# GIS Application on Arsenic Contamination and Its Risk Assessment in Ronphibun, Nakhorn Si Thammarat, Thailand

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**Abstract**

This paper presents a case study of GIS application on arsenic contamination and its toxicological effects in a tin mining area of southern Thailand. A GIS database was constructed which depicted the arsenic distribution profiles in different environmental media, i.e. the shallow groundwater, deep groundwater and near-surface soil. Estimation from the GIS interpolation showed that 72.31% of the study area had arsenic level higher than 0.05mg/L (Thailand standard) in shallow groundwater. The contamination situation in deep groundwater was more severe than shallow groundwater. Six major contamination sources were identified through correlation analysis between arsenic level in soil/groundwater sample sites with the distance to mining and waste dumping sites. The correlation between arsenism patients' distribution with arsenic concentration and other geological features were analyzed, the results showed a significant difference between the groundwater arsenic concentration inside and outside the distribution zone of arsenism patients. With the help of GIS, arsenic hot spots in each media were displayed. Arsenic risk assessment was also conducted in four villages based on the arsenic exposure from drinking water, which found that village 12 had the highest risk due to arsenic consumption.

## I. INTRODUCTION

Arsenic is a ubiquitous element presents in various compounds throughout the earth's crust. It is widely distributed in the environment, all humans are exposed to low levels of arsenic (EHC/WHO, 1981). However, high level arsenic exposure to human being has occurred for decades mainly via drinking water due to some natural (geological, volcanic activities) and anthropogenic activities (industrial pollution, mining, agriculture)(Arrykul, 1996; Chanpen, 1998). Among its four valence states of 0, -3, +3, +5, arsenic (+3) is known as the most toxic species (EHC/WHO, 1981; Hiroshi, 1994). EPA has listed arsenic as a known human carcinogen (Group A) (William, 1998). Arsenism is the outcome of long-term ingestion of arsenic from water, food, air or medicinal applications. It has such manifestations as cutaneous lesion (skin pigmentation changes, keratosis), peripheral vascular disease (Blackfoot Disease and Roynaud's syndrome), the higher mortality rate from cancer of liver, lung, kidney and bladder (Allan, 1999), the systemic arterial disease resulting in myocardial infarction, changes in electromyographic patterns, mutagenic and teratogenic effects (Robert, 1996; Gonzalo, 1996). WHO has recommended to lower permissible concentrations of drinking water standard for arsenic from 0.05mg/L down to 0.01mg/L, but in Thailand, the former standard is still in use. Arsenic contamination has been a problem in many parts of the world, for example, arsenic leaching from mine tailings in the United States (Lewis, 1999; Lubin, 2000), Canada, Mexico (Del, 1999), Thailand (Hjordis, 1992/1993; Thada, 1999; Williams, 1996), Japan (Tsuda, 1995), United Kingdom, and Australia; from arsenic in natural acquifers now or recently used for water supply in Bangladesh (Ahmed, 1998), India (Acharyya, 1999/2000), United States (Alan, 1988), Hungary, Chile (Smith, 1998), China (Belkin, 1997; Luo, 1993; Yu, 2001), Argentina (Hopenhayn, 1996), Taiwan (Byrd, 1996; Guo, 1998), Ghana, Mexico (Arminta, 1997), Philippines and New Zealand.

GIS is becoming a valuable scientific tool since its inception in 1960s. It is designed for storing, querying, and analyzing as well as for displaying data and/or information with spatial characteristics. It's applications now span to cover a wide range, from simple inventory and management to sophisticated analysis and modeling of spatial data. It is also widely used in environmental science, such as the successful models in atmospheric, land and subsurface, hydrological, biological and ecological system; in epidemiology field to disclose the relationship between a specific disease and a location (Goodchild, 1993); in the Environmental Impact Assessment process (ADB, 1997) to display the relationship between proposed project and environmental media, etc. All these applications not only facilitate the understanding of the applied field, but also provide strong supports for decision-makers to take necessary actions.

The control and management of arsenic contamination is becoming more and more important due to arsenic toxicities and risks to human being. The application of GIS on arsenic problem has been of more concerns. In Bangladesh, GIS was used in a groundwater arsenic mitigation program. It completed many aspects of arsenic problems, including analysis of present groundwater conditions, assessment of exposure and potential health consequences, planning and implementation of

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emergency and long term sanitation measures (Ahmadul, 1998). The evaluation of public health impact in a public health assessment is based on available environmental, demographic, health outcome data and community health concerns. The application of GIS into this field has showed advantages not only on the display of general site information, demographic data, environmental data, but also the analysis of spatial relationship between public health outcome and specific environmental events. Based on this evaluation, public health actions are taken or recommended to reduce, eliminate, communicate or further evaluate the possibility of health impact. The overall objective of this study is aimed at developing a GIS database so as to: (1) show the geospatial distribution of arsenic in groundwater and soil, (2) characterize the extent of arsenic contamination relative to the current Thailand limit of 0.05mg/L in drinking water, (3) identify the possible sources of arsenic contamination, (4) conduct arsenic risk assessment, provide guidance for the consecutive monitoring and management of arsenic pollution in study area.

