

Possible Sources of Elevated Arsenic in Surface and Ground Water, Amphoe Banrai, Changwat Uthai Thani, Thailand

Aporn Sardud¹, Onuma Khamphleang¹ and Jitisak Premmanee²

1 - Division of Mineral Resources Analysis and Identification, Department of Mineral Resources.

2 - An ex-official of the Department of Mineral Resources.

Corresponding author: *gi.geosciences@gmail.com*

Received ; Accepted ; Available online.....

Abstract

This study is cooperation between the Division of Mineral Resources Analysis and Identification, Department of Mineral Resources and the Uthai Thani Provincial Public Health Office to help and verify elevated arsenic level at Tambol Nongjok/Nongbomklouy, Amphoe Banrai, Changwat Uthai Thani because the elevated arsenic level may pose health risk to local residents. Geochemical techniques were employed by collecting water and stream/lake sediments, and analyzing for arsenic covering the target and adjacent areas. A total of 371 water samples were compiled. Assay results of 281 surface water samples range from <2–2,713 ppb, average 97 ppb; and of 90 groundwater samples range from <2–505 ppb, average 47 ppb. Integrated spatial studies of these water assays with geography, water flow pattern and arsenopyrite mineralization outline 2 tiers of risk areas. Tier 1 arsenic assays ≥ 300 ppb, covers 2 areas in south of Ban Thapfaimai and at Wat Nongmaitai, Tambol Nongjok and Tier 2 arsenic assay ≥ 100 ppb, encompasses 14 villages in Tambol Nongjok/Nongbomklouy Changwat Uthai Thani; Tambol Wangkan Changwat Suphanburi and Tambol Sukduenha Changwat Chainat. A total of 88 stream/lake sediments samples were compiled. Assay results range from <5–167 ppm, average 31 ppm. A group of high assays (75–167 ppm) are close to the expired tin-tungsten mining licenses at Ban Nongyaingern, Tambol Wangkan. Other high assays (≥ 50 ppm) are contained within the Tier 2 area. These findings indicate that water sampling is a more practical approach than sediment sampling in order to outline the arsenic risk areas and may identify the point sources. Four possible arsenic sources were identified: (1) Khao Kaktungkung, (2) west of Ban Putakien (3) Wat Nongmaitai and (4) west of Ban Nongmaikean where it was later found altered granite with quartz veins and disseminated arsenic rich sulfide minerals at an under-construction water reservoir.

Keywords: Arsenic, Banrai, geochemical exploration, sources, risk area, water sampling.

Introduction

This project was initiated by the Uthai Thani Provincial Public Health Office (UTPHO). The Office has actively followed up the elevated arsenic level in surface water as well as in local residents since 2011. Even though, elevated arsenic level in water of the area was known for many years. The Division of Mineral Resources and Identification, Department of Mineral Resources (DMR), Ministry of Natural Resources and Environment filed the first records in 2006. Later, some records were available from a cooperative project between the DMR and the Department of Disease Control, Ministry of Health in 2009. Also, the DMR Hazardous Element Project sampled surface water and sediments in this area during 2012 and 2013.

Nevertheless, most of the mentioned records did not study throughout the area but rather concentrated on the known problematic sites. The data under the DMR Hazardous Element

Project systematically cover parts of the area in Suphanburi and Uthai Thani, but no sampling in nearby Chainat provinces.

Therefore, the Division of Mineral Resources and Identification, DMR launched this project in early 2019 to systematically document elevated arsenic levels and hopefully identify the possible sources. Geochemical prospecting techniques were employed by collecting water and stream/lake sediments, and analyzing arsenic covering the target and adjacent areas.

Study Area

The initial study area consists of 5 villages (Banⁱ Tapfaimai, Maiphongan, Nongmaikean, Keanpetphailin and Nongmaitai) of Tambolⁱ Nongjok and 1 village (B. Lanka) of T. Nongbomklouy, Amphoeⁱ Banrai, Changwatⁱ Uthai Thani (Figure 1). However, after compilation of previous data, the study area was expanded to include the nearby villages of T. Nongjok /Nongbomklouy /Tapluang, A. Banrai, C. Uthai Thani, of T. Wangkan /Nongkratum, A.

i - Ban, Tambol, Amphoe and Changwat are local administrative names and refer to village, sub-district, district and province respectively. In this report, they are abbreviated to B., T., A. and C. respectively.

Danchang /Doembangnangbuat, C. Suphanburi, of T. Sukduenha /Kaboktia, A. Noenkham, C. Chainat. The final rectangle of entire study area covers about 16x20 km or 320 km².

