Korean Journal Of Agricultural Science

pISSN : 2466-2402
eISSN : 2466-2410

FOOD & CHEMISTRY

Heavy metals and pollution index of agricultural soils around industrial complexes in the Jeon-Buk regions of Korea

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Abstract

The aim of this study was to evaluate heavy metal contamination and pollution index of agricultural soils around industrial complexes in the Jeon-Buk Regions of Korea. Soil samples near industrial complexes in 2017 were collected at two depths (0 - 15 and 15 - 30 cm) within a 500- and 1000-meter radius before planting. Eight heavy metals (Arsenic (As), cadmium (Cd), chromium (Cr), Cupper (Cu), nickel (Ni), lead (Pb), mercury (Hg) and zinc (Zn)) and the pollution index (PI), geoaccumulation index (Igeo) and soil pollution index (SPI) were evaluated based on soil contamination warning standard (SCWS). Overall, the heavy metal concentrations were below the SCWS. The PI ranged from 0.1 to 0.9 and categorized into Group 1 which is not polluted with any heavy metals. The average Igeo values of all the soil samples ranged from - 2.56 to 3.22. The Igeo values of Cd and Hg may not represent well the pollution index because the heavy metal concentrations in the soil is lower compared to the SCWS. In fact, based on the heavy metal concentrations, the Igeo for monitored soils should be categorized into Group 1, uncontaminated to moderately contaminated. However, the Igeo of Cd and Hg are classified into heavily contaminated. These results suggest that for calculating the Igeo, the heavy metal concentration and background concentration should be used very carefully if the heavy metal concentration in the soil is lower than the background concentration. SPI for all the soil samples ranged from 0.00 to 0.11 which indicates no heavy metal pollution was observed.

Keywords: geochemical index, heavy metal, industrial area, pollution index, soil pollution index

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Citation: Suwanmanon S, Kim KI. 2019. Heavy metals and pollution index of agricultural soils around industrial complexes in the Jeon-Buk regions of Korea. Korean Journal of Agricultural Science 46:799-811. https://doi.org/10.7744/kjoas.20190063

Received: August 08, 2019

Revised: September 27, 2019

Accepted: September 30, 2019

Introduction

Soil pollution is the most important agricultural issues for the food safety in worldwide (Kong, 2014). Monitoring and evaluating soil and other agricultural quality can help make environmental policy better (Kloke, 1979; Sutherland, 1999; Wu et al., 2010; Ahmadi et al., 2017). Many countries reported a comparison of the results of different methods for evaluating soil contamination. These researches were based on geochemistry mapping including enrichment factor (EF), geoaccumulation index (Igeo), and pollution index (PI), along with principal component analysis (PCA) and comparisons of indices derived from different soil contamination. Industry expansion may negatively influence on the environment that results in critical issues on soil, water, and air pollution. The common pollution issues in soils near industrial complexes is from either wastewater input or solid waste input from the industrial process (Chen et al., 2005).

Currently, Ministry of Environment (MOE) in Korea has set up the levels of Soil Contamination Warning Standard (SCWS) which is regulated by Soil Environment Conservation La (SECL). Heavy metal warning levels for cultivated lands (Region 1) are 25, 4, 150, 100, 200, and 300 mg kg^{-1} for As, Cd, Cu, Ni, Pb, and Zn, respectively. Heavy metal contaminations in soils are due to smoke, dust, sewage, and industrial wastewater (Kim et al., 1996; Kim et al., 2003; Jung et al., 2005; Lee et al., 2010). Major heavy metals found in soils are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). Some of the heavy metals are the most hazardous elements for human health such as arsenic (As) (Karaca et al., 2010). These heavy metals in soils can be accumulated and certain levels of these heavy metals can be negatively influenced on crop growth and quality. For example, Cd and mercury (Hg) can be absorbed in the plant tissue and caused indirect hazard for human and animal health if they were consumed (Holmgren et al., 1993; Kim, 1996; Vulava et al., 1997). Kim et al. (2008) reported that human uptake levels of Cd and Pb concentrations in rice are 0.2 mg kg^{-1} each and heavy metal concentrations for As, Ni, and Zn at 2010 monitoring sites for paddy rice in South Korea tended to be increased, while Cd and Cu concentrations were decreased and Pb concentrations were similar. The effects of pollution in soils are highly related to the quality of agriculture products, food quality, and eventually human health (Jarup, 2003; Akoto et al., 2008; Cho et al., 2018; Kang et al., 2018; Kim et al., 2018). This paper will help us understand how much heavy metals in soils contain near industrial complexes in Jeon-Buk province. Also, this research can provide some important information on food and soil safety issues based on heavy metal level and distribution. The objective of this study was to investigate heavy metal concentrations and to provide soil contamination index in agricultural soils around industrial complexes in Jeon-Buk province, Korea.

