Geostatistical Spatial Interpolation Applied to Soil Geochemical Hazard Assessment of Abandoned Mining Lands in Ulu Johan, Kinta Valley, West Malaysia

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Abstract

Kinta Valley, West Malaysia is a mineralized district with a long history of metal mining. The mine soil of the abandoned land is laden with various species of hazardous chemicals that pose continued risk to human health and the environment. The residual hazard in the soil needs to be analyzed and managed before initiating development projects in the area. Geostatistics provide risk analysts with various techniques specialized for analyzing stochastic phenomena, such as pollution. In this paper, the residual geochemical hazard of soil arsenic and lead in the post-mining area of Ulu Johan, Kinta Valley was analyzed for human health and ecological receptors. A geochemical exploration procedure was undertaken to collect, prepare and analyze 25 soil samples extracted at average depth <40 cm by random sampling. The geochemical signature of each sampling location was used to establish the geotoxicity index that, in turn, formed an input information for estimating and interpolating the spatial distribution of hazard throughout the study area. The data was processed and thematically visualized in GIS environment. The results indicated that the most hazardous locations of exposure probability exceeding 50% are widely distributed along the northeast-southwest direction, parallel to mining activities. In these locations, soil imposes high risk to human and ecological receptors (hot spots), and therefore they should be scheduled for rehabilitation to manage the contamination risk to an acceptable level before re-developing the land asset.

Key words: Geotoxicity Index – GIS – Kriging – Land Contamination – Risk Assessment

Introduction

Land is a finite valuable resource. Natural and anthropogenic processes can cause degradation and contamination to land resources. Metallogenesis conceals a huge amount of mineral accumulations in the environment, naturally contaminating thereby different Earth systems (Siegel, 2002). On the other hand, excessive human exploitation of mine resources on an industrial mining scale have polluted mine environment and surrounding environment in a fast-pace mode (UNEP-DTIE, 2011), inducing thereby many geological hazards and severe environmental damage long after the mine has closed (Da Rosa, 1997). In particular, surface mining methods generate enormous quantities of waste that may diffuse many potentially hazardous elements from ore deposit (Siegel, 2002; Selinus, 2004). These hazardous chemicals often reside in the mine geological environment, embarking thereby many on-going challenges in terms of land development, public health, environmental protection, stakeholder demands and policy making, and impeding greatly the development of national economy. Identifying and dealing with such contaminated land is important in order to support increased quality of life for communities and conservation of biodiversity and to sideline economic and property damage. Unfortunately, much contaminated land is neither yet identified nor adequately described (Kibblewhite, 2001).

Solutions to environmental problems of contaminated land are many and varied, be they technological, personal, corporate, and governmental or other measures (Chiras and Reganold, 2005; Bell and Donnelly, 2006). However, these solutions depend largely on the quality of land contamination assessment (Kibblewhite, 2001). Assessment allows analysts to estimate the risk of adverse effects of potential chemical exposure, and to attend a sensible risk management decision to mitigate the hazard (Gerba, 2004). Apart from providing potential targets for mineral exploration and georesource evaluation, mining and economic geologists are invited more than ever to use their geological knowledge in dealing with contaminated environments, as their geo-investigations are essential to unveil significant information on land condition.

Environmental Hazard and Risk Assessment

Hazard is the potential for harm and adverse effect posed by a source (contaminant of potential hazard or hazardous situation) and its magnitude is equated with the severity of the expected consequences. Risk is a function or measurement of the magnitude of hazard by the probability and likelihood of its occurrence and consequence. The functional expression: risk = f (exposure + hazard) is commonly used in geohazard studies (Levitan, 2004). Given geochemical environment, McBean and Rovers (1998) stated that three components of pollutant linkages must exist for risk to occur: a contaminating source, a migration pathway and an exposed receptor (Figure 1). Exposure could be acute, exerting toxicity due to high dose of metal over short period; or chronic, exerting toxicity due to long-term exposure to low levels of metal, causing gradual development of health symptoms.

Fig. 1: Essential components of risk scenario (Source: McBean and Rovers, 1998)

The process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences of probabilities of occurrence is known as ‘risk management’. The main elements of risk management are 'risk assessment' and 'risk reduction'. Traditionally, ‘risk assessment' is the organized process of appraisal used to describe and estimate the likelihood/significance of an adverse outcome from environmental exposures to chemicals or observed levels of contamination on a site. Risk assessment procedure consists of hazard identification and assessment, risk estimation and risk evaluation. For 'risk reduction', the procedure generally aims at setting risk control measures and management actions (Connell, 2005; ICE, 1994).

In view of contaminated sites, 'hazard identification and assessment' study deals with comparing the observed level of contamination with generic reference data indicative of specific types and levels of risk (measuring the potential for harm to occur). However, in site-specific ‘risk estimation and evaluation’ study, the analyst estimates the probability that harm will occur (qualitative or quantitative estimates). A systematic risk assessment must be preceded by a complete Environmental Site Assessment (ESA) procedure to confirm the contamination at the site, to compare with regulatory requirements, to determine the compliance and to avoid the liability for and costs associated with the cleanup of a site. The risk analyst finally comes up with decisions related to the disposition of the property (Sharma and Eddy 2004). In recent times, the scientific community has realized that ecosystem receptors are acknowledged to show sometimes more sensitivity than human. Risks threatening human health are not necessarily doing the same to wildlife and vice versa (Bascietto et al., 1990). Therefore, modern risk studies of ground contamination have been refined to consider both human and ecosystem as two independent, but dynamically integrated, components of the total environment. Based on this consciousness, two principal areas of environmental risk assessment are recognized (EPA, 2017): human health risk assessment (HHRA) and ecological risk assessment (ERA).

