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ENVIRONMENTAL GEOCHEMISTRY OF SOLID MINE WASTES FROM KYITAUKPAUK – CHAUNGGYI AREA, SINGU AND THABEIKKYIN TOWNSHIPS, MANDALAY REGION

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Abstract

The chemical composition of soil and sediments from study area were characterized by high sulfur contents (1118-67500ppm) and high concentration of zinc (70-53600 ppm). Almost soil and sediments samples were observed highly significant concentrations of Cu value than the limit of 36mg/kg in part by EPA. SiO2 content is high in nearly almost solid samples including soil and rock. According to XRD result, prominent minerals observed quartz, calcite, pyrite and galena. The mean concentration of heavy metal in soils are ranging from S > Zn > Pb> Cu. Through the use of different indices of heavy metal contamination index (I_{geo}) and Enrichment rations (ER) results indicated that the study area was the most contaminated in As and Hg and followed by S and Cu.

Keywords: EPA, ER and I_{geo}

Introduction

1.1 Background

The high concentrations of potentially toxic elements in mine wastes can pose risks to ecosystems and humans, but these risks can be mitigated by implementing appropriate management or remediation schemes. Successful mine waste characterization is of paramount importance in light of the potential environmental, social and financial impacts from mining landforms constructed from geochemically reactive or erosive mine waste (Smedly et al. 2014).

Sulfur and carbon are commonly measured used in calculations of the acid producing and acid neutralizing potentials (Weber et al. 2005). Measurement of total metals and metalloids is commonly achieved through X-ray fluorescence (XRF) method.

Heavy metals can be present in the soil as a product of the weathering of the natural rocks, or because they come as part of pollution loads generated by human activities such as mining and agricultures may be in study area. It is very important to distinguish between the natural background values and anthropogenic inputs, and to recognize that the background values change from area to area and with the scale of the area investigated. For these reasons the geochemical monitoring of soil is important in the aim of evaluating the natural content of heavy metal in soils, related to parental materials and possible enrichment due to mining activities in study area.

1.2 Study Area

The study area lies in the Thabeikkyin and Singu Townships, Mandalay Region. It is located within one inch topographic maps of 93 B1 & B/2. This area falls within North Latitude 22°39′20″ to 22°46′30″ and East Longitude 96°00′00″ to 96°03′30″, area extends about 3.5 miles

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from east to west and 5.6 miles from north to south, totally 19.6 square miles and readily accessible throughout the year. The location map of the study area is shown in Fig (1).

The study area forms part of the highly deformed metamorphic rocks of Mogok Belt (Searle and Haq, 1964). Most of the metasedimentary rocks such as Hornblende gneiss, banded biotite gneiss, marble units and diopside calc-silicate rocks which of the age from Precambrian to Mesozoic are widely distributed throughout the whole area. Valuable gold mineralization occurs in marble, biotite gneiss and at or near the contact of marble and biotite microgranite. Principal metallic vein minerals are pyrite, chalcopyrite, sphalerite, lead in addition to gold. Gold veins in gneisses are observed as fissure filling type while more replacement nature occurs in marble unit.

