

Preliminary Assessment of Heavy Metal Contamination Level in Soils around Amarapura City, Mandalay Region

Kyu Kyu Mar¹, Than Than Nu²

Abstract

Heavy metals are natural constituents of soils and their concentration varies depending on parental materials. Heavy metals in soil may come from agriculture activities, urbanization, industrialization and mining activities. Due to these activities the life capacity of soils decreased; especially where the natural background is already high because of natural parental material richness in heavy metal. The main objective of this research was to investigate the degree of urban soil pollution and make a systematic evaluation of soil contamination based on index of geoaccumulation (Igeo), enrichment factor (EF) and pollution index (PI). In this research, three surface soil samples were collected and major element contents of the top soils were determined by using an energy dispersive X-ray fluorescence spectrometer (XRF) to highlight the influence of natural features on the heavy metal concentrations and their distribution. In addition, leaching experiments were conducted to investigate the physico-chemical parameters and the concentrations of heavy metals in soils. High concentration of lead (Pb) was observed in the collected soil samples with the concentration of 1.39, 1.42 and 1.61 mg/L although the concentrations of other heavy metals like copper (Cu), zinc (Zn) and arsenic (As) were very low and selenium (Se) was not detected.

Keywords: Heavy metal, Enrichment factor, Index of geoaccumulation

Introduction

Heavy metals are natural constituents of sediments and their concentration varies depending on parental materials at levels that are regarded as trace (< 1000 mg/kg) and rarely toxic (Wuana and Okieimen, 2011). They contribute to the environment through the processes weathering, erosion, transportation and deposition of rocks and soils. They can also be derived from anthropogenic sources in which case they are incorporated into sediments as artificial pollutants from industrial or urban releases and wastes (Benamar et al., 1999). Due to the human activities most soils as of industrial, as of rural and urban environments may accumulate one or more heavy metals. Many metals, such as Cu and Se, are essential elements for growth plant and for living organism, but high concentrations of these elements become toxic. Soil pollution due to heavy metals contamination is a serious problem as they are toxic and their bio-accumulation capacity is very dangerous for its effects on food chain.

It is estimated that the contribution of metals from anthropogenic activities in soils is higher than the contribution from natural ones (Nriagu and Pacyna, 1988). Many researchers observed that significant increases in soil metal content not only in areas of high industrial activity but also in areas far from industrial centers, due to long-range atmospheric transport (Saur and Juste, 1994, Steinnes and Njastad, 1995). The assessment of metal contamination is the most important for the human survival. This makes the study of sediments or soils

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important for determining the origin, distribution and level of heavy metal in urban surface environments. Although there have been numerous research articles providing assessments of various kinds of soil contamination, including urban soil contamination, agricultural soil contamination, and soil contamination in mining areas in developed countries, there are very few studies in developing countries (Teng et al., 2014). Such studies help to raise public awareness of soil contamination and to facilitate research on contamination and contamination control strategies. Therefore, the aim of this research was to evaluate the levels of toxic metals pollution in soil based on the geochemical indices such as geoaccumulation index (Igeo) enrichment factor (EF), contamination factor (CF) and pollution load index (PLI).

Study Area

The proposed research area, Amarapura, is located about 7 miles SW of Mandalay, Mandalay Township, Mandalay Region (Fig. 1). It is bounded by North Latitude $21^{\circ}49'00''$ to $21^{\circ}57'00''$ and East Longitude $96^{\circ}03'00''$ and $96^{\circ}16'00''$. It can be easily accessible by car or motorcycle from Mandalay throughout the year. There are many weaving industries in Amarapura and it is famous for its traditional silk and cotton weaving. According to the historical record, Myanmar textile industry has lasted over thousands of years and weaving industry is one of the main professions of the Amarapura people. They produced various kind of longyi, fine cotton fabric or silk in several designs and natural dyes as well as chemical dyes are used for various colour products. The chemical dye waste produced from weaving industries may effect on soil and water in and around the study area.