## II. MATERIALS AND METHODS

### Site selection and characterization

Ron Phibun area, composing of 16 villages, is a sub-district of Ron Phibun district at Nakhorn Si Thammarat Province, Thailand. It is at the center of a tin mineralized zone on the Malay Peninsula. Primary Tin-Wolfram-Arsenic (Sn-W-As) deposits and secondary placer tin deposits had been exploited 100 years ago. This area was selected because of its most serious arsenic-poisoning situation ever reported in Thailand. It is at the eastern side of the Khao Ron Na and Khao Suan Chan Mountains, which form the central ridge of the Malay Peninsula. In the western part of the study area, there are mountains with the highest peak of Khao Huai Mut Mountain, 925m high. The area over 50 m above sea level is steep and mountainous. In the eastern part, it is relatively flat with some undulations. The elevation of terrain surface is decreased from west to east. The Klong Nam Khun River is the main river in the study area, which flows from west to east; it has two major tributaries, the Huai Hua Mueng River and Huai Ron Na River. Five dredging ponds that were the former tin mining locations are present in selected zone. This area situates between longitude 99°50'-99°52'E and latitude 8°10'-8°12'N, which covers the most serious arsenism patients' zone of Ban Hudan, Ban Renna, Ban Talardron, and Ban Salakeelek (villages 1, 2, 12 and 13) with total area around 14 km$^2$ (4×3.5 km) (Figure 1).

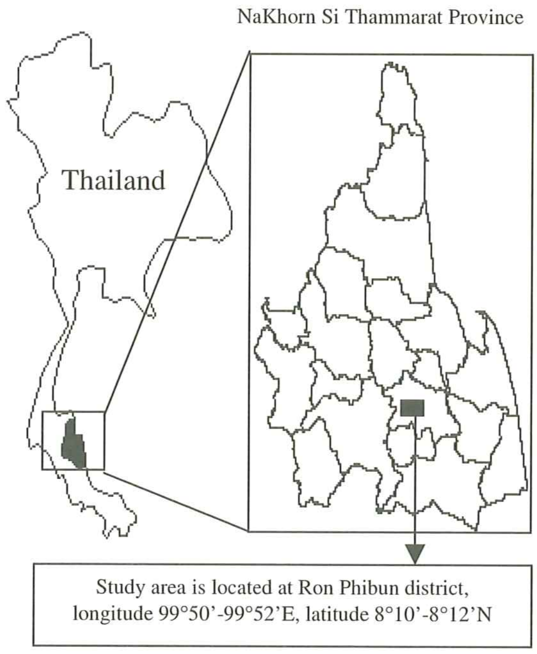


**Figure 1.** Study area in Nakhorn Si Thammarat province, Thailand

### Old mining sites and waste dumping sites

Ten abandoned mining sites, i.e. Yin In Soy, Mai Hom, Sang Son, Ngan Chan, Saijai, Nan Khaw, Ban Thai, Na Mun Mu, Sang Sak and Nan Moo locate on the eastern side of mountains at elevation from 150m to 500m. There are thousands of tons of mining wastes along each mining location and the head of Huai Ron Na River. The mining wastes are yellow stained granite and mineralized quartz vein, the latter used to contain arsenopyrite with wrapping of greenish scorodite (JICA, 1999). Six waste dumping sites: the foothill concentrator, town concentrator, reclaimed sites 32C and 32L, old and new waste dumps present in this area. They are the places with large amount of mining wastes or areas reclaimed by transporting mining wastes from mining site. The new and old dump sites heap up mixtures of mining wastes and domestic rubbish. All these old mining sites and waste dumping sites were carefully identified using an altimeter and GPS.

### Sample and analysis

Surface water (river and dredging ponds), groundwater (shallow and deep well) and soil were sampled in rainy season, October-November 1998. Forty river water-sampling sites were designed along the river course. Five samples were taken for five dredging ponds. There were 42 deep wells and 86 shallow wells within study area, in the location where there is no shallow well, auger-drilling technique was used to take groundwater sample. The auger stations were at 141m intervals, 50 stations/km$^2$ (361 in total). All the sample sites were located by GPS. Water was collected from the bottom of each auger hole wherever water was reached. Two soil samples were collected from each auger well at 30cm and 100cm underneath. But due to some reasons, the final arsenic detection used fewer samples than originally designed. (Table 1)

All water samples were analyzed in total arsenic contents as well as partitioning into two species of As(+3) and As(+5) by IC-AAS (Ion Chromatograph-Atomic Absorption Spectrophotometry) method at ERTC laboratory. Ion chromatograph can separate As(+3) and As(+5) by their

**Table 1.** Total arsenic concentration in different media from study area

| | Sample quantity | Mean | Range | SD |
|---|---|---|---|---|
| Shallow Groundwater (auger water)(mg/L) | 230 | 0.53 | 0.001-64.00 | 4.29 |
| Shallow well(mg/L) | 23 | 0.24 | 0.02-1.18 | 0.33 |
| Deep Groundwater(mg/L) | 23 | 0.47 | 0.002-4.01 | 1.03 |
| River Water(mg/L) | 18 | 0.25 | 0.02-0.64 | 0.18 |
| Pond Water(mg/L) | 5 | 0.33 | 0.04-1.10 | 0.4 |
| Soil total arsenic (mg/kg) at 30cm depth | 39 | 35.9 | 1.11-324.13 | 62.47 |
| Soil total arsenic (mg/kg) at 100cm depth | 39 | 32.75 | 2.69-314.74 | 52.25 |
| Soil elution total arsenic (ug/L) at 30cm depth | 245 | 71.28 | 2.00-1,600.00 | 179.33 |
| Soil elution total arsenic (ug/L) at 100cm depth | 234 | 61.4 | 2.10-1,261.00 | 143.7 |

difference in ionic character, the outflow from the chromatograph is connected to a hydride generator of the atomic absorption unit. Elution test was conducted for all soil samples and sequential extraction was employed using 39 samples with emphasis on partitioning arsenic into different fractions, ranging from water soluble, ion exchangeable, sorbed or bound with organic, sulfide and Fe/Mn oxide form at ERTC laboratory (Tessier, 1979).