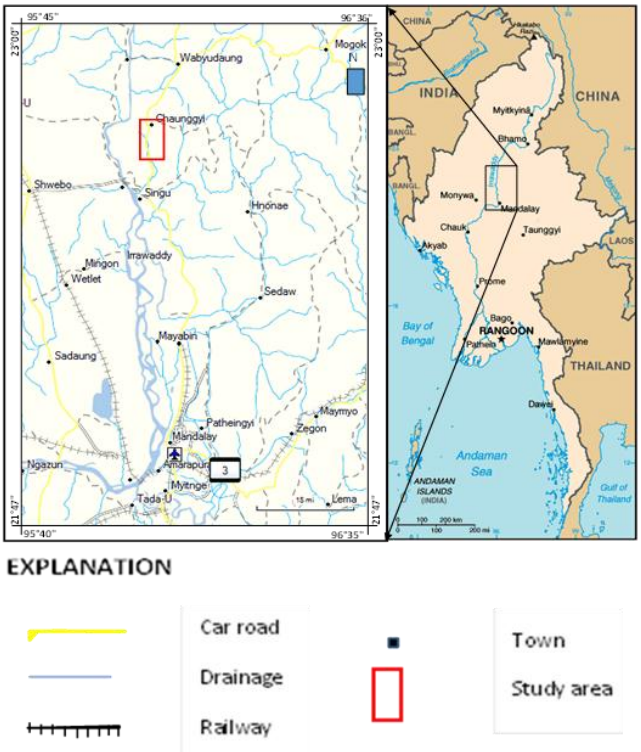

Figure 1 Location map of the study area.

Material and Methods

2.1. Sample Collection and Preparation

Totally, there have thirty-five gold mine sites in the study area; twenty-eight mine sites were existed in Kyitaukpauk area and seventeen were in Chaunggyi area. In the present study, samples collected from seven mine sites which were three from Kyitaukpauk area (SGU-6, SGU-189 and SGU-190) and four from Chaunggyi area (TPK-152, TPK-168 and TPK-171), shown in Fig.(2). In order to access the impacts of gold mining on the surrounding environment, totally of eighteen tailing soil samples, twelve ore sample including ore bearing soils and fourteen waste rock samples were collected in October,2018 and Janauary, 2019, respectively in the vicinity of mine from study area . Tailing soil samples were collected from mine waste dumps and processing sites.

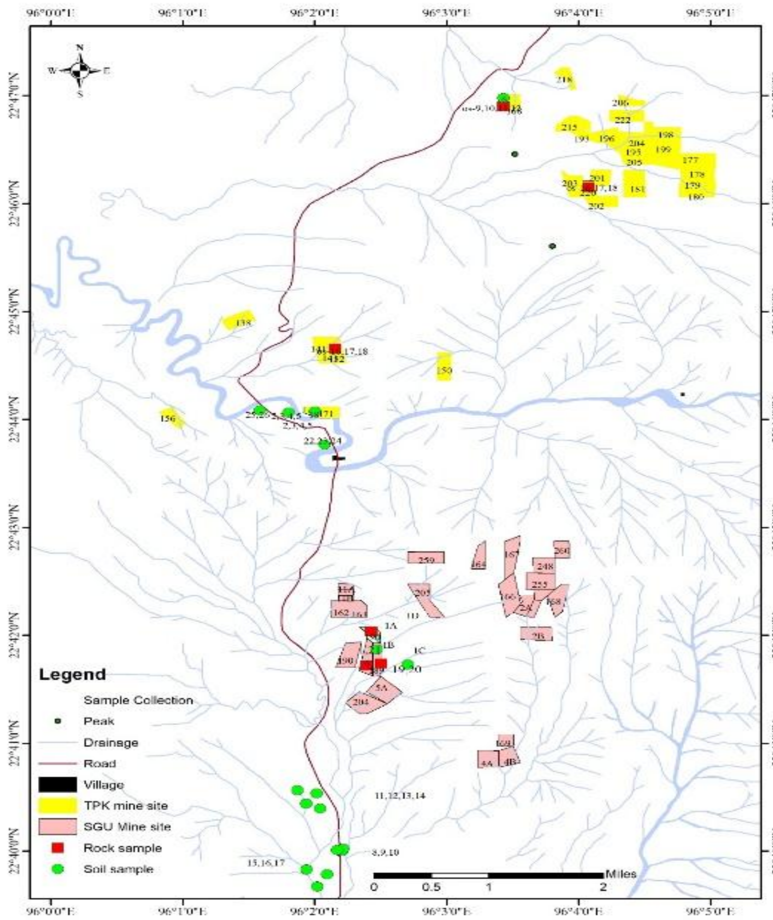

Figure 2 Collected samples location map of the study area.

2.2. Laboratory Works

After sample collection, soil and rock samples were transported to laboratory to analyze the chemical properties of solid mine wastes. XRD (X-ray Diffractometer), XRF (X-ray Fluorescence) and AAS (Atomic Absorption Spectrometer) method were used to analyze the chemical and mineralogical compositions of the collected samples.

