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Evaluating Pollution Indexes using Heavy Metal Concentrations in Agricultural Soils around Industrial Complexes in the Jeon-Nam Regions of Korea

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A B S T R A C T

The main purpose of this study was to investigate soil contamination using heavy metal analysis in agricultural fields around industrial complexes in the Jeon-Nam regions in Korea. Ten counties in Jeon-Nam province for soil samples near industrial complexes were Gwangyang, Muan, Yeongam, Hampyeong, Haenam, Naju, Jangheung, Boseong, Yeosu, and Damyang. At agricultural field sites soil samples were collected in the spring of 2018 at two soil depths (0-15 cm and 15-30) within a 500- and 1000-meter radius next to industrial complexes before planting. All soil samples were analyzed for the 8 heavy metals including arsenic (As), cadmium (Cd), chromium (Cr), cupper (Cu), nickel (Ni), lead (Pb), mercury (Hg) and zinc (Zn). The results showed that the heavy metal concentrations were below the levels of Soil Contamination Warning Standard (SCWS) for agricultural lands (Region 1) which is regulated by Soil Environment Conservation Law (SECL) established by Ministry of Environment (MOE), Korea. Other heavy metal indexes such as soil pollution index (SPI), pollution index (PI), and pollution load index (PLI) were evaluated to determine contamination of soils due to heavy metals. If SPI is less than 1.0, then soil heavy metal concentration is within the levels of soil contamination warning standard. In this study, SPI is less than 1.0 that means soil is not contaminated. Second, PI for the studied soils is less than 1.0, which classified into "Classification index 1" which means uncontaminated soils. Lastly, PLI for studied soils is between 0.10 and 0.24, classified into "Classification index 2" which is unpolluted soil. For interpreting the PI, 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. In this case, PI value of Hg can mislead interpretation if the soil heavy metal concentration is less than the background concentration. For example, Hg concentration for the background concentration is 0.025 mg kg^{-1} and Hg concentration for studied soils ranged from 0.000 to 0.004 mg kg^{-1}. Further research is needed to continue to monitor soil heavy metal distribution near industrial complexes in Jeon-Nam province of Korea.

Keywords: Agricultural field, Heavy metal, Soil Contamination warning standard, Soil pollution index, Pollution index, Pollution load index

Descriptive statistics of heavy metals concentration in agricultural soils near the industrial complexes in Jeon-Nam Province in Korea.

Element	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	5.0	5.1	0.1	0.1	19.7	19.9	8.8	8.5	0.0	0.0	8.2	8.3	43.5	44.3	43.8	43.2
Min.	1.0	1.2	0.0	0.0	3.6	3.9	1.4	1.7	0.0	0.0	1.4	1.9	6.2	7.0	19.7	20.4
Max.	19.6	20.5	1.4	1.6	58.9	79.8	49.1	48.2	0.2	0.1	26.8	34.9	98.4	113.9	193.5	197.0
Stdev.	3.5	3.8	0.2	0.2	11.5	11.9	5.6	5.6	0.0	0.0	4.9	5.1	11.1	11.9	19.3	19.1
C.V. (%)	70.0	74.8	129.4	139.3	58.5	59.9	64.2	66.3	360.7	386.3	59.5	61.7	25.6	26.9	44.0	44.3
Kurtosis	3.7	3.5	39.2	43.5	1.0	3.8	19.2	22.0	50.5	51.3	1.7	4.6	4.1	7.8	23.9	27.6
Skweness	1.9	1.9	6.1	6.5	1.2	1.6	3.4	3.8	7.1	7.1	1.3	1.7	0.4	1.1	3.7	4.0
SCWS Limit	25		4		n/a		150		4		100		200		300	
Number of Above SCWS	0		0		0		0		0		0		0		0	

Min., minimum; Max., maximum; Stdev., standard deviation; C.V., coefficients variations.

[†]Soil Contamination Warning Standard (SCWS) from Ministry of Environment (MOE) in Korea.

Introduction

One of the most urgent issue for agriculture is to secure safe food worldwide (Kong, 2014). Evaluating soil quality and monitoring the agricultural process can help make better food and environmental quality (Kloke, 1979; Sutherland, 1999; Wu et al., 2010; Ahmadi et al., 2017). Soil is an important material and essential medium for agricultural production system. Many researchers determined how to use and manage soils for growing crops (Rowell, 1937). But some of the human activities affect negatively and detrimentally on the environment. Economic and industry expansion around the world is influenced on the environmental side (Kim et al., 1996; Kim et al., 2003; Jung et al., 2005; Lee et al., 2010). Especially, serious pollution issues around the agricultural field near industrial complexes should be prevented (Chen et al., 2005).

