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Identifying Arsenic Pathway Using Electrical Resistivity Survey with GIS based Flow Modeling

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Arsenic contamination in the area around gold mine has been of very much concern for researching and attempting to solve the problem. This research methodology employed arsenic content in soil, soil profiles from electrical resistivity survey and flow modeling from GIS application, to find pathway of arsenic. Total of 240 soil samples were collected from 48 locations of which 39 locations are in the catchment where goldmine situates (called as inside catchment) and 9 locations are at nearby catchment (called as outside catchment). With the Box-and Whisker diagram, arsenic content at 3 locations inside catchment were considered as the extreme outliers. Intensive investigations were placed on location of high arsenic content to find out the most possible path of arsenic transportation and its potential source. By utilizing electrical resistivity survey, soil types and its profiles deeper into the ground around the location of extreme arsenic content can be obtained. Then, with cooperation of flow modeling of GIS associated with the direction of the deposited coarse grained soils, the water line passing through the interesting areas could be delineated. It indicated that water line initiated from the place close to tailing of goldmine, laid down along the natural creek and come across the study field in rainy season toward some villages. Results of arsenic content in soil samples along this finding line corroborated that the line was a significant path of arsenic transportation. Because of closing to mine tailing, it would be most possible that this line is a carriage pathway of arsenic leakage from goldmine.

Keywords: Toxic substance, site contamination, fate and transport, soil electrical indicator.

1. INTRODUCTION

Arsenic, the 20th most abundant element in the natural environment, is a trace element that poses toxic threat to animals, including humans, wildlife and aquatic species, particularly when incorporated into food and/or water supplies [1, 2]. Arsenic exists in the environment due both natural occurrence and anthropogenic source. Example of natural occurrence is dissolution of arsenic containing bedrock/minerals. While anthropogenic source is the main distribution of arsenic contamination such as percolation of water from mines, wood preservatives, agricultural chemicals and discharge from uncontrolled mining and metallurgical industry. Regarding the existence of arsenic, soil medium is an important sink for arsenic compounds. Arsenic deposited in the soil may rapidly accumulate compared to plant uptaking, leaching, methylation, or erosion [3]. Concentration of arsenic in soil and water can become elevated as a result of application of arsenical pesticide, disposal of fly ash, mineral dissolution mine drainage, and geothermal discharge [4].

As stated above, mining is one of arsenic dispersion source, particularly gold mine since the gold ore is attached with arsenopyrite. Gold mining at Wangsaphung district, Loei province, Thailand is of very interested to study due to the suspicion as being the source of arsenic distributing to the environment including soil, surface water, as well as to the plants in the vicinity of gold mine. Villagers in the nearby villages have complained about water contamination by arsenic since gold mine starting operation in 2006. At that time, determination of arsenic in surface water by the responsible agencies found the concentration was very low, less than 0.01 mg/l which is the designated maximum concentration level (MCL) set by the US.EPA[5]. However, so far as known by the researchers, there has been no investigation of arsenic levels in soil, sediment and plants in the area. The primary objectives of this research were (1) to investigate arsenic content in soil to characterize the area for extremely high arsenic content, (2) to investigate soil types and its profile for initial indicating a trend of arsenic moving direction toward the location of high arsenic content, and (3) to identify pathway of arsenic transportation.

2. STUDY AREA

The study area, where gold mine locates, is at Wangsaphung district, Loei province, Northeastern region of Thailand, where is mountainous and plateau area. The altitude of gold mine is about 300 meters from mean sea level (msl). Within 5 kilometers from the gold mine there are 13 villages located, of which 6 villages had complained about adverse impact from arsenic, including Ban (village) Nam Huai, Ban Na Nong Bong, Ban Huai Phuk, Ban Kok Sathon, Ban Kaeng Hin, and Ban Tak Daed (Figure 1). Counting from the gold mine site, Ban Na Nong Bong is the nearest village located at 250 meters and at the altitude of 277mmsl, and Ban Tak Daed is the farthest village located at 5 kilometers with the altitude of 276 mmsl. Most of field land are occupied with rice paddy field and crop cultivation such as bananas, tapiocas, nuts, and rubber trees.

Within catchment, there are many small waterways, such as Huai Nam Chan, Huai Muno, Huai Haeng, Huai Khok Yai and Huai San, flowing from high elevation at the top of plateau directing to low elevation area and combining to be one stream, called Nam Huai stream, before passing through villages and joining Loei river at the outside catchment.