Materials and Methods

Site description

Soil sampling sites were selected at agricultural fields near 15 industrial complexes in 11 counties in Jeon-Buk Province (Table 1). Ten agricultural fields at each industrial complex were randomly selected with four directions (east, west, south, and north) in 2017. Five of ten agricultural fields was located at within 0 meter to 500 meter radius from the borderline of each agricultural industrial complex, while the other was located at within 500 meter to 1000 meter radius from the borderline of each industrial complex.

Soil sample

Soil samples for each site were collected at two soil depth (0 - 15 cm and 15 - 30 cm) before planting from April through May in 2017. Ten soil cores were collected using soil auger (Eijelkamp one-piece soil

Table 1. Monitored industrial complexes in Jeon-Buk province in 2017 in Korea.

Site	Sample ID	The name of industrial complexes
Sunchang	Poongsan	Poongsan agricultural industrial complex
Imsil	Sinpyeong	Sinpyeong agricultural industrial complex
Wanju	Wanju	Wanju general industrial complex
Gunsan	Gunsan2	Gunsan-2 national industrial complex
	Okgu	Okgu agricultural industrial complex
	Sungsan	Sungsan industrial complex
Iksan	Wangung	Wangung agricultural industrial complex
Gochang	Gosu	Gosu agricultural industrial complex
Jeongeup	Nongso	Nongso agricultural industrial complex
	Bukmyeon	Bukmyeon agricultural industrial complex
Buan	Julpo	Julpo agricultural industrial complex
Muju	Ansung	Ansung agricultural industrial complex
Jangsu	Janggae	Janggae agricultural industrial complex
	Cheoncheon	Cheoncheon agricultural industrial complex
Jinan	Yeonjang	Yeonjang agricultural industrial complex

auger, Gempler's, Giesbeek, Netherlands) and combined them. Detailed information on sample ID and site of agricultural complexes are listed in Table 1. The total number of soil samples collected were 300 soil samples (150 for 0 - 15 cm depth and 150 soil sample for 15 - 30 cm depth). Wet soils were sub sampled and remained soil samples were air dried, then sieved with a 2 mm sieve for further analysis (MOE, 2016). Soil samples for heavy metal analysis were milled with Zirconia balls by mill machine (Daihan, Korea) for 5 days at 10000 rpm.

Heavy metal analysis

Soil samples were analyzed based on National Institute of Agricultural Science and Technology (NIAST) method (NIAST, 1998). Soil moisture content was measured at 105℃ for 8 hours. Finely ground soil samples were wet digested for heavy metal analysis. In details, three grams of soils were weighed and mixed with 21 mL of hydrochloric acid (HCl) and 7 mL of nitric acid (HNO_3). Then the wet digested solution was heated for 2 hours at 120℃ and filtered through Whatman filter paper No. 2 (Whatman, UK). These digested solution was used for heavy metal analysis, such as As, Cd, Cr, Cu, Ni, Pb, Hg, and Zn (MOE, 2016). The heavy metal concentration was measured using an ICP-OES (Optima 7300DV, Perkin Elmer, USA).

Igeo and soil pollution index (SPI) analysis

Two evaluating methods, such as Igeo and SPI for the assessment of the soil contamination were performed. For Igeo analysis, the contamination factor was calculated using the relation described (Hakanson, 1980).

$$PI = Cn/Bn \tag{1}$$

(1) where Cn is the concentration of the examined element in the soil and Bn is the geochemical background value. The background values was used from Liao and Chao (2004). The constant 1.5 helps to analyze natural fluctuation between the content of a given substance in environment and very small anthropogenic influences. The background values for this study were averaged values from 2070 paddy rice soil samples. The concentration of As, Cd, Cu, Ni, Pb, and Zn were 3.68, 0.22, 14.9, 14.1, 16.7, and 56.8 mg kg^{-1}, respectively.