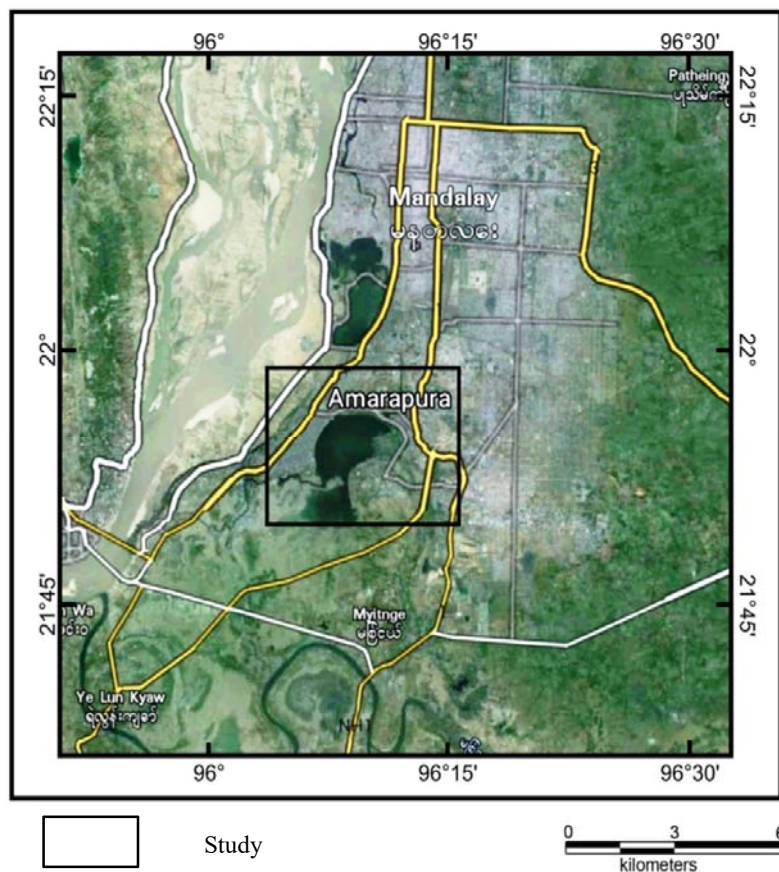


Figure (1). Location map of the study area.

Materials and Methods

Sample Collection

Soil samples were collected to a depth of 0 to 20 cm. Sampling was carried out where plants with superficial roots are not present in order to avoid effects due to the differential uptake of metals by vegetation. Several soil samples were taken within 10' x 10' at each sampling site and then mixed thoroughly to obtain a bulk sample for each site. Two soil samples (S1 and S2) were collected from near textile and silk weaving industries and another one (S3) was collected far from textile weaving to get the background value of heavy metals in the soil. The location points of soil samples were recorded by using GPS. All of the soil samples were put into a representative plastic zip bags. The sample location points of the study area are presented in Fig. 2.

