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Assessment of Abandoned Mine Impacts on Concentrations and Distribution of Heavy Metals in Surface Sediments of Catchments Around Sungai Lembing Abandoned Tin Mine

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Abstract: Influence of abandoned tin mine on concentrations, accumulation, mobility and distribution of (Fe, Cu, Ni, and Zn) in surface sediments of Sg. Lembing catchments were investigated in this work. Sediment samples were collected within an abandoned mine of Sg. Lembing Kuantan and also at vicinity area. The sequential extraction method was used to extract anthropogenic metals in sediments and inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the metal concentrations. Results indicate all metal in easily or freely leachable and exchangeable (ELFE), Acid reduction (AR) and organic oxidation (OO) fractions were higher than ambient concentrations which indicate heavily metals load from ex-mining into surrounding aquatic environments. The sequential extraction results showed Cu and Zn were the highest in EFLE fraction, which means these metals are more capable of leaching and cause adverse effects to aquatic organisms than Fe and Ni. On the other hand, Fe, Cu, Zn and Ni were detected high in OO fraction. Analysis of variance (one-way ANOVA) shows that metal concentrations in each fraction were significant varies between stations. Sediment contamination assessment result shows that sediments samples that receive direct acid mine drainage (AMD) water have the highest metals concentrations due to leaching and erosion process.

Key words: Abounded mining · Heavy metals pollution · Surface sediment · Tin

INTRODUCTION

Although mining input has considerable economic benefits, mining activities are the main responsible for releasing massive amounts of hazardous metals into surrounding aquatic environments. Heavy metals have been classified as one of the most threats to aquatic ecosystem and habitats [1, 2]. According to literature [3, 4], Heavy metal in our natural environment has received a great attention worldwide by environmental, biological and chemical scientists as well as public; due to their unique characteristics such as biological significance, toxic behavior, persistence, bioaccumulation and their tendency to be incorporated into food chains in harmful quantities. These metals are enriched in our environment by two major sources natural activities and anthropogenic activities [5]. In Malaysia, rapid development of the natural resource exploitation such as tin, iron and gold in the last decades has been severely polluted the natural aquatic environments surrounding mine area by considerable amounts of heavy metals [6]. Aquatic environment has been reported as one of the main sensitive environments to the negative effects of heavy metals pollution. This attributed to a direct and prolonged contact between aquatic organisms and soluble metals in these environments [2, 3]. As a consequence, the present heavy metals can be accumulated by aquatic organisms includes fish through water, food and sediments. In aquatic environments, heavy metals have high ability to cause toxicity to aquatic biota, which eventually affect human health as a final consumer through food chain. In this regard, assessment on heavy metals concentration and distribution mechanisms in sediments becomes extremely required.

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Thus, this study was conducted to determine Fe, Cu, Ni, and Zn concentration and distribution in surface sediments of Sungai Lembing ex-mining. In this regard, data of this study will contribute to the future control the negative impacts of abandoned mine and to contribute in development remediation techniques to preserve the aquatic ecosystem in these contaminated areas.

MATERIAL AND METHODS

Study Area: The study is located at Sungai Lembing (3°54'23"N and 103°2'30"E) which is located about 40 km west of the port of Kuantan and about 42 km northwest of Kuantan [7]. This city has very old tin mining activity history where the tin was export to China during at mid-13th century [6]. The abandoned mining area in Sungai Lembing is characterized by large quantities of mine waste deposits, old tools and tailings, which have become a heap around the area. Weathering processes for the heaped waste materials creates a long-term adverse effect and high potential risks to surrounding aquatic environments [8]. The majority of the Sg. Lembing catchments are used by local people for many of living purposes such as irrigation, drinking water and domestic purposes.

Reagents and Material: All the reagents used in this work were analytical reagent grade; which were HNO_3, $HClO_4$, NH_4CH_3COO, $NH_2OH.HCl$, H_3PO_4, and H_2O2 with concentration of 65, 70, 85, 85, 85 and 30%, respectively. To confirm purity of chemical solutions; several samples were used as blanks and then tested using ICP-MS the results showed that all elements were below the detection limits. Deionized distilled water was used for all dilution purposes. All glassware, sampling bottles, ice-boxes and plastic bags were initially washed in detergent solution, rinsed with tap water and then soaked in a solution of 10% (HNO_3) for three days and rinsed twice with distilled deionized water and dried in dry temperature room.