Results and Discussion

3.1 Chemical Composition of the Solid Mine Wastes

The SiO_2 content is (2.75–91.1wt%) in rock samples and (21.2 – 53.6wt%) in soil samples, average 50wt% in ore samples and 47wt% in tailings. SiO_2 content is high in nearly almost solid samples including soil and rock. Significantly high concentrations of CaO (90.5 and 89.2wt%) is observed in rock and ore samples while the concentrations of CaO (36.9, 33.6 and 31.3wt%) in soil sample respect. Although average of CaO contents is 21wt% in ore samples, only 3wt% in tailings. High concentration of Fe_2O_3 (42.7 - 57.3 wt%) were observed. The average concentration of Fe_2O_3 is about 7wt% in ore and 15wt% in tailing, respectively.

The chemical composition of soil and sediment samples were characterized by high sulfur contents and high concentration of copper. Almost of soil and sediment samples were observed highly significant concentrations of Cu value than the limit of 36mg/kg in part by EPA (United States Environmental Protection Agency).

The Pb concentration is (0.001 - 291mg/kg) in rock samples and (37.7 - 33500mg/kg) in soil samples, respect. The average concentration of Pb in rock samples is (16.23mg/kg) and (2014mg/kg) in soil sample. Therefore, the difference in Pb concentration is significantly high between rock and soil samples. Not only tailing soil samples except (SS-1) showed significantly higher Pb concentration value (714mg/kg – 2170mg/kg) than the standard limit of 300mg/kg in part by WHO Standard but also significantly observed the 33500mg/kg in soil sample (SS-25).

3.2. Mineralogical Composition of Solid Mine Wastes

Mineralogical examination is essential to understanding process, mineral habit, and reactive minerals that result in ARD (Acid Rock Drainage Potential) and metal leaching from mine-waste piles (Diehl et al., 2006a; Diehl et al., 2006b, Hammarstrom and Smith, 2002). Not only the abundance of sulfur and carbonate minerals but also mode of occurrence of chemical elements and reactive minerals are usually focus on mineralogical investigations. In addition, silicate and aluminosilicate minerals that may have long-term ARD neutralizing potential can be identified and quantified. Blows (1997) developed a mineralogically based sulfide alteration index to quantify the degree of oxidation of mine-waste materials.

X-ray diffraction (XRD) methods can be used in an initial screening to identify mineral phase in mine waste samples. The prominent minerals observed in all soil sample are quartz, calcite, pyrite, pectolite and elpidite. The galena content is significantly observed in waste rock sample (OS-9). The ore minerals sphalerite, galena, whereas copper sulfide minerals chalcopyrite, bornite, covellite, chalcocite and iron sulfide minerals marcasite and arsenopyrite were well observed in the rocks of study area (Thaire Phyu Winn,2002), although not detected in XRD results of present study. Acid generation from oxidation of sulfide minerals, such as pyrite and pyrrhotite in mine waste is one of the most significant issues facing the mining industry. Secondary Fe-bearing oxyhydroxysulfate, hydroxide and oxyhydroxide minerals play a major role in sequestering metals and metalloids from mine wastes (Hudson-Edwards and Dold, 2015).

3.3. Physiochemical characteristics of the solid mine wastes

The pH, EC and Temperature (T) parameters of soils from the study area are shown in table (1). These are able to provide sufficient information to understand the soils capacity to retain heavy metal pollutants.

Results obtained for the soil pH measurement showed a neutral to alkaline pH ranging from 7.13 to 8.2. pH variations are presumed to be related to heterogeneous deposits of sulfidic residues at the surroundings of the mine which can cause a decrease of the pH by corresponding oxidation and formation of sulfuric acid (Barkouch and Pineau, 2016). The medium alkaline pH condition of the tailings could be ascribed to the dominant potential acid-neutralizer or pH buffering minerals such as alumino-silicate minerals and traces of carbonate (i.e. calcite) present within the tailing system (Gitari, et al., 2018).

