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ORIGINAL ARTICLE

Distribution and contamination assessment of potentially harmful elements (As, Pb, Ni, Cd) in top soil of Penang Island, Malaysia

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Abstract

This study discusses the distribution and contamination levels of potentially harmful elements (As, Pb, Ni, and Cd) in the urban top soil of Penang Island, one of the most important urban areas in Malaysia. The total surface area of Penang Island is 297 km^2. Thirty-one surface soil samples (0–20 cm) were collected, digested and analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for As, Pb, Ni, and Cd. The result showed that the mean concentrations of selected metals in soils were arranged in the following decreasing order: Pb > As > Ni > Cd. In terms of different soil types, soils derived from quaternary deposit have higher mean concentration of Pb, Ni, and Cd as compared to the granite residual soils which accumulate higher mean concentration of As. On the spatial distribution maps, As, Pb, Ni, and Cd are mainly concentrated in the north-to-north eastern areas of Penang Island and near to the main city, which are characterized by major residential and business areas. Thus, it suggests that the anthropogenic source is the main contributor to the As, Pb, Ni, and Cd in the top soil of Penang Island. Both Pearson correlation analysis and principal component analysis showed a strong positive correlation between Pb and Cd which indicated that they may be derived from a similar source. The contamination factor assessment indicates moderate contamination level for Pb and Ni and no element enrichment level for As and Cd.

Keywords Metals · Urban · Top soil · Penang Island

Introduction

Metals' pollution in urban soils has been of great concern throughout the world due to increasing environmental awareness and interest in the quality and management of such soils (Mirsal 2008; Meuser 2010; Alloway 2013; Buttafuoco et al. 2016, 2017; Guagliardi et al. 2018). Urban soils are strongly influenced by humans and typically contain higher loadings of contaminants, especially metals' elements in the uppermost parts of soil horizons through different anthropogenic sources (Guagliardi et al. 2012, 2018; Guo et al. 2012; Buttafuoco et al. 2016, 2017; Ungureanu et al. 2016; Mehr et al. 2017). Anthropogenic sources include atmospheric deposition, fertilizers, liming, sewage sludge, manure, pesticides, coal combustion residues, metal-smelting industries, fossil fuel combustion, industrial and residential wastes, and uncontrolled factory emissions (Ungureanu et al. 2016; Buttafuoco et al. 2017). The study of elemental distribution through GIS and other mapping techniques allows direct appraisal of the variability of the elements in an area and enables rapid identification of areas that may contain excessive concentrations of potentially harmful elements such as metals (Cicchella et al. 2015; Ungureanu et al. 2016; Buttafuoco et al. 2016, 2017; Guagliardi et al. 2018).

Potentially harmful elements such as Arsenic (As), lead (Pb), nickel (Ni), and cadmium (Cd) in soils can be derived from parent rock or(and) anthropogenic sources (Meuser 2010; Alloway 2013). The common sources of As, Pb, Ni, and Cd in the parent rocks are represented by: (1) black shales are commonly contain high concentrations of As, Pb, Ni, and Cd; (2) limestones are commonly contain high

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concentrations of Pb, Ni, and Cd; (3) phosphorites are generally contain high concentrations of Pb, Ni, and Cd; (4) ultramafic rocks are commonly contain high concentration of Ni; and (5) sedimentary ironstones are commonly contain high concentrations of As, Pb and Ni (Alloway 2013). The example of ore minerals that are generally enriched in As, Pb, Ni, and Cd are: (1) sphalerite (ZnS) and smithsonite ($ZnCO_3$) are relatively high concentrations of As and Pb; (2) bornite (Cu_5FeS_4) and chalcocite (Cu_2S) are relatively high concentrations of Pb, Ni, and Cd; and (3) galena (PbS) is relatively high concentration of Cd (Alloway 2013).

Arsenic, Pb, Ni, and Cd are the typical metal elements found in urban soil that may be related to anthropogenic activities (Birke and Rauch 2000; Zhengyu et al. 2006; Wei and Yang 2010; Lu and Bai 2010; Guagliardi et al. 2012; Guo et al. 2012; Simasuwannarong et al. 2012; Benhaddya and Hadjel 2013; Buttafuoco et al. 2016; Ungureanu et al. 2016; Mehr et al. 2017). Anthropogenic source of As in urban environment includes dust from ores smelting, pesticides manufacturing, coal combustion, geothermal power plants, sulphide ore roasting and smelting, wood preserving agents, and pig and poultry sewage (Kabata-Pendias and Mukherjee 2007; Buttafuoco et al. 2016). Industrial emissions, high-temperature processes in smelters, lead-acid batteries, previously used leaded petrol, erosion, and chemical weathering of tailings in mining areas are sources of Pb in urban areas (Simasuwannarong et al. 2012; Ağca 2015). Nickel can be derived from thermal power plant, metal processing operation, increased combustion of coal and oil, sewage sludges, phosphate fertilizers, and municipal sludges (Alloway 2013; Özkul 2016). Pollution of Cd in urban can be originated from the use of phosphate fertilizers, a by-product in mining and refining of zinc (Zn), battery production, stabilizers for various plastics and traffic emissions (Hamzeh et al. 2011; Ağca 2015; Huang et al. 2018).

Arsenic is highly toxic to humans and animals which some As compounds may interfere with activities of some enzymes (Kabata-Pendias and Mukherjee 2007). Excessive amount of Pb in human body may cause detrimental health effects such as damage to nervous systems, kidney problem, and impairment of mental development in young children (Kabata-Pendias and Mukherjee 2007). On the other hand, excess of Ni in human body may retain in the lung or excrete in the urine (Kabata-Pendias and Mukherjee 2007). Toxic effects of the excess of Cd on humans include renal damage, emphysema, skeletal deformation due to impaired calcium (Ca) metabolism and reduced reproduction functions (Kabata-Pendias and Mukherjee 2007).