The Concern of Geo-Hazard in Post-mining Lands of Kinta Valley

In Kinta Valley, West Malaysia the physicochemical landscape of mining lands has been largely disturbed since the downturn of mining business in the late decades of the last century. Human involvement in re-inhabiting these derelict lands has resulted in developing land resource for many purposes (Sani, 1998). Many of these purposes are now operating extensively on historical mine lands, such as Ulu Johan, west Kinta Tinfield. Ulu Johan is a watershed catchment area facing an increasing expansion of urbanization and industrialization, e.g. Bukit Merah and Lahat industrial zones, agricultural, fishery, mining and recreational uses. However, shortage of building land (particularly for industrial concerns) means that developers are re-using more and more land in areas distinct with a history of mining, and by which, Ulu Johan’s land and water resources will naturally expect a soon invasion by this fast national development wheel.

The abandoned mining lands and reclaimed tailings in Kinta Valley impose serious threats of residual hazardous metals that continue to give precedence of unsafe conditions to human and the environment. Among the many hazardous chemicals in mine soil, arsenic (As) and lead (Pb) are the most important: they are persistent contaminants as they bind strongly to soil and usually remain in the environment without breaking down or losing their toxicity, and thus can be a source of exposure for many decades (Task Force, 2003). In order to be appropriate for redevelopment, the contaminated soil needs to be quickly assessed and rehabilitated, and the ecosystem to be restored to its natural state of health. However, the time required for treatment is limited in the face of the current great development expansion in Kinta Valley. Although some mined-out lands in the district have their soils been reclaimed to reduce the visual landscape impact, there is no comprehensive characterization of these lands on a large scale (Muhd Razali et al., 1993; Mohamad and Hassan, 1997). The concern over soil contamination stems primarily from health risks, both of direct contact and from secondary contamination of water supplies (Cross and Taylor, 1996). People living on or near a mining contaminated site will often be concerned about potential effects on their health (a geohealth issue). The quality of ecosystem in contaminated lands will also be vulnerable to degradation by concealing geo-hazards in the environment. Uncertainties about remediation requirements and liability for contaminated lands can also cause blight, deterring development of land; adding to pressures on greenfield sites and affecting urban regeneration (UTF, 1999). To determine the need for intervention and to avoid future liabilities, hidden costs and work delay, the risk from a contaminated site needs to be assessed. Unfortunately, the non-availability of good baseline geochemical data in tropical countries has become a major constraint in risk management of contaminated lands. Furthermore, mapping is one of many inputs to environmental assessment procedure of contaminated sites; but it is time consuming and expensive task, requiring extensive amounts of geology, hydrology, chemistry and computer modeling skills (Cross and Taylor, 1996). Unfortunately, detailed geochemical hazard maps are rare in tropical areas and there is an urgent need for high resolution geochemical data as necessitated by environmental and epidemiological studies (Plant et al., 1996).

It is obvious that many challenges conceal in dealing with mining contaminated land and they are awaited to be accomplished by highly skilful geoprofessionals and risk engineers to ensure integrated value judgments and science-based practice to manage the hazard.

Problem Statement

The residual geochemical hazard of soil arsenic and lead in mining contaminated lands of Ulu Johan, Kinta Valley impose potential risk to human health and ecosystem. The risk needs to be urgently analyzed and communicated in order to support a rapid science-based decision-making pertaining to land resource management and site-user protection. The traditional methodologies currently used in site assessment and risk analysis are costly, time-consuming and highly sophisticated; thus delaying the implementation of land development.

Research Hypothesis

In the face of the many challenges associated with contaminated lands in Kinta Valley, it is necessary to carry out a quick procedure for analyzing the risk and implementing carefully designed plans to redevelop the area. The use of stochastic modeling techniques found in GIS and geostatistics can help risk analysts attaining these tasks in a simple, cost- and time-effective manner. This is attributable to the powerful capabilities of these techniques that enable the analyst to attain best solutions and optimization mechanisms for analyzing geoenvironmental data. This in turn will reflect on maximizing the revenue of knowledge that is coherent and necessary to serve best the decision-making process pertaining to hazard control and environmental management.

Research Objectives

The general goal of the current study is directed towards integrating geostatistical modeling and GIS techniques with the risk assessment procedure in order to facilitate a rapid and automated approach of analysis. The objectives of the study are: (1) spatial modeling of arsenic and lead contamination distribution in soil system; (2) identifying locations where observed levels of contamination are likely to pose unacceptable risk to human health and ecosystem; and (3) deciding whether the risk requires applying the urgency methodology to manage the geochemical hazard to an acceptable level.

The Study Area

The 14-km-square land of Ulu Johan (Figure 2) lies near the historical mega metallogenic territory of Kinta Valley, West Malaysia. It is coordinated at Longitude: 100˚ 59́ 49.32″ E to 101˚ 02́ 01.28″ E, and Latitude: 4˚ 30́ 48.35″ N to 4˚ 32́ 42.29″ N. Three types of lithology are recognized in the study area: granite (Paleozoic-Mesozoic), limestone (Upper Paleozoic), and schist (Upper Paleozoic-Mesozoic) in addition to the Quaternary alluvium cover. The Paleozoic sedimentary rocks near granite formations had been folded, faulted, jointed, sheared and cut by strike-slip and low-angle oblique faults striking generally N-S of the valley. Tin mineralization is abundant at contact zones. The general characteristics of Ulu Johan can be summarized as the following:

a. The locality is situated spatially at the most enriched mineralization belt in Southeast Asia (Scrivenor, 1931; Hosking, 1973; Hutchison, 1989)
b. The locality is spatially located at a geological contact between different types of lithology, chemistry, history and emplacement. Being under sever tropical environment, the geological materials have been significantly under intense weathering and chemical adversity that reflect on the spatial distribution of metal loads in the environment (Ingham and Bradford, 1960).
c. The locality is proximal to an unlimited source of chemicals associating the ore-bearing granites (Hosking, 1973); therefore, continuous metals flux develop implicit geochemical hazard in the environment.
d. The locality has been under prolonged human exploitation, e.g., metal mining, fishing, plantation and recreation (Sani, 1998).
e. Several incidents of human health disorders and disease symptomology have been observed in the inhabiting community (SAM, 1984; Rasiah, 1999; NST, 2005).