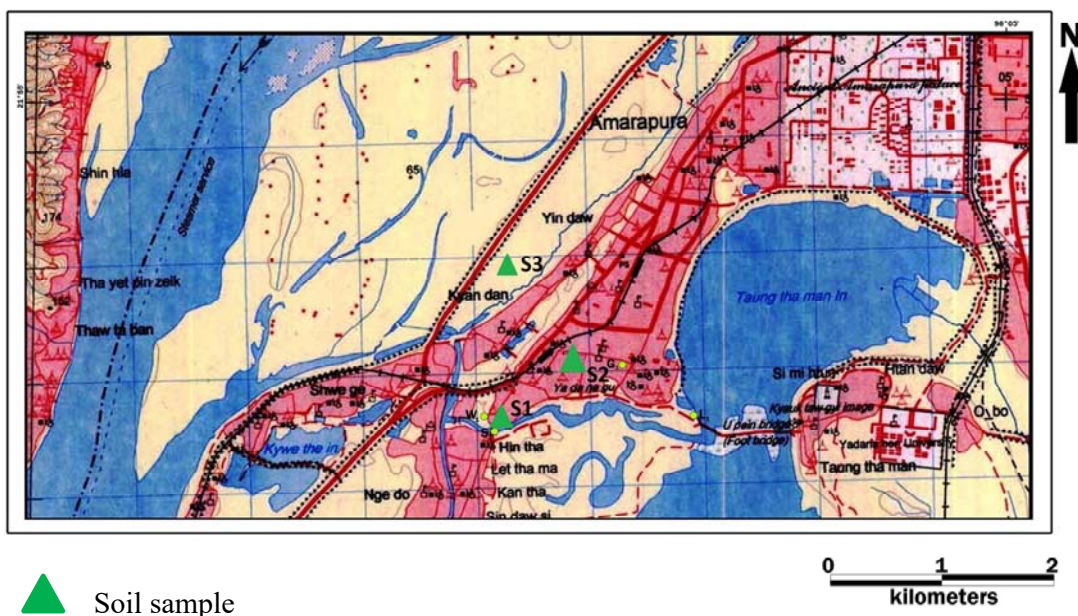


Figure (2). Soil sampling points of the study area.

Sample Preparation and Characterization

After collecting, the samples were air-dried at room temperature and the samples were sieved through a 18 mesh (< 2 mm). Finally, soil samples were stored in the air-tight containers in order to minimize their exposure to moisture before experiments. Parts of these materials were further ground into < 50 μm for the chemical analyses. To identify the chemical composition, an X-ray fluorescence spectrometer, Spectro Xepos (Rigaku Corporation, Japan) was employed at the Laboratory of Groundwater and Mass Transport, Division of Sustainable Resources Engineering, Hokkaido University, Japan.

Batch Leaching Experiments

Soil is a major transmitter of heavy metals to atmosphere, surface water, groundwater and plant. Leaching experiments were conducted to investigate the concentration of heavy metals in the soil and < 2 mm particle sizes of the soil samples were used for experiments. The leaching experiments were done by mixing 15 g of soil sample and 150 mL of deionized water (DI) and the suspensions were shaken for 6 hr with the speed of 200 rpm at room

temperature. After mixing, the pH, ORP and EC of the suspensions were measured immediately followed by filtered by using 0.45 μm Millex® sterile membrane filters (Millipore Corporation, USA). Hydrochloric acid is one of the strong acids that many researchers recommended for the first screening for potential chemicals in the soil. Therefore, for the extraction of potential heavy metals in the soil samples, 100 mL of 1 M HCl solution was added to 3 g of each soil sample and shaken at room temperature for 2 hr at 200 rpm. After mixing, the suspensions were filtered and stored in the containers for heavy metals analyses.

Chemical Analyses of Liquid Samples

Heavy metals concentration in the liquid samples collected after leaching experiments were conducted by using an inductively-coupled plasma atomic emission spectrometer (ICP-AES) ICPE-9000, Shimadzu Corporation, Japan.

Contamination Assessment Methods

In order to assess the heavy metal pollution levels in the soil samples; the enrichment factor (EF) has been employed by using the equation described by Sutherland (2000), as shown in Eq. 1.

$$EF = (C_m/C_{Fe})_{\text{sample}} / (C_m/C_{Fe})_{\text{earth crust}} \quad \text{Eq. 1}$$

where, $(C_m/C_{Fe})_{\text{sample}}$ is the ratio of concentration of metal to that of Fe in the sample and $(C_m/C_{Fe})_{\text{earth crust}}$ is the ratio of concentration of metal to that of Fe in the earth crust. Fe is selected as the reference element because of one of the widely used elements (Sekabira, et al., 2010, Hakanson, 1980).

Geo-accumulation index (I_{geo}) is also calculated to assess metal pollution in the soil samples as follows Eq. 2 (Muller, 1979, 1981).

$$I_{\text{geo}} = \log_2 (C_n / 1.5 B_n) \quad \text{Eq. 2}$$

where C_n is the concentration of metal defined in the sample and B_n is the background concentration of metal in the earth's crust.

The contamination factor (CF) is obtained by using the following equation, Eq. 3 (Hakanson, 1980, Olatunji, 2009).

$$CF = C_n/B_n \quad \text{Eq. 3}$$

where, C_n is the concentration of each metal in soil and B_n is the background value of each metal in soil of the study area. For the entire sampling site, the pollution load index (PLI) has been determined as the n-root of the product of the n CF:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times \dots \times CF_n} \quad \text{Eq. 4}$$

For assessing the level of heavy metal pollution this empirical index provides a simple, comparative means. $PLI > 1$, means that a pollution exists; otherwise, if $PLI < 1$, there is no metal pollution (Tomlinson et al. 1980, Kumar and Edward, 2009, Mohiuddin, et al, 2010).