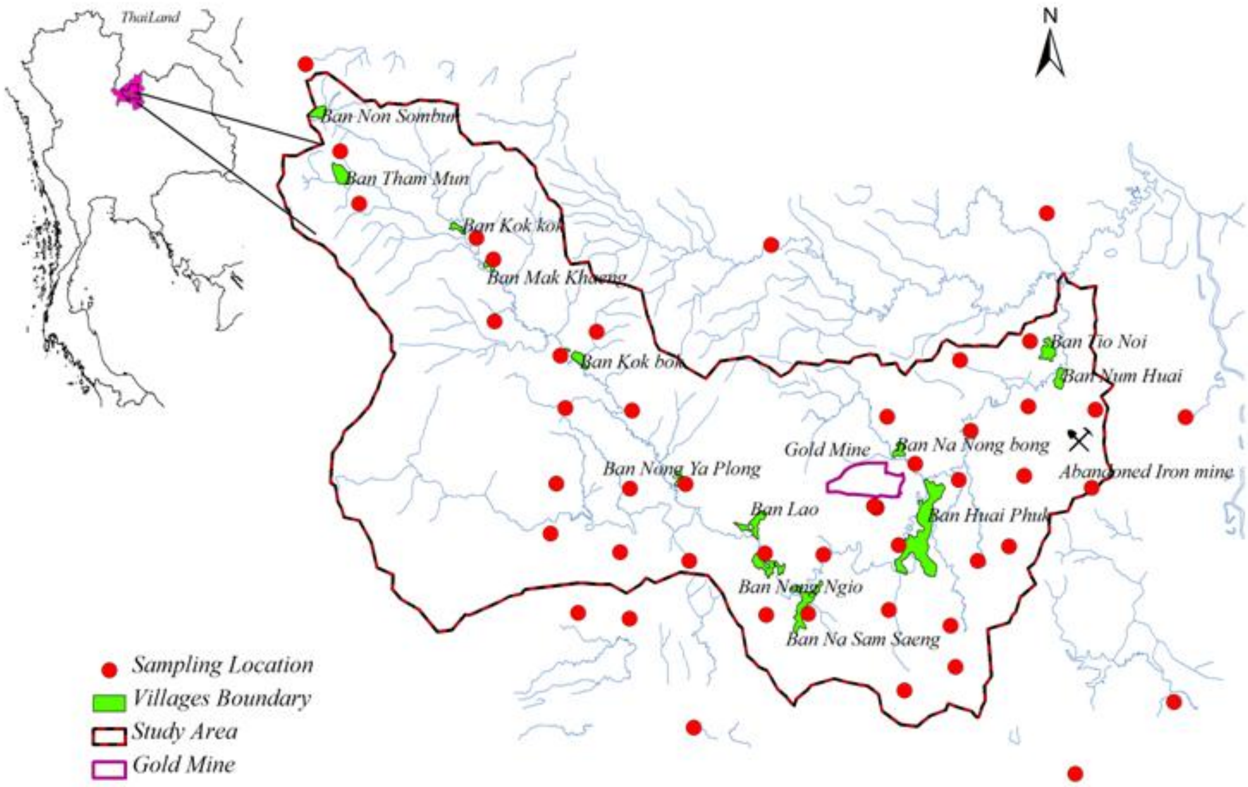


Figure 1. Watershed boundary and location points of soil sampling, villages, and gold mine

3. MATERIALS AND METHODS

The study methods have been performed in sequential steps. Each step has the detail described as following:

3.1 Investigation of arsenic content in soil.

Total of 240 soil samples had been collected from 39 locations within the catchment where gold mine locates (called inside catchment) and 9 locations at nearby catchment (called outside catchment) as presented in Figure 1. At each location, soil samplings were taken from the depth of 0.00 m, 0.50 m, 1.00 m, 1.50 m and 3.00 m from the existing ground level. Method of drilling and collecting soil samples were performed in accordance with the guidance of American Society for Testing and Materials [6]. Each soil sample was wrapped with foil sheet and coated with paraffin to protect against the moisture loss and oxidizing reaction that might be occurred during carrying on for further laboratory analysis. Some properties such as temperature, pH values and oxidation-reduction potential (ORP), were also measured at site.

All soil samples were analyzed for arsenic content, iron content, OC, CEC soil type and its associated parameters such as moisture content, unit weight, etc. Arsenic content of all samples were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method. This technique provides high precision determination of substance, even metallic or non-metallic, from relatively small amount of samples [7, 8]. Soil types were classified by using mechanical sieve analysis and hydrometer test. Soil group name associated with soil symbols were designated as recommended by Unified Soil Classification System [9].

3.2 Identification of extremely high value of arsenic location

All data of arsenic content in soil at each depth were individually grouped and interpreted by Box-and-Whisker diagram in descriptive statistics. Any data values that are more than 3 box length away from the edge of their box are classified as extreme outliers [10]. Regarding the assessment of heavy metal in soil, it is precarious to ignore outliers as these may actually represent potentially severely pollution areas. The location of remarkably high arsenic content; therefore, were the focusing area in this study. To reassure that the very high arsenic content values at location previously investigated did not come from the erroneous or inconsistent data, additional 12 soil samples at the area around those locations were collected for arsenic analysis.

3.3 Electrical resistivity survey

Electrical resistivity measurement, the geophysical survey, had been conducted at places around the locations of the extreme outliers of arsenic content. The aims of resistivity measurements are to create an image of underground profiles encircled the locations of extreme arsenic contamination. Soil profiles obtained can provide the possible soils and their position that water can easier flow through. The principle of geophysical resistivity technique is based on the response of the earth to the flow of electrical current. Electrical current is passed through the ground and two potential electrodes providing the potential difference between them, giving a way to measure the electrical impedance of the subsurface material [11]. The apparent resistivity is a function of the measured impedance and the geometry of the electrode array. Depending upon the survey geometry, the data can be plotted as 1-D sounding or in 2-D cross section in order to look for anomalous regions. In addition, there are two electrical resistivity methods, the profile or traverse method and the sounding method. For an electrical profiling, the electrode separation is fixed and then the information concerning lateral variations in resistivity is obtained. Whereas the electrical sounding method, the center of the electrode spread is maintained at a fixed location and the electrode spacing is gradually increased [12].