The field observations in the study area indicated that the sources that might adversely affect soil quality could be classified into the following groups based on severity and impact:

a. Primary sources: waste rocks, tailings, heaps and slag enriched with contaminants of potential hazard (Figure 3);
b. Secondary sources: groundwater beneath ponds, sediments in streams and water channels, open excavations and abandoned lands, floodplain soils mixed with

sediments of contaminants of potential hazards, and emissions from nearby mineral processing plants (Figure 4);

c. Tertiary sources: stream sediments reworked from floodplains and groundwater from contaminated pond sediments.

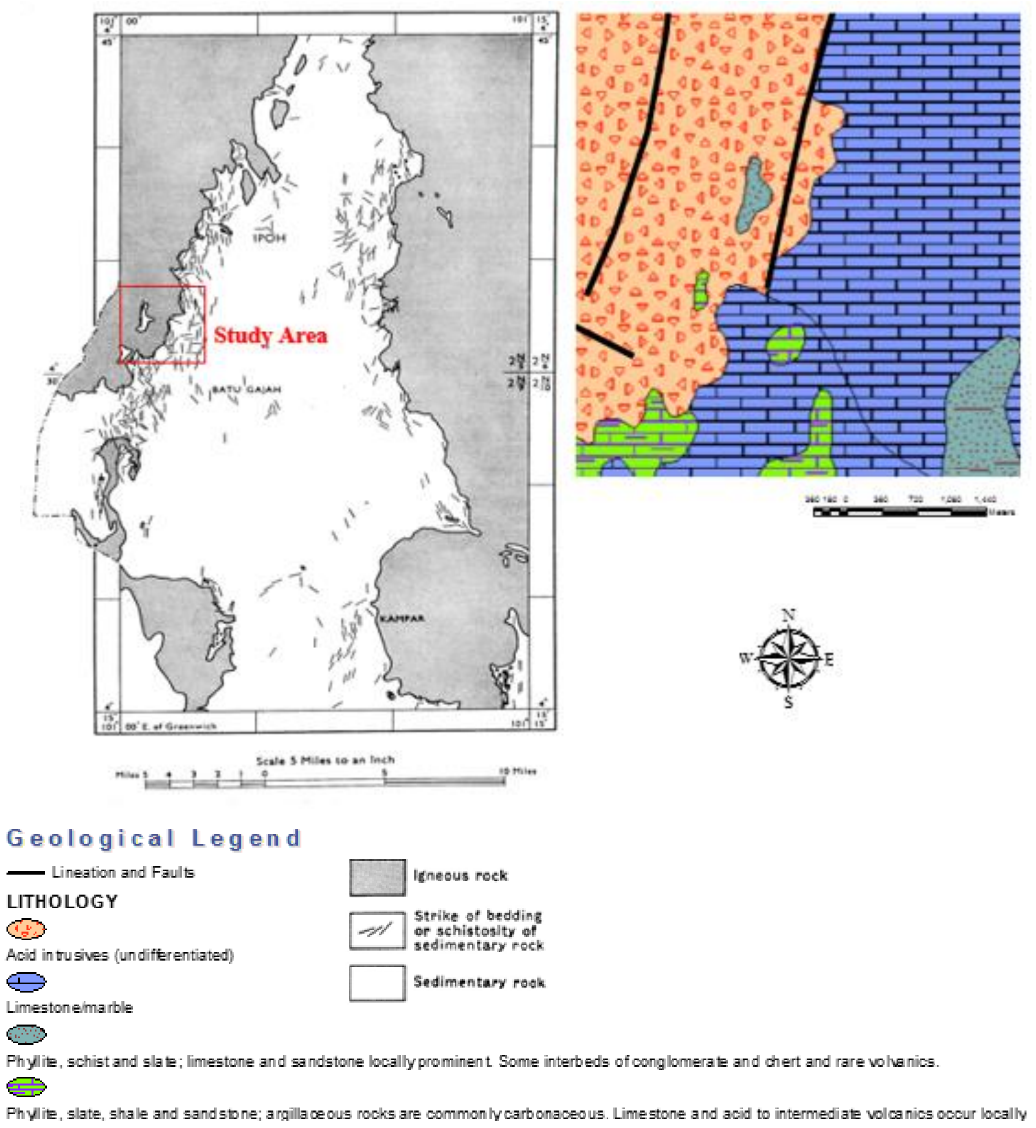


Fig. 2: Physical attributes of the study area. Instilled box not to scale. (Source: Ingham and Bradford, 1960)

Fig. 3: Mining wastes and relics in the study area (Source: author)

Fig. 4: Acid mine drainage entering the fluvial system of the study area (Source: author)

Research Methodology

The developed methodology in this study entails: (1) generating risk standard for soil quality, (2) transforming soil quality parameters (contaminant concentrations of arsenic and lead) into geotoxicity indices, (3) mapping-based risk assessment for biological site users (human and ecosystem).

Generic Risk Standards

The regulatory guidance pertaining to assessing the risk of contaminated sites rely on the development of environmental assessment criteria for soils and ground waters against which analytically determined site concentrations can be assessed. The actual risk on a site is a function of soil characteristics, therefore; soil guideline values are used as a screening tool in geo-hazard analyses. To characterize soil quality, site-specific environmental criteria are determined in order to know ‘how safe is safe’ for the protection of biological receptors. Benchmark values and biological exposure limits are formulated through a huge databank that involves multi-parameters, such as ecology and human health interventions, national soil background values and metal kinematics in the environment. Unfortunately, there is no relevant background concentration levels or biological exposure threshold data of chemicals under tropical conditions, neither on national Malaysian scale nor on Southeast Asia regional scale. To overcome this problem, the Dutch National Institute of Public Health and the Environment's generic soil standards (RIVM, 2001) had been adopted in this study.

Risk-based soil quality objectives are an important instrument in the Dutch soil policy (RIVM, 2001), especially in relation to assessing the degree of pollution in the soil and to decide on remediation strategies. The Dutch system classifies historical soil contamination based on risk that would occur under standardized conditions, irrespective to the type and pattern of land-use, thus; making these standards completely based on generic criteria (Rutgers and Besten, 2005). In this system, Serious Risk Concentrations (SRCs) for soil, water and sediments in which human risk limit and ecotoxicological risk limit are specified. The benchmark values for soil toxicity by arsenic and lead contaminants (at pH =6) are 576 ppm and 622 ppm, respectively in human receptors, and 85 ppm and 580 ppm, respectively in ecological receptors. Above these levels, an unacceptable risk may impose serious disorders on biological receptors.