The electrical conductivity values could be attributed to excessive amount of heavy metal in the soil. High electrical conductivity may occur as a result of poor irrigation, water quality and excessive use of fertilizer. The high values of temperature recorded in the soil samples of study area may have affected carbon turn-over and organic matter.

Table 1 Physiochemical properties of soil samples in study area.

Sr. no.	Sample	pH	EC (μ/s cm)	Temp(°C)
1	SS-5	7.76	608	29.5
2	SS-8	7.63	191.2	29.7
3	SS-10	7.13	796	29.7
4	SS-11	7.76	155.7	29.7
5	SS-12	7.98	81.7	29.7
6	SS-13	8.06	185.3	29.6
7	SS-14	7.88	222	29.6
8	SS-18	7.64	692	29.6
9	SS-19	8.2	104.5	29.1
10	SS-20	7.27	277	29.3
11	SS-21	7.86	176.6	29.3
12	SS-25	7.74	619	29.3
13	SS-26	7.5	638	29.3
14	OS-18	8.04	193	29.4
MEAN		7.76	7.76	29.55

3.4. Major Element Geochemistry

Table 2 is the summary stastics of the major and trace elements concentrations of solid mine wastes in study area.The table include the results of present study, along with the crustal averages and soil guideline values for some of the potentially toxic elements by EPA, and the elements concentration of solid materials in study area.

Table 2 Summary of XRF data for major (wt%) and trace elements(ppm) in solid materials from study area, along with published concentrations values of continental crust guideline values for potentially toxic elements.

	Soil sample				Rock and ore sample				*Cont. Crust	Soil
No.	Min	Max	Mean	St. Dev.	Min	Max	Mean	St. Dev.	Background value	Guideline value of EPA
SiO_2	21.2	70.76	53.6	12.75	2.75	91.1	64.8	25.39	66	
Al_2O_3	3.98	18.71	11.17	4.64	0.46	18.7	11.4	6.27	15	
Fe_2O_3	2.93	42.73	10.48	10.48	0.23	57.3	3.23	12.58	5	
CaO	1.75	6.09	9.75	9.12	0.09	90.5	6.01	25.01	4.2	
K_2O	1.01	6.09	2.78	1.22	0.02	9.43	2.04	3.43	3.4	
MgO	0.96	10.04	2.78	1.88	0.08	4.61	1.11	1.32	2.2	
Na_2O	0.21	10.63	3.28	2.84	0.20	3.55	3.49	1.06	3.9	
TiO_2	0.03	1.76	0.72	0.42	0.01	1.34	0.15	0.38	0.5	
MnO	0.04	0.27	0.14	0.04	0.01	0.39	0.07	0.09	0.1	
Pb	37.7	33500	221.5	6895.15	0.0006	1.11	0.0027	0.24	20	30
S	1118	67500	2960	15973.22						
Hg	20.8	210	30.4	58.02						
Cu	32.6	2510	32.6	608.03					25	22
Zn	37.56	53600	689	13034.29					71	66
Au	12.17	203	31.36	40.51						
Ag	15.2	120	22.9	30.99						
Pt	28.2	444	43.2	132.75						
U	7.72	19.1	13.85	4.074	16.6	95.8	30.6	24.68		
As	12.1	2010	129	402.79	0.0004	1800	2.97	402.79	1.5	