Results and Discussion

Chemical Properties of Soil Samples

The chemical compositions of the collected soil samples in the study area are summarized in Table (1). The contents of major elements in the soil samples were expressed

in wt.% as their oxide forms. Generally, the main constituent minerals are aluminosilicate minerals and consequently the relatively high content of SiO₂ and Al₂O₃ were detected in the collected samples with the average concentration of 43.6 and 14.5 wt.%, respectively. In addition, slightly high content of Fe₂O₃ was observed in the investigated soil samples ranged from 5.86 to 8.06 wt.%. Arsenic content in sedimentary rocks ranges from 5 – 10 mg/kg (Webster, 1999). The As content in all the collected soil samples was relatively low with the concentration of 0.3 mg/kg. Similarly, very low sulfur (S) content was observed in S2 and S3 with the concentration of 0.2 wt.% while no sulfur (S) was found in S1.

Table (1). Chemical composition of soil samples.

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	P ₂ O ₅ wt.%	S wt.%	As mg/kg
S1	38.5	0.33	12.4	5.86	0.06	3.38	11.9	0.85	2.19	0.38	0.0	0.3
S2	48.5	0.36	14.1	6.02	0.09	2.13	6.33	1.82	3.11	1.85	0.2	0.3
S3	43.8	0.41	17.2	8.06	0.14	2.87	8.08	1.22	3.07	1.01	0.2	0.3

The main physico-chemical parameters determined for soil samples in the study area are shown in Table 2. The pH values of ranging 8.39 to 8.62, which suggest the subalkaline conditions for the collected surface soil samples. The Eh data shows that the soil samples were under oxidizing condition during the experiments. The observed EC values were low with the values of 205 to 372 mV indicating that the concentrations of dissolved ions may be slightly low in the surface soil samples.

Table (2). Some physico-chemical parameters heavy metal concentrations of soil samples.

Variable	Units	S1	S2	S3	WHO (2011)
Physico-chemical parameter					
pH		8.62	8.39	8.39	6.5 – 8.5
Eh	mV	307	332	339	–
EC	μS/cm	227	372	205	–
Heavy metal concentration					
Cu	mg/L	1.38	0.856	0.796	2.0
Pb	mg/L	1.39	1.42	1.61	0.01
Zn	mg/L	2.78	2.95	2.63	3.0
Se	mg/L	<0.001	<0.001	<0.001	0.01
As	mg/L	0.031	0.002	0.005	0.01

Concentrations of Cu, Pb, Zn, Se and As in the collected surface soil samples are listed in Table 2. As can be seen in the table, the concentrations of Cu, Pb and Zn were within the WHO permission limit and that of Se was not detectable. However, the detected concentration of Pb was ranging from 1.39 to 1.61 mg/L in the surface soil samples of the study area indicating higher than the WHO permission limit of 0.01 mg/L. Pb is one of common heavy metal in urban soils which have been shown to be very useful tracers of environmental pollution. The concentrations of Pb in the surface soil samples collected near and far from the textile weaving industry were almost the same with the value of 1.39 and

1.42 mg/L, respectively. Although Pb concentration was higher in the collected surface soil samples, it was not detected in surface water samples including waste water sample of weaving textile industry and groundwater samples (Kyu Kyu Mar, 2018). The concentrations of Pb in the surface soil samples (S3) collected far from the textile weaving industry was 1.61 mg/kg, as background concentration. Therefore, high concentration of Pb in the soil samples may not be due to the activity of textile weaving only and also due to the urbanization and the growth of population density and increase of vehicles in and around the study area.