Geotoxicity Index

Exploration geochemists have been long developing several geoindices to optimize and quantify metal interactions with environmental entities. Examples are the metal coefficients and enrichment factors that correlate metal abundance in a sample to a reference material value (Brooks, 1972; Müller, 1979; Kovalevskii, 1995). In this context, the very concept could be extended to characterize how far chemical soil variables impose risk on human and wildlife endpoints by ratio-ing the detected geochemical signals of a contaminant in the sample to the safe threshold of that contaminant in the soil. Using the RIVM's generic standards, SRC is the baseline level (reference) of maximum concentration of a soil contaminant above which human or wildlife is subject to serious risk. On the other hand, C_{sample} represents the maximum concentration of contaminant measured in the soil sample. The ratio between these maximum limits is referred to in the current study as 'geotoxicity index'. It is a geohealth index purposed here to characterize how far the soil is safe and healthy to biological endpoints. The geotoxicity index (*Geotox.I*) is expressed for human and ecological receptors as the following:

$$Geotox.\ I_{human} = \frac{\text{Maximum Geomaterial Concentration in Sample } (C_{sample})}{\text{Human Toxicological Serious Risk Concentration } (SRC_{human}) \text{ in the Geomaterial}} \qquad \text{(Eq. 1)}$$

$$Geotox.\ I_{ecosystem} = \frac{\text{Maximum Geomaterial Concentration in Sample } (C_{sample})}{\text{Eco-Toxicological Serious Risk Concentration } (SRC_{ecosystem}) \text{ in the Geomaterial}} \qquad \text{(Eq. 2)}$$

If a location shows high *Geotox. I* then there is a serious risk on biological site users that needs to be mitigated to an acceptable level. Opposite to this condition means there is no serious risk on the site users and, therefore, undertaking correction actions is unnecessary. It is noted that this geoindex of soil toxicity is an indicative to the exceedance of permissible level of concentration that prompts serious illness in biological receptors, rather than a reference of pollution level in the soil, which is not stressing necessarily on health factor. The developed geoindex in this methodology is purposed to work as hazard indicator variable (standard characterization criterion) for risk mapping and assessment.

Risk Mapping

In order to spatially map out the contamination risk in the study area, the geotoxicity index need to be characterized at unsampled location points from interpolating the values at sampled (measured) location points in order to generate a continuous field of risk values. One way to do this is through spatial interpolation by Ordinary Kriging technique (ESRI, 2016). The basic idea in interpolation is to discover something about the general properties of the surface, as revealed by the measured values, and then to apply these properties in estimating the missing parts of the surface. Kriging calculates weights for measured points in deriving predicted values for unmeasured locations based on distance between points and the variation between measured points as a function of distance. Kriging is mathematically expressed by the formula (Grunwald, 2006):

$$Z_0^* = \sum_{i=1}^{N} \lambda_i Z_i \qquad \text{(Eq. 3)}$$

where Z_0^* is the estimated magnitude of unmeasured parameter at interpolation location C_{0xy}; Z_i is the measured value of the parameter; N is the number of sites used for the estimation and λ_i is the weight of the Kriging estimator.

In Ordinary Kriging method, the procedure of surface modeling uses the ‘proximity’ of data value to threshold data, which can result in more accurate probabilities. This will allow recognizing the data values that exceed the reference values (Grunwald, 2006). In the process, a model of uncertainty around the unknown value $Z(s)$ is used to configure the autocorrelation between residual errors $\varepsilon(s)$ and the known constant mean μ (the threshold) and the trend of variation in space s, such that:

$$Z(s) = \mu + \varepsilon(s) \qquad \text{(Eq. 4)}$$

In locations where data had not exceeded μ, this implied to low exposure probability; whereas in locations where data had exceeded μ, this implied to high exposure probability.

Materials and Procedures

Soil Sampling

The procedure for collecting and preparing sample materials for analysis was in accordance with the general procedure used in geochemical surveys. Manual auguring was used to collect, by random sampling, a package of 25 GPS-georeferenced soil samples at average depth < 40 cm, and each weighed 1 kg (Figure 5). This depth was in accordance with the geochemical investigations done on Australian laterites (Taylor and Eggleton, 2001), and as specified in the extensive geochemical data factsheets on baseline elemental concentrations in tropical soil environment (Reimann and Caritat, 1998). During boring, a PVC-based material was used to support the walls of the dug hole and prevent contamination. Ten rapid measurements of soil acidity were acquired on the spot by a pre-calibrated portable pH-meter. For this purpose, slurry of soil-water (1:1) and 1 *N* KCl was prepared quickly on-site. The electrodes were placed into the slurry and after 30-60 seconds, the meter gave reading. This in-situ procedure had been done randomly throughout the site irrespective to the sampling procedure. In general, pH readings of the site ranged between the values of 4 and 6. All samples were properly preserved, seriated, itemized, inventoried, labeled by waterproof ink and transported safely to lab after 3-5 hours of the collection time.