Figure 1 shows the topography of the area which consists of broad and gentle slope with higher ground formed as an axis at the middle, like a turtle back. The axis orients almost north-south direction and divides water flow into east and west directions. To the east, water curves to southeast direction and drain into the Thachin River, C. Chainat. The west part, water runs into Krasiao stream, then to Krasiao reservoir, A. Danchang, C. Suphanburi. Khaoⁱⁱ Phuklang and Urkhwai exhibit karst topography in the north and mainly consist of Ordovician limestone. A group of hills, K. Kaktungkung, Puchi and Pongngam present in the south and consist of meta-sediments, limestone and granite of Silurian/Devonian, Ordovician and Triassic Periods respectively. Contacts of these meta-sediments and limestone with granite host tungsten deposits. A few mines operated around 1987 in secondary elluvial and alluvial

deposits at K. Kaktungkung and at B. Tapfaimai. Jariyawat (1996) reported that the mineralization formed in 1-10 cm quartz veins oriented N45W and N60E within granitic rock.

Interestingly, those southern hills formed natural geographic boundaries of 7 Tambols (Nongjok, Nongbomkluay, Wangkan, Nongmakhamong, Nongkrathum, Sukduenha and Kaboktia), 4 Amphoes (Banrai, Danchang, Dermbangnangbuat and Noenkham) and 3 -Changwats (Uthai thani, Suphanburi and Chainat).

Previous Data and Additional Sampling

Figure 2 shows sample points including previous and additional samples. The previous water and sediment samples (Figure 2A) were compiled from many sources, such as DMR’s reports, UTPHO, the DMR’s Hazardous Elements Project (Uthai Thani and Suphanburi provinces) and others, detailed in Premmanee (2019a). The samples consist of 32 stream sediments, 139 surface water, 50 ground water, and total 221 samples.

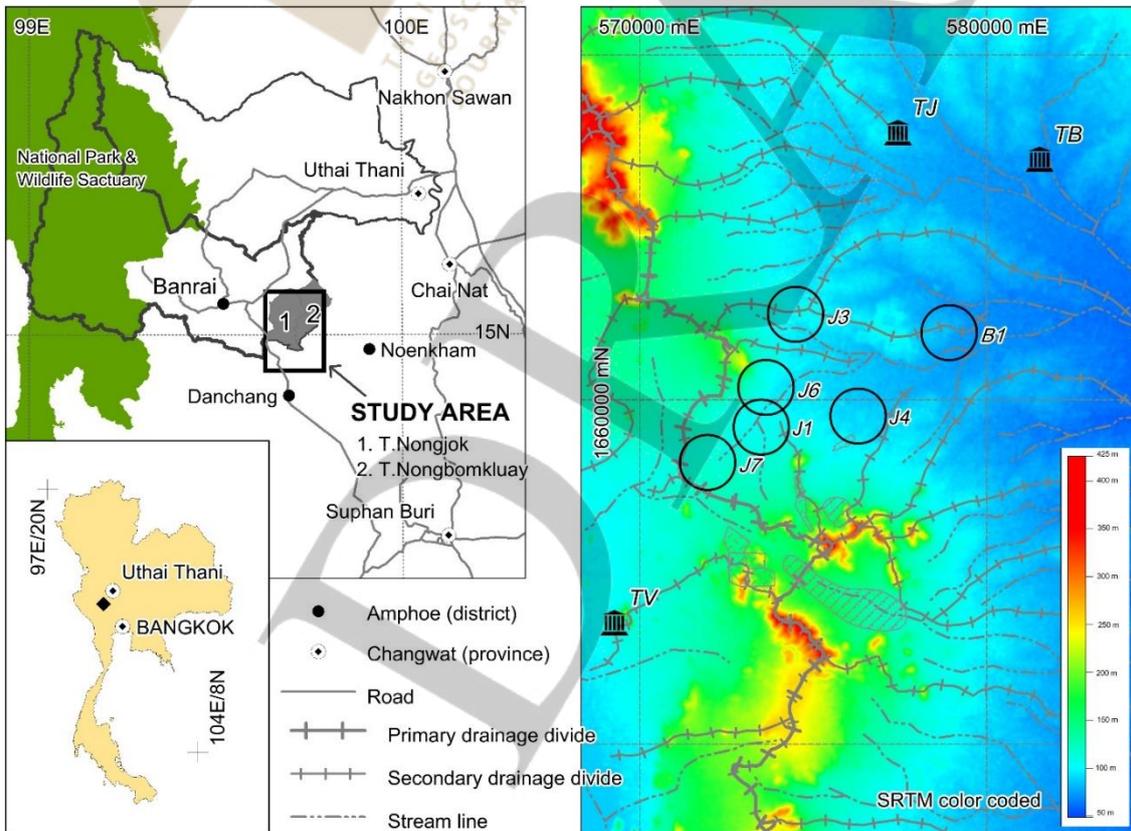


Figure 1. Location and topography of study area, Banrai, Uthai Thani

ii-Khao refer to mountain or hill and in this report is abbreviate to K.