### GIS data compilation and database development

Due to the lack of digital data and updated paper map in study area, an edited map with scale of 1: 5,000 was created from a well-organized set of aerial photograph taken in 1995. The spatial data was obtained from this map, including main roads, rivers, ponds, and topography. For environmental survey data, the sample sites of surface water, groundwater, auger station, tin mining plants/waste dumping sites and surface soil types were created as respective layers. Arsenism patients' with skin lesion of stage II was demarcated based on the clinical survey conducted in 1997(JICA, 1999). ArcView GIS (version 3.1 ESRI, 1998) program was used for the GIS process. The major GIS processes are as follows:

- Digitization of paper map
- Creation of layers from environmental survey data
- Input of attributes for each layer
- Interpolation of arsenic level in soil and ground water, auger water within study area using arsenic value in each sample site.
- Query and analysis between arsenic level and mining sites, location of patients' distribution.

### Statistical analysis

SPSS program was used to test the difference between arsenic concentration among different location and the correlation relationship between arsenic concentrations in groundwater with the distance from the sample site to mining and waste dumping sites.

## III. RESULTS AND DISCUSSIONS

### Arsenic level in shallow groundwater

The shallow groundwater is the water from the first aquifer above 10 meters depth. This is the major source of drinking water for local population. The shallow groundwater arsenic concentrations were mapped as an interpolated grid surface to create a visual representation of the concentration gradients throughout the study area. The interpolation was performed on the auger water point theme. The interpolated grid map was adjusted to identify hot spots above the current 0.05mg/L limit for arsenic. The total interpolated area is 8,408,600m$^2$, however, the area with arsenic level higher than 0.05mg/L is 6,080,450m$^2$ that occupies 72.31% of the total. On the other hand, the area with arsenic level lower than 0.05mg/L is 2,328,150 m$^2$, stands for 27.69%. The mean value of total arsenic was 0.53mg/L, 10.6 times higher than limit. This showed the arsenic contamination in shallow groundwater was very severe. This map also shows the zone with the highest arsenic value of 64mg/L (Table 1). (Figure 2)

The map in Figure 2 shows that most of the hot spots with arsenic level greater than 0.5mg/L (1,511,925 m$^2$) locate in the vicinity of mining plants and waste dumping sites, where huge amount of mining waste is disposed. This indicates that all these mining and waste dumping sites are expected to be the pollution source of shallow groundwater in this area. In order to testify whether these sites act as a point arsenic pollution source in shallow groundwater, a correlation test was computed and the results showed that the farther the shallow groundwater sample from mining and waste dumping sites, the lower the arsenic concentration in groundwater ($R=-0.827$, $P<0.01$, Table 2). This