With the purpose on obtaining underground cross section, this study used dipole-dipole array in resistivity measurement. This method places two current electrodes (A and B) to one side with a spacing between them denoted as “a”. A pair of two potential electrodes (M and N) which spacing between them also equal an a-spacing are placed collinearly a distance “na” away from those current electrodes (A and B). The “na” is a distance equal an integer multiple of “a”. As measurements are taken at various n's, that is, the pairs of electrodes are moved apart, a sounding is obtained. The "n" factor is increased for subsequent measurements in order to have wider range penetration. To increase the depth of investigation, the spacing between the A-B dipole pair is increased to "2a", and another series of measurements with different values of "n" is made [12].

For this study, at the areas surrounding location of an extreme arsenic contaminant, seven arrays with different directions were located for electrical resistivity measurement. For each array, the spacing "a" of 1.5 m, 3 m and 10 m were used in the subsequent series of measurement, acquiring exploration depths to 5 m, 9 m and 30m, respectively. Numerous electrodes were deployed along transect, and measuring equipment was used to automatically switch the transmitting and receiving electrode pairs through a single multi-core cable connection. After the field survey, the resistance measurements were transform to apparent resistivity values and 2-D resistivity models were then calculated by using the inversion computer program. Computer program creates a model of resistivity in a pseudosection and adjusts this model to fit the measured data by applying a non-linear least squares optimization technique. Referring to geophysical properties of soils [13], the electrical resistivity results in units of ohm-m can be interpreted to classify underground stratification. Determining these soil profiles can initially lead to the position and direction of arsenic coming.

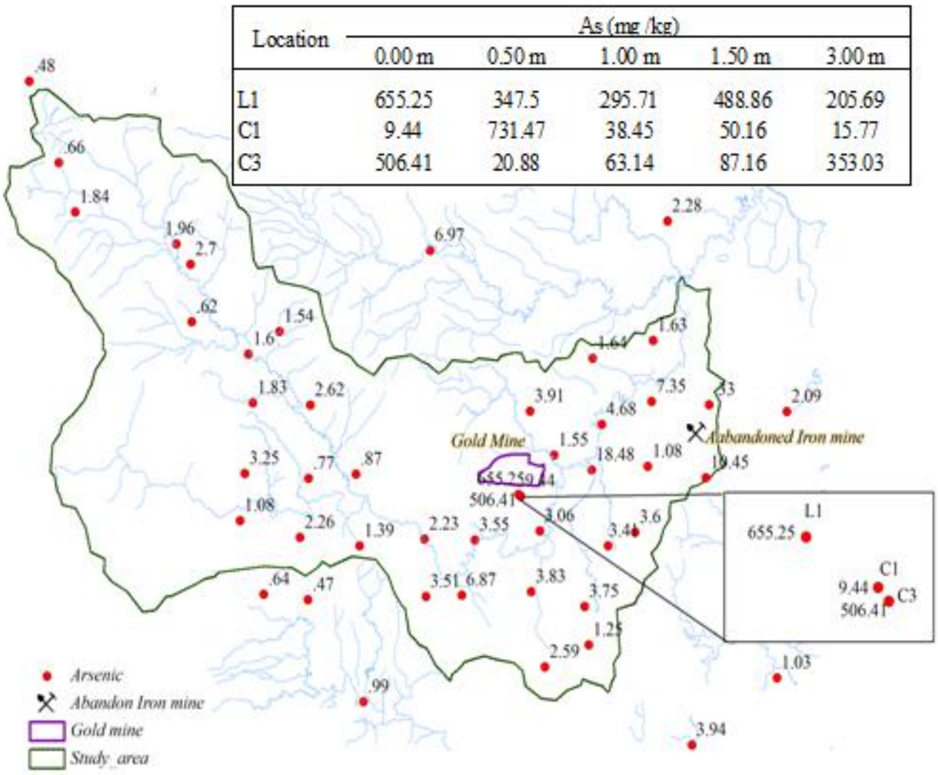
3.4. Tracking pathway with GIS

Flow modeling application in GIS can give useful information about where the water flow and what it travels over or what the affected area is. Flow model depends on a flow direction which is in turn created from an elevation surface map. In this study, the 5 x 5 m resolution of digital elevation model (DEM) available from the government agencies had been utilized for creating map of flow direction surface. Once flow direction surface in GIS had been created, drainage pathway and drainage area for specific pour points could be made. The process for delineating drainage pathway consists of acquiring flow direction surface from DEM, employing flow accumulation feature toolbox in GIS to obtain flow accumulation layered map, reclassifying flow accumulation layer to be the raster map called stream raster, and finally establishing stream feature from both flow directions surface and stream raster using stream to feature toolbox in GIS, respectively [14]. Figure 4 presents such processes of delineating water path in GIS. The results usually give all drainage line in catchment. However, it can express only the drainage path and drainage area of particularly interested. With these applications of GIS, the possible pathway of arsenic transportation could be traced back from the location of extreme arsenic content.

3.5. Verification of arsenic pathway

In order to verify whether the line obtained from flow modeling can be pathway of arsenic, soil samples along that line were collected for arsenic content analysis. Although during dry season it could not locate the actual route at site easily, GPS (global positioning system) could be useful guide for tracking this path.