The contamination level of soil was evaluated using Igeo. Igeo values are classified into 6 classification index (Table 2). The Igeo were calculated using the modified formula based on Chester and Stoner (1973) and Hakanson (1980).

$$\mathrm{Igeo} = \log_2 [\mathrm{Cn}/1.5 \times \mathrm{Bn}] \tag{2}$$

The PI and Igeo values were compared with the classification of soil contamination assessment degree index. Four categories of PI and Igeo were defined Hakanson (1980) and Muller (1979) and Praveena et al. (2008). SPI was evaluated based on the levels of SCWS which is regulated by SECL. Warning levels for cultivated lands (Region 1) were 25, 4, 150, 100, 200, and 300 mg/kg for As, Cd, Cu, Ni, Pb, and Zn, respectively. Soil pollution index was calculated the equation below.

$$\mathrm{SPI} = \frac{\sum \dfrac{\text{Heavy metal concentration in soil}}{\text{Soil contamination warning standard}}}{\text{Number of heavy metals}} \tag{3}$$

If SPI is greater than 1 each heavy metal concentration is higher than soil contamination warning standard, while SPI is less than 1 soil heavy metal concentration is within the levels of soil contamination warning standard.

Table 2. Classification of different soil contamination assessment of geochemical index (Igeo).

Classification index	Igeo value	Designation of soil quality
0	Igeo ≤ 0	Practically uncontaminated
1	0 < Igeo < 1	Uncontaminated to moderately contaminated
2	1 < Igeo < 2	Moderately contaminated
3	2 < Igeo < 3	Moderately to heavily contamination
4	3 < Igeo < 4	Heavily contaminated
5	4 < Igeo < 5	Heavily to extremely contaminated
6	5 < Igeo	Extremely contaminated

Statistical analysis

All experiments data are expressed as means and standard deviation. The 0.05 p-value were considered a statistically significant using SPSS program (version 12.0, IBM, USA).

Results and Discussion

Summary statistics of heavy metals

Statistical summary of heavy metal concentrations in soils near industrial complexes in Jeonbuk province in Korea are listed in Table 3. Average, minimum (Min.), maximum (Max.), standard deviation (stdev), coefficients of variation (C.V. (%)), kurtosis, and skewness were listed based on two soil depths (0 - 15 cm depth and 15 - 30 cm depth). Overall, eight heavy metals in the soil samples were found. Total averaged heavy metal concentrations for top and sub soils were 3.8, 3.4 mg kg^{-1} for As, 2.3, 2.2 mg kg^{-1} for Cd, 21.2, 19.5 mg kg^{-1} for Cr, 10.7, 9.1 mg kg^{-1} for Cu, 0.1, 0.1 mg kg^{-1} for Hg, 12.1, 11.3 mg kg^{-1} for Ni, 17.4, 14.2 mg kg^{-1} for Pb, and 58.9, and 53.5 mg kg^{-1} for Zn, respectively (Table 3). Yun et al. (2018) reported that the averaged heavy metal concentrations of general paddy rice soils (2110 soil samples) for As, Cu, Ni, Pb, and Zn were 3.68, 14.9, 14.0, 16.7, and 56.8 mg kg^{-1}, respectively. These heavy metal concentrations were below heavy metal warning levels for cultivated lands (Region 1) which were 25, 150, 100, 200, and 300 mg kg^{-1} for As, Cu, Ni, Pb, and Zn, respectively. Arsenic concentration was ranged from 0.0 to 24.9 mg kg^{-1}, Cd concentration was ranged from 0.0 to 3.9 mg kg^{-1}, Cr concentration was ranged from 0.0 to 83.7 mg kg^{-1}, Ni concentration was ranged from 0.0 to 34.8 mg kg^{-1}, Pb concentration was ranged from 0.0 to 58.9 mg kg^{-1}, Hg concentration was ranged from 0.0 to 2.7 mg kg^{-1}, and Zn concentration was ranged from 0.0 to 162.2 mg kg^{-1}. These results showed that all of heavy metal concentrations for 300 soil samples was lower than the levels of SCWS and did not exceed the level limits of SECL.

Table 3. Descriptive statistics of selected heavy metals in agricultural soils near the industrial complexes in Jeon-Buk Province in Korea.

Parameter	As		Cd		Cr		Cu		Hg		Ni		Pb		Zn	
	(mg·kg^{-1})															
Soil depth	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
Average	3.8	3.4	2.3	2.2	21.2	19.5	10.7	9.1	0.1	0.1	12.1	11.3	17.4	14.2	58.9	53.5
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Max.	24.9	24.9	3.9	3.9	83.7	65.0	53.6	36.9	2.7	2.7	34.8	32.6	58.9	45.2	162	143
Stdev.	4.7	3.9	0.9	1.0	13.0	11.9	7.9	6.6	0.3	0.3	6.5	6.5	11.8	7.3	28.7	25.8
C.V. (%)	123	114	41	45	61	61	74	73	440	482	54	57	68	51	49	48
Kurtosis	7.8	8.6	- 0.3	- 0.4	3.8	1.1	7.1	3.2	64.0	64.2	0.4	- 0.1	2.9	2.6	2.0	0.7
Skweness	2.6	2.4	- 0.2	- 0.2	1.3	0.8	2.1	1.5	7.4	7.4	0.6	0.5	1.6	1.0	0.8	0.2
SCWS[z] Limit	25		4		n/a		150		4		100		200		300	
Number of Below SCWS	0		0		0		0		0		0		0		0	

Min., minimum; Max., maximum; Stdev., standard deviation; C.V., coefficients variations.
[z] Soil Contamination Warning Standard (SCWS) from Ministry of Environment (MOE) in Korea.

