were calculated for each surface sample (0-20 cm) to assess the level of heavy metal pollution. Ordinary Krigging (OK) method was used to delineate the spatial distribution of heavy metals. The results show that the average values of all PIs and NIPI values are at a safe level, except for cobalt which show slightly polluted. The analysis showed that around 3.23 and 8.76% of soil samples were slightly contaminated with cadmium and cobalt, respectively. The finding can be used as a reference for stakeholders to manage paddy fields against heavy metal contamination.

1. Introduction
Heavy metals are divided into two categories, namely as essential elements (Mn, Zn, Cu, Mo, Fe) and toxic elements (As, Hg, Pb, Cr, Cd) for plant growth [1,2]. Heavy metals are needed as essential elements by plants in small amounts but remain toxic in excessive amounts. Although in small amount, toxic heavy metals elements still toxic to plants. Sources of heavy metals in the soil come from soil parent materials and human activities, including agriculture, industry, transportation, and other activities [3–6]. In agricultural sector, the increase in heavy metals can come from the use of excessive amount of pesticides, chemical and organic fertilizers.

Paddy fields in Bandung District are the central areas for horticultural production and rice cultivation. Demands for increasing land productivity encourage farmers to use fertilizers and pesticides excessively. In addition, climate change and outbreak of pest infestation also contribute to increase-use of pesticides [7]. The behaviour of farmers in using excessively fertilizers and pesticides contributes to the accumulation of heavy metals in paddy fields [8]. On the other hand, the increase in the industrial activities around agricultural lands in Bandung Regency has become the sources of heavy metals contamination in agricultural land. Several studies have shown that paddy fields are exposed to heavy metals from industrial waste [9,10], causing the lands to be unhealthy so that the safety of the horticulture and rice produced from the land is also of concern.

To ensure that agricultural land conditions are suitable for cultivation, an assessment is carried out. This assessment is intended to assess how much heavy metal accumulation in agricultural land.
Several methods have been developed by researchers to assess the accumulation of heavy metals in the soil [11,12]. The spatial assessment has also been developed to see the distribution of heavy metals. With a spatial assessment, it can be seen the areas having high potential risks of heavy metal accumulation so that rehabilitation activity can be carried out more focused on these specific areas. This study aimed to assess spatial distribution of heavy metal contamination in agricultural land in Bandung District.

2. Materials and methods
The research was carried out on paddy fields in Bandung District (6° 48' to 7° 18' S and 107° 15' to 107° 55' E) which is a center for horticultural development. Total of 273 soil samples were taken from the topsoils (0-20 cm) with a grid method of 1 x 1 km² per soil sample. Each soil sample was taken compositely from 5 subsamples within a radius of 50 m. Details of the sampling locations are presented in figure 1.

![Figure 1. Map of soil sampling locations for assessment of heavy metal pollution in Bandung District.](image)

The soil samples were then dried, mashed, and sieved using a 0.5 mm sieve, and then digested using a wet ashing method. The filtrate was filtered and measured using Atomic Absorption Spectrophotometry (AAS) [13].

The assessment of the critical limit for heavy metals in the soil was analysed using Alloway method [1]. Soil quality was assessed using the Pollution Index (PI) and Nemerow Integrated Pollution Index (NIPI) [12]. The equation for calculating PI and NIPI, i.e.:

\[
P_I = \frac{C_i}{S_i}
\]  

(1)
\[ NIPI = \sqrt{\frac{(PI_{\text{max}})^2 + (\overline{PI})^2}{2}} \]  

(2)

Where \( C_i \) is the concentration of heavy metal \( i \) and \( S_i \) is the critical limit for heavy metal \( i \). \( PI_{\text{max}} \) is the maximum PI of each heavy metal and \( \overline{PI} \) is the mean of PI. Assessment of the contamination degree for each and whole heavy metals is presented in Table 1.

**Table 1. Classification of PI and NIPI [12].**

| PI degree | NIPI degree |
|-----------|-------------|
| PI ≤ 1   | unpolluted  | NIPI ≤ 0.7   | Safe         |
| 1 < PI ≤ 2 | slightly polluted | 0.7 < NIPI ≤ 1.0 | Precaution   |
| 2 < PI ≤ 3 | moderately polluted | 1.0 < NIPI ≤ 2.0 | slight pollution |
| PI > 3   | highly polluted | 2.0 < NIPI ≤ 3.0 | moderate pollution |
|          |              | NIPI > 3.0   | heavy pollution |

Simple statistical analysis used Microsoft Excel 2007 while spatial analysis of heavy metal distribution used Ordinary Krigging of ArcGIS 10.2.