Distribution and Enrichment of Metals

Table 3 summarizes the minimum, maximum and mean concentrations of Cu, Pb, Zn and As in the collected soil samples of the study area. The concentration of metals detected in S3 sample was applied as the background concentration (Bn) of the study area. The elements' dominance was in the order: Zn > Pb > Cu > As >. The range of concentration (ppm) of metals in the study area were: Cu (0.796-1.38), Pb (1.39-1.61), Zn (2.63-2.95), and As (0.002-0.031). The variability in the range of all the metal distributions as compared with their means respectively is an indication of pollution of the sample with that metal ion. Among the investigated heavy metals, the mean concentrations of Zn (2.78 ppm) and that of As (0.012 ppm) was lowest in the collected soil samples of the study area.

The EF, Igeo values and pollution intensity for the investigated metals obtained in this study are shown in Table 4. The EF values of the all investigated metals such as Cu, Pb, Zn and As observed in the present study were within the level of deficiency to minimal enrichment with the EF values < 1. In general, it was found that the surface soils were negligibly enriched with these metals as in background concentration. The calculated Igeo values indicated that moderately contaminated of Pb and Zn was observed in the study area whereas it was uncontaminated by Cu and As.

Table (3). Basic statistical parameters for the distribution of heavy metals in the soil sample.

Elements	Min (ppm)	Max (ppm)	Mean (ppm)	Background conc. (study area)	Cont. crust Background value
Cu	0.796	1.38	1.01	0.796	25
Pb	1.39	1.61	1.47	1.61	17
Zn	2.63	2.95	2.78	2.63	71
As	0.002	0.031	0.012	0.005	1.5

Table 5 presented the contamination factor (CF) and pollution load index (PLI) calculated from CF of the heavy metals in the study area. The CF values (0.008-0.086) indicated that the soils were low contamination by investigated metals. According to calculated PLI values, The study area was free from contamination of Pb, whereas, base line level of pollution was observed as Cu, Zn and As. It may be due to the anthropogenic activity like textile weaving, urbanization and the growth of population density and increase of vehicles in and around the study area and or naturally as geological background concentration. Moreover, the calculated non-lithogenic metal value % ranged from 17.9 to 37.9 indicated that the metal value from anthropogenic % was low, meaning that the concentration of these metal would be geogenically present in the soil of the study area.

Table (4). Average enrichment factor, geoaccumulation index and pollution intensity of heavy metals in the soil samples.

Variable (mg/kg)	EF	EF class	Degree of enrichment (Muller, 1981, Sutherland, 2000)	Igeo	Igeo grade	Pollution intensity (Muller, 1981, Sutherland, 2000)
Cu	0.030	1	Deficiency to minimal enrichment	-0.898	0	Practically uncontaminated
Pb	0.065	1	Deficiency to minimal enrichment	0.661	1	Uncontaminated to moderately contaminated
Zn	0.029	1	Deficiency to minimal enrichment	2.28	3	Moderated to heavily contaminated
As	0.006	1	Deficiency to minimal enrichment	-14.5	0	Practically uncontaminated

Table (5). Contamination factor, pollution load index and contamination level of heavy metals in the soil samples.

Variable (mg/kg)	CF	CF indices	Degree of contamination (Hakanson, 1980)	PLI (Hakanson, 1980)	non-lithogenic metal value %
Cu	0.040	CF < 1	Low	1.23	23.4
Pb	0.086	CF < 1	Low	0.913	27.4
Zn	0.039	CF < 1	Low	1.05	17.9
As	0.008	CF < 1	Low	1.35	37.9

Conclusions

Heavy metals in soil may come from agriculture activities, urbanization, industrialization and mining activities. Due to these activities the life capacity of soils decreased; especially where the natural background is already high because of natural parental material richness in heavy metal. High concentration of Pb was observed in the collected soil samples with the concentration of 1.39, 1.42 and 1.61 mg/L. The calculated EF and Igeo indicates that moderately contaminated of Pb and Zn was observed in the study area whereas it was uncontaminated by Cu and As. The calculated PLI > 1 indicated that the study area was slightly polluted with Cu, Zn and As, The concentration of heavy metal in the study area could come from anthropogenic activities was about 20 % in average and it would be geogenically present in soil.

Acknowledgements

The author would like to express deeply thanks to Dr. Than Than Nu, Professor and Head, Department of Geology, University of Mandalay, for her kind permission to carry out this research.

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