Sediment Sampling and Preparation: A total of 25 surface sediment samples were collected from five sampling stations that expected to receive waste water from tin ex-mine (Figure 1). Sediment samples were kept in cleaned plastic bags and dried in the laboratory. The sediment samples were then prepared in 63 ìm size for extraction purpose.

The pH, Texture and Organic Matter Measurement: The top 5-cm of the surface sediment samples were collected for physical analysis (pH, grain size and organic matter content). The pH was determined followed the method discussed in literature [9]. Sediment grain size was measured according to the method discussed in [10] and organic matter content was measured according to literature [11]. Sequential extraction method was used to extract heavy metals from the sediments [10]. The sequential extraction method was described in Table 1.

Validation of Analytical Methods: To validate of accuracy of sequential extraction method, certified standard reference material form sediment sample (Reference Material 8704 Buffalo River Sediment, National Institute of Standards & Technology) was used. Recoveries of all of the target elements ranged from100.1 to 104.53% of the certified value, as shown in Table 2.

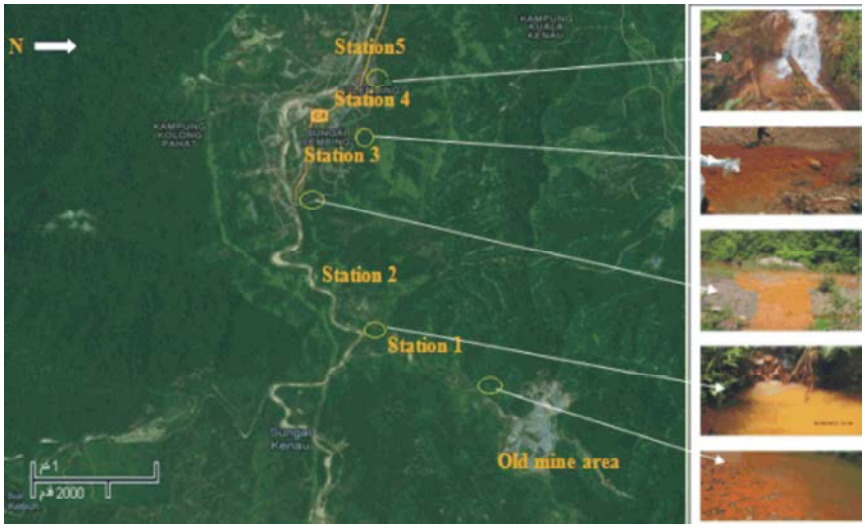

Fig. 1: Tin ex-mining area and selected sampling locations

Table 1: Sequential extraction steps

FRACTION	REAGENT	PROCESS
Easily and freely leachable and exchangeable fraction (EFLE) (fraction 1)	1.0M ammonium acetate (NH_4 CH_3COO) (pH 7)	Samples were shaken for 1½ hours then centrifuged and filtered
Acid reduction fraction (RA) (fraction2)	0.25M of Hydroxylamine chloride ($NH_2OH.HCl$) (pH 2)	Samples were shaken for 1½ hours then centrifuged and filtered
Organic oxidation fraction (OO) (fraction 3)	Hydrogen peroxide (H_2O_2) (30%) and NH4CH3COO at (pH 3.5).	Samples were placed in water bath for 1-1½ hours, and followed by 50 ml NH4CH3COO at (pH 3.5). Samples were shaken for 1½ hours then centrifuged and filtered
Resistant fraction (RR) (fraction 4)	HNO_3:$HClO_4$ at 25:10	Samples were digested using reagent ratios on a sand bath at 100°C until whites

Table 2: Measured and certified values of metal concentrations in sediments SRM (mg/kg)

Element	Fraction 1	Fraction 2	Fraction 3	Fraction 4	Total	SRM	Recovery (%)
Cu	5.5337	9.00	59.6	36.1	110.23	-	-
Zn	48.29493	87.846	96.39983	175.8765	408.42	408±15	100.10%
Fe	0.10	1.51	1.40	1.14	4.15	3.97±0.10	104.53%
Ni	1.90	2.8	4.9	34.4	44.00	42.9±3.7	102.56%

Statistical Analysis: SPSS version 21.0 was used to calculate statistical analysis. The correlation between sediments characteristics (pH, organic matter) with heavy metals concentrations at third fraction (the organic oxidation fraction) was calculating using Pearson's correlation coefficients (r^2). A one-way (ANOVA) was used to determine significant differences between sampling stations and means were compared using Tukey test.