The metals variation in urban soils in Malaysia has not been yet extensively studied especially in Penang Island. Urbanization of Penang Island was started since at the end of 18th century when George Town became the first British port town (Shamsuddin et al. 2012). George Town is also the oldest British colonial town in South East Asia (Shamsuddin et al. 2012). Since the 1970s, Penang Island was undergoing rapid urbanization and industrialization which has resulted in drastic changes to her physical and social landscapes (Ghazali 2013). Large-scale and long-term urbanization and corresponding various human activities in Penang Island may release considerable amounts of potentially harmful elements.

The objectives of this study were to: (1) to determine the concentration and distribution of As, Pb, Ni, and Cd in top soils of Penang Island; (2) to predict the source of the respective metals by comparison of their mean concentrations in different geology types of soils, spatial distribution analysis and statistical analysis; and (3) to assess the contamination level of As, Pb, Ni, and Cd in the surface soil.

Materials and methods

Study area

Penang Island, one of the most rapidly developing regions in Malaysia, is located in the northwest of Peninsular Malaysia between 5°15′N to 5°30′N of latitudes and between 100°10′E and 100°20′E of longitudes (Fig. 1). Penang Island is one of the largest islands in Malaysia with the total surface area of 297 km^2. Penang Island is characterized by an average rainfall of 2254–2903 mm annually and has relative humidity at 70–90%. Penang Island has elevation ranges from 0 to 820 m above sea level and the slope gradients range from 0° to 87° (Tay et al. 2014).

Land use map of Penang Island is shown in Fig. 1. Development of Penang Island comprises industrial activity (7.5%), business activity (11%), quarry sector (1.3%), and agricultural and farm activities (48%) (Town and Country Planning Department, Penang 2015). Most residential areas are located in the northeast of Penang Island, whereas most agriculture areas are located in the southwest of Penang Island (Town and Country Planning Department, Penang 2015). Northeast of Penang Island contains many attraction sites such as George Town, the main city of Penang Island and the tourism place in Batu Feringgi. According to Department of Statistics Malaysia (2013), northeast district accommodated by 535.2 thousand inhabitants, whereas southwest district accommodated by 205.9 thousand inhabitants.

Geologically, Penang Island is made up of granitic rocks and Quaternary deposits (Fig. 2). On the basis of proportions of alkali feldspar to total feldspar, granites of Penang Island are divided into two main groups which are the North Penang Pluton and the South Penang Pluton. The North Penang Pluton exhibits orthoclase to intermediate microcline granite, whereas the South Penang Pluton exhibits microcline granite (Ong 1993; Ahmad et al. 2006). Quaternary

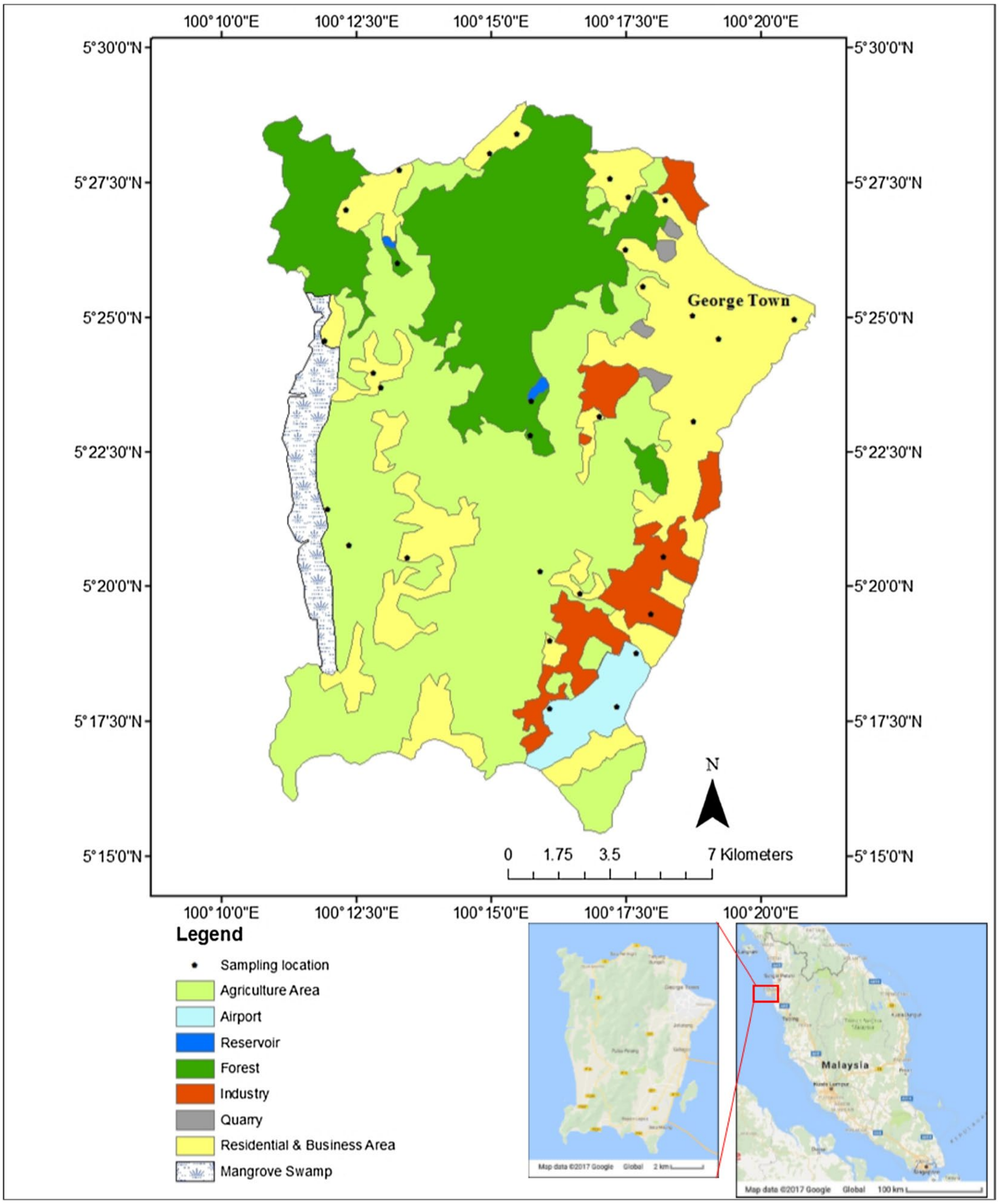

Fig. 1 Land use map of Penang Island with the sampling locations. The map was digitized from original map sourced from the Department of Agriculture Malaysia using ArcGIS