4. RESULTS AND DISCUSSION



Location	As (mg /kg)				
	0.00 m	0.50 m	1.00 m	1.50 m	3.00 m
L1	655.25	347.5	295.71	488.86	205.69
C1	9.44	731.47	38.45	50.16	15.77
C3	506.41	20.88	63.14	87.16	353.03

Figure 2. Locations of extreme arsenic contents and their concentrations in paddy field nearby the south of goldmine

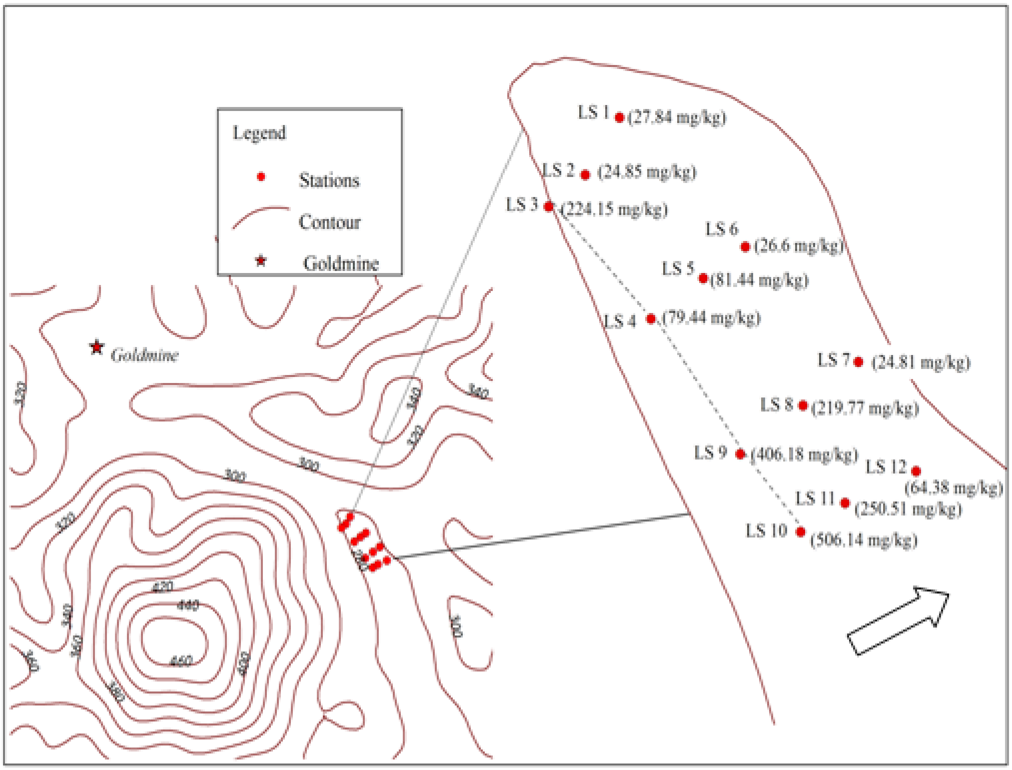


Figure 3. Twelve points of additional soil samplings and their values at locations around the extremely high arsenic contents.

All arsenic datasets of five depth layers (48 locations x 5 depths/location = 240 samples) exhibit very high concentration at the same locations which are at the paddy fields close to the boundary of gold mine as depicted in Figure 2. Comparing to the other locations, location C1, C3 and L1, as shown in Figure 2, presents much higher arsenic contents in soils. Especially at the location of L1, arsenic content was greater than 200 mg/kg, whereas arsenic content in other locations were 3.16 ± 3.34 mg/kg, 3.44 ± 3.54 mg/kg, 3.90 ± 3.57 mg/kg, 4.00 ± 3.60 mg/kg and 3.61 ± 3.60 mg/kg for the depth at 0.00 m, 0.50 m, 1.00 m, 1.50 m and 3.00 m, respectively, as shown in Table 1.

Table 1. Arsenic content in soil in side watershed excluding extreme outlier values

	Depth(m)	Measured range^{+} (*Mean value* ± *SD*)	Median	Skewness	Kurtosis
As (mg/kg)	0.00	0.33 - 18.48(3.16 ± 3.34), N=36	2.25	3.23	12.75
	0.50	0.32 - 17.44(3.44 ± 3.54), N=36	2.18	2.69	7.71
	1.00	0.29 - 16.03(3.90 ± 3.57), N=36	2.37	1.88	3.60
	1.50	0.21 - 14.01(4.00 ± 3.60), N=36	2.96	1.45	1.40
	3.00	0.19 - 13.27(3.61 ± 3.60), N=36	2.18	1.61	1.53
pH	0.00	4.30 - 8.53(7.64 ± 0.83), N=36	7.89	-2.48	7.42
	0.50	5.05 - 8.52(7.56 ± 0.67), N=36	7.71	-1.94	5.12
	1.00	4.20 - 8.40(7.53 ± 0.87), N=36	7.81	-2.16	5.60
	1.50	5.32 - 8.83(7.67 ± 0.70), N=36	7.86	-1.43	2.75
	3.00	6.10 - 8.90(7.73 ± 0.52), N=36	7.84	-0.99	2.02
Temp (° C)	0.00	22.50 - 38.20(37.50 ± 3.75), N=36	26.75	0.85	0.51
	0.50	23.00 - 40.00(27.74 ± 4.15), N=36	27.10	1.13	1.43
	1.00	22.70 - 36.40(27.38 ± 3.52), N=36	26.65	0.60	-0.26
	1.50	22.80 - 36.50(27.15 ± 3.19), N=36	26.45	0.81	0.56
	3.00	22.60 - 33.50(26.73 ± 2.78), N=36	26.40	0.32	-0.65
ORP (mV)	0.00	-82.70 - 402.00(197.77 ± 113.32), N=36	221.50	-0.60	-0.19
	0.50	-104.80 - 413.70(198.29 ± 120.59), N=36	226.65	-0.60	0.01
	1.00	-91.30 - 351.30(233.09 ± 106.88), N=36	264.90	-1.49	1.74
	1.50	2.70 - 398.90(231.71 ± 98.03), N=36	250.05	-0.74	0.14
	3.00	-1.30 - 322.90(212.02 ± 86.57), N=36	228.65	-0.71	-0.50

With the descriptive statistics using box plots, the high values at C1, C3 and L1 locations were classified as the extreme outliers.