RESULTS AND DISCUSSION

Physical Properties: The descriptive statistic for sediment samples properties (pH, TOM and grain size) is shown in Table (3). The sediment pH value was in acidic conditions and ranges between 4.37- 6.11. The pH values were significantly different between stations (ANOVA, $<$ 0.05). Total organic matter in sediments at all stations is ranges between 2.25-3.36 %. High organic matter in sediment enhances heavy metals accumulation in sediments [12]. There were no significant differences between the stations in total organic matter (ANOVA, $>$ 0.05). The grain size with <63µm% was only 31% and was found statistically significant differences between stations (ANOVA, $<$ 0.05). Smaller grain size has higher ability to absorb metal ions by their outer sheath of hydroxyl groups and the negative charge of clay surface also facilitated absorption metals ions onto sediments surface [2].

Heavy Metal Concentrations: The mean concentrations and percentages of Fe, Zn, Cu and Ni in surface sediments for five different stations in Sg. Lembing ex-mine catchments are presented in Table 5. Heavy metal concentrations in natural earth crust have been commonly used to represent natural concentrations of metal in sediments [12]. Total heavy metals in sediments of Sg. Lembing ex-mine catchments were higher than the concentration of metals in natural earth crust as described by [13]. In this regard, sediments of ex-mine catchments of Sungai Lembing are extremely polluted with elevated concentrations of metals. This indicates there is highly anthropogenic metals-load into the surrounding aquatic environments by tin ex-mining.

Easily and Freely Leachable and Exchangeable Fraction (EFLE): This fraction involves extraction of heavy metals that are weakly bounded (electrostatically bound) and

Table 3: The mean value of the selected sediments properties

Station	pH	Grain Size %<63µ	Organic Matter %
1(n= 5)	4.47±0.06	29.27±0.42	3.23±0.11
2(n= 5)	4.37±0.15	24.83±0.35	2.25±0.29
3(n= 5)	5.47±0.06	37.04±0.6	3.36±0.40
4(n= 5)	5.03±0.91	33.59±0.32	3.08±0.58
5(n= 5)	6.11±0.58	30.96±0.91	3.32±0.30

directly adsorbed on surface of sediment particles [1, 12]. These metals can be easily release into water column by ion-exchange with cations like NH^{4+}, Mg^{2+} and Ca^{2+} [14]. This fraction closely associated with metals that have high bioavailability and mobility which can cause a great adverse effect on all kinds of aquatic environments [15]. According to literature [16], heavy metals have the potential to enter the aquatic environments as a result of natural weathering processes and anthropogenic activities via runoff from contaminated area into rivers, from dumping, and atmospheric deposition. From analytical results, Cu was found to be the highest accumulated in this fraction followed by Zn, Fe and Ni. The concentrations of Cu in EFLE fraction ranged from 0.44 to 22.15 mg/kg in station 5 and 3 respectively; with mean percentage of 1.31%. The presence of Cu, Zn, Fe and Ni with high concentrations in surface sediments indicated high anthropogenic loading into the catchments.