deposits of Penang Island are divided into Simpang Formation, Beruas Formation, and Gula Formation. Simpang Formation is old alluvium of Pleistocene and consists of gravel, sand, silt, clay, and locally minor amount of peat deposited in the terrestrial environment. Beruas Formation is used to describe young alluvium of Holocene that overlies Simpang Formation and contains gravel, sand, silt, clay, and locally minor peat intercalations deposited in the terrestrial environment (Hassan 1990). Gula Formation is the latest quaternary deposit that can be distinguished by its lithology, green–grey colour, the presence of marine fossils, and low heavy mineral content (Suntharalingam 1984).

Soil sampling and laboratory analysis

Thirty-one topsoil samples (0–20 cm) were collected using hand auger from different geology types of soils of Penang Island which including 12 from granite residual top soils and 19 from quaternary deposit top soils. The purpose of the selection of different geology types of soil samples was

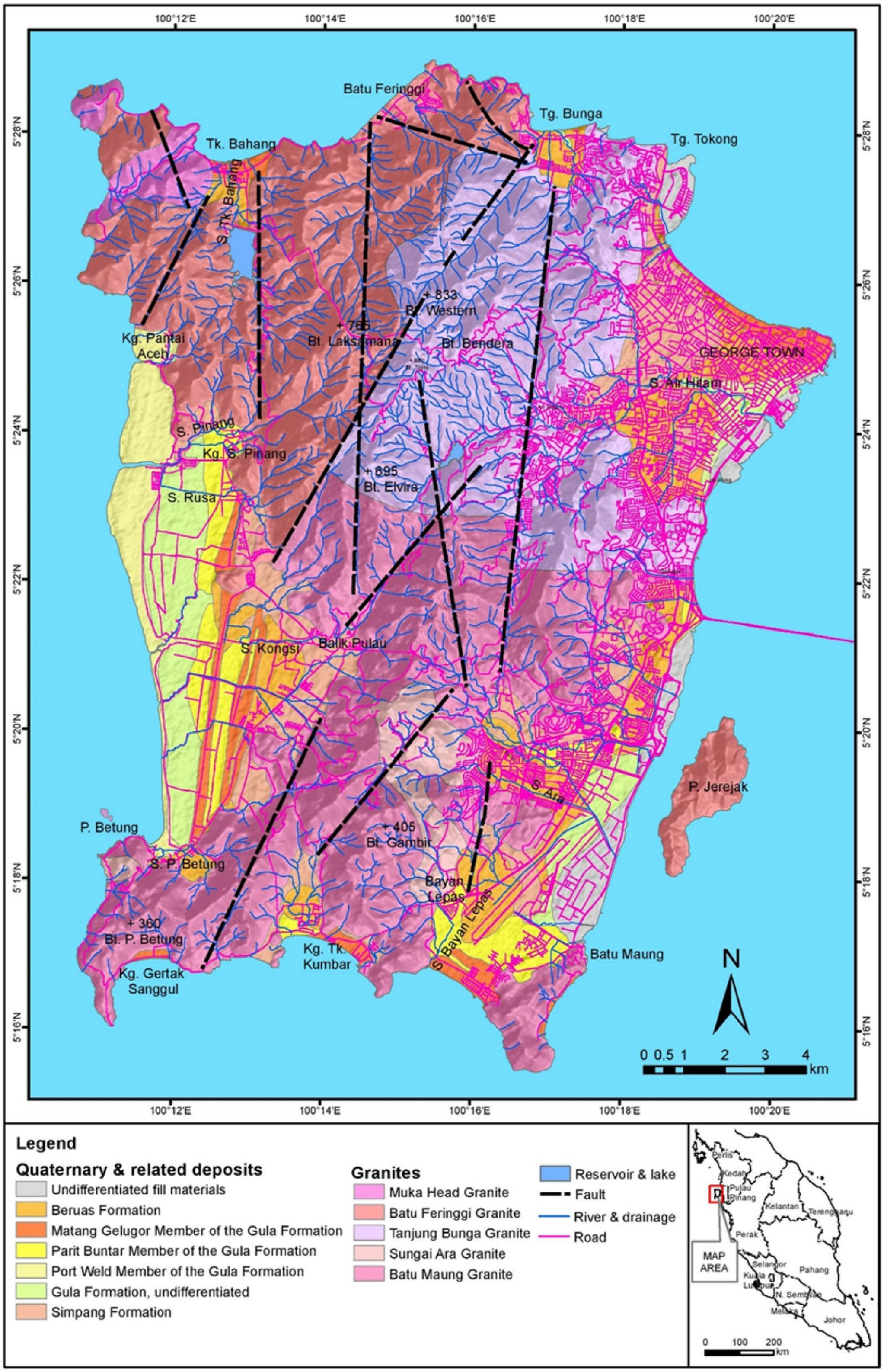

Fig. 2 Geological map of Penang Island. The map was generated using ArcGIS with data obtained from Hassan (1990) and Ahmad et al. (2006)

to compare the concentration of the metals between granite residual soils and quaternary deposit soils and to identify the origin of the As, Pb, Ni, and Cd. The coordinates of the sample location were recorded using a GPS, and all the sampling locations are shown in Fig. 1. All the samples collected were kept in clean polythene bags and transported to the laboratory immediately. Soil pH was determined using a pH meter by mixing the soil which was dried at room temperature with ultra-pure water with a ratio of 1:5 as recommended by International Standard NF ISO 10,390 (1994) (Pansu and Gautheyrou 2006). Methylene blue spot test method was applied to determine cation exchange capacity (CEC) of soil (Yukselen and Kaya 2008). Soil organic matter (SOM) content was determined using the loss on ignition method (BS 1377). For the particle size distribution analysis of the soil, percentage of sand particles (%) was determined using dry sieving method following British Standard (BS 1377) and percentage of silt and clay contents (%) were determined using laser particle-measure instrument, Malvern (Pansu and Gautheyrou 2006). A textural triangle of U.S. Department of Agriculture (USDA) was used to determine the soil textural classes.