Standard deviations for the top and sub soils were 4.7, 3.9 for As, 0.9, 1.0 for Cd, 13.0, 11.9 for Cr, 7.9, 6.6 for Cu, 0.3, 0.3 for Hg, 6.5, 6.5 for Ni, 11.8, 7.3 for Pb, and 28.7, and 25.8 for Zn, respectively. The lowest stdev. was Hg for sub soil and the highest stdev. was Zn for top soil. Coefficients variations (C.V. (%)) for the top and sub soils were 122, 113 for As, 40, 44 for Cd, 61, 61 for Cr, 73, 72 for Cu, 439, 482 for Hg, 53, 57 for Ni, 67, 51 for Pb, and 48, 48 for Zn, respectively. The lowest C.V. was Cd for top soil and the highest C.V. was As for top soil. Kurtosis is a measure of the tailedness of the probability and the kurtosis of normal distribution is 3. Kurtosis for the top and sub soils were 7.8, 8.6 for As, - 0.3, - 0.4 for Cd, 3.8, 1.1 for Cr, 7.1, 3.2 for Cu, 64, 64 for Hg, 0.4, - 0.1 for Ni, 2.9, 2.6 for Pb, and 2.0, 0.7 for Zn, respectively. The lowest kurtosis was Cd for sub soil and the highest kurtosis was As for top soil. Skewness for the top and sub soils were 2.6, 2.4 for As, - 0.2, - 0.2 for Cd, 1.3, 0.8 for Cr, 2.1, 1.5 for Cu, 7.4, 7.4 for Hg, 0.6, 0.5 for Ni, 1.6, 1.0 for Pb, and 0.8, 0.2 for Zn, respectively. The lowest skewness was Cd for sub soil and the highest skewness was As for top soil. These results showed that there were great heterogeneity in the content of As in the soil across the study area, indicating that anthropogenic inputs may be the main sources of As in this area (Wang et al., 2010; Hu et al., 2016). Overall, all the soil samples did not exceed the levels of SCWS for cultivated lands, which is regulated by SECL, MOE in Korea (MOE, 2016).

Average heavy metal concentration for top and sub soils

Averaged heavy metal concentration for top and sub soils were listed in Table 4. Among 8 heavy metal concentration, Zn was the highest followed by Pb > Cr > Ni > Cu > As > Cd and Hg. The As concentration was shown the highest in Jinan than Imsil and Gunsan counties. But the highest concentrations for Zn, Pb, Ni, and Cr were in Imsil county. However, all of heavy metal concentrations were lower than SCWS. Arsenic concentration was ranged from 1.6 to 13.0 for top soil and from 1.1 to 10.3 mg kg^{-1}, for sub soil. Cadmium concentration was ranged from 1.3 to 3.1 for top soil and from 1.1 to 3.1 mg kg^{-1}, for sub soil. Chromium concentration was ranged from 12.8 to 33.8 for top soil and from 11.2 to 32.1 mg kg^{-1}, for sub soil. Copper concentration was ranged from 6.9 to 22.5 for top soil and from 5.7 to 21.4 mg kg^{-1}, for sub soil. Mercury concentration was ranged from 0.0 to 0.3 for top soil and from 0.0 to 0.3 mg kg^{-1}, for sub soil. Nickle concentration was ranged from 7.3 to 18.2 for top soil and from 6.7 to 18.4 mg kg^{-1}, for sub soil. Lead concentration was ranged from 7.5 to 30.9 for top soil and from 7.6 to 22.7 mg kg^{-1}, for sub soil. Zinc concentration was ranged from 28.8 to 92.3 for top soil and from 29.2 to 77.2 mg kg^{-1}, for sub soil. Jung et al. (2000) studied 20 sites and reported that As was 7.5 mg kg^{-1}, Cd was 0.396 mg kg^{-1}, Cu was 15.8 mg kg^{-1}, Ni was 13.3 mg kg^{-1}, Pb was 19.0 mg kg^{-1}, respectively.