Acid Reduction Fraction (AR): This fraction is used to extract metals that high potential to become soluble and mobile under changing conditions and used commonly to extraction metals bound to Fe/Mn oxides and hydroxides [1]. According to [17] iron and manganese oxides and hydroxides serve as scavenger of heavy metals and are thermodynamically unstable under anoxic conditions. In this fraction, Iron was found the highest followed by Cu, Zn and Ni. Fe concentrations were ranged from 29.21to 1406.43 mg/kg in station 5 and 4 respectively, with mean percentage of 2.48%. According to [18], acid condition enhances the Fe mobility. In addition to, Cu and Zn were also found in high concentrations; Cu concentrations were ranged from 0.29 to 82.74 mg/kg in station 5 and 3, respectively, with mean percentage of 3.45% and Zn concentrations were ranged from 1.41 to 60.54 mg/kg in station 5 and 4, respectively, with mean percentage of 5.25%. It has been reported [19] that Cu levels in gold ex-mining at AR fraction were 87.5 mg/kg. [18], reported Cu was the highest metals in AR fraction

Organic Oxidation Fraction (OO): This fraction explains organic matter and metals that bound to pyrite compounds [1]. In this fraction, the presence of humic and fulvic acids in organic materials plays a major role in enhancing heavy metal adsorption on sediment surface and consequently reduce the availability and toxicity of heavy metals. According to literature [20], organic matter has been recognized as a main electron donor in the system, thus, this fraction is considered as the sink for heavy metal accumulations [1, 12]. From this study all metals were found in high concentrations in this fraction. Iron was found accumulated highest followed by Cu, Zn and Ni. The Fe concentration ranged from 170.29 to 3410.87 mg/kg at station 3 and 5, respectively, with mean percentage of (9.16%). The Cu concentration was found to be high and ranged from 56.69 to 517.54 mg/Kg at station 5 and 4, respectively, with mean percentage of (45.51%). In general, copper has high ability to absorb on organic matter [18]. Our findings were in agreement with reported values in literature [18, 21]. According to literature [22], copper is essentially bound to the organic matter to form organic-copper compounds. The Zn concentration in the organic oxidation fraction ranged from 93.81 to 463.97 mg/Kg at station 2 and 5 respectively, with mean percentage of (33.04%). Zn concentrations were high, and this may due to the different types of organic matter that discharged from direct influx of mining wastes from ex-mining areas such as fulvic and humic acids that enhance metals absorption in this fraction. Also reported in literature [19], that Zn levels in sediments of gold mining areas in southern Brazil were ranges from 26.5 to 75.8 mg/Kg. The Ni concentration ranges from 4.49 to 33.81 mg/Kg at station 3 and 5 respectively, with mean percentage of (25.93%). According to literature [23], solubility of Cu and Zn increase as increase in oxidation degree. Heavy metals concentration and distribution in sediments can be influence by several factors such as pH, OM and oxidation–reduction potential [1, 15]. In this study, the relationship between heavy metals concentrations at organic oxidation fraction (fraction 3) and sediment's pH and OM were determined. The result shows there are significant positive linear correlations between concentrations of (Fe, Ni and Zn)in organic oxidation fraction and TOM and sediments pH; whiles a negative linear correlation were between Cu concentrations with TOM and sediment pH. From the result, the correlation data reflect that TOM and the pH have high capability to absorb Fe, Zn and Ni in the surface sediments of Sg. Lembing ex-mine catchments. According to literature [1], organic compounds (humic and fulvic substances) in sediment play a major role in the absorption process, due to the various organic material compounds have a high cation exchange capacity that enhances sequester metal ions from water [15].

Non-Resistant Fractions: Assuming that EFLE, acid reduction and organic oxidation fractions represents the non-resistant fractions or metals that arise by human activities (mining). According to literature [22], metals