Near industrial complexes, growing vegetables and crops could be potential threat for human because crops containing heavy metals may be consumed by human. Heavy metals in soil is one of the major environment concerns at every industrial complex. Toxicity of heavy metals can be negatively influenced on crops growth, enzymatic and photosynthesis activity and also damages the root system (Johansson et al., 1998). The researchers in the many countries have found that various crops are accumulated with heavy metal through contaminated soil, and these heavy metals have detrimental effects on human health (Nriagu, 1996; Saby et al., 2011; Schneider et al., 2016; Hu et al., 2016). Heavy metals are easily transferred into food chains and stayed in the human body, such as the heart, liver, and kidney that can result in serious health disorders such as gastrointestinal cancer (Jarup et al., 2003; Duruibe et al., 2007; Jolly et al., 2013). Cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) were found in soils. Soil Contamination Warning Standard (SCWS) which is regulated by Soil Environment Conservation Law (SECL) in the Republic of Korea is categorized. 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. Some of the heavy metals are the most hazardous elements for human health such as arsenic (As) (Karaca et al., 2010). Cadmium (Cd) and mercury (Hg) can be absorbed in the plant tissue and cause direct impact on human and animal health if they were consumed (Holmgren et al., 1993; Kim, 1996; Vulava et al., 1997). Lead (Pb) and cadmium (Cd) were accumulated in rice, basil, ginger, and onion (Kim et al., 2008). The quality of agricultural products is closely related to human health and environment (Jarup, 2003; Akoto et al., 2008).

This study will help us understand how much heavy metals in soils contain near industrial complexes in Jeon-Nam province. Also, this research can provide some important information on food and soil safety issues based on Soil Contamination Warning Standard (SCWS) which is regulated by Soil Environment Conservation Law (SECL). The objective of this study was to investigate heavy metal concentrations and to provide heavy metal concentrations in agricultural soils around industrial complexes in Jeon-Nam province, Korea.

Materials and Methods

Site description   This study was conducted in 2018 in Jeon-Nam Province. Soil sampling sites were selected at agricultural fields near industrial complexes in 10 counties (Gwangyang, Muan, Yeongam, Hampyeong, Haenam, Naju, Jangheung, Boseong, Yeosu, Damyang) in Table 1. Ten agricultural fields near industrial complexes in each county were randomly selected, with four directions (east, west, south, and north). Two depth soils (0 - 15 and 15 - 30 cm) were collected within 0 - 500 meter and 500 - 1000-meter radius at each industrial complex. Five of ten agricultural fields were located at within 0 to 500-meter radius from the borderline of each industrial complexes, while the other half was located within 500- to 1000-meter radius from the borderline of each industrial complexes.

Table 1. Monitored industrial complexes in Jeon-Nam province in 2018 in Korea.

Site	Sample ID	The name of industrial complexes
Gwangyang	Gwangyang	Gwangyang Industrial Complex
Muan	Illo	Illo agricultural industrial complex
Yeongam	Sinbuk	Sinbuk agricultural industrial complex
	Gugseo	Gugseo agricultural industrial complex
Hampyeong	Hampyeong	Hampyeong agricultural industrial complex
Haenam	Ogcheon	Ogcheon agricultural industrial complex
Naju	Munpyeong	Munpyeong industrial complex
	Ilban	Ilban industrial complex
	Noan	Noan agricultural industrial complex
Jangheung	Jangheung	Jangpyeong agricultural industrial complex
Boseong	Milyeog	Milyeog agricultural industrial complex
	Joseong	Joseong agricultural industrial complex
Yeosu	Hyayang	Hyayang agricultural industrial complex
Damyang	Ecohightech	Ecohightech agricultural industrial complex
	Geumseong	Geumseong agricultural industrial complex

Soil sample   Five soil cores were collected using soil auger (Eijelkamp one-piece soil auger, Gempler's, Giesbeek, Netherlands) and thoroughly mixed well and stored in a plastic bag. The total numbers of soil samples were 300 soil samples (150 for 0 - 15 cm depth and 150 soil sample for 15 - 30cm depth). Collected soil samples were air-dried and sieved with a 2 mm sieve for further analysis (MOE, 2016).