Figure 2b shows the additional samples collected in April 2019. The new sample set aim to fill-up spaces, create more density and verify some assays in the problematic areas. Additional samples consist of 56 stream/lake sediments, 142 surface water, 40 ground water, and total 238 samples. Note that these samples were collected, prepared and analyzed according to protocols in the Standard Method for Examination of Water and Waste Water no.3113 (2017) for water samples and the Hazardous Waste Test Methods no.SW-846 (2019) for solid samples.

These assays were combined into a single set, total 459 samples (Table 1). Arsenic contents in surface water, ground water and sediments average at 97 ppbⁱⁱⁱ 47 ppb and 31 ppmⁱⁱⁱ respectively. These averages lay about 20, 10 and 2 times higher than the averages in surface water (4 ppb) and stream sediments (12-15 ppm) under the DMR Hazardous Element Project (Premmanee, 2019b). Note

that World Health Organization (WHO, 2020) has suggested an arsenic safe content limit in drinking water of 10 ppb, while the Pollution Control Department (PCD, 2020) of Thailand has tabulated the standard arsenic values (refer to maximum permissible limit or MPL) in water and agricultural soil at 10-50 ppb and 3.9 ppm respectively.

Beside the water and sediments, UTPHO collected urine samples from local residents periodically every other year, since 2011 (Table 2) (Ms. Sukanya Pataisophon, personnel communication). The samples were in the 5 villages of T. Nongjok and 1 villages of T. Nongbomkluay (village J1, J3, J4, J6, J7 and B1 on Figure 1). Results showed that 288 (55%) samples out of 520 samples are above acceptable levels^{iv}

Arsenic Distribution

Figure 3 shows arsenic distribution in surface water (3A), ground water (3B) and sediments (3C). Elevated arsenic in surface water, ground water and sediments scatter

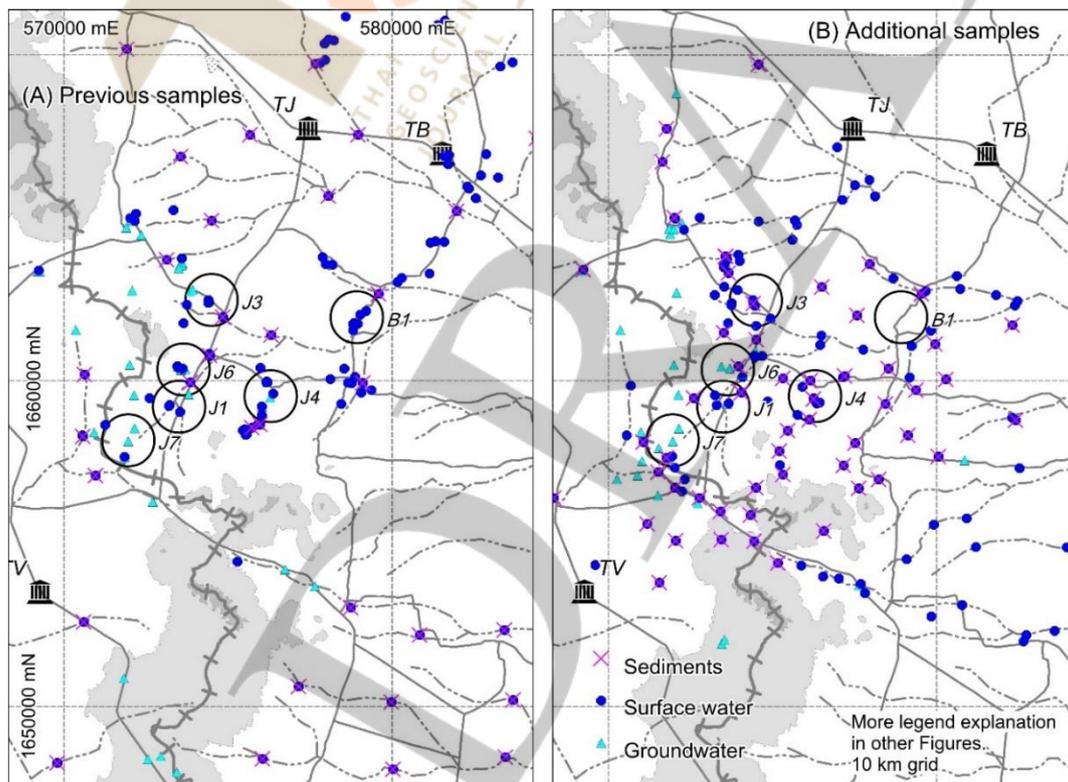


Figure 2. Samples location maps, (A) previous samples and (B) additional samples.