Prior to selected metals concentration analysis, all soil samples were dried for 3 days at 40 °C, disaggregated and homogenized to pass through 2-mm mesh. Then, the samples were manually grounded by mortar and pestle and passed through a nylon sieve of 0.063 mm. The soil samples were digested using Perkin Elmer microwave sample preparation system with aqua regia mixture of 65% (v/v) nitric acid and 37% (v/v) hydrochloric acid in triplicate following 3051A standard method of United States of Environmental Protection Agency. The concentration of As, Pb, Ni, and Cd in the digested soil samples was analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent Technologies 7500 Series).

Ultra-pure filtered water stabilized at 18.2 µs/cm was used in sample analysis. All reagents used for the soil digestion process were of analytical reagent grade (Merck, Germany). ICP-MS instrument was calibrated using solutions containing a known concentration of the selected analyte elements from Agilent Technologies. Standard certified references (SRM 8704 from National Institute of Standards and Technology, NIST USA) were analysed with soil samples for quality assurance purposes. The recoveries of the ICP-MS analytical results were ranged between 98.68 and 121.52%. The detection limit is 0.06 mg/kg for As, 0.07 mg/kg for Pb, 0.05 mg/kg for Ni, and 0.06 mg/kg for Cd, respectively.

Spatial distribution mapping

Surfer 11 software (Golden Software Inc., Colorado) has been used to produce the maps showing As, Pb, Ni, and Cd spatial distributions. Grid file was built to create a grid-based map. In the grid file, spaced XYZ data were taken randomly and regularly spaced grid file was created. Grid node is located at a particular XY location which associated with Z value. Different options for gridding methods can be selected in Surfer and each option has its own set of gridding options. In this study, the kriging gridding method was selected to generate 2D contour maps of As, Pb, Ni, and Cd distributions. Kriging is a technique of interpolation which can be used to predict unknown values from data obtained at known locations. This method also offers an automatic variogram modeling procedure to express spatial variation and minimizes the error of predicted values which are estimated by spatial distribution (Webster and Oliver 2001, https://support.goldensoftware.com). Kriging can be functioned as a generalized linear regression technique used with a variogram model for spatial data interpolation in geostatistical approach. The spatial data in this study are the measured concentrations of selected metals in the top soils. The unknown concentration (linear regression estimator),$Z^*(u)$ is estimated by kriging and defined as (Eq. 1)

$$Z^*(u) - m(u) = \sum_{\alpha=1}^{N(h)} \lambda_\alpha \left[Z(u_\alpha) - m(u_\alpha) \right], \tag{1}$$

where λ_α is weight assigned to the measured concentration $Z(u_\alpha)$, which is interpreted as a realization of the random variable $Z(u_\alpha)$, the means $m(u)$ and $m(u_\alpha)$ are the expected values of the random variables, $Z^*(u)$ and $Z(u_\alpha)$, and the mean $m(u)$ is used to represent the large-scale variation or trend in the data (Ramanitharan et al. 2005).

In this study, linear variogram model has been applied with a slope of 0.096 for all the metals. The negative Z values represented by As and Pb data were eliminated by clamping the grid values with formula max (A,0). Interested readers are referred to Webster and Oliver (2001); Zheng et al. (2010), among others.

Statistical analysis

Pearson correlation analysis and principal component analysis (PCA) were used for statistical analysis in this study. The coefficient of Pearson correlation, r, in the test will represent the strength of the relationship between two variables, where the relationships between the selected elements can provide important information on the element sources and pathways (Manta et al. 2002). Principal component analysis (PCA) is a multivariate technique which used to reduce high dimensionality of the complex data set by transforming the data into orthogonal components that are linear combinations of the original variables (Slavkovic´ et al. 2004; Ağca 2015). The relationship showed between metals in both principal component analysis (PCA) and Pearson correlation analysis can be used to predict the sources of contamination (Benhaddya and Hadjel 2013; Ağca 2015).

For PCA, a normal distribution of variables is desirable in the multivariate statistical analysis (Webster and Oliver 2001). As the sample data were not more than 50 samples, Shapiro–Wilk's test was selected to test the normality of the raw data. The raw data set for metals did not follow the normal distribution after tested using Shapiro–Wilk's normality test. A logarithmic transformation is one of the data transformation methods and widely applied by many researchers to normalize the non-normal data distribution (Webster and Oliver 2001). However, many studies showed that environmental variables do not always follow lognormal distribution (Zhang and McGrath 2004). Box–Cox transformation is an alternative transformation method which can be applied to get more normal and less skewed data (Wu and Zhang 2010). In this study, Box–Cox transformation was used to normalize the non-normal data distributions of all metals after the raw data were still not normal after logarithmic transformation. IBM SPSS Statistics 21 software Microsoft Excel was used in the statistical analysis.

Soil contamination assessment

A common principle to assess element or metal contamination in soil is the contamination factor (CF), which was initially defined by Hakanson (1980) to determine element contamination in soil. The CF value was calculated as (Eq. 2)

$$C_f = C_i / B_i, \tag{2}$$

whereC_i The element concentration, B_i background value of the element, and CF value can be described as following terminology (Hakanson 1980; Pekey et al. 2004):

$C_f < 1$ No element enrichment.
$1 \leq C_f < 3$ Moderate contamination.
$3 \leq C_f < 6$ Considerable contamination.
$C_f \geq 6$ Very high contamination.