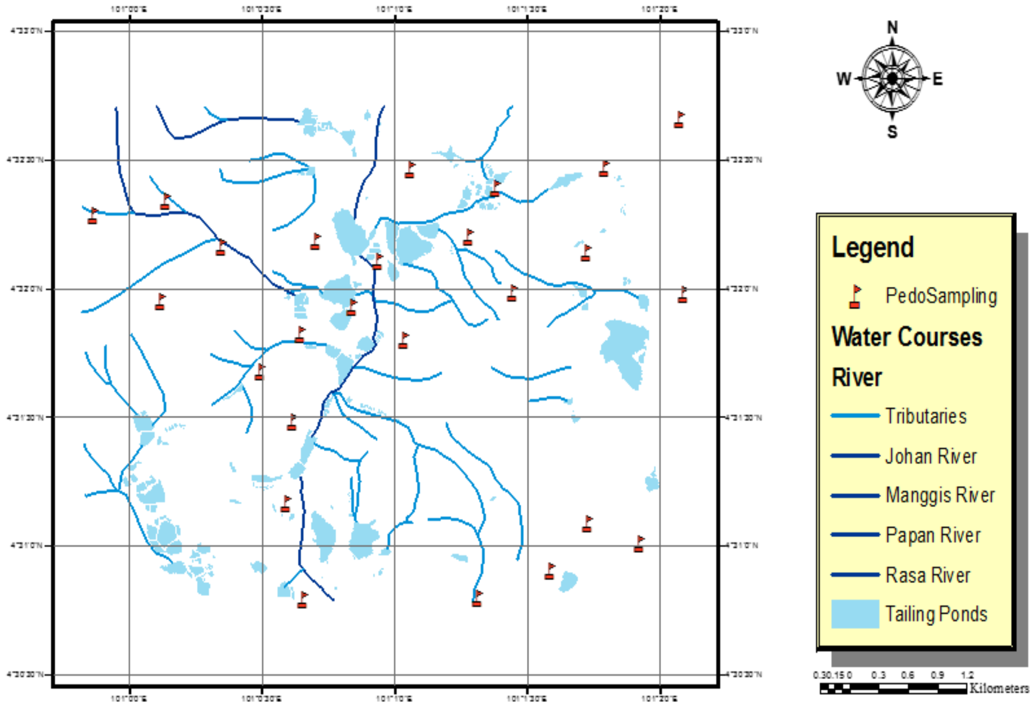


Fig. 5: Soil sampling locations in the study area

Sample Preparation, Treatment and Testing

In the lab, samples were aerated and then dried in a drying oven below 60° C for 2 hours. Following drying, each sample was split into two halves: one 500g-part for lab use and the other half was kept as a duplicate. The split sample matrix was crushed and grinded by a stainless steel device (mortar). The fine fragments were mixed thoroughly and then passed through a dry, 10-mesh (<2 mm) screen to yield a homogenized, uniform and storable sample. A 3g-weighed sub-sample was extracted for chemical analysis.

The wet method of leaching by reagent aqua regia, $HCl:HNO_3$ (3:1) method was used for disintegration and elemental extraction according to ISO 11466: 1995. The 3g-weighed test sample was added to 100 mL of reagent solution and mixed in a glass vessel for 15 minutes over a steam bath. After the sample cooled, a 0.45-µm filter membrane was used to get a filtrate from the sample solution, with the aid of a pressure pump to accomplish separation and concentration. Completing this procedure, the sample then was tested for arsenic and lead metals by ICP-OES. Each sample was exposed to test twice per element. The results were displayed numerically in mg/L and later transformed into ppm units.

Geodatabase Development

All geoscientific data of the study area was acquired from Malaysian Remote Sensing Agency and later converted into GIS format using ArcGIS software. The power of GIS lies in its ability to use both spatial and statistical methods to analyze attribute and geographic information together. The soil geochemical dataset was brought into the geodatabase, transformed and tabulated in a GIS queriable format. All the spatial data were georeferenced and worked under a unified projection system of GCS WGS 1984.

In the modeling process, the spatial interpolation by Ordinary Kriging incorporated the difference between concentration value of soil sample (C_{sample}) and the threshold (SRC). This assisted in figuring out the data proximity or exceedance, and in categorizing the site into hazard zones. The mapping helped in identifying the ‘hot spot’ sites of anomalous (hazardous concentration) levels. Risk of exposure to geotoxicity hazard was measured as ratio scale data (percentage), expressing the site probability of being a ’hot spot’. A model Cross-Validation report was generated to verify the accuracy of prediction. The report indicates the ‘prediction mean error’, which should be close to zero. Furthermore, health data (descriptive) on epidemics and disease outbreak in the inhabiting community collected from previous reports was provided to support risk-mapping outcomes.

Results and Discussion

Arsenic Risk Assessment

The hazard probability of human and ecological exposure to soil arsenic contaminant in the study area is illustrated in Figure 6 and Figure 7, respectively. The indicators of prediction error were close to 0 in both models. From the figures, it can be seen that As contamination is widespread in the study area. The most risky locations (exceeding 50% exposure) were found orienting to the northeast-southwest direction, parallel to mineralization and mining operations. At these locations, human and ecological receptors are critically endangered by arsenic epidemics.