PI, Igeo, and SPI

Soil contamination assessment is calculated using PI and Igeo and listed in Table 6. PI is the single factor pollution index of each heavy metal. It is ranged from 0.1 to 0.9 for top and sub soils (Table 5). The contamination level of heavy metal in top-soils using pollution index was Group 1 which is not polluted for any heavy metals. Mohammadpour Roudposhti et al. (2016) and Jorfi et al. (2017) categorized PI into 4 groups: Group 1 : PI < 1 (no polluted); Group 2 : 1 ≤ PI < 2 (slightly polluted); Group 3 : 2 ≤ PI < 3 (moderately polluted); and Group 4 : PI < 3 (Highly polluted). Wu et al. (2014) studied soil contamination indices in a mining area of Jiangxi, China and reported PI was ranged from 1.12 to 2.57. The average PI values of all 8 heavy metal

Table 4. Heavy metal concentrations for top and sub agricultural soils near the industrial complexes in Jeon-Buk Province in Korea.

Site	Soil depth	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		(mg·kg^{-1})							
Sunchang	Top	3.4	2.7	28.1	10.5	0.0	15.2	30.5	59.9
	Sub	3.2	2.6	21.3	7.8	0.0	13.0	18.8	49.3
Imsil	Top	6.3	3.0	31.2	13.9	0.0	18.2	29.8	92.3
	Sub	5.9	3.1	30.4	12.1	0.0	18.4	22.7	77.2
Wanju	Top	4.5	3.1	33.8	13.3	0.1	16.4	22.7	71.9
	Sub	4.7	1.9	32.1	10.8	0.0	16.3	19.3	65.2
Gunsan2	Top	3.7	1.3	15.2	7.6	0.0	8.7	20.3	28.8
	Sub	3.4	1.1	14.3	6.3	0.0	8.4	17.9	29.2
Okgu	Top	9.2	1.8	21.4	22.5	0.1	11.8	24.1	64.0
	Sub	5.7	1.9	22.2	21.4	0.1	15.4	17.9	58.5
Sungsan	Top	6.5	2.7	30.7	14.9	0.0	15.8	30.9	65.6
	Sub	6.8	1.8	17.9	14.4	0.1	17.7	13.0	63.3
Iksan	Top	2.3	1.6	14.5	10.0	0.1	8.0	13.9	46.9
	Sub	2.5	1.8	13.0	8.3	0.0	6.7	12.5	37.9
Gochang	Top	2.4	2.6	16.0	6.9	0.0	10.5	11.6	62.3
	Sub	2.1	2.4	14.5	5.7	0.0	9.5	12.0	55.0
Nongso	Top	2.2	2.0	14.6	13.8	0.3	9.0	16.8	69.4
	Sub	1.1	1.8	11.2	8.6	0.3	7.1	12.4	54.5
Bukmyeon	Top	2.5	1.8	12.8	6.6	0.0	7.3	15.6	48.4
	Sub	2.1	2.0	13.0	7.0	0.0	8.0	16.9	54.6
Buan	Top	3.0	2.8	20.3	9.9	0.0	13.4	14.5	66.6
	Sub	3.8	2.8	20.3	8.3	0.0	12.7	13.3	61.4
Muju	Top	10.4	2.7	27.3	10.5	0.0	13.3	11.7	62.8
	Sub	6.2	2.8	26.7	9.1	0.0	12.9	11.9	62.2
Janggae	Top	1.6	2.5	26.7	12.4	0.0	14.3	11.2	67.0
	Sub	2.3	2.7	27.3	14.5	0.1	14.8	12.4	78.0
Cheoncheon	Top	2.7	1.7	16.5	7.0	0.0	9.3	7.5	43.5
	Sub	3.7	1.9	18.0	7.9	0.0	10.6	7.6	46.5
Jinan	Top	13.0	2.5	16.3	12.2	0.0	11.8	13.5	69.7
	Sub	10.3	2.2	14.5	9.3	0.0	10.4	11.9	59.5

elements were less than 1. These results suggested that 11 counties agriculture soils near industrial complexes in Jeon-Buk province were not contaminated by 8 heavy metals. The background values for this study were in part from 2070 paddy rice soils in Korea and individual concentrations for As, Cd, Cu, Ni, Pb, and Zn were 3.68, 0.22, 14.9, 14.1, 16.7, and 56.8 mg kg^{-1}, respectively (Jung et al., 2000). Jung et al. (2000) reported that natural heavy metal concentrations for As, Cd, Hg, and Pb with hot extraction was 4.49, 0.832, 0.0251, and 34.1 mg kg^{-1}, respectively, while natural heavy metal concentrations for As, Cd, Cu, and Pb with cold extraction was 0.0348, 0.0246, 0.204, and 3.18 mg kg^{-1}, respectively. Local background values for As, Cd, Cr, Cu, Hg, Pb, and Zn were 19.0, 0.17, 92.0, 48.0, 0.15, 47, and 108.0 mg kg^{-1}, respectively.