ii - Khao refer to mountain or hill and in this report is abbreviated to K.

iii - ppb – part per billion or microgram per liter ($\mu\text{g/l}$) and ppm – part per million or milligram per liter (mg/l)

iv - Based on the Department of Disease Control (2019), the acceptable levels refer to 2 conditions. Urine sample collected from seafood consuming restricted of 48-72 hours is at $<50 \mu\text{g/l}$ and from the unrestricted seafood consuming is at $<100 \mu\text{g/dl}$.

Table 1. Statistics of arsenic assays in surface water, ground water and sediments.

Assay statistics		Surface water (ppb)	Ground water (ppb)	Combined water (ppb)	Sediments (ppm)
Number of samples		281	90	371	88
Minimum		<2	<2	<2	<5
Maximum		2713	447	2713	167
Average*		97.0	46.8	85.9	31.1
Standard deviation*		167.2	83.1	153.8	30.7
Detection limit (DL)		2	2	2	5
Number of <DL		8	27	35	3
Outlier		6 (2713, 1589, 1350, 1295, 1206, 1170)	1 (505)	6 (2713, 1589, 1350, 1295, 1206, 1170)	

Note: * If the assay is <DL, then DL/2 will use for calculation

Table 2. Urine arsenic levels in local residents.

Testing year		T. Nongjok	T. Nongbomkluy	Combined
2011	Total samples	202	-	202
	Anomaly (%)	73 (36%)	-	73 (36%)
2013	Total samples	86	-	86
	Anomaly (%)	49 (57%)	-	49 (57%)
2015	Total samples	101	-	101
	Anomaly (%)	86 (85%)	-	86 (85%)
2017	Total samples	96	75	171
	Anomaly (%)	38 (40%)	42 (56%)	80 (47%)
Total		520 samples with 288 (55%) anomalous values		