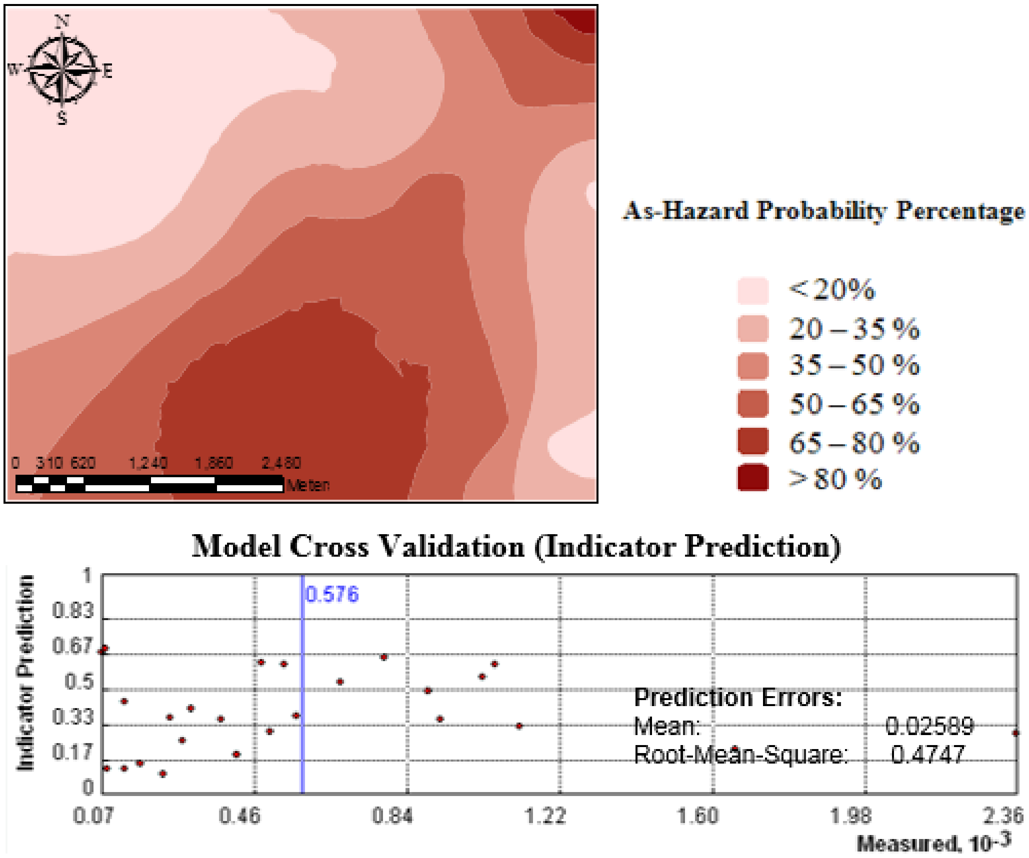


Fig. 6: Arsenic-hazard exposure probability map for human receptors in the study area

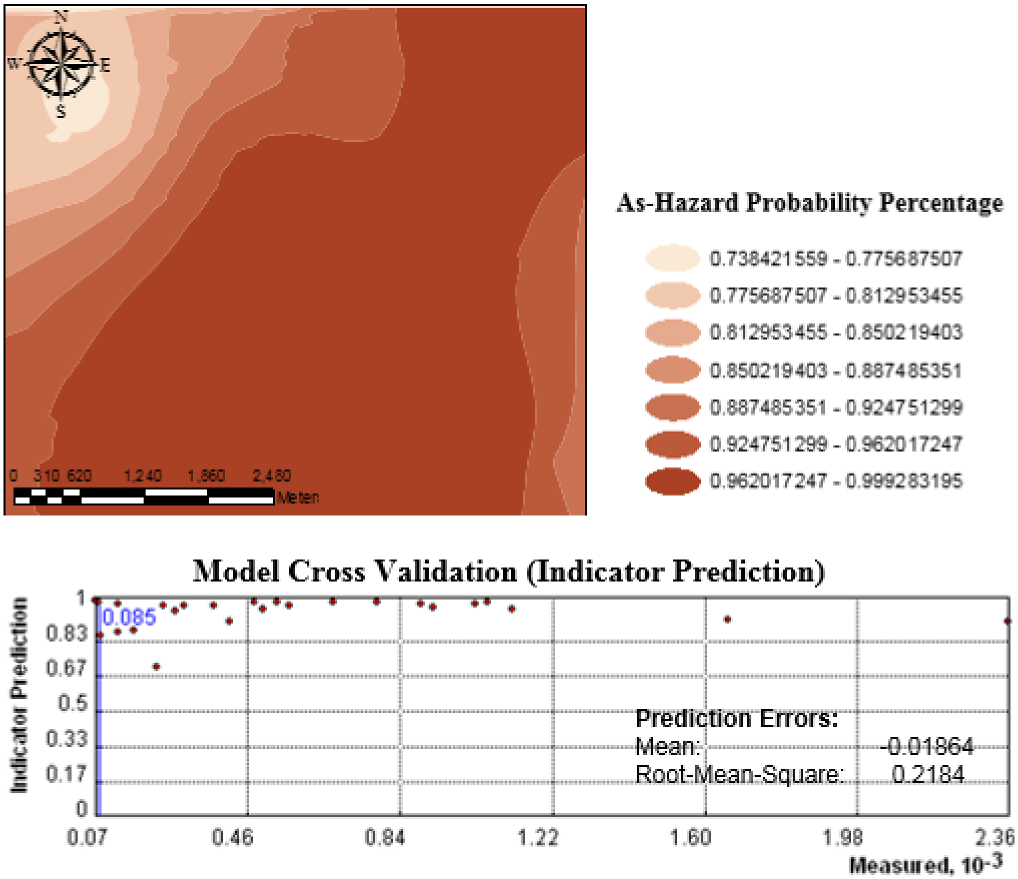
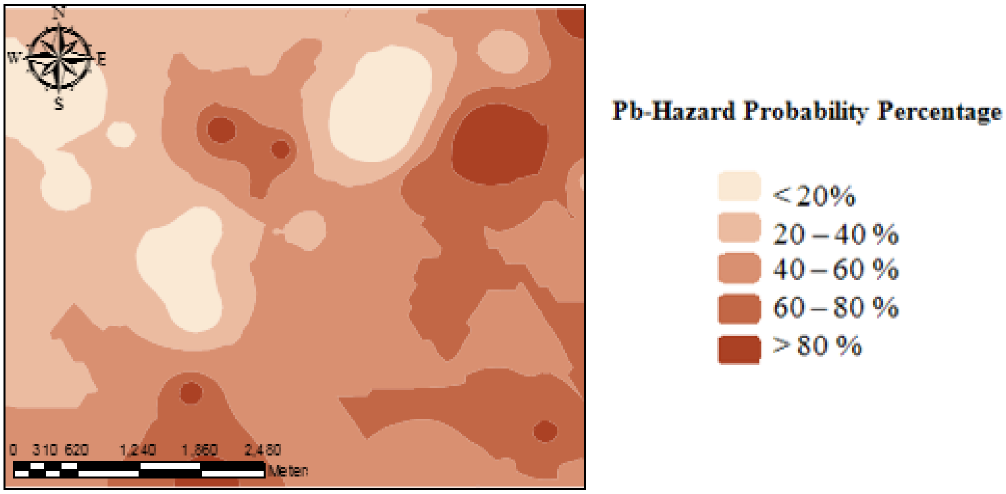


Fig. 7: Arsenic-hazard exposure probability map for ecological receptors in the study area