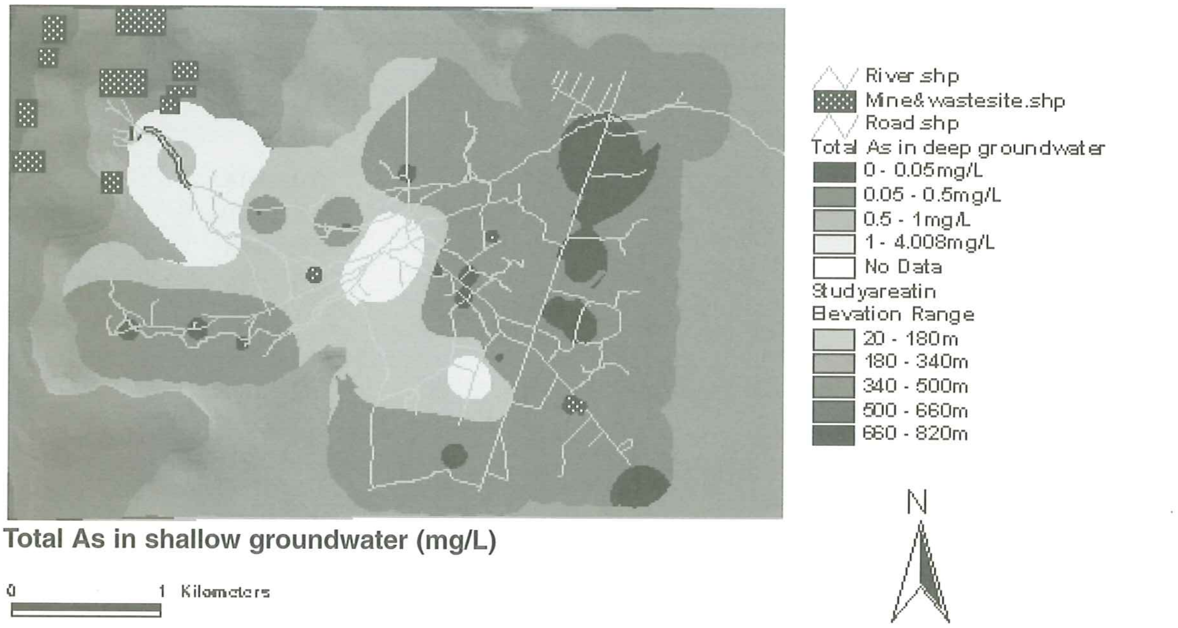


**Figure 2.** Interpolated total arsenic distribution map in shallow groundwater, 1998.

helps in confirmation that the arsenic in shallow groundwater has originated from the mining site and waste dumping sites where the arsenic were dissolved and transported by surface runoff or erosion due to precipitation. Field survey revealed that at almost every mining site there were piles of yellow stained granite and mineralized quartz vein. Quartz vein contains arsenopyrite together with greenish scorodite mineral. After complete transformation of arsenopyrite to scorodite, only one third of the arsenic content is left within its original mineral, arsenopyrite. Some arsenic will still remain as scorodite and the rest will either dissolve in water or precipitate in rocks by filling cracks or on the rock surface. As weathering continues, due to mechanical disintegration, scorodite becomes a smaller particle and transported downstream together with soil and rock fragments, part of it dissolved as an As-ion (JICA, 1999). This part of arsenic can be transported by runoff and enter into surface/ groundwater finally.

## Arsenic Level in Deep Groundwater

The deep groundwater is the water from the lower aquifer, normally from depth at 15m to 50m in study area. The map of total arsenic level in deep groundwater was also interpolated using deep well arsenic value. The area with arsenic level higher than 0.05mg/L is 7,057,125 $m^2$ that occupies 83.93% of the total. On the other hand, the area with arsenic level lower than 0.05mg/L is 1,351,475 $m^2$ that stands for 16.07%. This showed the contamination situation in deep groundwater was also very severe. The mean value of total arsenic is 0.47mg/L, which is lower than that of the shallow groundwater (0.53mg/L). However this average value is still 9.4 times higher than standard allowed whereas the highest arsenic is at 4.01mg/L. (Figure 3)

The map in Figure 3 shows the hot spots to be mostly in the vicinity of foot hill concentrator, where huge amount of mining waste were dumped along the river bank. The sample with the highest arsenic level was also observed at this site. The other sample sites with higher arsenic level were identified among the center of study area, where mining waste dumping sites are present. Comparing with the shallow groundwater arsenic level, this map shows a larger area with arsenic level higher than 0.05mg/L. This may be contributing to the long-term recharge from shallow groundwater. In order to gauge the relationship between the mining waste sites and arsenic level in deep groundwater, a correlation test was performed and result showed a significant relationship between the distance to mining/waste dumping sites and the arsenic level in deep groundwater ($R=-0.661$, $P<0.05$, Table 3). This result illustrates that the shallow groundwater is strongly affected by arsenic-containing surface runoff, in turn, it recharges back to the deep groundwater within long geological period. Leaching as well as lateral movement of arsenic from the mining sites and waste dumping sites is the key process of arsenic contamination in deep groundwater.

**Table 2.** Correlation test between total arsenic level in shallow groundwater and distance to mining & waste dumping sites

| Distance to Mining and Waste dumping sites(m) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 | SPSS Correlation test (Spearman s rho, 1-tailed) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total arsenic in Groundwater (ppm) | 12.32 | 0.39 | 0.27 | 0.29 | 0.12 | 0.09 | 0.15 | 0.23 | 0.18 | 0.07 | 0.02 | R=-0.827, P<0.01 |