Background value, B_i, for the metals was determined by statistical method due to the geochemical baseline data for the study area has not yet been established. The statistical method which was proposed by Reimann et al. (2005) has use the [median ± 2 median absolute deviation (MAD)] rule to determine background value of element in soil for soil quality investigation purposes (Dung et al. 2013). According to Reimann et al. (2005), symmetrical distribution data are compulsory before any threshold estimation methods are applied. The metals' concentration data were log-transformed before the [median ± 2 median absolute deviation (MAD)] calculated, as the data did not follow symmetrical distribution. The results of the metals concentration [median ± 2 median absolute deviation (MAD)] were anti-logged to get the natural value.

Results and discussion

Soil physicochemical properties

The summary statistics for soil properties and content of metals in top soils of Penang Island are given in Table 1. The soil texture of collected samples was mostly classified as sand and some classified as silty clay (Fig. 3). The soil pH ranges from 3.84 to 8.30, with an average value of 6.53 suggesting acid to slightly alkaline conditions. The acidic condition of the soil is expected to be derived from the parent rock, granite. Soils that derived from granites are normally acidic (Mirsal 2008). The effect of human activities such as industrial and transport emissions in urban may also eventually contribute to the increasing acidity of soils by forming acid deposits in rainwater (Mirsal 2008). The decreased soil pH may be related to acid sulfate marine deposit (Fanning et al. 2017), as the study area is surrounded by sea. However, some soil samples showed elevated pH which can be associated to the presence of building rubble containing brick, cement, plaster, mortar, and concrete in urban environment that produce calcium during weathering process (Mehr et al. 2017).

Minimum, maximum and average values of organic matter (OM) were 1.14%, 17.05%, and 3.67%, respectively. The observed variation in OM content probably derived from

Table 1 Summary statistics of the metals concentration and soil physicochemical properties of Penang Island top soils

Metals (mg/kg)	Mean	Minimum	Maximum	Median	SD	Skewness	Kurtosis
As	366.6	67.9	2942.1	190.9	544.7	3.9	17.3
Pb	422.9	42.1	7019.6	100.0	1326.0	4.6	22.2
Ni	51.7	6.5	1049.2	13.6	186.1	5.5	30.3
Cd	1.6	0.2	16.7	0.6	3.0	4.4	21.4
Physicochemical parameters							
pH	6.53	3.84	8.30	6.74	1.26	− 0.50	− 0.81
OM (%)	3.67	1.14	17.05	3.01	3.02	3.16	12.83
CEC (meq/g)	4.10	1.24	19.93	3.32	4.29	2.84	7.57

SD standard deviation

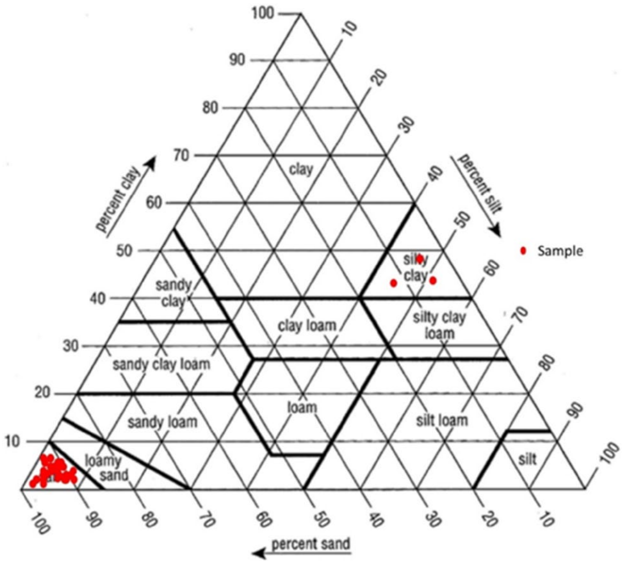

Fig. 3 Triangular plot showing the texture of collected top soils surrounding Penang Island. Most of the soils were classified as sand and some soils were classified as silty clay

plant and animal litter which contained much in the upper layer of soil (Mirsal 2008). The cation exchange capacity (CEC) ranges from 1.24 to 19.93 meq/g with a mean value of 4.10 meq/g. CEC value in soil depends largely on the organic and clay contents in the soil which CEC value tends to be highest in soils with high clay and organic content (Mirsal 2008).

Metals Concentration Levels

Metals in study area show variation in terms of concentration levels. Concentration of metals in the soil samples ranged from 67.9 to 2942.1 mg/kg for As, 42.1 to 7019.6 mg/kg for Pb, 6.5 to 1049.2 mg/kg for Ni, and 0.2 to 16.7 mg/kg for Cd. Based on the mean concentration, the metals in the soils were arranged in the following decreasing order: Pb > As > Ni > Cd.

Numerous studies have been reported on metals contamination in urban soils around the world. Compared to average concentrations in urban soils in the world (Table 2), the average values of As and Pb in the analysed soils are much higher than those reported for samples from Isfahan province, North east of Vaslui county, Rayong province, Chicago, and Arica. However, the average value of Pb in the analysed soils is nearly similar to the average value of Pb reported for samples from Chicago. The average value of Ni in the analysed soils is higher than Chicago and Arica, but nearly to the reported samples from North east of Vaslui county, and lower than those reported for samples from Isfahan province and Hamburg. The average values of Cd in Isfahan province, Rayong province, and Hamburg are higher than the average value of Cd in the analysed soils, whereas the average values of Cd in North east of Vaslui county and Hangzhou city are lower than the average value of Cd in the analysed soils.

Metal contents vs. soils' type

Summary average values for As, Pb, Ni, and Cd concentrations in the two types of soils are presented in graph, as shown in Fig. 4. The average value of As in the granite residual soils is higher than the average value of As in quaternary deposit soils. In contrast, in quaternary deposit soils, the average values of Pb, Ni, and Cd are higher than in granite residual soils.