The effect of high arsenic loads in the contaminated soil of the study area could also extend to contaminate air, water resources and food, particularly pond fish, meat, poultry, grain and dairy products. Arsenic attached to very small particles may suspend or travel long distances throughout the environment. The dust arising from the mine tailing may cause concerns about contamination of rainwater tanks. Surface water can be contaminated by contact with soils, sediments and mine tailings that contain arsenic. In mine tailings, the percolation of contaminated surface water to subsurface strata and the prolonged processes of soil leaching and element fractioning under tropical conditions can escalate As-levels in groundwater. In geologically As-mineralized grounds, higher levels of arsenic tend to be found in ground water than in surface water (Csuros and Csuros, 2002) making communities that get their drinking water from underground potentially exposed to excessive arsenic (Moreno, 2007). The consumption of groundwater through digging wells may also cause water levels to drop and release arsenic from rock formations. These effects could add further risks on biological systems. When postmining groundwater rebound, As-levels increase. Therefore, it is important to examine the arsenic content of surface and ground waters of the study area as well as in foodstuff and pond fisheries.

Lead Risk Assessment

The hazard probability of human and ecological exposure to soil lead contaminant in the study area is illustrated in Figure 8 and Figure 9, respectively. The indicators of prediction errors were close to 0 in both models. From the figures, high contamination levels are largely aggregating in the eastern parts of the study area, and the most risky locations (exceeding 50% exposure) were found orienting to the northeast-southwest direction, parallel to mineralization and mining operations. At these locations, human and ecological receptors are critically endangered by lead epidemics.



Model Cross Validation (Indicator Prediction)

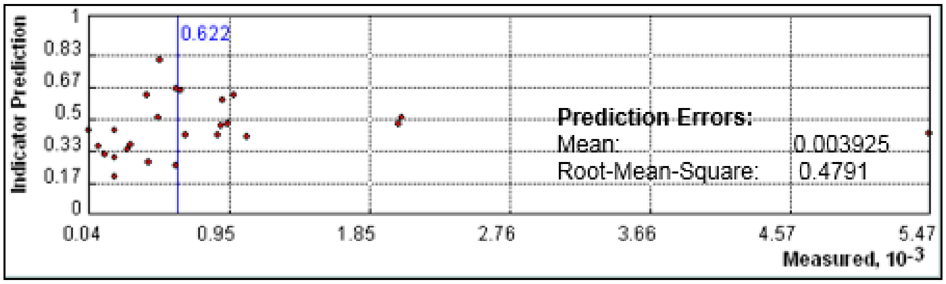


Fig. 8: Lead-hazard exposure probability map for human receptors in the study area

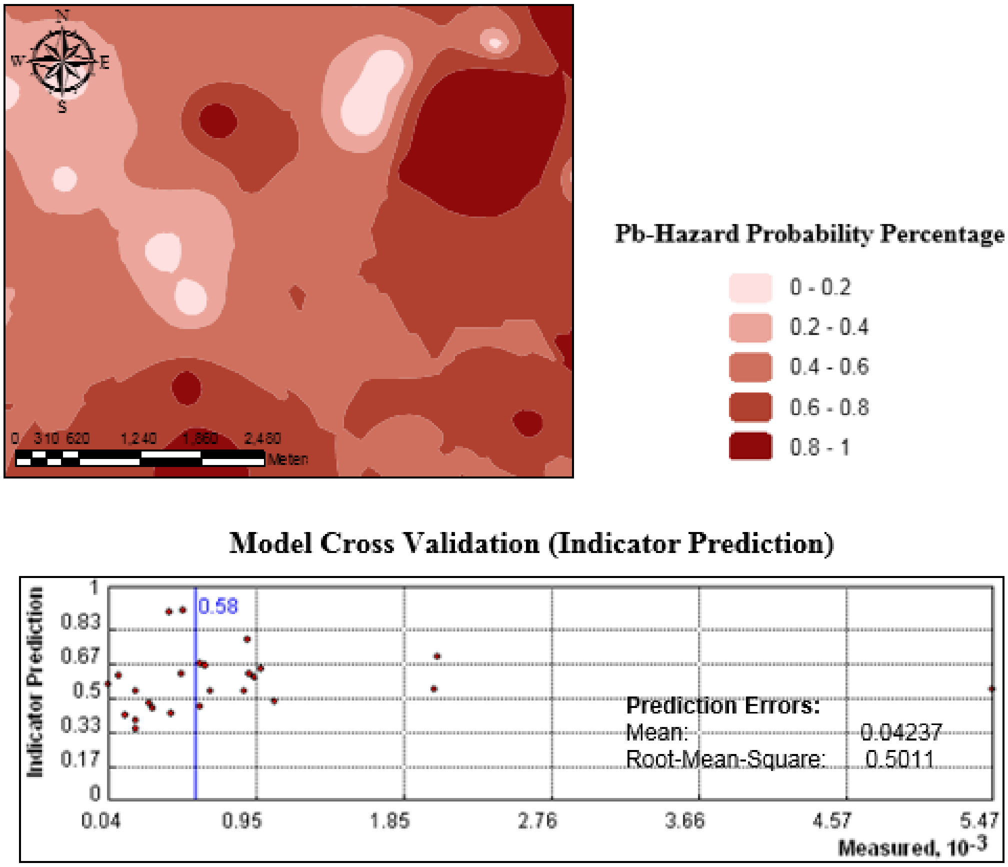


Fig. 9: Lead-hazard exposure probability map for ecological receptors in the study area

In the study area, the risk of Pb poisoning could come from pathways of biological ingestion of lead-contaminated water, mine tailing soil or dust in air, and ingestion of foods that contain lead from mine soil or water. Water resources may also be possible pathway of Pb as galena (Hosking, 1973) is a common mineral component in the geological formation of the study area. Lead in the food chain may also come mostly from direct deposit from the air to plants and from livestock eating tailing soil laced with lead as they eat the plants. The general population may be under the risk of leaded food through eating fruits and grains such as the above ground crops of tomatoes and beans that are better grown in "leaded soils" than root vegetables of potatoes and carrots (LEAD, 2007; ATSDR, 2007).