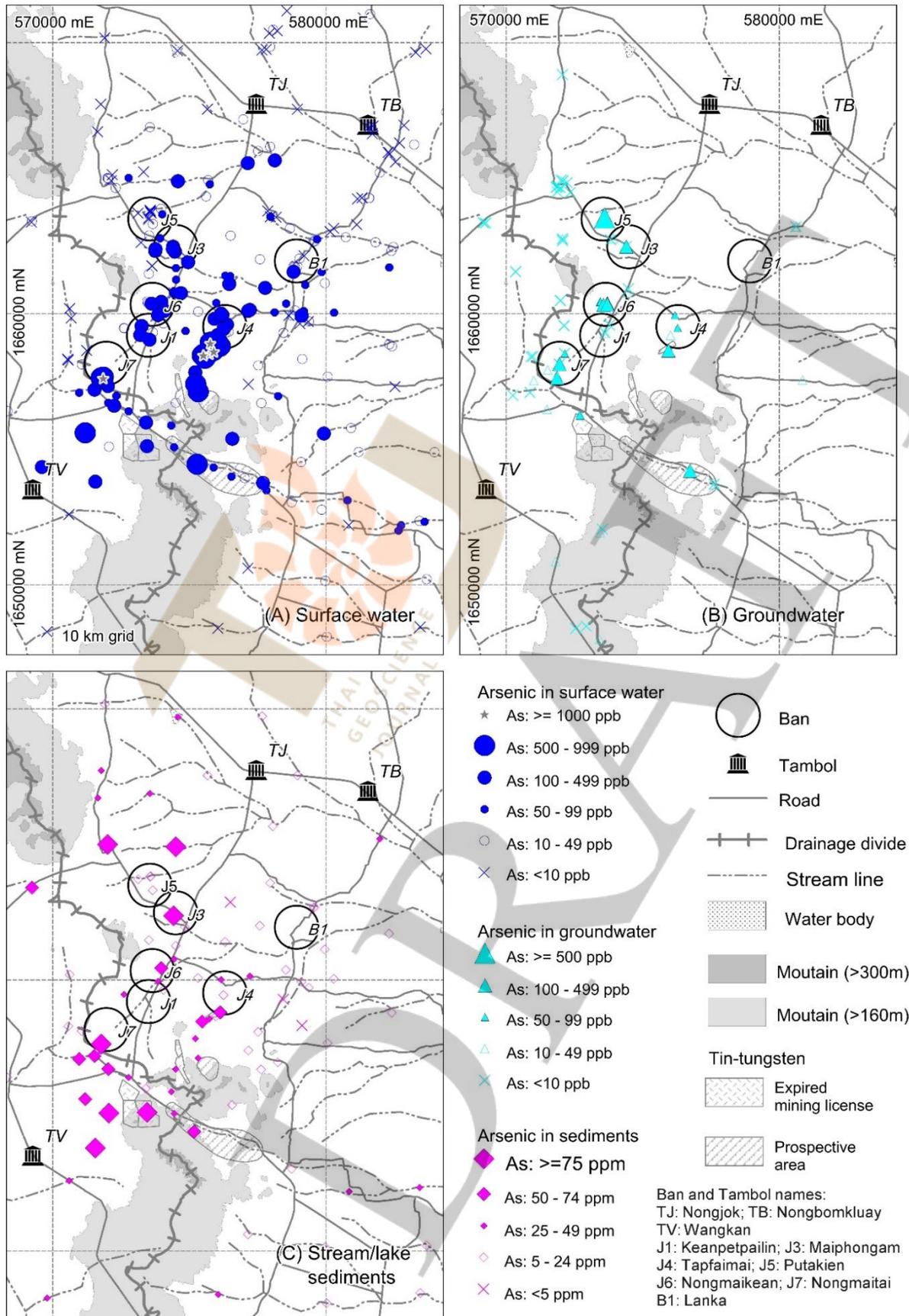


Figure 3. Arsenic distribution in (A) surface water, (B) groundwater and (C) stream/lake sediments.

around the tin-tungsten prospective areas of K. Koktungkung and more densely to the north, especially at abandoned tin mining pits, south of B. Tapfaimai. The furthest north high arsenic assays distribute along water channels north of B. Maiphongam and Putakien.

The highest arsenic assay (2,713 ppb) in surface water was collected from a small water channel, south of B. Tapfaimai. 4 more high assays (>1,000 ppb) were detected at the tin mining pits in this area. The 6th high assay (1,170 ppb) is located at Wat Nongmaitai, B. Nongmaitai, about 3.5 km east of the Tapfaimai's tin pits. Interestingly, a group of high arsenic values (100-499 ppb) in surface water depicted at B. Maiphongam and further north which is located in different drainage catchment to the one of B. Tapfaimai. These show that arsenic sources may not only originated from the tin mining/prospective areas of K. Koktungkung but from unidentified natural sources northeast of B. Maiphongam as well.

High arsenic assays in ground water display similar patterns to surface water, but at B. Phutakien (Figure 3A and 3B) where mixed of very low and high arsenic assays (≤ 50 to ≥ 100 ppb) detected in ground water. The highest assay (505 ppb) was found in 30 m water well here, but all surface water yield <50 ppb. In addition, the downstream assays of surface water gradually increase for about 5 km, i.e. 10, 22, 59, 72, 135 and 128 ppb, from the village. These findings are illustrated (Figure 4) showing possible transport mechanism of arsenic in water of this area. It is estimated that arsenic may be mobilized as far as 10 km from the sources

High arsenic (≥ 75 ppm) in sediments distributed in 2 areas, east/northeast of K. Koktungkung and around B. Maiphongam and Phutakien. Medium high assays (25-74 ppm) located in those tin pits at B. Tapfaimai. These results do not quite agree with water assays. It seems that arsenic in sediments disperse irregularly around the sources. However, due to sampling period during the dry season, very limited stream sediments were collected, but the majority

were lake/pond sediment which may not represent transported materials. So, sediments sampling may not be practical in this case.

Risk Areas and Possible Point Sources

Many spatial factors (such as topography, drainage system, arsenic mineralization style, geological environment and others) will help to outline the risk areas and to identify arsenic point sources. As mentioned, water assays will limit the risk areas compared to sediment assays. And yet, many authorities recommend MPL in consumable water at 10-50 ppb. So, the practical threshold arsenic assays in surface water should be higher than the MPL in order to separate the risk areas. In this study, arsenic in surface water average at 97 ppb while 47 ppb in ground water. Therefore, surface water assay at 100 ppb is selected for the practical threshold value.