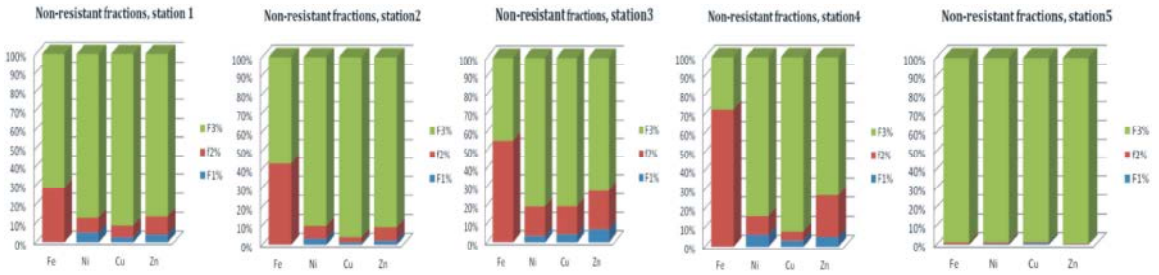

Fig. 2: Composition of anthropogenic fractions in all sampling stations

Table 4: The mobility of heavy metals at different sequential fractions

FRACTION NAME	MOBILITY
Easily and Freely Leachable and Exchangeable Fraction (EFLE)	Cu > Zn > Fe > Ni
Acid Reduction Fraction (RA)	Fe > Cu > Zn > Ni
Organic Oxidation Fraction (OO)	Fe > Cu > Zn > Ni
Resistant fraction (RR)	Fe > Cu > Zn > Ni

Table 5: Concentrations and percentages of metals of four chemical speciation fractions in sediments samples at different locations using a modified sequential extraction methods and comparison of non-resistant (anthropogenic), resistant (natural) percentage (%) and the (ICF and GCF). fraction1. easily and freely leachable and exchangeable fraction; fraction 2, an acid reduction fraction; fraction 3, the organic oxidation fraction and fraction 4, the resistant fraction. total: F1+F2+F3+F4. SD: standard deviation.

metal	Fraction 1(EFLE) n = 5	Fraction 2(RA) n = 5	Fraction3(OO) n = 5	Fraction4 n = 5	TOTALmg/kg	Non Resistant %	Resistant%	ICF
				Station 1				
Fe	0.62±0.13(0.00)	293.43±0.00(1.65)	743.02±13.33(4.17)	16,793.52±490.15(94.18)	17830.59	5.82	94.18	0.062
Ni	0.36±0.04(0.99)	0.59±0.04(1.62)	6.32±0.50(17.38)	29.08±1.78(80.00)	36.35	20.00	80.00	0.250
Cu	9.07±0.36(1.71)	23.68±2.3(4.47)	347.66±29.14(65.64)	149.23±12.48(28.18)	529.64	71.82	28.18	2.549
Zn	4.91±1.29(1.74)	12.5±0.6(4.43)	109.54±8.52(38.85)	155.04±13.23(54.98)	281.99	45.02	54.98	0.819
GCF								3.68
				Station 2				
Fe	0.60±0.17(0.01)	347.57±3.76(2.94)	464.22±27.40(3.92)	11,026.67±1431.27(93.14)	11839.05	6.86	93.14	0.074
Ni	0.31±0.03(0.61)	0.65±0.06(1.28)	8.99±0.73(17.68)	40.89±3.86(80.43)	50.84	19.57	80.43	0.243
Cu	4.27±0.71(0.71)	10.07±1.08(1.67)	357.14±25.02(59.10)	232.80±18.30(38.53)	604.28	61.47	38.53	1.596
Zn	2.24±1.81(0.72)	6.94±0.77(2.24)	93.81±6.27(30.33)	206.26±17.88(66.70)	309.25	33.30	66.70	0.499
GCF								2.412
				Station 3				
Fe	0.43±0.10(0.00)	206.50±52.59(1.03)	170.29±27.29(0.85)	19,724.43±382.83(98.12)	20101.65	1.88	98.12	0.019
Ni	0.19±0.02(0.91)	0.88±0.12(4.19)	4.49±0.80(21.39)	15.43±3.11(73.52)	20.99	26.48	73.52	0.360
Cu	22.15±2.96(2.28)	82.74±7.93(8.52)	434.27±26.66(44.70)	432.40±102.60(44.51)	971.56	55.49	44.51	1.247
Zn	10.36±1.96(3.04)	31.8±1.66(9.34)	109.90±6.61(32.28)	188.43±26.46(66.34)	340.49	44.66	55.34	0.807
GCF								2.433
				Station 4				
Fe	0.84±0.17(0.00)	1406.43±4.12(6.50)	543.79±71.80(2.51)	19, 684.89±379.00(90.98)	21635.95	9.02	90.98	0.099
Ni	0.46±0.04(2.30)	0.75±0.03(3.76)	6.31±1.81(31.61)	12.45±0.45(62.33)	19.97	37.67	62.33	0.604
Cu	18.35±1.08(1.81)	25.68±2.02(2.54)	517.54±19.70(51.16)	450.13±25.93(44.49)	1011.70	55.51	44.49	1.248
Zn	14.03±2.44(2.35)	60.54±3.25(10.16)	202.91±59.03(34.05)	318.38±14.41(53.43)	595.87	46.57	53.43	0.872
GCF								2.823
				Station 5				
Fe	8.49±0.16(0.09)	29.21±14.79(0.29)	3410.87±0.81(34.37)	6,475.98±339.82(65.25)	9924.56	34.75	65.25	0.533
Ni	0.19±0.00(0.23)	0.21±0.06(0.26)	33.81±4.18(41.57)	47.11±4.85(57.93)	81.31	42.07	57.93	0.726
Cu	0.44±0.32(0.05)	0.29±0.04(0.04)	56.69±13.48(6.93)	760.14±139.53(92.98)	817.56	7.02	92.98	0.076
Zn	0.44±0.23(0.03)	1.41±0.87(0.09)	463.97±46.71(29.69)	1097.09±129.75(70.20)	1562.91	29.80	70.20	0.425
GCF								1.76