Additionally, the analysis results of twelve additional soil samples collected at grid points covering locations of the extreme arsenic content as shown in Figure 3, also exhibited very high arsenic content. Therefore, it is reassured that this specific area actually contaminated with arsenic in a great order of magnitudes.

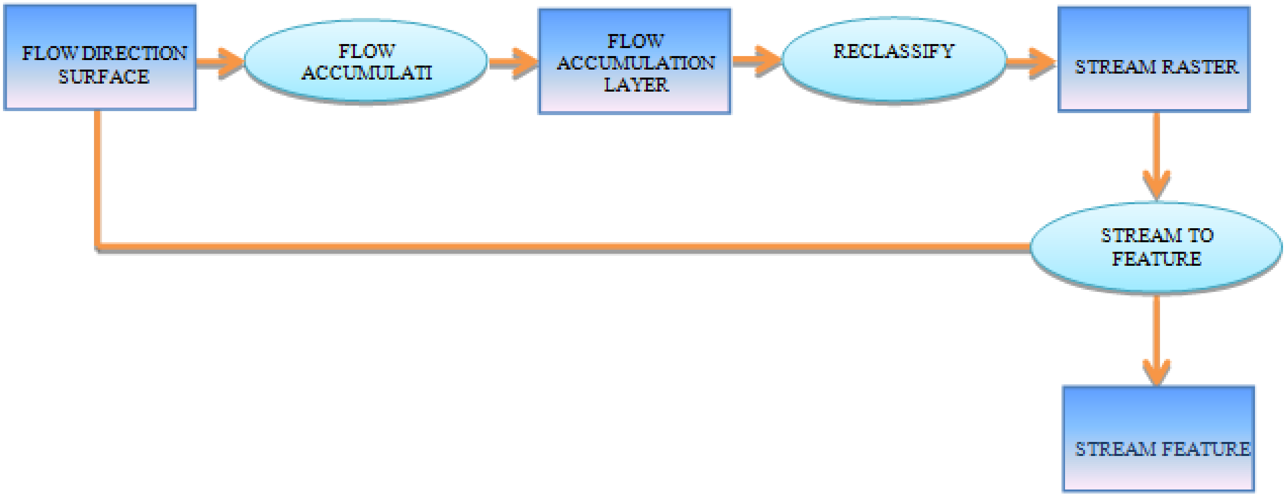


Figure 4. Process for delineating possible water pathway

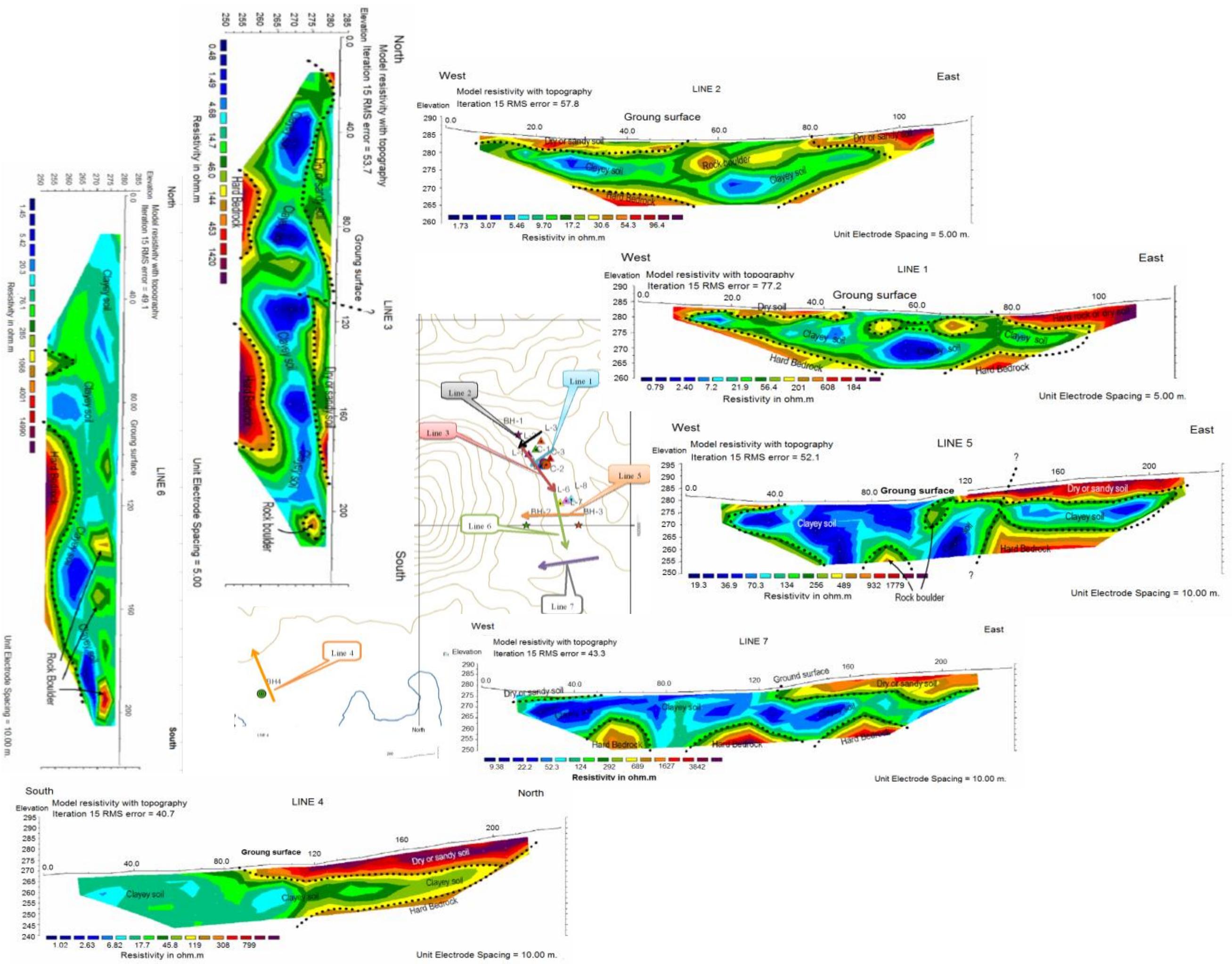


Figure 5. Soil profiles of seven lines obtained from electrical resistivity survey

Moreover, noting from Figure 3 that arsenic content in soil were high at the lower left and gradually lower in the direction to the right (see arrow symbol in Figure 3). Furthermore, the dash line connecting grid points of high arsenic content as shown in Figure 3 might be the possible pathway of water and arsenic. However, by the time of investigation there is no evidence of river or stream passing through this area.

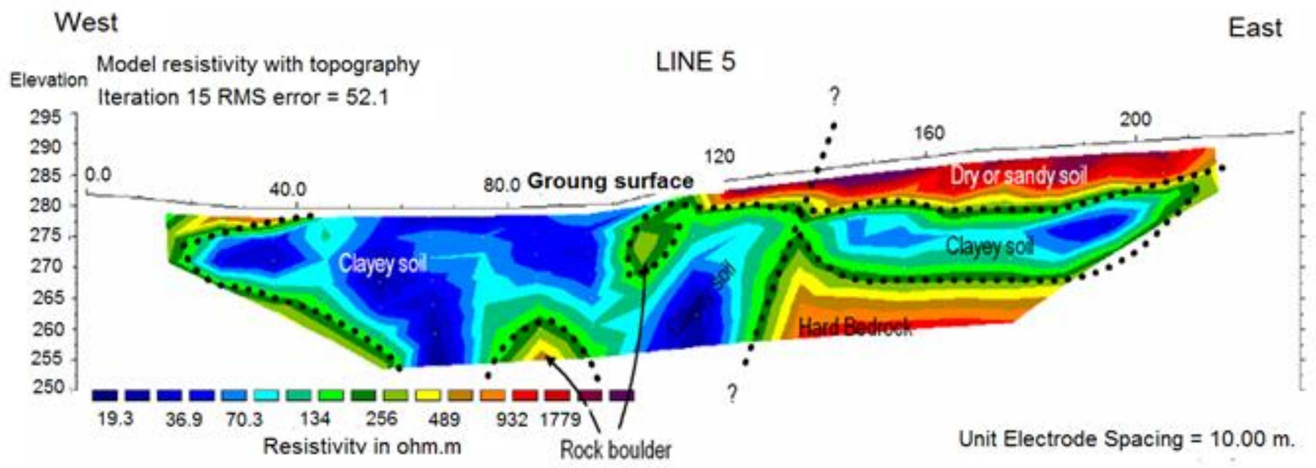


Figure 6. Enlarge view of line 5 illustrating clayey soil is the major part deep in to the ground overlying bedrock. Sandy soil is at top soil of some areas.

In accordance with the result of electrical resistivity survey, the apparent resistivity pseudosection (Wenner array) of seven survey lines around the study locations exhibited the soil types with depth (Figure 5). All profiles exhibit soil stratification which composed of the large zone of clayey soil, trace of rock boulder, hard rock near hill slope and sandy soil at the top surface of survey lines 1, 2, 5, and 7. Figure 6 is the magnifier view of survey line 5 displaying sandy soil at the top right. According to the unified soil classification system, soils symbol and group name can be utilized for determining their properties [9]. Sand and silty sand, also called sandy soil, are classified as being coarse grained soils having much voids which water can easily flow through. With the properties of higher permeability than fine grain soils, sandy soil can be more chance for transportation path of arsenic carried by water.

Such that the sandy soil strata at the topmost of lines 1, 2, 5 and 7 are of interest because they could link together forming the pathway.

With the application of flow modeling in GIS and selecting pour point on the deposited line of sandy soil just obtained, the water pathway could be delineated. Digital elevation model (DEM) with cell size of 5 x 5m was used as an input map for ArcGIS software. Following with subsequent process as depicted in Figure 4, all channels within the catchment could be illustrated. In the case of finding little or tiny water path, it needs a quite smaller number of grid cells for collecting water.