According to FOREGS (2005), As is not preferentially enriched in igneous rocks. In general, in granitic rock, As concentration ranges between 1.5 and 1.9 mg/kg (FOREGS 2005). In the studies reported by Cobbing et al. (1992), Ghani et al. (2013) and Ng et al. (2015), the As content in granitic rock of Penang Island ranged from 0 to 3 mg/kg. This suggests that the As content may probably not be derived from the granite in the study area. The high content of As in the granite residual soils may be related to As geochemistry in the soils. Arsenic in ionic form easily replaces other elements in primary rock-forming silicate minerals (i.e., granite) such as replacement of Fe^{3+} or Al^{3+} by As^{3+} (FOREGS 2005). The granitic rock of Penang Island also contained phosphate mineral, apatite as reported by Cobbing et al. (1992). The substitution of P^{5+} by As^{5+} could

Table 2 Comparison of As, Pb, Ni and Cd average concentrations in urban soils in different areas (mg/kg)

Urban area	As	Pb	Ni	Cd	References
Isfahan province, Iran	16.17	179.97	61.65	2.17	Mehr et al. (2017)
North east of Vaslui county, Romania	10.14	25.27	47.36	0.32	Ungureanu et al. (2016)
Rayong Province Thailand	26.23	19.97	–	3.56	Simasuwannarong et al. (2012)
Hangzhou city, China	–	88.20	–	1.20	Lu and Bai (2010)
Chicago (USA)	20	395	36	–	Mehr et al. (2017)
Hamburg	–	218.2	62.5	2.0	Manta et al. (2002)
Arica, Chile	22.8	267	5.3	–	Tume et al. (2018a)
Penang Island	366.6	422.9	51.7	1.6	This study

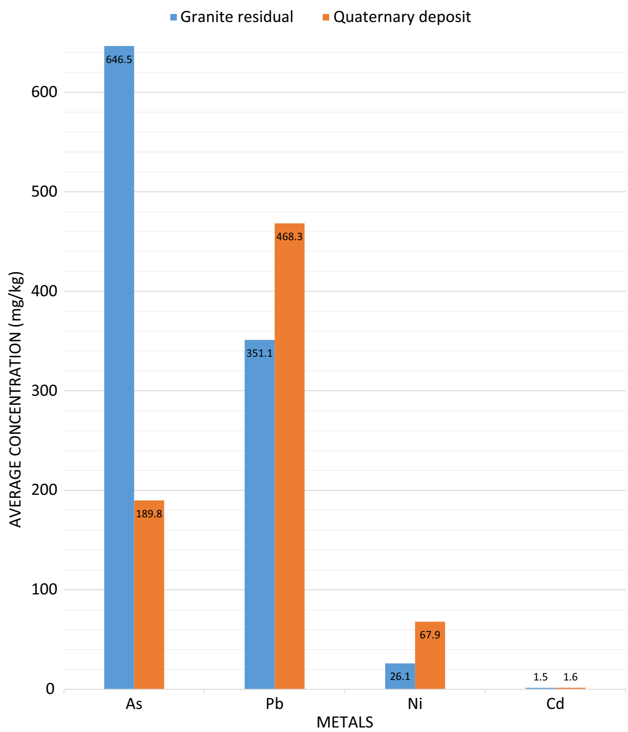

Fig. 4 Comparison of As, Pb, Ni, and Cd average concentrations (mg/kg) in granite residual soil ($n=12$) and Quaternary deposit soils ($n=19$)

lead to the elevation of As content in the phosphate mineral (FOREGS 2005). Thus, the high concentration of As in granite residual soils could be related to geochemistry.

Higher average values of Pb, Ni, and Cd in quaternary deposit soils than granite residual soils suggest an anthropogenic source for these elements. The concentration of Pb in granitic rock is generally ranged between 15 and 19 mg/kg (FOREGS 2005). The concentration of Pb in granitic rock of Penang Island ranged from 16.6 to 47 mg/kg (Cobbing et al. 1992; Ghani et al. 2013; Ng et al. 2015). In general, Ni content in granitic rock is low and ranges between 4.5 and 15 mg/kg (FOREGS 2005). Granitic rock of Penang Island contained Ni ranged from 2 to 28.3 mg/kg (Cobbing et al. 1992; Ghani et al. 2013; Ng et al. 2015). Cd concentration in granitic rock also is commonly low, typically 0.09 mg/kg (FOREGS 2005). This suggests that the Pb, Ni, and Cd contents may probably not be derived from the granite in the study area. The high content of As in the granite residual soils may be related to As geochemistry in the soils.

Spatial distribution of metals

Spatial distribution maps of the selected metals in the Penang Island are presented in Fig. 5. Based on the As distribution map, elevated As concentration was located in central of north eastern part of Penang Island. The high contents of As in the study area could be related to the agriculture, industry, and quarry activities in this areas. According to Alloway (2013), the elevated As concentration in soil is mainly attributed to agriculture, where As has been used in pesticides, fertilizer, sludge, and manure. In Rayong province, Thailand, elevated As distribution trends coinciding with the location of agriculture and industry (Simasuwannarong et al. 2012).

The high Pb concentrations were located in the northern and north eastern parts of the study area. In fact, the highest value of Pb was presented in the northeast, where the oldest and main city of Penang Island, George Town is located. The high value of Pb in the northern part is the main tourism place in Penang Island (Batu Feringgi). Elevated Pb concentrations in above areas could be related to the high traffic density using vehicular exhausts arising from the use of leaded gasoline. The long-term accumulation of Pb in the environment is due to their non-biodegradability and long residence time (Benhaddya and Hadjel 2013).

Based on the Ni distribution map, elevated concentration area of Ni was observed in eastern part of the study area which near to George Town. Elevated contents of Ni in this area could be related to residential and industrial activities. This finding is in agreement with study of Zhai et al. (2003) in Gaborone, Botswana. The observed high Ni content in the urban soil mostly related to residential waste, especially liquid waste. According to Alloway (2013), Ni pollution could be associated with emissions from metal processing operations and also from increasing combustion of coal and oil.