Heavy metal analysis preparation   Dried soil samples were milled with Zirconia balls (DAIHAN, Korea) by mill machine for 5 days at 10000 rpm. The soil samples are finely ground. For heavy metal analysis, three grams of soils were weighed and mixed with 21 ml. of hydrochloric acid (HCl) and 7 ml of nitric acid (HNO_3). Then, soils with mixed solution were heated for 2 hours at 120°C using heating plate (Block Heating Sample Preparation System, US/MHB-250, Ctrl-M Science). Total volume of wet-digested samples as filled up to 100 ml. The wet-digested samples were filtered through filter paper No. 2 (Advantec No.2, 110 mm), and analyzed for arsenic (As), cadmium (Cd), chromium (Cr), cupper (Cu), nickel (Ni), lead (Pb), mercury (Hg), and zinc (Zn) (MOE, 2016). The heavy metal concentration was measured using an ICP-OES, (Optima 7300DV, Perkin Elmer, USA). The standard solutions were prepared using ICP grade multi-element standard for Cd, Cr, Cu, Ni, Pb, and Zn (Inorganic ventures, USA) and single-element standard for As and Hg (Kriat Co.,Ltd., Korea). A calibration curve using a standard solution was obtained. An individual heavy metal standard solution was prepared. In details, single-element standard As and Hg concentrations were 0.1, 0.5, 1, 5, 10, 20, 50 and 100 mg kg^{-1} and multi-element standard (Cd, Cr, Cu, Ni, Pb and Zn) were 0.1, 0.5, 1, 5, 10, 20, 50 and 100 mg kg^{-1}. For soil sample analysis a batch of 20 samples were a blank, control (lab soil standard), BAM (BAM-U112a) (Federal Institute for materials research and testing, Germany), a soil sample, duplicate the first soil sample, and rest of soil samples.

Soil contamination index and Soil Pollution index analysis   The assessment of the soil contamination was carried out using several evaluating methods, pollution index (PI) and pollution load index (PLI), and the soil pollution index (SPI). The pollution index (PI) was calculated using the modified formula based on Hakanson (1980).

PI = Cn/Bn   (Eq. 1)

Where Cn is the concentration of the examined element in the soil, Bn is the geochemical background value. The background values were used from a study (Liao and Chao, 2004). The selected reference background values are usually background concentration of heavy metals in earth's crust. The background values for this study were averaged values from 2070 paddy rice soil samples (Yun et al., 2018; Lee et al., 2019). The background values serve to assess contamination by comparing current and pre-industrial concentration of heavy metal concentrations. 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 PI values are classified into 4 classification index (Table 2).

Table 2. Classfication of different soil contamination assessment of pollution index (PI).

Classification index	PI value	Description of class
1	PI<1	Uncontaminated
2	1≤PI<2	Slightly polluted
3	2≤PI<3	Moderately polluted
4	3<PI	Highly polluted

Table 3. Classification of different soil contamination assessment of pollution load index (PLI).

Classification index	PLI	Description of class
1	PLI=0	Background concentration
2	0<PLI≤1	Unpolluted
3	1<PLI≤2	Moderately polluted
4	2<PLI	Highly polluted

The contamination level of heavy metals was assessed by pollution load index (PLI). The pollution load index was evaluated for the extent of the metal pollution. Where n is the number of metals studied, for in this paper is 7 elements and PI is the pollution index value from equation (1). The pollution load index (PLI) was calculated using the modified formula based on Angulo (1996) and Jorfi et al. (2017). The PLI values are classified into 4 classification index (Table 3).

$$PLI = \sqrt[n]{PI1 \cdot PI2 \ldots \ldots PIn} \tag{Eq. 2}$$

Soil pollution index was evaluated based on the levels of Soil Contamination Warning Standard (SCWS) which is regulated by Soil Environment Conservation Law (SECL). Warning levels for cultivated lands (Region 1) were 25, 4, 150, 100, 200, and 300 mg kg^{-1} for As, Cd, Cu, Ni, Pb, and Zn, respectively. Soil pollution index was calculated the equation below.

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

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.

Statistical analysis   All experiments data are expressed as means and standard deviation. The 0.05 p values were considered a statistically significant using SPSS program version 12.0, USA.

Results and Discussion

Assessment of heavy metals in soil The descriptive statistics of heavy metal concentration in soil in Jeon-Nam province was listed in Table 4. The values in table 4 showed for average, minimum (Min.), maximum (Max.), standard deviation (stdev), coefficients of variation (C.V(%)), Kurtosis, and Skweness with two soil depths (0 - 15 cm depth for top soil and 15 - 30 cm depth for subsoil). Eight heavy metals were As, Cd, Cu, Hg, Ni, Pb, and Zn,. Averaged value for top and sub soils were 5.0, 5.1 mg kg^{-1} for As, 0.1, 0.1 mg kg^{-1} for Cd, 19.7, 19.9 mg kg^{-1} for Cr, 8.8, 8.5 mg kg^{-1} for Cu, 0.0017, 0.0014 mg kg^{-1} for Hg, 8.2, 8.3 mg kg^{-1} for Ni, 43.5, 44.3 mg kg^{-1} for Pb, 43.8, 43.2 mg kg^{-1} for Zn. Overall, averaged eight heavy metals for all soil samples were below the levels of Soil Contamination Warning Standard (SCWS) for cultivated lands, which is regulated by Soil Environment Conservation Law (SECL), Ministry of Environment (MOE) in Korea.