Table 5. Pollution index (PI) for top and sub agricultural soils near the industrial complexes in Jeon-Buk Province in Korea.

Site	Soil depth	As	Cd	Cr	Cu	Ni	Pb	Zn
Sunchang	Top	0.2	0.9	0.3	0.1	0.3	0.3	0.2
	Sub	0.2	0.9	0.2	0.1	0.3	0.2	0.2
Imsil	Top	0.3	1.0	0.3	0.1	0.4	0.3	0.3
	Sub	0.3	1.0	0.3	0.1	0.4	0.2	0.3
Wanju	Top	0.2	1.0	0.3	0.1	0.3	0.2	0.2
	Sub	0.2	0.6	0.3	0.1	0.3	0.2	0.2
Gunsan2	Top	0.2	0.4	0.2	0.1	0.2	0.2	0.1
	Sub	0.2	0.4	0.1	0.1	0.2	0.2	0.1
Okgu	Top	0.5	0.6	0.2	0.2	0.2	0.2	0.2
	Sub	0.3	0.6	0.2	0.2	0.3	0.2	0.2
Sungsan	Top	0.3	0.9	0.3	0.1	0.3	0.3	0.2
	Sub	0.3	0.6	0.2	0.1	0.4	0.1	0.2
Iksan	Top	0.1	0.5	0.1	0.1	0.2	0.1	0.2
	Sub	0.1	0.6	0.1	0.1	0.1	0.1	0.1
Gochang	Top	0.1	0.9	0.2	0.1	0.2	0.1	0.2
	Sub	0.1	0.8	0.1	0.1	0.2	0.1	0.2
Nongso	Top	0.1	0.7	0.1	0.1	0.2	0.2	0.2
	Sub	0.1	0.6	0.1	0.1	0.1	0.1	0.2
Bukmyeon	Top	0.1	0.6	0.1	0.1	0.1	0.2	0.2
	Sub	0.1	0.7	0.1	0.1	0.2	0.2	0.2
Buan	Top	0.1	0.9	0.2	0.1	0.3	0.1	0.2
	Sub	0.2	0.9	0.2	0.1	0.3	0.1	0.2
Muju	Top	0.5	0.9	0.3	0.1	0.3	0.1	0.2
	Sub	0.3	0.9	0.3	0.1	0.3	0.1	0.2
Janggae	Top	0.1	0.8	0.3	0.1	0.3	0.1	0.2
	Sub	0.1	0.9	0.3	0.1	0.3	0.1	0.3
Cheoncheon	Top	0.1	0.6	0.2	0.1	0.2	0.1	0.1
	Sub	0.2	0.6	0.2	0.1	0.2	0.1	0.2
Jinan	Top	0.7	0.8	0.2	0.1	0.2	0.1	0.2
	Sub	0.5	0.7	0.1	0.1	0.2	0.1	0.2

Averaged Igeo values in all samples were ranged from - 2.56 to 3.22 (Table 6). Each average value of Igeo of As was range from - 2.37 to 1.24, Igeo of Cd was ranged from 1.78 to 3.22, Igeo of Cu was ranged from - 1.97 to 0.01, Igeo of Hg was ranged from - 2.56 to 3.11, Igeo of Ni was ranged from - 1.65 to - 0.2, Igeo of Pb was ranged from - 1.74 to 0.3, and Igeo of Zn was ranged from - 1.56 to 0.12. Igeo value of Cd was the highest followed by Hg > As > Pb > Zn > Cu > Ni. Monitored soil data were classified within 5 groups, Group 0: Igeo < 0 (practically uncontaminated), Group 1: 0 < Igeo < 1 (uncontaminated to moderately contaminated), Group 2: 1 < Igeo < 2 (moderately contaminated), and Group 3: 2 < Igeo < 3 (moderately to heavily contaminated), Group 4: 3 < Igeo < 4 (heavily contaminated) (Wu et al., 2014; Kim et al., 2015; Jorfi et al., 2017). Wu et al (2014) reported that Igeo values was ranged from - 0.07 to - 0.64 in mining area in China and suggested that a lack of

Table 6. Geochemical index (Igeo) for top and sub agricultural soils near the industrial complexes in Jeon-Buk Province in Korea.