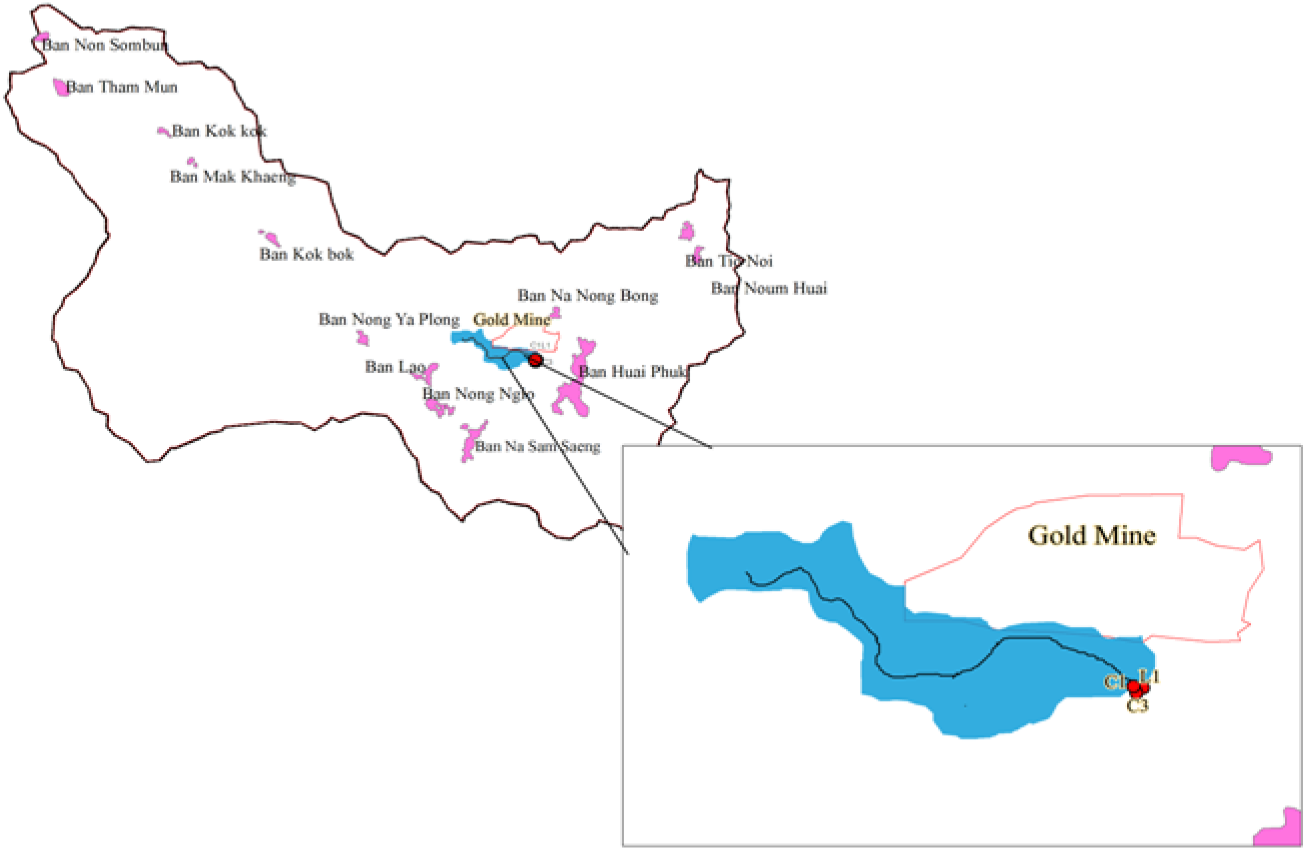


Figure 7. Water line and its drainage area passing through the location of interest.

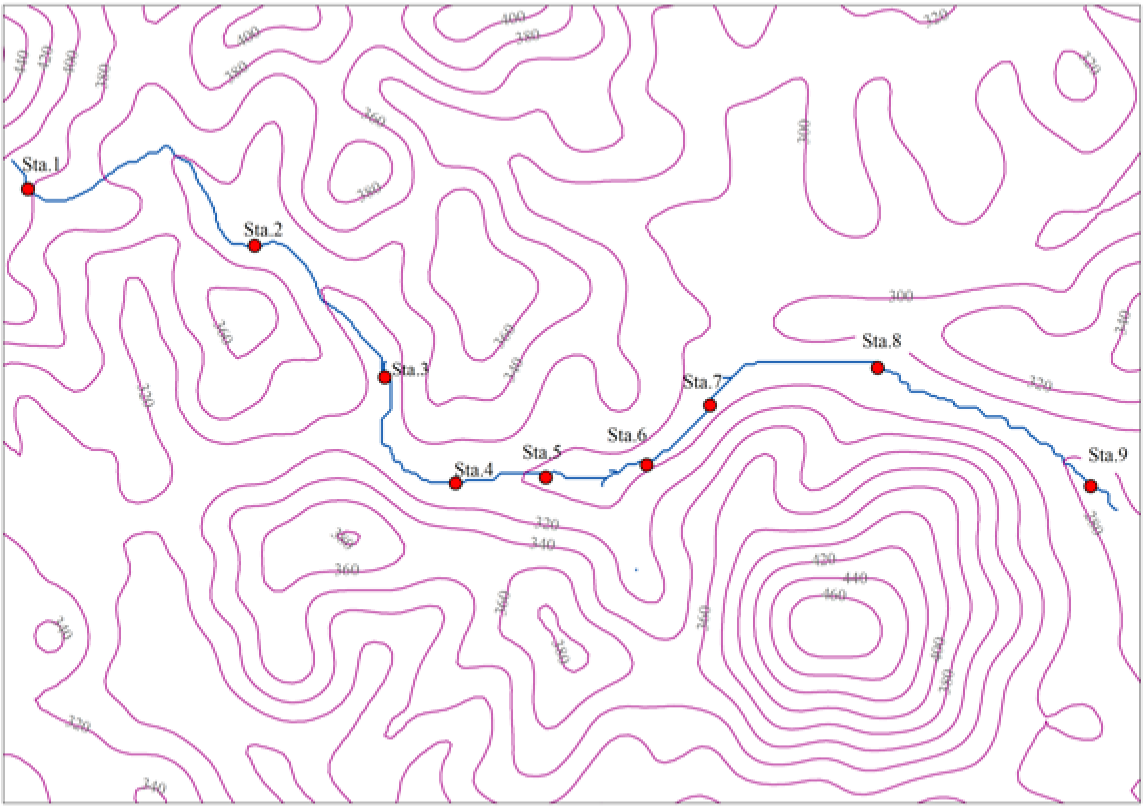


Figure 8. Station points of soil sampling to identify arsenic pathway.