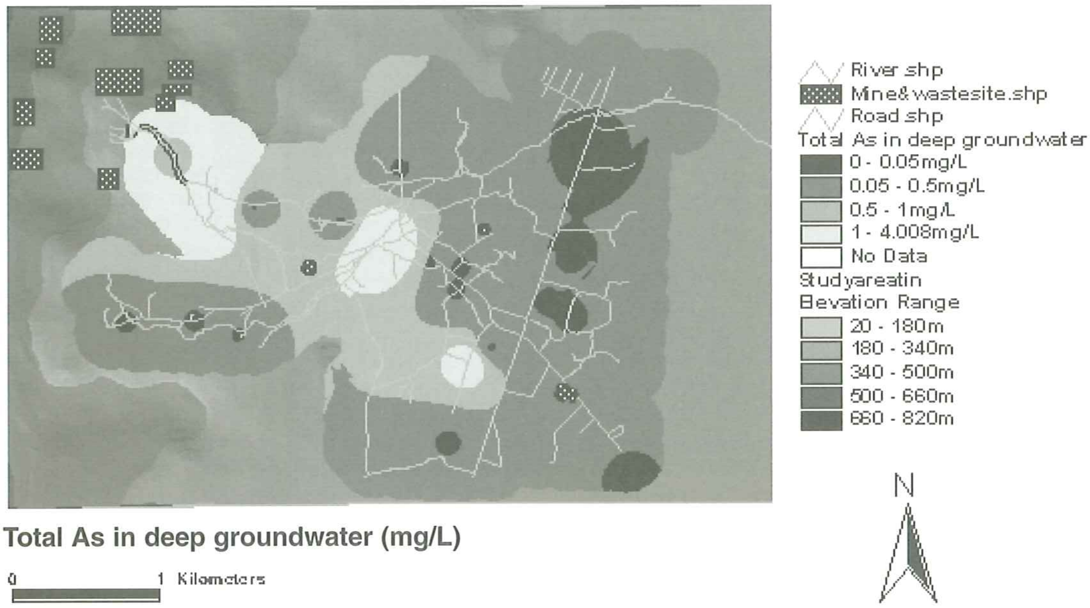


**Figure 3.** Interpolated total arsenic distribution map in deep groundwater, 1998.

### Arsenic Level in Soil

The total arsenic level in near-surface soil (30cm depth) was interpolated in Figure 4. According to Thailand standard, arsenic contaminated soil is defined as the total soil arsenic level over 30mg/kg. Based on this criterion, the area with total arsenic level higher than 30mg/kg are 2,752,850 $m^2$, occupies 32.73%. While the area with total arsenic level lower than standard are 5,657,300 $m^2$, stands for 67.27% of total area. The mean arsenic level was 35.9mg/kg, with the highest value of 324.13mg/kg. Comparing the area with higher arsenic than standard, near-surface soil arsenic contamination is not as serious as in groundwater. Provided the surface soil in study area is 1-2 meters deep (average 1.5meters), the total contaminated soil would add up to 4,129,275 $m^3$. It is very clear that the near-surface soil with arsenic level greater than 30mg/kg is localized within the very close range from mining sites and head of Huai Ron Na river where large amount of mining wastes are dumped. Although the correlation test between soil total arsenic level with distance to mining and waste sites shows no significance, the soil elution arsenic has a very strong significant relationship within 300 meters range(R= -1, Table 4). Analysis along with the distance covering from the mining and waste sites to 1,000 meters range, a less significance is observed(R= -0.636, $P<0.05$, Table 4). Take this into consideration, together with findings in groundwater arsenic distribution, we could infer that the mining and waste dumping sites are the two kinds major pollution source for surface soil and groundwater arsenic contamination.

### Arsenism patients' distribution and geological features

The acute toxicity of arsenic depends on not only its concentration, but also its valence state, and the physical/chemical properties of the compound in which it occurs. One of the most toxic inorganic arsenic compounds is arsine gas ($AsH_3$), followed by the arsenites [arsenic (+3)], the arsenates [arsenic (+5)] and organic arsenic compounds, the more water soluble compounds are usually more toxic and more likely to have systemic effects than the less soluble compounds. Lethal doses in human range from 1.5mg/kg of body weight (diarsenic trioxide) to 500 mg/kg of body weight (DMAA, Dimethyl Arsinic Acid)(EHC/WHO, 1981; NAP, 1999). Early clinical symptoms of acute intoxication include abdominal pain, vomiting, diarrhoea, muscular pain, and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping, and the appearance of a papular erythematous rash. (Murphy, 1981). Within a month, symptoms may include burning paraesthesias of the extremities, palmoplantar hyperkeratosis, Mee's lines on fingernails, and progressive deterioration in motor and sensory responses. Signs of chronic arsenic poisoning, in rodents, the critical effects appear to be immunosuppression and hepato-renal dysfunction, whereas in humans the skin (namely hypopigmentation, hyperpigmentation,

**Table 3.** Correlation test between total arsenic level in deep groundwater and distance to mining & waste dumping sites

| Distance to Mining sites(m) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 | SPSS Correlation test (Spearman s rho, 1-tailed) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total arsenic in Groundwater (ppm) | 0.35 | 1.34 | 0.31 | 1.39 | 0.02 | 0.02 | 0.36 | 0.002 | 0.005 | 0.02 | No data | R=-0.661 P<0.05 |

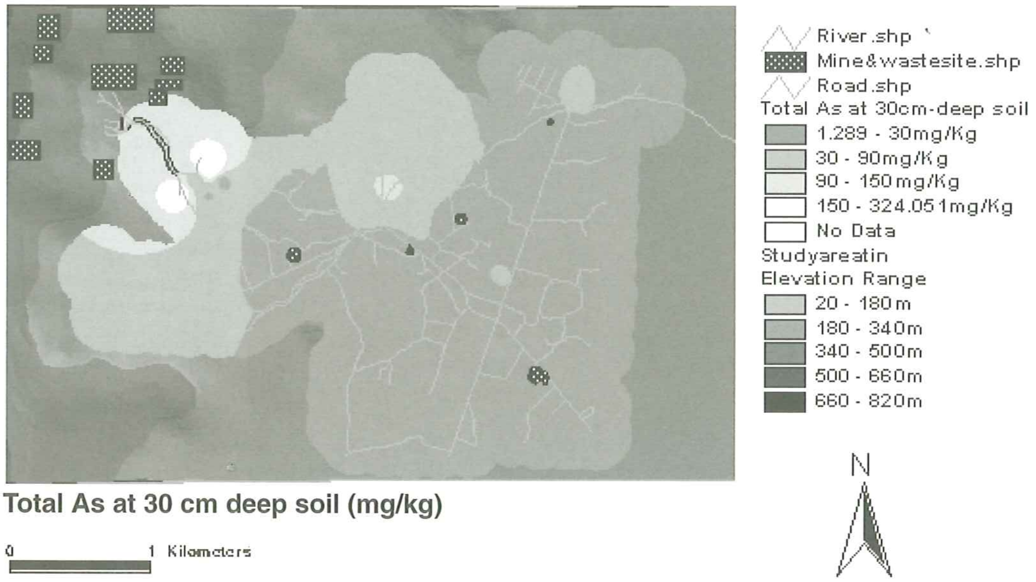


**Figure 4.** Interpolated total arsenic distribution map in near-surface soil at 30 cm depth

keratosis), vascular system, and peripheral nervous system are the primary target organs. Dermal lesions were the most commonly observed symptoms, occurring after minimum exposure periods of approximately 5 years. (Hindmarsh, 1977; Robert, 1996)