The averaged heavy metal concentrations of top and sub soils for each individual averaged industrial complexes in Jeon-Nam province were shown in Table 5. The highest As concentrations were shown in Jangheung and Milyeog counties. The highest concentration of Cr and Ni were shown in Milyeog and Joseong counties. However, all of the heavy metal concentrations were lower than SCWS.

Contamination index of heavy metals in soil The pollution index (PI) is another indicator to evaluate pollution. The average PI values of all seven heavy metals ranged between 0.0 to 0.6 for top and sub soils (Table 6). Pollution index indicated that all soil sample are not polluted because pollution index values are less than 1 (Table 2) (Wu et al., 2014; Mohammadpour et al., 2016; Jorfi et al., 2017). Kim et al. (2016) reported that PI was ranged from 0.29 to 0.47. The average PI values of all 8 heavy metal elements were less than 1. These results suggested that agricultural

Table 4. Descriptive statistics of heavy metal concentrations in agricultural soils near the industrial complexes in Jeon-Nam Province in Korea.

Element	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	5.0	5.1	0.1	0.1	19.7	19.9	8.8	8.5	0.0	0.0	8.2	8.3	43.5	44.3	43.8	43.2
Min.	1.0	1.2	0.0	0.0	3.6	3.9	1.4	1.7	0.0	0.0	1.4	1.9	6.2	7.0	19.7	20.4
Max.	19.6	20.5	1.4	1.6	58.9	79.8	49.1	48.2	0.2	0.1	26.8	34.9	98.4	113.9	193.5	197.0
Stdev.	3.5	3.8	0.2	0.2	11.5	11.9	5.6	5.6	0.0	0.0	4.9	5.1	11.1	11.9	19.3	19.1
C.V. (%)	70.0	74.8	129.4	139.3	58.5	59.9	64.2	66.3	360.7	386.3	59.5	61.7	25.6	26.9	44.0	44.3
Kurtosis	3.7	3.5	39.2	43.5	1.0	3.8	19.2	22.0	50.5	51.3	1.7	4.6	4.1	7.8	23.9	27.6
Skweness	1.9	1.9	6.1	6.5	1.2	1.6	3.4	3.8	7.1	7.1	1.3	1.7	0.4	1.1	3.7	4.0
SCWS Limit	25		4		n/a		150		4		100		200		300	
Number of Above SCWS	0		0		0		0		0		0		0		0	

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

soils near industrial complexes in Jeon-Nam province were not contaminated by heavy metals. For this study, heavily to extremely contaminated and extremely contaminated were not observed. The highest PI values were shown for As at Milyeog and Jangheung agricultural industrial complex and for Pb at Milyeog agricultural industrial complex.

The PLI for all trace elements ranged from 0.10 to 0.24 for top and sub soils (Table 7). The pollution load index (PLI) was classified into Group2: 0<PLI≤1 (Unpolluted) (Table 3) (Jorfi et al., 2017). The highest PLI values were

Table 5. Heavy metal concentrations for top and sub agricultural soils near the industrial complexes in Jeon-Nam Province in Korea.