Site	Soil depth	As	Cd	Cu	Hg	Ni	Pb	Zn
Sunchang	Top	- 0.69	3.06	- 1.09	- 2.51	- 0.48	0.28	- 0.51
	Sub	- 0.79	2.96	- 1.52	NA	- 0.70	- 0.42	- 0.79
Imsil	Top	0.18	3.16	- 0.68	0.31	- 0.22	0.25	0.12
	Sub	0.10	3.21	- 0.89	- 1.31	- 0.20	- 0.14	- 0.14
Wanju	Top	- 0.30	3.22	- 0.75	1.20	- 0.37	- 0.14	- 0.24
	Sub	- 0.25	2.51	- 1.05	- 1.33	- 0.37	- 0.38	- 0.39
Gunsan2	Top	- 0.59	2.00	- 1.55	NA	- 1.29	- 0.30	- 1.56
	Sub	- 0.71	1.78	- 1.83	NA	- 1.33	- 0.49	- 1.54
Okgu	Top	0.73	2.44	0.01	1.63	- 0.85	- 0.06	- 0.41
	Sub	0.05	2.50	- 0.06	1.07	- 0.46	- 0.48	- 0.54
Sungsan	Top	0.23	3.02	- 0.59	- 1.13	- 0.42	0.30	- 0.38
	Sub	0.29	2.42	- 0.64	0.47	- 0.25	- 0.95	- 0.43
Iksan	Top	- 1.26	2.25	- 1.16	0.83	- 1.40	- 0.85	- 0.86
	Sub	- 1.15	2.45	- 1.44	- 1.15	- 1.65	- 1.00	- 1.17
Gochang	Top	- 1.22	2.97	- 1.69	- 2.56	- 1.02	- 1.11	- 0.45
	Sub	- 1.39	2.86	- 1.97	NA	- 1.15	- 1.06	- 0.63
Nongso	Top	- 1.33	2.61	- 0.69	3.11	- 1.23	- 0.58	- 0.30
	Sub	- 2.37	2.45	- 1.38	2.99	- 1.57	- 1.01	- 0.64
Bukmyeon	Top	- 1.15	2.43	- 1.75	NA	- 1.53	- 0.68	- 0.81
	Sub	- 1.37	2.59	- 1.67	NA	- 1.40	- 0.57	- 0.64
Buan	Top	- 0.90	3.11	- 1.18	NA	- 0.66	- 0.78	- 0.36
	Sub	- 0.53	3.09	- 1.43	NA	- 0.74	- 0.91	- 0.47
Muju	Top	0.92	3.03	- 1.09	- 1.81	- 0.67	- 1.10	- 0.44
	Sub	0.16	3.09	- 1.29	- 0.95	- 0.71	- 1.07	- 0.45
Janggae	Top	- 1.81	2.94	- 0.85	- 1.09	- 0.57	- 1.16	- 0.35
	Sub	- 1.28	3.02	- 0.62	- 1.75	- 0.51	- 1.01	- 0.13
Cheoncheon	Top	- 1.05	2.38	- 1.68	NA	- 1.18	- 1.74	- 0.97
	Sub	- 0.57	2.52	- 1.51	NA	- 1.00	- 1.72	- 0.88
Jinan	Top	1.24	2.90	- 0.88	NA	- 0.84	- 0.90	- 0.29
	Sub	0.90	2.70	- 1.26	- 1.63	- 1.03	- 1.07	- 0.52

NA, not available.

soil contamination because it is lower than 0. Kim et al. (2015) studied paddy rice soils located no downstream of the closed metalliferous mine and reported that Igeo of Cd, Pb, and Zn was ranged from 2.49 to 3.10 which were categorized in groups 3 and 4. For this study, heavily to extremely contaminated and extremely contaminated were not observed. The highest Igeo values were shown for Cd and Hg although Cd and Hg concentrations were below SCWS. In Hg elements, Igeo values may not be well present because of Hg concentration in soil is lower than pollution background factor. Based on heavy metal concentrations, monitored soils should be categorized into Ground 1, uncontaminated to moderately contaminated. These results suggested that for calculating Igeo value, heavy metal concentration in soil and background concentration are very carefully used if heavy metal

Table 7. Soil Pollution index (SPI) for top and sub agricultural soils near the industrial complexes in Jeon-Buk Province in Korea.