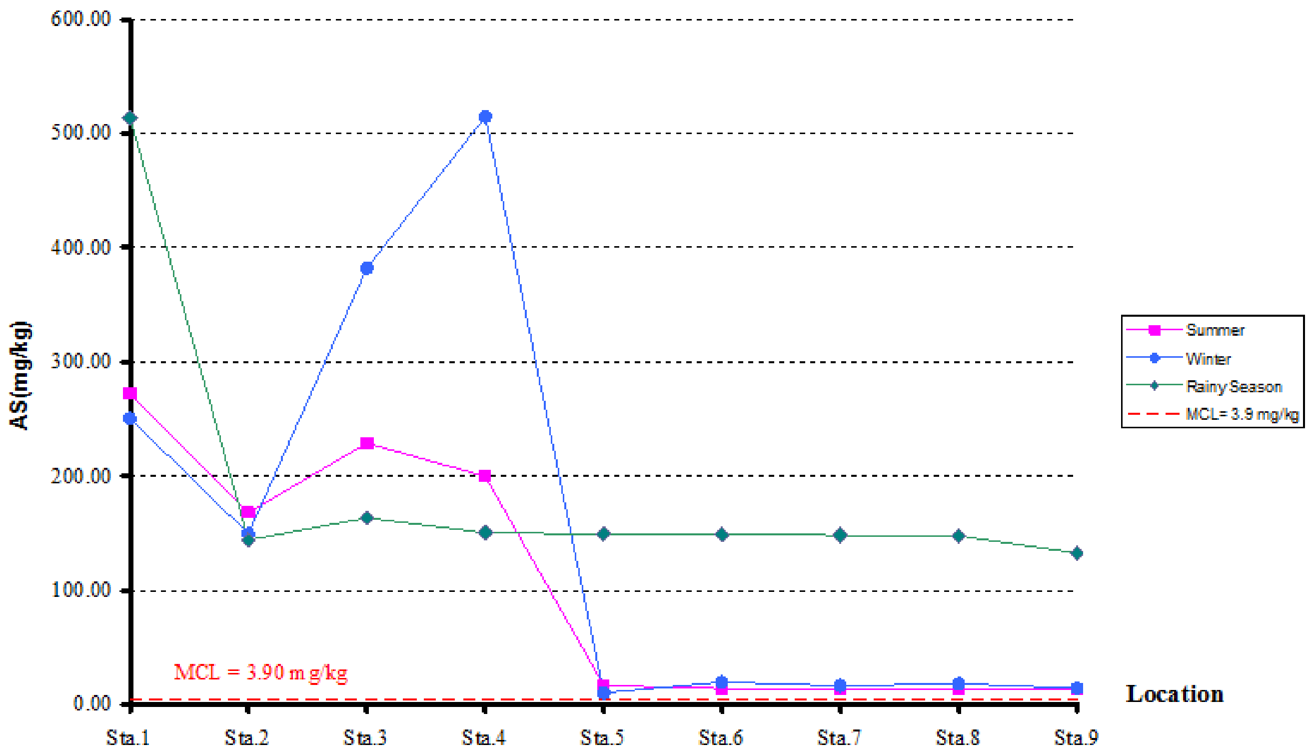


Figure 9. Arsenic content in soils along pathway at various seasons

As a trial and error, it found that 40,000 grid cells adequate for delineating water line passing through the interesting area. It can be noticed that the finding path has an initial point at the place close to mine tailing at southwest of goldmine and goes downward as a wavy line passing through the disturbed deciduous forest toward the study locations., as illustrated in Figures 7 and 8.

In order to verify whether arsenic transported in this pathway, soil samples were collected along the finding line for arsenic analysis. The first verification was performed the first on April 2010 (summer seasons). The results revealed that there exists very high arsenic content in soil along that line. In addition, repeating soil sampling and analysis were also made in July 2010 (rainy season) and in January 2011 (winter season). The results still exhibited the high value of arsenic content. Seasonal comparing as in Figure 9 exhibited that arsenic transports much farther in the rainy season than the other seasons.

5. CONCLUSION

Intensive investigation had been emphasis on the locations of the extremely high arsenic content in soil to identify pathway of arsenic transportation. With the application of electrical resistivity and flow modeling in GIS, arsenic pathway can be delineated. Finding path has its started point adjacent to goldmine's tailing and pass deciduous forest toward the concerning area where is the paddy field. Investigation along pathway presented much large arsenic contaminant in soil. Arsenic contents were higher at the starting point of path line and subsequently lower down along the pathway, expressing the behavior of arsenic being carried by water. flowing from the higher elevation at southwest to paddy field at southeast of goldmine. Evidently, rainy season present a farther pathway than summer and winter seasons. The immobilization and remediation at the upstream of pathway should be right away procured. The responsible governmental agencies should place the effective preventive measures and appropriate remediation on this pathway

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