Cadmium shows similar highest concentration area with the highest Pb concentration area which in George Town. The elevated contents of Cd in this area could be associated with high traffic density. It has been reported that high content of Pb in urban soils was always associated with Cd which could be related to traffic emissions (Wong et al. 2006; Hamzeh et al. 2011; Ağca 2015). Cadmium is added to the rubber used for tires and is also used as an antioxidant in lubricating oils (Hamzeh et al. 2011).

Prior to the results and observations, north-to-north eastern areas of Penang Island highlighted an enrichment of As, Pb, Ni, and Cd which characterized varied human activities and the major residential and business areas. Thus, the main source of As, Pb, Ni, and Cd in top soil of Penang Island is expected to be derived from the anthropogenic source.

Relationship between metals and their possible origin

The result of Pearson correlation between metals elements are listed in Table 3. A very significant positive correlation was discovered between Pb and Cd. The relationship between Pb and Cd suggested that they may be derived from a similar source. In the study of spatial distribution of heavy metals in Southern Turkey, the correlation analysis also

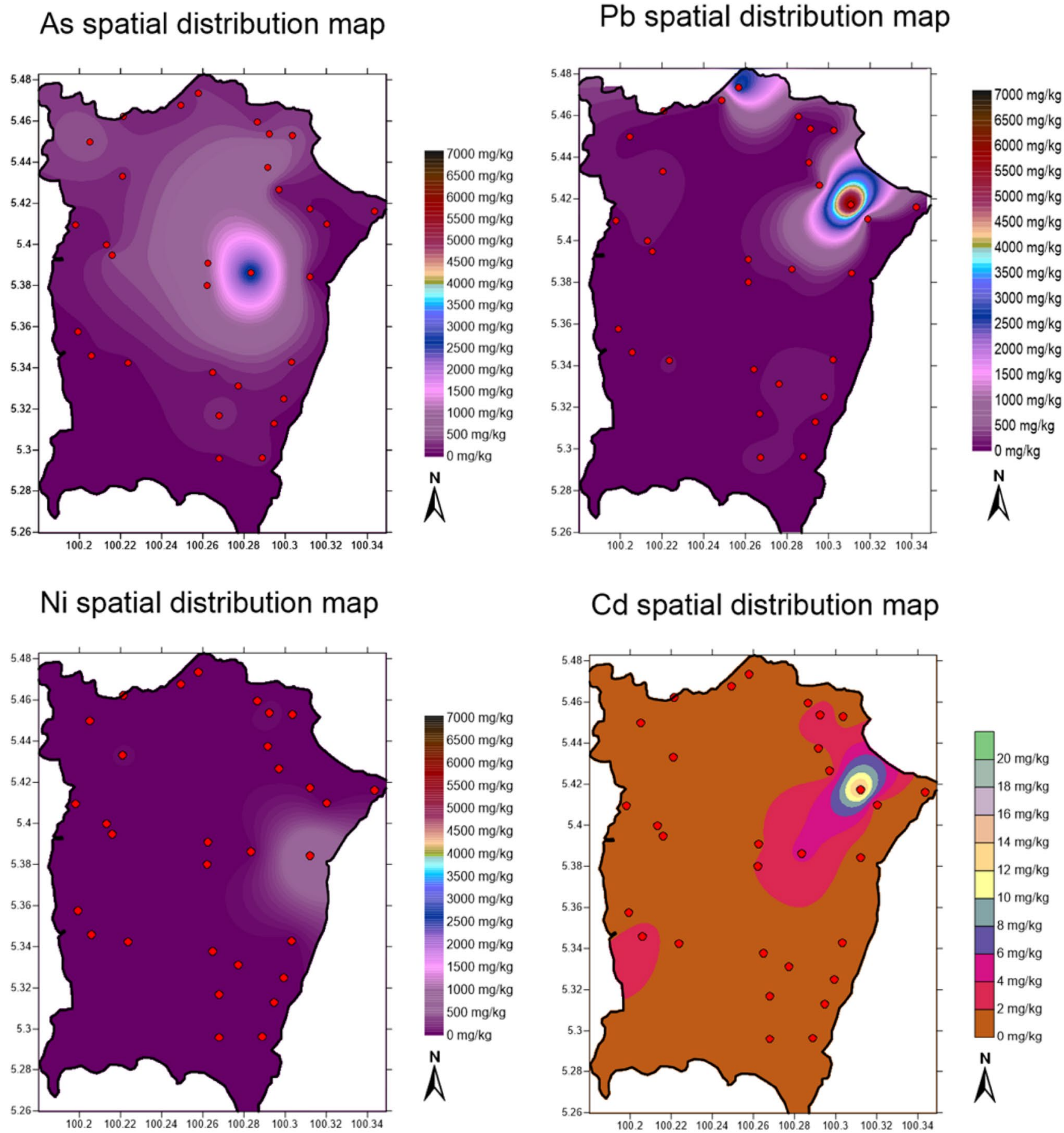

Fig. 5 Spatial distribution maps of As, Pb, Ni, and Cd in Penang Island

discovered significant positive correlation (0.914) between Pb and Cd (Ağca 2015).

Principle component analysis result showed a two-factor model, accounting for 67.353% of data variability, was considered, choosing factors characterized by eigenvalues > 1. The varimax rotated with Kaiser normalization factors of four metals for 31 top soil samples of Penang Island is reported in Tables 4 and 5. The rotated component matrix shows that As, Cd, and Pb were associated with the first component (F1). F1 was responsible for 40.135% of total variance with As showed negatively associated –0.691) with Pb (0.595) and Cd (0.869). F2 which responsible for 27.218% of total variance was represented by Ni (0.941). Lead and Cd could be derived from similar source, since

Table 3 Pearson correlation coefficient (*r*) between metals studied

	As	Pb	Cd	Ni
As	1			
Pb	− 0.086	1		
Cd	0.157	**0.839****	1	
Ni	− 0.099	− 0.044	− 0.043	1

** Correlation is significant at the 0.01 level (2-tailed)

they were grouped under similar factor and positively associated with each other. In Southern Turkey, the study of spatial distribution of heavy metals in urban soils also represented positive correlation between Pb and Cd which grouped under similar factor in PCA (Ağca 2015).