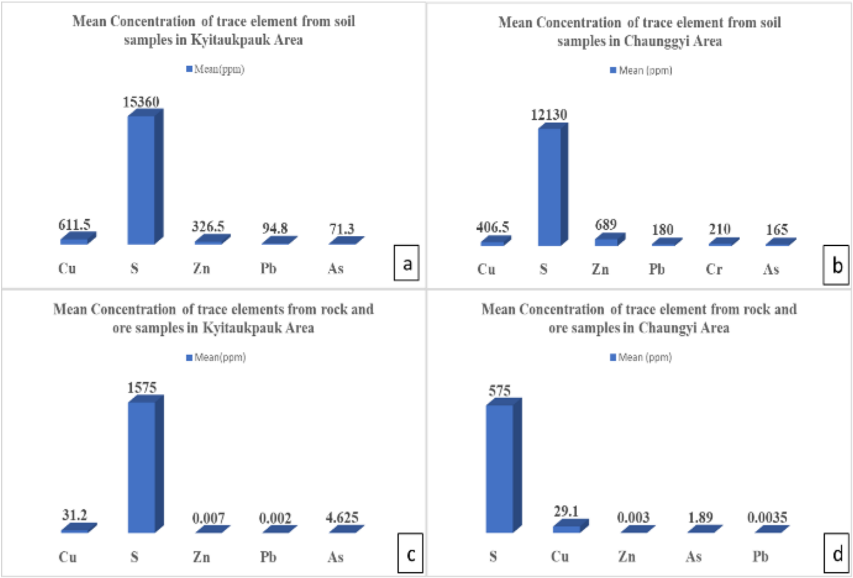

Figure 3 Mean concentrations of oxide in study area, (a & b) for soil and (c &d) for rocks and ore samples.

As can be seen in Fig. (3), the mean concentration in all soil samples SiO_2, TiO_2, Al_2O_3 and Fe_2O_3 are 54.35, 1.57, 25.02 and 24.1wt% in Kyitaukpauk area and 35.1, 0.34, 8.25, 23.6 in Chaunggyi area respectively.The result further show that the mean concentration of MgO and CaO are high, and Na_2O,MnO are similar compared to their crustal averages in both area.

3.5. Trace Element Geochemistry

The results of potentially toxic element analysis are summerized in table (2) and Fig (4). The results show that all heavy metal in soil and sediments of study area have mean concentration above the published crustal abundances. The results were also compared with trigger and guideline value for potentially toxic elements in soils and this shows that the mean concentration of As is above the limit set for median soil content. The mining of gold is an important source of As in the environment. The mean concentration of As in rock sample from Kyitaukpauk area is 4.62 mg/kg and Chaunggyi 1.89mg/kg area while 71.3mg/kg and 165mg/kg in soil samples. Chaunggyi area is significantly high the concentration of As in soil sample than Kyitaukpauk area although less concentration in rock and ore samples than Kyitaukpauk area. The Enrichment ratio (ER) in metal and Geoaccumulation Index(I_{geo}) are indicators used to assess the presence and inttensity of anthropogenic contaminant deposition on surface soil.

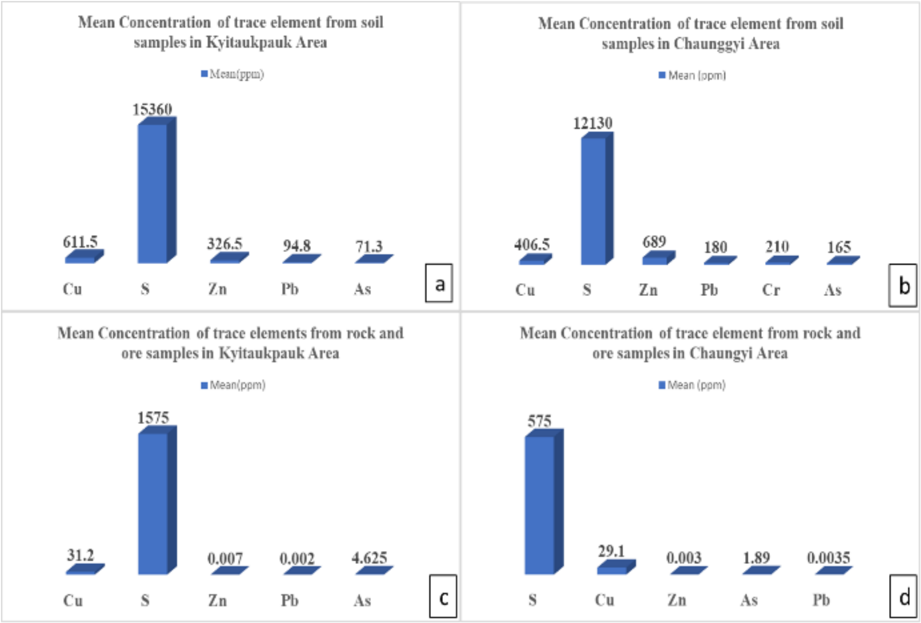

Figure 4 Mean concentrations of trace elements in study area, (a & b) for soil and (c &d) for rock and ore samples.