bioavailability and mobility decreases in the order of exchangeable forms > acid reduction forms > organic forms > residual forms. The comparison of non-resistant (anthropogenic) and resistant (natural)of all studied elements in surface sediments of Sg. Lembing ex-mine catchments is tabulated. According to literature [15], Zn has high affinity to bound with the non-resistant fractions, thus, classified as one of the most unstable metals. As a comparison, the highest heavy metals accumulation is in organic oxidation fraction followed by AR and EFLE fractions (Figure 2). The Mobility of heavy metals at different sequential fractions is showed in Table (4).

Sediment Contamination Assessment

Individual and Global Contamination Factor: The individual contamination factors (ICF) for each metal was calculated by dividing sum of metal concentration in the ELFE, AR and OO fractions (the non-resistant fractions) by the residual fraction [15, 23, 24]. This calculation is

Table 6:

Station No.	Fe	Ni	Cu	Zn
1	17830.59	36.35	529.64	281.99
2	11839.05	50.84	604.28	309.25
3	20101.65	20.99	971.56	340.49
4	21635.95	19.97	1011.70	595.87
5	9924.56	81.31	817.56	1562.91
TEL	-	18	35.7	123
PEC	-	36	197	315
TET	-	61	86	540
TEL-HA28	-	20	28	98
PEL-HA28	-	33	100	540

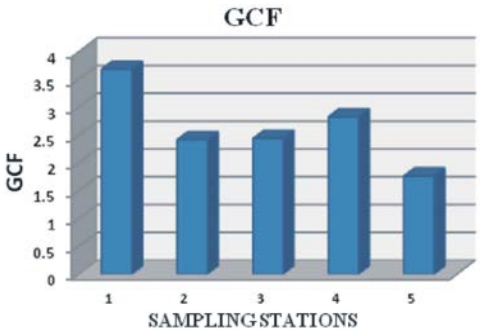

Fig. 3: Global contamination factor (GCF) based on accumulation of heavy metals in surface sediments at all sampling stations

used to assess the bioavailability and mobility of heavy metals from sediments to water body [15, 24]. While the sum of the individual factors (ICF) for all metals in a station represent the global contamination factor (GCF) [18]. The (ICF and GCF) for studied metals at different study stations around of Sungai Lembing ex-mine are tabulated in Table (5). The ICF values decreases in the order of Cu > Zn > Ni > Fe. Therefore, Cu in sediments of Sg. Lembing poses the highest potential environmental risk to water and aquatic organisms that living in these catchments followed by Zn, Ni and Fe. The GCF results shows majority of heavy metal concentrations tend to decrease as away from the ex-mining area along the flow direction. Stations 1, 4, 2 and 3 that located within the ex-mining area has the highest potential risk to aquatic environments due to formation of acid mine drainage (AMD) more than stations 5 (Fig 3). Stations (1, 4, 3 and 2) that receive direct AMD have the highest metals concentrations; due to metals leaching and erosion.