Site	Soil depth	As	Cd	Cu	Hg	Ni	Pb	Zn
Sunchang	Top	0.02	0.10	0.01	0.00	0.02	0.02	0.03
	Sub	0.02	0.09	0.01	0.00	0.02	0.01	0.02
Imsil	Top	0.04	0.11	0.01	0.00	0.03	0.02	0.04
	Sub	0.03	0.11	0.01	0.00	0.03	0.02	0.04
Wanju	Top	0.03	0.11	0.01	0.00	0.02	0.02	0.03
	Sub	0.03	0.07	0.01	0.00	0.02	0.01	0.03
Gunsan2	Top	0.02	0.05	0.01	0.00	0.01	0.01	0.01
	Sub	0.02	0.04	0.01	0.00	0.01	0.01	0.01
Okgu	Top	0.05	0.06	0.02	0.00	0.02	0.02	0.03
	Sub	0.03	0.07	0.02	0.00	0.02	0.01	0.03
Sungsan	Top	0.04	0.10	0.01	0.00	0.02	0.02	0.03
	Sub	0.04	0.06	0.01	0.00	0.03	0.01	0.03
Iksan	Top	0.01	0.06	0.01	0.00	0.01	0.01	0.02
	Sub	0.01	0.06	0.01	0.00	0.01	0.01	0.02
Gochang	Top	0.01	0.09	0.01	0.00	0.01	0.01	0.03
	Sub	0.01	0.09	0.01	0.00	0.01	0.01	0.03
Nongso	Top	0.01	0.07	0.01	0.01	0.01	0.01	0.03
	Sub	0.01	0.06	0.01	0.01	0.01	0.01	0.03
Bukmyeon	Top	0.01	0.06	0.01	0.00	0.01	0.01	0.02
	Sub	0.01	0.07	0.01	0.00	0.01	0.01	0.03
Buan	Top	0.02	0.10	0.01	0.00	0.02	0.01	0.03
	Sub	0.02	0.10	0.01	0.00	0.02	0.01	0.03
Muju	Top	0.06	0.10	0.01	0.00	0.02	0.01	0.03
	Sub	0.04	0.10	0.01	0.00	0.02	0.01	0.03
Janggae	Top	0.01	0.09	0.01	0.00	0.02	0.01	0.03
	Sub	0.01	0.10	0.01	0.00	0.02	0.01	0.04
Cheoncheon	Top	0.02	0.06	0.01	0.00	0.01	0.01	0.02
	Sub	0.02	0.07	0.01	0.00	0.02	0.01	0.02
Jinan	Top	0.07	0.09	0.01	0.00	0.02	0.01	0.03
	Sub	0.06	0.08	0.01	0.00	0.01	0.01	0.03

concentration in soils is lower than background concentration.

SPI was ranged from 0.00 to 0.11 (Table 7). The average value of SPI of As was ranged from 0.01 to 0.07, SPI of Cd was ranged from 0.04 to 0.11, SPI of Cu was ranged from 0.01 to 0.02, SPI of Hg was ranged from 0.00 to 0.01, SPI of Ni was ranged from 0.01 to 0.03, SPI of Pb was ranged from 0.01 to 0.02, and SPI of Zn was ranged from 0.01 to 0.04. If SPI is higher than 1, it indicated that soil is polluted due to one of heavy metal or more heavy metals. These results suggested that no heavy metal pollution was found for this monitoring study. Kim et al. (2015) reported that SPI for As, Cd, Cu, and Pb was 0.92 for sub soil and 0.68 for sub soil from closed mine area, while Min et al. (2016) reported that SPI was ranged from 0.03 to 0.27.

Conclusion

In this study, 300 agricultural soils near industrial complexes in Jeon-Buk, Korea were analyzed for 8 heavy metals. Heavy metal concentrations were below the SCWS. PI is ranged from 0.1 to 0.9 that is categorized into Group 1 which is not polluted for any heavy metals. Averaged Igeo values for all soil samples were ranged from - 2.56 to 3.22. Each average value of Igeo of As was range from - 2.37 to 1.24, Igeo of Cd was ranged from 1.78 to 3.22, Igeo of Cu was ranged from - 1.97 to 0.01, Igeo of Hg was ranged from - 2.56 to 3.11, Igeo of Ni was ranged from - 1.65 to - 0.2, Igeo of Pb was ranged from - 1.74 to 0.3, and Igeo of Zn was ranged from - 1.56 to 0.12. For Igeo of Cd and Hg, Igeo values may not be well present for pollution status because heavy metal concentrations in soil is lower than SCWS. Therefore, Igeo of Cd and Hg should be classified into no contamination instead of heavily contaminated. These results suggest that for calculating Igeo, heavy metal concentration and background concentration should be used very carefully if heavy metal concentration in soil is lower than background concentration. SPI for all soil samples was ranged from 0.00 to 0.11 that indicates no heavy metal pollutions was observed.

Acknowledgement

This paper was fully supported by Rural Development Administration, National Institute of Agricultural Science.

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