Site		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		-- (mg kg^{-1}) --							
Gwangyang	Top	5.1	0.2	22.7	11.6	0.004	11.0	47.9	53.4
	Sub	6.0	0.2	26.5	11.9	0.003	12.5	53.6	59.5
Muan	Top	5.9	0.1	26.4	11.5	0.003	9.8	50.6	43.1
	Sub	4.8	0.1	23.0	9.1	0.003	8.4	43.6	34.1
Sinbuk	Top	4.2	0.1	16.8	8.9	0.002	6.6	41.9	40.8
	Sub	3.9	0.1	17.8	8.9	0.002	7.2	43.5	41.0
Gugseo	Top	4.2	0.1	18.2	6.4	0.000	8.1	41.9	43.1
	Sub	4.4	0.1	18.1	6.5	0.000	8.0	43.2	41.0
Hampyeong	Top	3.8	0.1	15.4	6.4	0.002	6.0	37.8	36.1
	Sub	3.5	0.1	12.9	5.9	0.002	5.6	37.5	32.8
Haenam	Top	3.7	0.1	17.9	7.2	0.002	7.1	40.4	42.6
	Sub	3.5	0.1	16.9	7.0	0.001	6.9	39.5	40.2
Muanpyeong	Top	2.8	0.1	12.4	6.5	0.001	4.5	33.7	29.9
	Sub	2.9	0.1	14.0	6.4	0.002	4.7	35.2	31.0
ilban	Top	4.1	0.1	10.8	6.0	0.002	4.6	36.6	34.9
	Sub	4.1	0.1	12.2	5.1	0.000	5.4	38.4	37.1
Noan	Top	4.2	0.1	16.6	12.3	0.002	7.1	43.8	61.8
	Sub	4.1	0.1	17.9	11.9	0.002	6.7	43.3	60.5
Jangheung	Top	11.4	0.5	19.4	8.4	0.000	9.6	34.0	44.3
	Sub	11.8	0.5	18.4	7.7	0.000	8.8	33.5	40.5
Milyeog	Top	10.8	0.1	42.4	13.2	0.000	18.2	57.3	48.0
	Sub	12.1	0.1	40.7	12.4	0.000	17.5	57.1	46.0
Joseong	Top	6.1	0.1	41.9	11.0	0.004	15.8	52.7	42.0
	Sub	6.3	0.1	44.5	11.1	0.003	17.0	54.2	42.0
Yeosu	Top	3.1	0.1	11.5	10.5	0.003	5.1	52.1	46.9
	Sub	3.5	0.1	12.5	11.2	0.002	5.5	57.3	49.9
Ecohightech	Top	3.1	0.1	10.7	5.7	0.000	4.8	40.4	42.0
	Sub	3.1	0.1	11.2	5.9	0.000	5.1	43.1	43.8
Geumseong	Top	2.5	0.1	13.0	6.3	0.000	5.9	41.2	48.1
	Sub	2.5	0.1	12.4	6.1	0.001	5.4	41.6	48.2

at Milyeog and Joseong agricultural industrial complex, and Jangheung agricultural industrial complex. The PLI values were less than 1. These results suggested that agriculture soils near industrial complexes in Jeon-Nam province were unpolluted by heavy metals and safe for agriculture activities.

These results were suggested that 10 counties agriculture soils near industrial complexes in Jeon-Nam province was unpolluted by heavy metals. For this study, the pollution index (PI) and pollution load index (PLI) were categorized in Group 1, unpolluted. In case of mercury (Hg) elements, the Hg data were not present because Hg concentration in soil is lower than pollution background factor.

Soil contamination assessment was evaluated with soil pollution index (Table 7). All soil sample is unpolluted

Table 6. Pollution index (PI) and pollution load index (PLI) for top and sub agricultural soils near the industrial complexes in Jeon-Nam Province in Korea.

Site		As	Cd	Cr	Cu	Ni	Pb	Zn	
		-- PI --							PLI
Gwangyang	Top	0.3	0.1	0.2	0.1	0.2	0.5	0.2	0.18
	Sub	0.3	0.1	0.3	0.1	0.2	0.5	0.2	0.20
Muan	Top	0.3	0.0	0.3	0.1	0.2	0.5	0.1	0.18
	Sub	0.2	0.0	0.2	0.1	0.2	0.4	0.1	0.15
Sinbuk	Top	0.2	0.0	0.2	0.1	0.1	0.4	0.1	0.13
	Sub	0.2	0.0	0.2	0.1	0.1	0.4	0.1	0.13
Gugseo	Top	0.2	0.0	0.2	0.1	0.2	0.4	0.1	0.13
	Sub	0.3	0.0	0.2	0.1	0.2	0.4	0.1	0.14
Hampyeong	Top	0.2	0.0	0.2	0.1	0.1	0.4	0.1	0.12
	Sub	0.2	0.0	0.1	0.1	0.1	0.4	0.1	0.11
Haenam	Top	0.2	0.0	0.2	0.1	0.1	0.4	0.1	0.13
	Sub	0.2	0.0	0.2	0.1	0.1	0.4	0.1	0.13
Muanpyeong	Top	0.1	0.0	0.1	0.1	0.1	0.3	0.1	0.10
	Sub	0.1	0.0	0.1	0.1	0.1	0.4	0.1	0.10
ilban	Top	0.2	0.0	0.1	0.1	0.1	0.4	0.1	0.11
	Sub	0.2	0.0	0.1	0.1	0.1	0.4	0.1	0.11
Noan	Top	0.2	0.0	0.2	0.1	0.1	0.4	0.2	0.16
	Sub	0.2	0.0	0.2	0.1	0.1	0.4	0.2	0.16
Jangheung	Top	0.6	0.2	0.2	0.1	0.2	0.3	0.1	0.20
	Sub	0.6	0.2	0.2	0.1	0.2	0.3	0.1	0.20
Milyeog	Top	0.5	0.0	0.4	0.1	0.4	0.6	0.2	0.24
	Sub	0.6	0.0	0.4	0.1	0.4	0.6	0.2	0.24
Joseong	Top	0.3	0.0	0.4	0.1	0.3	0.5	0.1	0.20
	Sub	0.3	0.0	0.4	0.1	0.3	0.5	0.1	0.21
Yeosu	Top	0.2	0.0	0.1	0.1	0.1	0.5	0.2	0.13
	Sub	0.2	0.0	0.1	0.1	0.1	0.6	0.2	0.14
Ecohightech	Top	0.2	0.0	0.1	0.1	0.1	0.4	0.1	0.10
	Sub	0.2	0.0	0.1	0.1	0.1	0.4	0.1	0.11
Geumseong	Top	0.1	0.0	0.1	0.1	0.1	0.4	0.2	0.11
	Sub	0.1	0.0	0.1	0.1	0.1	0.4	0.2	0.11