3.6. Enrichment Ratios

Element enerichment ratios were calculated to evaluate the extent of enrichment and / or depletion of trace elements in the soils of the study area relative to their crustal concentrations. In this study, the Upper Continental Crust concentrations of the elements were used as baseline or background values and the enrichment ratio (ER) was calculated using the equations (Waziri, 2014):

ER= Cn/ Bn

where Cn is the concentration of an element measured in a sample and Bn is the background or baseline concentration, in this study, the upper crustal concentration of the element. The results and define qualities of the enrichment ratios are shown in table (3). The numerical results are different pollution level. Values of 0.5-1.5 suggest that the trace metal concentration may come entirely from natural weathering process (Yongming et al., 2006). Hower, an ER value >1.5 indicates that a significant portion of the trace metals was delivered from non-crustal materials (Yongming et al., 2006 and Klerks et al., 1989), so these trace metals were delivered by other sources, like point and non-point pollution and biota (Yongming et al., 2006,). With ER index, soil quality state can be indicate by different classes in table (3) range from ER<2 (Deficiency to minimal enrichment) to ER> 40 (Extremely high enrichment). (Klerks et al., 1989)

Table 3 Contamination categories based on ER values. (Source: Yongming et al., 2006)

Class	ER Value	Soil quality
1	<2	Deficiency to minimal enrichment
2	2-5	Moderate enrichment
3	5-20	Significant enrichment
4	20-40	Very high enrichment
5	>40	Extremely high enrichment

The enrichment ratios are summarized in (table 4 and table 5) and and show the factor by which the concentration of elements except As and Cu in the samples of study area exceeds their crustal abundances. An enrichment ratio, ER of 1 indicates that the soil or sediment is neither enriched nor depleted in a particular element relative to the average crustal concentration. On the other hand an ER of >1 or <1 is an indication of enrichment or depletion.

The results (table 4 and table 5) show that As is extremely high enriched element relative to the baseline value, with ER of about 47.5 in Kyitaukpauk to 110 in Chaunggyi area. This is avidence of higher As concentrations obtained in the top soils and sediments. The concentration of Cu and Pb are about 15 times and 12 times respectively its upper crustal concentration.

As shown in (table 4 and table 5), the ER rank of the study area is ranging from As > Cu > Pb > Zn in Kyitaukpauk Area and As > Cu > Zn > Pb in Chaunggyi area.

Table 4 Summary of enrichment ratios, ER for the soil samples from Kyitaukpauk area.

No.	Element	Enrichment ratios, ER			ER Class	Soil Quality
		Min	Max	Mean		
1	Cu	4.28	100.4	22.84	4	Significant enrichment
2	Zn	0.99	12.04	4.6	2	Significant enrichment
3	Pb	1.89	31.75	4.74	2	Significant enrichment
4	As	8.07	225.33	47.53	5	Extremely high enrichment

Table 5 Summary of enrichment ratios, ER for the soil samples from Chaunggyi area.

No.	Element	Enrichment ratios, ER			ER Class	Soil Quality
		Min	Max	Mean		
2	Cu	1.30	74.4	16.26	3	Significant enrichment
3	Zn	2.11	754.92	9.70	3	Significant enrichment
6	Pb	6	1675	9	3	Significant enrichment
9	As	31.33	1340	110	5	Extremely high enrichment

3.7. Index of Geoaccumulation (I_{geo})

One of the method used in estimating the enrichment of concentration of an element above the background or baseline values is to calculate the index of geoaccumulation, I_{geo} proposed by Muller. Muller (1981) has defined seven classes of geoaccumulation Index ranging from class 0 (I_{geo}=0, unpolluted) to class 6(I_{geo} > 5, extremely polluted). The highest class (class 6) reflects at least a 100-fold enrichment factor above background. The pollution by using seven enrichment classes based on an increase on the numerical value of the scale are shown in Table (4 and 5).