3. Results and discussion

The averaged contents of Pb, Cd, Cr, Ni, Co, Cu, and Zn in soils were 21.12, 1.98, 13.44, 11.36, 14.86, 21.80, and 13.65 mg kg\(^{-1}\), respectively. The variation coefficients for heavy metal concentrations decreased in the following order: Zn > Cu > Cr > Pb > Co > Ni > Cd. Among them, Cd, Ni, Co, Pb, and Cr exhibited moderate variability, with variation coefficients of 0.25%, 8.70%, 10.93%, 18.60%, and 28.67%, respectively, and Zn and Cu exhibited the greatest variability, with variation coefficients of 118.30% and 103.28% (as shown in Table 2).

**Table 2. Descriptive statistics of heavy metal concentrations in the research area.**

| Heavy Metal Concentrations (mg kg\(^{-1}\)) | Pb  | Cd  | Cr  | Ni  | Co  | Cu  | Zn  |
|-------------------------------------------|-----|-----|-----|-----|-----|-----|-----|
| n                                         | 273 | 273 | 273 | 273 | 273 | 273 | 273 |
| Mean                                      | 21.12 | 1.98 | 13.44 | 11.36 | 14.86 | 21.80 | 13.65 |
| Standard Deviation                        | 4.31 | 0.50 | 5.35 | 2.95 | 3.31 | 10.16 | 10.88 |
| Minimum                                   | 13.11 | 0.53 | 4.68 | 6.39 | 2.93 | 6.39 | 1.28 |
| Maximum                                   | 34.32 | 3.35 | 51.71 | 22.15 | 25.25 | 74.32 | 28.55 |
| Coefficient of Variance                   | 18.60 | 0.25 | 28.67 | 8.70 | 10.93 | 103.28 | 118.30 |
| Critical limit [1]                        | 60 | 3 | 100 | 50 | 20 | 100 | 200 |

**Table 3. Descriptive statistics of the single pollution index (PI) of heavy metals in the study area.**

| Descriptive | Pb  | Cd  | Cr  | Ni  | Co  | Cu  | Zn  |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| n           | 273 | 273 | 273 | 273 | 273 | 273 | 273 |
| Mean        | 0.35 | 0.66 | 0.13 | 0.23 | 0.74 | 0.22 | 0.07 |
| Standard Deviation | 0.07 | 0.17 | 0.05 | 0.06 | 0.17 | 0.10 | 0.05 |
| Minimum     | 0.22 | 0.18 | 0.05 | 0.13 | 0.15 | 0.06 | 0.01 |
| Maximum     | 0.57 | 1.12 | 0.52 | 0.44 | 1.26 | 0.74 | 0.14 |
| Coefficient of Variance                | 0.01 | 0.03 | 0.00 | 0.00 | 0.03 | 0.01 | 0.00 |
| NIPI        | 0.47 | 0.92 | 0.38 | 0.35 | 1.04 | 0.55 | 0.11 |
Figure 2. Spatial distribution of heavy metal concentrations.
The mean PIs of studied heavy metals Pb, Cd, Cr, Ni, Co, Cu, and Zn in soil were 0.35, 1.98, 0.13, 0.23, 0.74, 0.22, and 0.07, respectively (table 3). The mean PI of all the heavy metals in the samples was less than 1, indicating the heavy metals content of soil in the study is at safe levels. Assessment of surface soil contamination by heavy metals evaluated using PI and NIPI in a coastal industrial city in YRD China showed that the average value of NIPI was 0.59 which is also at a safe level [12]. The mean value of the NIPI was 0.55, which being in a safe level. However, the maximum NIPI was 1.04, and this level indicates a slight pollution level. Overall, the soil contamination in the study area was considered at safe levels.

The source of heavy metal contamination in paddy fields generally comes from agricultural activities. Fertilization does not always accumulate cadmium and lead in the soil [14]. The distribution of the heavy metals (figure 2) shows that nothing has accumulated at a single point indicating no external source of contaminants. Based on this assessment, it shows that the paddy fields in Bandung Regency are safe for agricultural cultivation activities, which is not different from the assessment of paddy fields in Jombang Regency, East Java in which paddy fields are safe against heavy metal accumulation. Only a small portion of the sample contains Pb and Cr above their critical limit [15]. Heavy metal assessment in a coastal industrial city in the YRD of China using PI and NIPI indicators show at a safe level [12]. This means that heavy metal contamination on agricultural land is generally still safe, even around industrial areas.

4. Conclusions
The content of heavy metals in the paddy fields and dryland of Bandung Regency is still at safe limits for agricultural cultivation activities. Industrial development and changes in farmer behavior using excessive fertilizers and pesticides did not has a significant impact on the accumulation of heavy metals in paddy fields and dryland. A small proportion of soil samples contain Pb and Co above their critical limit in the soil, so it is necessary to be aware of the source of their accumulation. Information on the distribution of heavy metals in paddy fields and dryland in Bandung district can be a reference for stakeholders to manage the use of fertilizers, pesticides, and industrial waste so that they do not accumulate beyond their critical limits.

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