The 100 ppb lines were manually drawn following drainage system and catchment areas, so as the 300 ppb lines (very high arsenic values). Figure 5 shows results of the 2 tiers of risk areas as follow.

Tier 1: arsenic assays ≥ 300 ppb in surface water, encompass 2 areas: (1) south of B. Tapfaimai where there are many abandoned tin mining pits and (2) Wat Nongmaitai, B. Nongmaitai; both at T.Nongjok A. Banrai C. Uthai Thani, covering approximately 4 square km or 2,500 rai.

Tier 2: arsenic assays ≥ 100 ppb in surface water, encompass 14 villages of B. Putakien, Maiphongam, Koksard, Nongmaikuan, Tapfaimai, Keanpetpilin, Nongmaitai, T. Nongjok; B. Lanka, T. Nongbomklouy, A. Banrai, C. Uthai Thani; B. Nongyaingern, Bungyang, Wangthong, Wangkan, Phunglouang, T. Wangkan, A. Danchang, C. Suphanburi; and B. Huaisong, T. Sukduenha, A. Noen Kham, C. Chainat; covering approximately 65 square km or 40,000 rai.

Note that the 100 ppb line is open at T. Wankan due to the fact that not enough samples in the area.

Point sources of arsenic are picked from distribution pattern of arsenic in water and sediment, topography, arsenic mineralization style as well as geological environment.

Although, initial fieldwork at the tin-tungsten prospective area of K. Koktungkung found no evidence of primary sulfide minerals such as pyrite or arsenopyrite, only some iron oxides are found on the surface. Still, K. Koktungkung remains the most likely important point source of arsenic. Arsenic in this area radially distribute into water channels of 10 villages: Tapfaimai, Lanka, Huaisong, Bungyang, Wangthong, Wangkan, Phungluang, Nongyaingern, Nongmaitai and Keanpetpailin. Arsenic from this source is limited to the south-east side of the water channel running from B.Nongmaitai to Nongmaikean.

On the other north-west side of the water channel, west of B. Nongmaitai, Keanpetpailin, Nongmaikean, arsenic remains high in water indicating other sources beside from the K. Koktungkung. High arsenic assays were obtained around B. Putakien and Maiphongam which located in different catchment basin to the K. Koktungkung, so, the areas may hold some concealed arsenic sources. Very high arsenic in water (Tier 1 area) is present at Wat Nongmaitai; so an arsenic source should be in this area as well.

In summary, there are 4 possible point sources: (1) K. Koktungkung, (2) west of B. Putakien and Maiphongam, (3) Wat Nongmaitai, B. Nongmaitai, and (4) west of B. Nongmaikean (Figure 5).

Luckily, later field work at an under-construction water reservoir of B. Nongmaikean in July 2019, has found outcrops of altered granite with thin (<5cm) quartz veins and arsenic rich sulfide minerals (Figure 6). Rock chip samples of mixed altered granite with weathered sulfides minerals and altered granite gave 4,890 and 25 ppm arsenic respectively. This evidence confirms an arsenic source. However and inexplicably, 2 water assays at this reservoir gave 20 and 23 ppb arsenic which are in the normal range.

Conclusions and Remarks

1. Geochemical prospecting techniques are an effective tool to outline the risk areas and to identify the sources. It also demonstrates that elevated arsenic sources not only from known tin-tungsten mining areas but also from other concealed sources. In this case, water samples are more practical than sediment samples, but both should be concurrently conducted for