To discriminate distinct groups of metals, the component plot in rotated space diagram was performed on the available data set. The obtained results (Fig. 6) enabled the identification of nearest distance of metals represented by Pb and Cd which discriminating from As and Ni. This result is consistent with elemental relationships, indicating that Pb is strongly correlated with Cd, thus supporting a similar origin for these elements.

Soil contamination assessment

The summary calculated CF values of the selected metals in top soils of Penang Island are presented in Table 6. The CF values ranged from 0.10 to 4.25 (mean 0.53) for As, 0.23 to 38.58 (mean 2.32) for Pb, 0.22 to 35.56 (mean 1.75) for Ni, and 0.06 to 6.80 (mean 0.64) for Cd. The mean values of CF decreased in the order of Pb > Ni > Cd > As. The mean CF of As and Cd pointed to no element enrichment level, while the mean CF obtained for Pb and Ni indicates moderate contamination level.

The contamination level of mean CF values of As, Pb, Ni, and Cd in urban soils of different cities worldwide is given in Table 7. In comparison with other cities, CF level of As in this study shows similar level (no element enrichment) with reported CF level of As in Arica, Isfahan province, and residential area of Patuakhali. However, the CF level of As in Baghdad is slightly higher (moderate contamination)

Table 5 Component matrix and rotated component matrix for four metals concentrations for 31 top soil samples from Penang Island

Element	Component matrix		Rotated component matrix	
	F1	F2	F1	F2
Ni	0.222	0.917	0.067	**0.941**
As	− 0.682	0.113	**− 0.691**	− 0.002
Cd	0.903	0.131	**0.869**	0.279
Pb	0.525	− 0.466	**0.595**	− 0.373

As, Cd and Pb are correlated with F1. Ni is correlated with F2 (in bold)

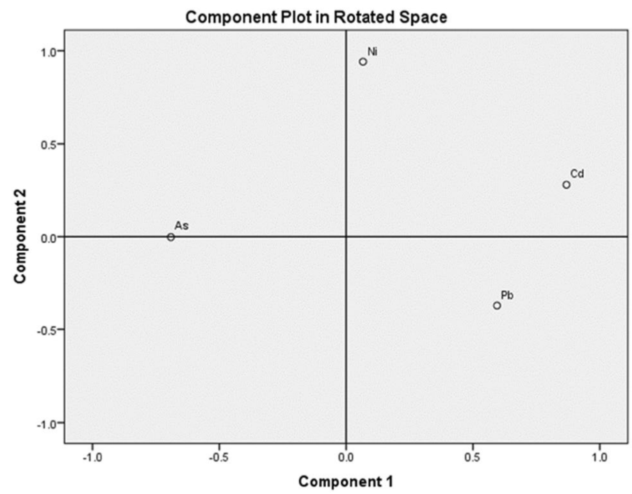

Fig. 6 Component plot in rotated space diagram of four metals concentrations for 31 top soil samples from Penang Island

Table 6 Summary calculated CF values of As, Pb, Ni, and Cd in top soils of Penang Island

Metals	Contamination factor (CF)		
	Mean	Minimum	Maximum
As	0.53	0.10	4.25
Pb	2.32	0.23	38.58
Ni	1.75	0.22	35.56
Cd	0.64	0.06	6.80

Table 4 Total variance explained

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.605	40.135	40.135	1.605	40.135	40.135	1.591	39.777	39.777
2	1.089	27.218	67.353	1.089	27.218	67.353	1.103	27.576	67.353
3	0.958	23.944	91.297						
4	0.348	8.703	100.000						

Table 7 Comparison of contamination level of mean contamination factor (CF) values of As, Pb, Ni, and Cd in urban soils in different areas

Study area	Contamination factor (CF)				References
	As	Pb	Ni	Cd	
Arica, Chile	No element enrichment	No element enrichment	No element enrichment	–	Tume et al. (2018a)
Isfahan province, Iran	No element enrichment	Considerable contamination	No element enrichment	Moderate contamination	Mehr et al. (2017)
Talcahuano, Chile	–	No element enrichment	–	–	Tume et al. (2018b)
Baghdad, Iraq	Moderate contamination	No element enrichment	Moderate contamination	–	Hamad et al. (2014)
Residential area, Patuakhali, Bangladesh	No element enrichment	Moderate contamination	No element enrichment	Moderate contamination	Islam et al. (2017)
Penang Island	No element enrichment	Moderate contamination	Moderate contamination	No element enrichment	This study

than the CF level of As in this study. The CF level of Pb in Isfahan province is the highest (considerable contamination) among the presented study areas. The CF level of Pb in this study (moderate contamination) is relatively similar to that residential area of Patuakhali but greater in Arica, Talcahuano, and Baghdad (no element enrichment). Similar to Baghdad, CF of Ni in this study appears to be at moderate contamination level. However, Arica, Isfahan province and residential area of Patuakhali presents lower CF level of Ni (no element enrichment) than this study. Isfahan province and residential area of Patuakhali have high CF level of Cd (moderate contamination) compared to this study.

Conclusions

The decreasing order of metals mean concentration in top soils of Penang Island was: Pb > As > Ni > Cd. Pb, Ni, and Cd showed higher mean concentrations in quaternary deposit soils and most probably related to anthropogenic source of these elements. However, elevated mean concentration of As in granite residual soils suggests that the enrichment of As in the soil could be related to the geochemistry of parent materials. All selected metals, As, Pb, Ni, and Cd represented elevated concentrations in the north-to-north eastern area of Penang Island which dominated by many human activities, major residential, and business areas, and near to the main city, George Town. The strong positive correlation between Pb and Cd in Pearson correlation analysis and PCA represented that they could be derived from a similar source which most probably from the traffic emission. The CF assessment indicated no element enrichment level for As and Cd and moderate contamination level for Pb and Ni.

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