Table 5. Concentrations and percentages of metals of four chemical speciation fractions in sediments samples at different locations using a modified sequential extraction methods and comparison of non-resistant (anthropogenic), resistant (natural) percentage (%) and the (ICF and GCF). fraction1. easily and freely leachable and exchangeable fraction; fraction 2, an acid reduction fraction; fraction 3, the organic oxidation fraction and fraction 4, the resistant fraction. total: F1+F2+F3+F4. SD: standard deviation.

Sediment Quality Guidelines (SQGs): Analytical results of this study was compared to SQGs include threshold effect level (TEL), probable effect concentration (PEC) and toxic effect threshold (TET) [25] to determine the true extent of sediment contamination and to predict the potential biological effects on aquatic wildlife that induced by sediment contamination [26] of Sg. Lembing ex-mining catchment. The TEL mean concentration for metal in sediments is supposed to be safe to biota, PEC means concentrations of metal above safe concentration which has ability to cause adverse effects to biota and TEL is sediments are considered to be heavily polluted and toxic to all aquatic biota. TEL-HA28 means Threshold effect level for *Hyalella azteca*; during 28 day test introduced by US EPA [26]. Adverse effects on sediment dwelling organisms are expected when this concentration is exceeded [25]. From comparison, majority of heavy metal concentrations were much higher than the TEL, PEC, TET and TEL-HA28values; which means there are high potential adverse effects on aquatic organisms in this area by exposed to elevate concentrations of metals in particular Cu and Zn (Table 6).Therefore, future monitoring and conservation are extremely required to avoid and reduce environmental risks.

Table 6. Comparison of Total Concentrations of Fe, Cu, Ni and Zn (mg / Kg, DW) with Sediment Quality Guideline of Threshold effect level, toxic effect threshold, Toxic Effect Threshold (TET) and Probable Effect Concentration (PEC).TEL-HA28 = Threshold effect level for *Hyalella azteca*; 28 day test; dry weight [26]; PEL-HA28 5 Probable effect level for *Hyalella azteca*; 28-day test; dry weight (US EPA 1996); TEL = Threshold effect level; dry weight; PEL = Probable effect level; dry weight and TET = Toxic effect threshold; dry weight [25, 26].

CONCLUSION

Results of this investigation show that heavy metal levels in surface sediments of ex-mining catchments are extremely hazardous. The SQGs result indicates that Sg. Lembing tin ex-mining catchment is heavily polluted with heavy metals which produce high potential risk to aquatic organisms, groundwater, surface water and food chain. Therefore, there is an urgent need to evaluate environmental hazard risk and to conserve the ex-mine environments.

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Persian Abstract

چکیده

دراین مقاله برحسب کمیت معادن قلع انباشتگی غلظت فلزات سنگین Fe, Cu, Ni, and Zn بر سطح رسوبات رودخانه لمبینگ مورد بررسی قرار گرفته است. از رسوبات مصب رودخانه لمبینگ ایالت کوانتن در محدوده معادن قلع نمونه برداری شد.سپس بروش استخراج فلزات از نمونه ها صورت گرفت و بروش اسپکتروسکوپی مورد سنجش قرار گرفت. نتایج نشان داده است که کلیه فلزات آزاد قابل استحصال بروش اکسیداسیون مواد آلی و کاهش با اسید در مقایسه با فلزات محیط اطراف بیشتر بوده است. با استخراج پیاپی فلزات مس و روی بیشتر از سایر یون های فلزی بوده است. بعلاوه یون فلزات اثر سوء بر محیط ابزیان داشته است. فلزات Fe, Cu, Zn و Ni عناصری با جزء اکسیداسیون آلی بالا تشخصی داده اند. آنالیز واریانس ANOVA نشان میدهد که غلظت فلزات سنگین از نطر الودگی حائز اهمیت بوده و انالیز رسوبات رودخانه مذکور از ایستگاه به ایستگاه دیگر تغییرات قابل ملاحطه ای داشته است. بیشترین الودگی فلزات سنگین در نمونه های آب نشتی معادن اسیدی AMD بوده که موجب فرسایش خاک گردید.