In 1998, a medical survey found 334 arsenism patients among 24,004 population of 16 villages. The total prevalence of arsenism (skin lesion) was 13.91‰. The study area covers the four most serious villages 13, 1, 12 and 2 with arsenism prevalence 46.12‰, 36.03‰, 33.25‰ and 12.79‰ respectively (JICA, 1999). Arsenism patients with skin lesion of stage II was displayed in Figure 5. On this map, it shows that the patients appear only at the area with sandy surface soil and arsenic level in shallow or deep groundwater above 0.05mg/L, arsenic in soil elution of water soluble fraction is above 0.05mg/L. After making a buffer zone of 200 m from the patients' location, all the arsenic values in groundwater and soil inside or outside this zone were identified and compared. The arsenic level in shallow and deep groundwater inside the zone of arsenism patient was significantly higher than outside zone, while the difference of arsenic level in surface soil elution inside or outside of the patients' zone is not significant (Table 5). This indicates that arsenic is undoubtedly the cause of arsenism and the major pathway of arsenism is through drinking water, while the inhalation and ingestion of soil dust may be less important. The sandy soil facilitates the leakage of arsenic containing surface runoff into groundwater, results in the higher arsenic level in it. In addition, due to its lack of ferric and manganese oxides comparing with clay soil which can adsorb arsenic effectively, arsenic in sandy soil is easily mobilized and could be transferred to plants and vegetables.

## Arsenic level in surface water

Eighteen river water samples and five pond water samples were taken for the measurement of total arsenic. The arsenic level in river water is ranged from 0.02 to 0.62mg/L with its mean value of 0.25mg/L, pond arsenic from 0.04 to 1.1mg/L with mean value of 0.33mg/L. Because the exchange between river and groundwater usually occurs during the wet season, river may interfere the groundwater arsenic concentration in some extent. Table 6 shows that within 600 meters, groundwater arsenic concentration is decreasing significantly with the distance to river (Table 6). It must be mentioned that high arsenic level in river/pond water (0.25/0.33) mg/L would have been another polluting source of arsenic in groundwater providing that mixing of the two waters occur.

## Arsenic risk Assessment process

Risk assessment is a tool used to organize, structure, and compile scientific information in order to help identify existing hazardous situations or problems, anticipate potential problems, establish

**Table 4.** Correlation test between total arsenic level in surface soil elution and distance to mining & waste dumping sites

| Distance to mining sites(m) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total arsenic in soil elution (ppb) | 357.14 | 134.48 | 61.48 | 39.62 | 92.5 | 95.93 | 41 | 48.46 | 65.56 | 47.5 | 10 |

SPSS correlation test: 1. Distance within 300 meters: (Spearman's rho, 1-tailed) R=-1
2. Distance from 0 to 1,000 meters: (Spearman's rho, 1-tailed) R=-0.636, P<0.05

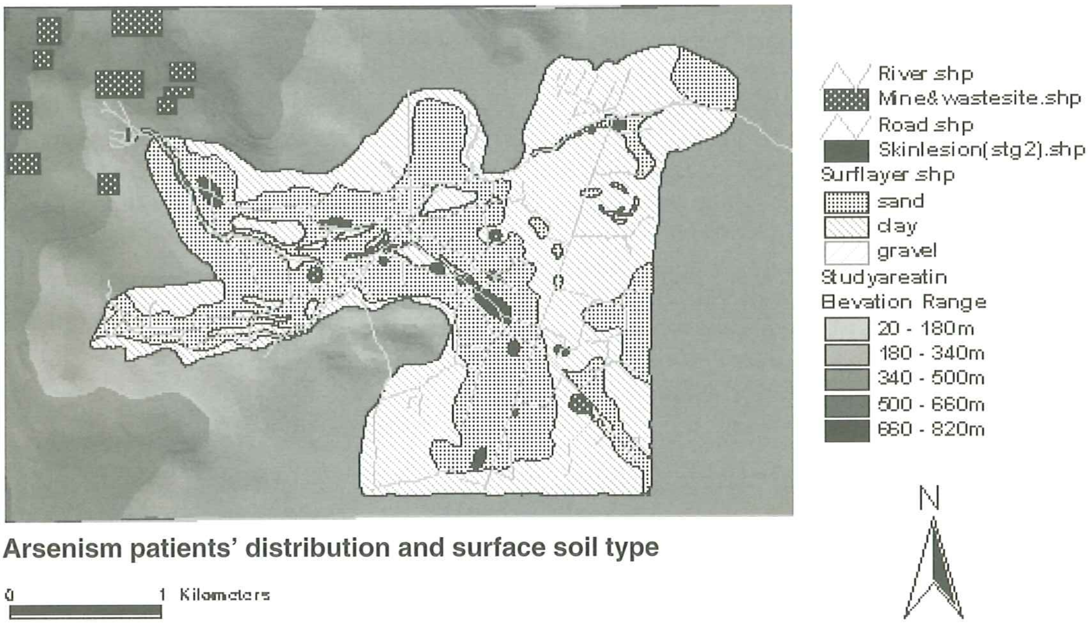


**Figure 5.** Arsenism patient's (skin lesion stage II) distribution map in study area. It is very clear that patients appear mostly in the zone with sandy surface soil. Arsenic concentrations in shallow/deep groundwater inside the patients' zone are higher significantly than those outside the patients' zone (Table 5).