The impact of soil contamination on health status of the biological receptors is evident in the study area. Several health disorders in the exposed human population were reported (SAM, 1984; Rasiah, 1999; and NST, 2005). These included choking, dry coughing, and rashes on skin, colds, tearing, attention deficit disorder and mental retardation. There were also incidents of leukemia in children under 13 and caner development in adults as well as high rate of infant mortality, congenital diseases, miss-carriages and lead poisoning. It was noticed that some inhabitants in the study area were scooping up the soil by their bare hands to use in their gardens or planting crops on ex-mine soil. These acts could be a direct source of metal poisoning. When firstly observed by the public, the ailments were claimed as largely related to mining-induced radiation, yet; the government officials and mine operators have never found a substantial evidence to prove this claim. However, between 1987 and 1992, Dr. Jayabalan, a local medical expert, researched the health conditions of the population inhabiting the study area as well as other neighboring centers. He found that the number of leukemia incidents in the area was high for the area's population. In 1987, he studied lead levels in human blood and congenital birth defects. All sixty children in his survey had 20 micrograms per deciliter of lead – a metal load that is considered toxic to human body. There was also evidence of abnormal white blood counts and a high rate of ailments associated with lowered immune resistance. In 1988, he tested another 44 children, and each had similarly high levels of lead in their blood. In his another house-to-house survey in 1989, he found 7.5 percent of women had miscarriages, which was considered above what was considered normal for the rest of the country. Dr. Jayabalan believed that there was a concealing linkage between mining activities and disease outbreak in the inhabiting community, which yet needs further investigation to uncover.

Regarding the impact on the ecosystem of the study area, the ground truth study of vegetation cover showed several symptoms of physiological stress. This included foliar chlorosis, vegetation disappearance, mortality, dwarfism and stunting. Plants in the farms, house backyards and gardens showed inclination to shrink or die young (Figure 10). This is attributable to the hostile chemical conditions in the soil. Previous geobotanical studies supported by remotely sensed data in Kinta Valley (Abu-Libda, 2016) reported unhealthy conditions in the local vegetation due to soil degradation, metal loading in the environment and surface mining operations.

Fig. 10: Agricultural crop of sweet potato, known locally as *Keledek*, growing unhealthy on metalliferous soil (Source: author)

The results of GIS geostatistical analysis of contamination risk in the present study showed that the application of geostatistical spatial interpolation has speeded up all processes pertaining to estimating and visualizing the spatial distribution of geochemical hazard of soil arsenic and lead. It also assisted in locating highly geotoxic sites that urgent decision should be taken on. The results of risk analysis in this study indicate that to prevent loss in Ulu Johan's environment, it is necessary to implement the urgency methodology before any development project sets off. For the identified hot spot sites in the study area, the urgency methodology must be directed towards either avoiding these hazardous locations or remediating the soil from arsenic and lead contaminants. The preference of adopting either decision depends largely on the type of proposed land-use application. This also includes contaminated sites that are currently utilized as living areas that their reclamation is now urgently necessary to protect human health and the environment. Contrary to the highly contaminated sites on the east, the soil in the western sites may be less hazardous, making the land favorite for development with reduced costs of remediation.

The results of GIS risk mapping in this study also coincided with findings established in previous works done in other countries. For example, Da Silva et al. (2004) integrated geostatistical modeling in GIS on soil As and Pb data collected from old gold mining areas in Portugal to assess the risk imposed on the ecology and human health. They used the ‘target values’ of ecological intervention and human toxicological intervention value in kriging variances that calculated the probabilities of exceeding these limits. They were able to assign locations of hazardous levels as ‘require further investigation’ for the ecosystem, while probability maps of exceeding human health risk values showed that soil is hazardous to human. Probability maps that showed slight contamination had assisted in assigning locations as ‘require no further investigation’ as metal concentrations were near or slightly above the intervention values.

Conclusion

The geostatistical method of spatial interpolation by Kriging is an important tool in estimating and mapping the geochemical hazard of soil contamination, and a supportive technique to risk assessment studies. The benefit is magnified when geostatistical modeling is integrated with GIS capabilities. The generated risk maps of soil contaminants in this study can be readily used in keeping the public informed on issues concerning land-use, and in providing guidance on avoiding hazardous sites/conditions. The public of the study area need to calm their emotional reaction, fear and concern to the contamination problem by wishing to build trust and credibility with risk experts. Here, the spatial-based mapping in this study may work towards increasing the public awareness and perception on risk by presenting meaningful information with minimum levels of interactivity. Visualizing GIS risk maps will promote public self-education and preparedness for disasters by knowing where paradoxically worsen exposures could be located at, facilitating by that an earlier stage of risk communication with risk engineers. The generated geospatial maps in this study could be presented in many forms; be they reports, atlases, brochures, wall-maps, signboards, press, etc. These communication products aim at improving the process of people understanding of environmental issues, opening channels of cooperation and creating a meaningful dialogue with the responsible authorities. In turn, the success of this communication will work towards an opportunity to the public to involve on certain aspects of the site, such as participating proactively in conducting surveys/inventories, data collection and sampling campaigns, updating information, reporting incidents, or attending social discussions on certain values with a diversity of viewpoints. Feedback from public response will also improve the risk specialist's cognitive learning on many issues of land contamination (e.g., social, scientific, economic, etc.). This ultimately helps in improving the quality of mapping products and building strong risk communication channels with downstream audiences.

The methodology designed in this study can benefit many concerned parties in different ways:

a. Helping authorities in making quick decisions on the geohazard, and identifying best locations to assign resources and task groups to assure efficient, cost-effective and real-time emergency response in Kinta Valley.
b. Categorizing/classifying the site into hazard zones and deciding the need to apply the urgency methodology.
c. Assisting epidemiologists and ecologists in portraying scenarios for exposure, environmental pathways of contaminants and disease etiology, and in deciding effective control measurements.
d. Helping science community in understanding the nature of the mining environment and the effect of geology and earth processes on the development of diseases in living communities.
e. Increasing the public awareness on the interrelationships between geoenvironment, public health and sustainability.

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