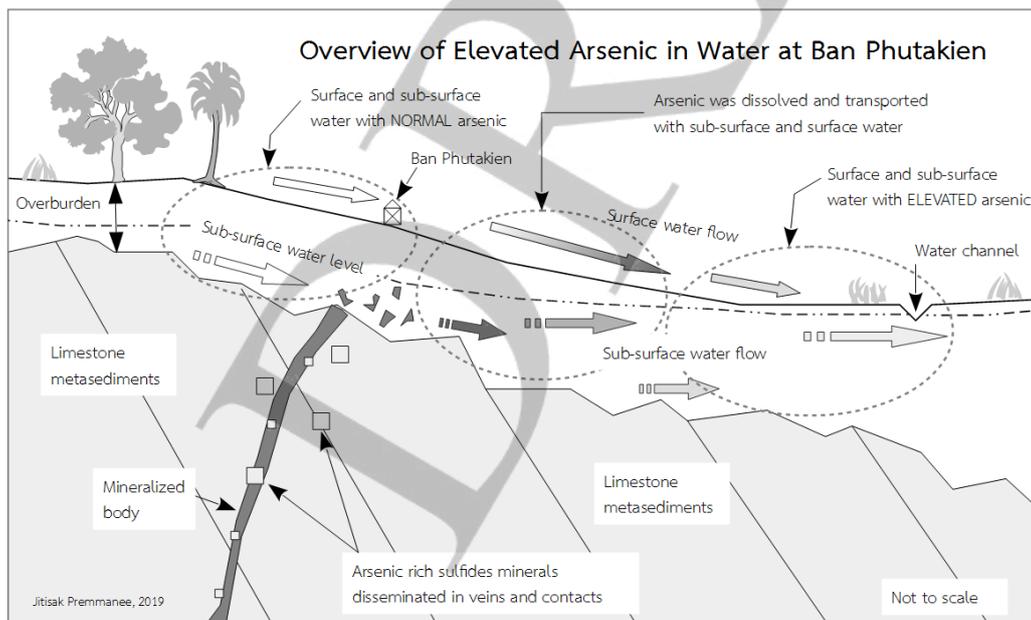


Figure 4. Possible transport mechanism of arsenic at Ban Phutakien, Banrai, Uthai Thani.

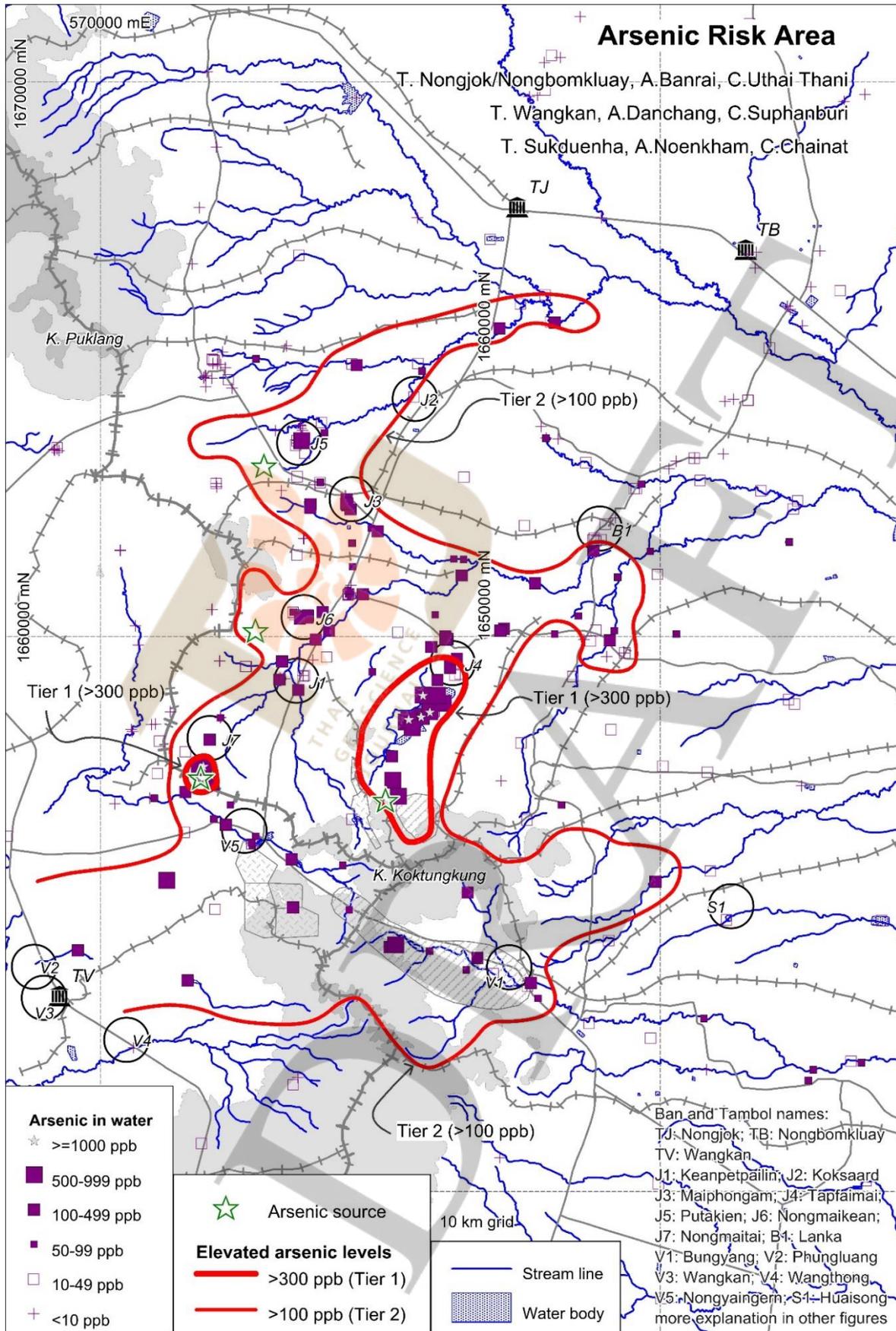


Figure 5. Arsenic risk areas, Banrai/Danchang/Noenkham, Uthai Thani/Suphanburi /Chainat.