Table 6 Classes of the index of geoaccumulation, I_{geo}. (Muller, 1981)

Value	Class	Pollution Intensity
>5	6	Extremely polluted
4-5	5	Strongly polluted to extremely polluted
3-4	4	Strongly polluted
2-3	3	Moderately polluted to strongly polluted
1-2	2	Moderately polluted
0-1	1	Unmoderately polluted to moderately
0	0	Unpolluted

The index of geoaccumulation, I_{geo} was calculated for all the samples according to the equations:

$$I_{geo} = \text{Log2}(Cn/1.5\ Bn)$$

where Cn is the concentration of the element measured in a sample and Bn is its concentration in some reference sample or background concentration, which in this study is the average crustal value, while 1.5 is a constant which is introduced to minimize the effect of the variation of background values.

(Table 7 and 8) are shown in summary of the results. Based on the I_{geo} classes in (Table 6) , the results of this work show that the study area may have problems relating to As contamination. The mean I_{geo} value of 4.91 and 9.54 for As falls within class 5-6 which is maximum Igeo values >5 of the Muller scale, indicating that the soils from this area are extremely polluted with respect to As. Similarly, all samples have I_{geo} values exceed than 6 for Hg corresponding to also extremely polluted conditions, showing that the area has problem with respect to Hg and heavy metal contamination of surface soils and sediments. The mean index of geoaccumulation 1-2 for Zn is indicating no pollution to moderate pollution.

Table 7 Summary of indices of geoaccumulation, Igeo for trace elements in soils and sediments from the Kyitaukpauk area.

No.	I_{geo}					Pollution intensity
	Element	Min	Max	Mean	Class	
1	S	0.34	10.24	3.89	4	Strongly
2	Hg	52.28	233.13	89.805	6	Extremely
3	Pb	0.22	12.44	2.09	3	Moderately to strongly
4	Cu	0.86	20.15	4.59	5	Strongly to extremely
5	Zn	0.2	2.42	0.93	1	Unpolluted to Moderately
6	As	1.62	45.22	9.54	6	Extremely

Table 8 Summary of indices of geoaccumulation, Igeo for trace elements in soils and sediments from the Chaunggyi area.

No.	I_{geo}					Pollution intensity
	Element	Min	Max	Mean	Class	
1	**S**	**0.43**	19.35	3.48	4	Strongly
2	Hg	20.8	151	28.1	6	Extremely
3	Pb	0.69	192.08	1.03	1	Unpolluted to Moderately polluted
4	Cu	0.22	12.44	2.7	3	Moderately to strongly
5	Zn	0.33	119.52	1.54	2	Moderately
6	As	1.57	67.23	4.91	5	Strongly to extremely

Conclusion

The study area Kyitaukpauk- Chaunggyi is significant mineralized zone especially the gold metal in Thabeikkyin- Singu area. There have many gold mines in this area but seven mines can be analyzed in the present study. Therefore, its need to many research in environmental impacts of gold mining for these area. Heavy metal distribution in soils ,mine tailings and waste rock piles from study area were investigated. The ER shows five different classes in the investigated soils: extremely high enrichment is observed for As in both area. Although Cu is more enriched in Kyitaukpauk area than in Chaunggyi, Zn and Pb are more enriched in Chaunggyi area. These elements are directly related to mineral paragenesis and mining activities in study area.

According to I_{geo} results, study area observed in extremely polluted for As and Hg and, strongly polluted for S and Cu. High metal concentrations in the soils of study area are derived, for their most important part, from the geological background of which the soils ultimately derived. The abundance of metals and trace elements in soils also reflect (i) their release from mining and smelting derived particles, and (ii) their partioning into different soil compartments. The smelting process of gold ore had significant impacts on the enrichment of As and Hg in the mine wastes.

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