priorities, and provide a basis for regulatory controls and/or corrective actions. It may also be used to help gauge the effectiveness of corrective measures or remedial actions (Kofi, 1998). It has become a routine component of decision making for setting limits of acceptable environmental exposures to chemicals in air, food and water although substantial controversy still exists regarding the policy assumptions and uncertainties in it. Due to the various toxicities of arsenic compounds to human body, it is very important to conduct health risk assessment in any case of arsenic contamination so that a clear view would be achieved.

In Ron Phibun area, the skin manifestation of chronic arsenic poisoning was first highlighted in 1987. Clinical survey during 1987-1988 showed that more than 1,000 people between age from 4 months to 85 years were affected, mainly were hyperpigmentation, hypopigmentation and keratosis. Six skin cancer patients had been diagnosed. However, other internal cancer, such as liver, lung, kidney and bladder due to arsenic consumption were not found yet (Munehiro, 1998; Shoko, 1998; Chanpan, 1997,1998). Till now, total cumulative patients of 6,120 among 24,665 population have been found. In the next 5-10 years, 5,000 extra cases will appear (PCD, 1998a).

Drinking water is the major exposure route of arsenic administration by local people. After the inception of first

**Table 5.** Arsenism patients' distribution and arsenic level/geological features

| Zone | Arsenic in shallow groundwater ppm (Mean±SD) | Arsenic in deep groundwater ppm (Mean±SD) | Arsenic in surface soil elution ppb (Mean±SD) | Type of surface soil |
|---|---|---|---|---|
| Zone with arsenism patients | 1.24±7.02(85) | 0.68±1.26(13) | 105±210.53(74) | Sand |
| Zone outside arsenism patients | 0.11±0.28(146) | 0.07±0.33(28) | 77.58±185.66(124) | Clay |
| Significance | t=1.94,P<0.05, 1-tailed | t=2.40, P<0.05, 1 or 2-tailed | t=0.95, P>0.05 | |

**Table 6.** Correlation test between total arsenic level in shallow groundwater and distance to river

| Distance to river(m) | 50 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total arsenic in shallow groundwater (ppm) | 2.28 | 1.22 | 0.19 | 0.73 | 0.2 | 0.05 | 0.02 | 0.03 | 0.15 | 0.2 | 0.08 |

SPSS correlation test: 1. Distance within 600 meters: (Spearman's rho, 1-tailed) R=-0.893, P<0.01
2. Distance from 50 to 1,000 meters: (Spearman's rho, 1-tailed) R=-0.624, P<0.05

arsenism patient, the local people were provided with tap water and bottle water. Measures to collect rain water were also taken by local government. A water use survey conducted in 1997 showed that most people have abandoned their behavior of using contaminated surface water (Table 7). Most of the vegetables and fruits from study area have undetected arsenic concentration (PCD, 1998b). So, when we neglect of the arsenic intake by consumption of vegetables and fruits, drinking water was considered as the only route of arsenic intake for local people. The rain water, shallow well water, deep well water, bottle water and water provided by PWA were integrated as the total arsenic source. As a result, the arsenic exposure dose, cancer risk and non-cancer risk (Hazard Quotient) was calculated (Table 8, Figure 6) based on following assumptions:

Exposure dose was estimated using the mathematical model (Becker, 1996a):

DOSE (mg/kg-day) =C×CR×EFD/(BW×AT)

where,

DOSE = Daily Intake (mg/kg-day) of Contaminant (=Exposure)

C = Concentration in drinking water (mg/L)

CR = Contact Rate with drinking water (3L/d)

EFD = Exposure Frequency & Duration Terms (365 days/year for 70years)

BW = Body Weight (70 kg, average, US.EPA, NAP, 1999)

AT = Averaging Time, for carcinogens 70 year×365day/year

Oral RfD of arsenic=1E-3 mg/kg-day (Becker, 1996b)

Cancer Slope Factor (oral)=2$(mg/kg\text{-}day)^{-1}$(Becker, 1996b)

Village 12 has the highest exposure dose of arsenic, 1.13E-3 mg/kg-day, followed by village 13, 2 and 1, which are 7.59E-3, 5.90E-4, and 8.36E-5 respectively. Consequently, this results in the same order in cancer risks of 2.26E-3, 1.52E-3, 1.18E-3 and 1.7E-4, and hazard quotients of 1.13, 0.76, 0.59 and 0.08 respectively. According to EPA estimation, the average total intake of inorganic arsenic from food, water and other beverages to be about 17 ug/day, of which 5 ug/day come from drinking water (Allan, 1994). However, village 12 has 79.1ug/day arsenic only from drinking water, this is far higher than EPA estimation. As to the cancer risk, higher risk value than 1E-4 are in village 2, 12 and 13 which should be of concern according to EPA standard of arsenic induced cancer risk which is between 1E-6 and1E-4. The highest non-cancer risk occurs in village 12 where urgent measures must be considered to reduce the arsenic exposure, such as provide bottle water, increase the percentage of rain water using and so on.