because soil SPI is lower than 1. SPI of As ranged from 0.01 to 0.07, SPI of Cd ranged from 0.00 to 0.02, SPI of Cu ranged from 0.00 to 0.01, SPI of Hg ranged from 0.00 to 0.00, SPI of Ni ranged from 0.01 to 0.03, SPI of Pb ranged from 0.02 to 0.04, and SPI of Zn ranged from 0.01 to 0.03. Although, highest SPI values were shown in As. SPI values of As was the highest at Jangheung and Miyeog agricultural industrial complex than other sites. These results suggested that agriculture soils near industrial complexes in Jeon-Nam province was uncontaminated by heavy metal. 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.

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

Site		As	Cd	Cu	Hg	Ni	Pb	Zn
Gwangyang	Top	0.03	0.01	0.01	0.00	0.02	0.03	0.03
	Sub	0.03	0.01	0.01	0.00	0.02	0.04	0.03
Muan	Top	0.03	0.00	0.01	0.00	0.01	0.04	0.02
	Sub	0.03	0.00	0.01	0.00	0.01	0.03	0.02
Sinbuk	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.02	0.00	0.01	0.00	0.01	0.03	0.02
Gugseo	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.03	0.00	0.01	0.00	0.01	0.03	0.02
Hampyeong	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.02	0.00	0.01	0.00	0.01	0.03	0.02
Haenam	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.02	0.00	0.01	0.00	0.01	0.03	0.02
Muanpyeong	Top	0.02	0.00	0.01	0.00	0.01	0.02	0.01
	Sub	0.02	0.00	0.01	0.00	0.01	0.03	0.01
ilban	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.02	0.00	0.00	0.00	0.01	0.03	0.02
Noan	Top	0.02	0.01	0.01	0.00	0.01	0.03	0.03
	Sub	0.02	0.01	0.01	0.00	0.01	0.03	0.03
Jangheung	Top	0.07	0.02	0.01	0.00	0.01	0.02	0.02
	Sub	0.07	0.02	0.01	0.00	0.01	0.02	0.02
Milyeog	Top	0.06	0.01	0.01	0.00	0.03	0.04	0.02
	Sub	0.07	0.00	0.01	0.00	0.03	0.04	0.02
Joseong	Top	0.03	0.00	0.01	0.00	0.02	0.04	0.02
	Sub	0.04	0.00	0.01	0.00	0.02	0.04	0.02
Yeosu	Top	0.02	0.00	0.01	0.00	0.01	0.04	0.02
	Sub	0.02	0.00	0.01	0.00	0.01	0.04	0.02
Ecohightech	Top	0.02	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.02	0.00	0.01	0.00	0.01	0.03	0.02
Geumseong	Top	0.01	0.00	0.01	0.00	0.01	0.03	0.02
	Sub	0.01	0.00	0.01	0.00	0.01	0.03	0.02

Conclusions

In this study, 300 agricultural soil near industrial complexes in Jeon-Nam, Korea were analyzed for 8 heavy metals. All of heavy metal concentrations were below the SCWS and categorized into Group 1 which is not polluted for any heavy metals. Other soil pollution indicators, such as PI, PLI, SPI showed that monitored sites near industrial complexes in Jeon-Nam province are not polluted. For PI of Hg element, the Hg data may not be well present for pollution status because Hg concentration in soil is lower than pollution background factor. These results suggest that for calculating PI, heavy metal concentration and background concentration should be used very carefully if heavy metal concentration in soil is lower than background concentration. Further research is needed to monitor and evaluate soil contaminations based on heavy metals levels.

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References

Ahmadi, M., S. Jorfi, A. Azarmansuri, N. Jaafarzadeh, A.H. Mahvi, R.D.C.S. Soltani, H. Akbari, and R. Akhbarizadeh. 2017. Zoning of heavy metal concentrations including Cd, Pb and As in agricultural soils of Aghili plain. Khuzestan province. Iran. Data Brief 14:20-27. doi:10.1016/j.dib.2017.07.008.