Figure 6. Nongmaikeyan water reservoir showing quartz veins in altered granite with disseminated arsenic rich sulfide minerals.

should be concurrently conducted for confirmation. It is estimated that arsenic may be mobilized for 10 km from a source.

2. The 100 ppb threshold value in surface water assay, a simple and rational figure, has separated the risk area in this study, but may not be effective in the others. However, the figure may be used for a quick evaluation basis beside the MPL values (10-50 ppb for drinking and consumable water).

3. Local residents in the risk and nearby areas should be made aware of this elevated arsenic in surface water. Large water supply system should consider bringing from outside the risk area with acceptable arsenic level. Rain water is the best alternative for drinking water.

4. Any related government authorities should continue their roles in the area, such as

UTPHO, DMR, Local Administrative Offices, etc.

5. A few research type questions remain un-answered, such as low arsenic content in water at the reservoir where some rich arsenic sulfide minerals was identified, distribution pattern or behavior of arsenic in surface and ground water at B. Phutakien, or dispersion distance of arsenic from source into water system and surrounded area.

Acknowledgement

The authors gratefully thank the Department of Mineral Resources who provide funding and gave us opportunity to study this project.

We would like to thank the Uthai Thani Public Health Office personnel, especially to Ms. Sukanya Pataisophon who provide all information related to this study

as well as helping us in the field, to all health care personnel at Ban Maiphongam Health Promoting Hospital, T.Nongjok, A.Banrai, C.Uthai Thani who help collecting samples. Also, we like to express our sincere to T. Nongjok, Khun Sangop, who assist us in the field.

Last, we like to give special thanks to the officials in the Division of Mineral Resources Analysis and Identification, DMR who help to collect all samples, preparation and analysis. They also help to review and compile the data for this project. Thank to K. Thawatchai Cheulaowanich, K.Nikhon Chaiwongsen who gave us valuable comments and discussion.

References

- Jariyawat, P. (1996). Tin Deposit in Central Thailand, in *Economic Geology Division Meeting Year 1996* (in Thai) (pp.132-143). Bangkok: Department of Mineral Resources.
- Premmanee, J. (2019a): *Study on Possible Sources of Arsenic Distribution in Uthai Thani province* (in Thai) (p.75). Bangkok: Department of Mineral Resources.
- Premmanee, J. (2019b): Arsenic and Cadmium: Under the DMR Hazardous Elements Project, in *Geothai 2562* (pp. 3-5). Bangkok: The Berkley Hotel Pratunam, 16-17 September 2019.
- World Health Organization (2020). *Arsenic*, from <https://www.who.int/news-room/fact-sheets/detail/arsenic>
- Standard Methods For the Examination of Water and Wastewater (2017). 3113 Metals by Electrothermal Atomic Absorption Spectrometry, from <https://www.standardmethods.org/doi/10.2105/S-MWW.2882.045>
- Hazardous Waste Test Methods (2019). *Hazardous Waste Test Methods / SW-846.*, from <https://www.epa.gov/hwsw846>
- Pollution Control Department of Thailand (2020). *Standard for Arsenic in Drinking Water*, from http://www.pcd.go.th/info_serv/reg_std_water01.html#s3 (in Thai)
- Pollution Control Department of Thailand (2020). *Standard for Arsenic in Surface Water*, from http://www.pcd.go.th/info_serv/reg_std_water05.html#s3 (in Thai)
- Pollution Control Department of Thailand (2020). *Standard for Arsenic in Ground Water*, from http://www.pcd.go.th/info_serv/reg_std_water03.html (in Thai)
- Pollution Control Department of Thailand (2020). *Standard for Arsenic in Agricultural Soil*, from http://www.pcd.go.th/info_serv/reg_std_soil01.html (in Thai)
- Department of Disease Control (2019). *Disease Caused by Arsenic or Its Toxic Compound*, from <http://envocc.ddc.moph.go.th/contents/view/187> (in Thai)