## IV. CONCLUSIONS

The arsenic pollution situation in Ron Phibun district, Nakhorn Si Thammarat Province was depicted with GIS aid. The groundwater arsenic concentrations had a large distribution ranging from 0 to 64mg/L throughout the study area. The mappings of the groundwater arsenic concentrations in study area showed that groundwater arsenic concentrations are always higher in the vicinity of mining sites and waste dumping sites than the other parts. These were identified to be the arsenic pollution sources in study area. Taking into consideration of all measured environmental media, shallow groundwater, deep groundwater, the pollution situation was rather severe according to arsenic standard of 0.05mg/L in drinking water. Village 12 must be given urgent concerns for its high exposure dose and cancer/non-cancer risk; village 13 and 2 should also be put under surveillance. With the cancer, non-cancer risk maps and GIS database, the local government can develop the action for arsenic alleviating, monitoring of arsenic level, provide support for decision-making. As to the severity of arsenic pollution in groundwater, it is strongly suggested that the groundwater should be treated efficiently before drinking to lower the arsenic level in it. Mining waste and waste dump as well as the contaminated

**Table 7.** Water usage in four villages

| Village | Rain water | | Shallow well | | Bottle water | | Deep well | | PWA | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | As (ppb) | % | As (ppm) | % | As (ppm) | % | As (ppm) | % | As (ppm) |
| 1 | 96.6 | 0.58 | 0 | 0.22 | 2.6 | 0.05 | 0.9 | 0.01 | 0 | 0.05 |
| 2 | 94.7 | 1.58 | 3.1 | 0.36 | 0.3 | 0.05 | 0 | 0.72 | 1.9 | 0.05 |
| 12 | 56.4 | 0.25 | 2.6 | 0.22 | 28.6 | 0.05 | 0 | 0.51 | 12.4 | 0.05 |
| 13 | 67.2 | 0.28 | 0.7 | 0.21 | 24.2 | 0.05 | 0 | 0.06 | 7.9 | 0.05 |

Note: Vlg-Village, RW-Rain water, SW-Shallow well water, BW-Bottle water, DW-Deep well water, PWA-Provincial Waterworks Authority, As-Arsenic

**Table 8.** Arsenic risk assessment in four villages

| Village | Dose (mg/kg.day) | Arsenic ug/day | Population | Cancer risk | Cancer patients in future | Hazard Quotient |
|---|---|---|---|---|---|---|
| 1 | 8.36E-05 | 5.85 | 805 | 1.70E-04 | 0 | 0.08 |
| 2 | 5.90E-04 | 41.3 | 2,423 | 1.18E-3* | 3* | 0.59* |
| 12 | 1.13E-03 | 79.1 | 3,128 | 2.26E-3** | 7** | 1.13** |
| 13 | 7.59E-04 | 53.13 | 1,561 | 1.52E-3* | 2* | 0.76* |

**: The risk is of great concern, measures should be taken immediately

*: The risk is of concern

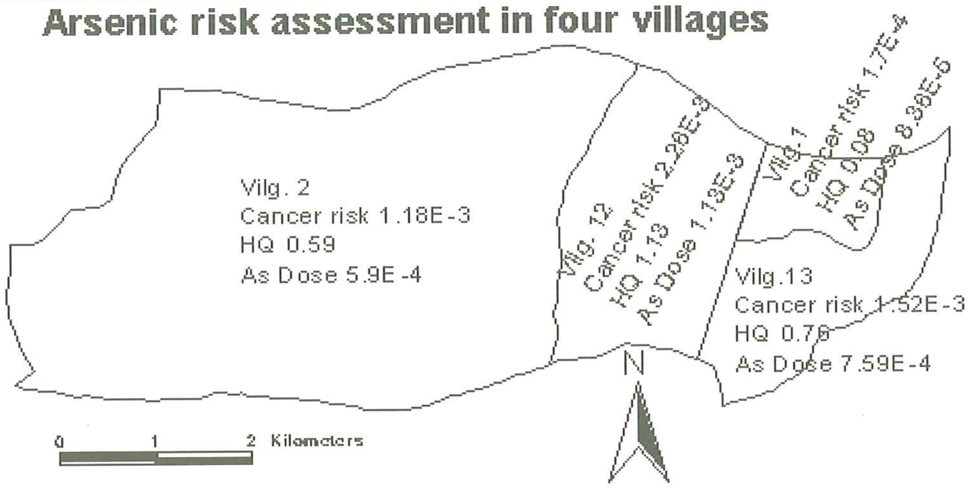


**Figure 6.** Arsenic risk assessment in village 1, 2, 12 and 13. Arsenic exposure dose (mg/kg-day), Hazard Quotient (HQ) and Cancer risk are indicated in the map. This is based on the assumption that drinking water is the only exposure route of arsenic.

soil should also undergo remediation in order to alleviate the pollution sources. Alternative drinking water must be provided because of the current high arsenic content in groundwater. Site remediation of the hot spots of the study area need further research to identify appropriate clean-up technology for implementation.

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