Akoto, O., J.H. Ephraim, and G. Darko. 2008. Heavy metals pollution in surface soils in the vicinity of abundant railway servicing workshop in Kumasi. Ghana Int. J. Environ. Res. 2:359-364. doi:10.22059/ijer.2010.215.

Angulo, E. 1996. The Tomlinson Pollution Load Index applied to heavy metal, 'Mussel-Watch' data: a useful index to assess coastal pollution. Sci. Total Environ. 187:19-56. doi:10.1016/0048-9697(96)05128-5.

Chen, M.C., A. Ruijs, and J. Wesseler. 2005. Solid waste management in small islands: The case of green island, Taiwan. Resources Conservation & Recycling 45:31-47. doi:10.1016/j.resconrec.2004.12.005.

Duruibe, J.O. and M.O.C. Ogwuegbu. 2007. Heavy metal pollution and human biotoxic effects. Int. J. Phys. Sci. 2:112-118.

Hakanson, L. 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res.14:975-1001. doi:10.1016/0043-1354(80)90143-8.

Holmgren, G.G.S., M.W. Meyer, R. Chaney, and R.B. Daniels. 1993. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States of America. J. Environ. Qual. 22:335-348. doi:10.2134/jeq1993.00472425000200020015x.

Hu, W.Y., B. Huang, Y. He, and K.K. Yusef. 2016. Assessment of potential health risk of heavy metals in soils from a rapidly developing region of China. Int. J. Hum. Ecol. Risk Assess. 22:211-225. doi:10.1080/10807039.2015.1057102.

Jarup, L. 2003. Hazards of heavy metal concentration. British Medical Bulletin 68:167-182. doi:10.1093/bmb/ldg032.

Johansson, S.A. and J.L. Campbell. 1998. "PIXE: A novel technique for elements analysis". Campbell's first book on PIXEL. John Wiley & Sons. Inc. New York.

Jolly, Y.N., A. Islam, and S. Akbar. 2013. Transfer of metals from soil to vegetables and possible health risk assessment. Springer Plus. 2:385. doi:10.1186/2193-1801-2-385.

Jorfi, S., R. Maleki, N. Jaajarzadeh, and M. Ahmadi. 2017. Pollution load index for heavy metals in Mian-Ab plain soil, Khuzestan, Iran. Data Brief 15:584-590. doi:10.1016/j.dib.2017.10.017.

Jung, G.B., J.S. Lee, W.I. Kim, J.H. Kim, J.D. Shin, and S.G. Yun. 2005. Fractionation and potential mobility of heavy metals in tailings and paddy soils near abandoned metalliferous mines. Korean J. Soil Sci. Fert. 38:259-268. (in Korean)

Karaca, A., S.C. Certin, O.C. Turgay, and R. Kizilkaya. 2010. Effects of heavy metals on soil enzyme activities. In Sherameti I, Varma A (Ed). Soil Heavy Metals, Soil Biology, Heidelberg 19:237-265.

Kim, B.Y. 1996. Real condition and countermeasure of the environmental pollution. Symposium of Problem and improvement of the agricultural environment in Korea. Korean J. Environ. Agric. 15:27-53. (in Korean)

Kim, D.J., J.H. Park, and J.H. Lee. 2016. Assessment of Selected Heavy Metal Concentrations in Agricultural Soils around Industrial Complexes in Southwestern Areas of Korea. Korean J. Soil Sci. Fert. 49(5):524-530. (in Korean) doi:10.7745/kjssf.2016.49.5.524.

Kim, M.J., K.H. Ahn, and Y. Jung. 2003. Vertical distribution and mobility of arsenic and heavy metals in mine tailings and nearby paddy fields. J. Korean Soc. Environ. Eng. 25:544-553. (in Korean)

Kim, M.K., S.C. Hong, M.H. Kim, S.K.Choi, J.S. Lee, K.H. So, and G.B. Jung. 2015. Assessment of the heavy metal contamination in paddy soils below part of the closed metalliferous mine. Korean J. Environ. Agric. 34:6-13. doi:10.5338/kjea.2015.34.1.08.

Kim, S.J., S.H. Baek, and K.H. Moon. 1996. Fractionation of heavy metals and correlation with their contents in rice plant grown in paddy near smelter area. Korean J. Environ. Agric. 15:1-10. (in Korean)

Kim, W.I., M.S. Kim, and Y.S. Kim. 2008. Long-term monitoring of heavy metal contents in paddy soils. Korean J. Soil Sci. Fert. 41:190-198. (in Korean)

Kloke, A. 1979. Content of arsenic, cadmium, chromium, fluorine, lead, mercury, and nikel in plants grown on contaminated soils 51-53. United Nations-ECE Symposium. Geneva. Swiss.

Kong, X.B. 2014. China must protect high-quality arable land. Nature 506(7486):7. doi:10.1038/506007a.

Lee, T.G., M.S. Kong, E.J. Lee, H.I. Jung, Y.H. Kim, G.B. Jung, J.E. Yang, S.C. Kim, G.I. Kim, G.R. Kim, and M.J. Chae. 2019. Assessment of Heavy Metal Concentrations in the Arable Soils near Industrial Complexes in Gangwon, Chungnam, Jeonnam, and Gyeongnam Provinces of South Korea. Korean J. Soil Sci. Fert. 52(4):541-550. (in Korean) http://doi:10.7745/kjssf.2019.52.4.541.

Lee, Y.H., S.T. Lee, J.Y. Heo, M.G. Kim, K.P. Hong, E.S. Kim, W.D. Song, C.W. Rho, J.H. Lee, W.T. Jeon, B.G. Ko, K.A. Roh, and S.K. Ha. 2010. Monitoring of heavy metal contents from paddy soil in Gyeongnam Province. Korean J. Soil Sci. Fert. 43:289-295. (in Korean) doi:10.7745/kjssf.2016.49.5.524.

Liao, G. and W. Chao. 2004. "Assessment of heavy metallic ions pollution for a river near a metal mine". J. Mining and Metallurgy 13(1):86-90.

Min, K.J., Y.K. Hong, W.S. Choi, D.B. Kim, and S.C. Kim. 2016. Assessment of heavy metal (loid) pollution using pollution index in agricultural field adjacent to industrial area. Korean J. Soil Sci. Fert.49:768-775. (in Korean) doi:10.7745/kjssf.2016.49.6.768.

MOE (Ministry of Enviroment). 2016. Soil environment conservation act. MOE, Sejong, Korea.

Mohammadpour, R.G., A.R. Karbassi, and A. Baghvand. 2016. A pollution index for agricultural soils. Arch. Agron. Soil Sci. 62:1411-1424. doi:10.1080/03650340.2016.1154542.

Nriagu, J.O. 1996. "History of global metal pollution." American Association for The Advancement of Science. 272:223-224. doi:10.1126/science.272.5259.223.

Rowell and L. David. 1937. Soil Science: methods and applications. Longman published. United Kingdom. ISBN

0-470-22141-0.

Saby, N.P.A., B.P. Marchant, R.M. Lark, C.C. Jolivet, and D. Arrouays. 2011. Robust geostatistical prediction of trace elements across France. Geoderma. 162:303-311. doi:10.1016/j.geoderma.2011.03.001.

Schneider, A.R., X. Morvan , N.P.A. Saby, Be. Cancès, M. Ponthieu, M. Gommeaux, and B. Marin. 2016. Multivariate spatial analyses of the distribution and origin of trace and major elements in soils surrounding a secondary lead smelter. Environ. Sci. Pollut. Res. 23:15164-15174. doi:10.1007/s11356-016-6624-2.

Sutherland, R.A. 1999. Distribution of organic carbon in bed sediments of Manoa Stream, Oahu, Hawaii. Earth Surf. Process. 27:571-583.

Vulava, V.M, B.R. James, and A. Torrents. 1997. Copper solubility in Myersville B horizon soil in the presence of DTPA. Soil Sci. Soc. Am. J. 61:44-52.

Wu, J., Y. Teng, S. Lu, Y. Wang, and X. Jiao. 2014. Evaluation of soil contamination indices in a mining area of Jiangxi, China. PLoS One 9(11):e112917. doi:10.1371/journal.pone.0112917.

Wu, Y.G., Y.N. Xu, J.H. Zhang, and S.H. Hu. 2010. Evaluation of ecological risk and primary empirical research on heavy metals in polluted soil over Xiaoqinling gold mining region, Shaanxi, China. Trans. Nonferrous Met. Soc. China 20:688-694. doi:10.1016/S1003-6326(09)60199-0.

Yun, S.G., M.J. Chae, Y.H. Kim, M.S. Kong, H.I. Jung, S.C. Kim, M.S. Kim, S.J. Park, C.H. Kee, J.E. Yang, S.C. Kim, G.I. Kim, G.R. Kim, and G.B. Jung. 2018. Evaluation on heavy metal contents in agricultural soils around industrial complexes in Korea. Korean J. Environ. Agric. 37:141-145. (in Korean) doi:10.5338/kjea.2018.37.2.16.