The impact of heavy metals from toxic hotspots in Thailand on inhabitants and the environment

Authors: Vaclav Mach, Marek Sir, Akarapon Teebthaisong
Supporting data: Martin Bystriansky, Jindrich Petrlik, Autthaporn Ritthichat, Penchom Saetang, Jitka Strakova

EUROPEAN UNION

ARNIKA

ECOLOGICAL ALERT AND RECOVERY-THAILAND

GLOBAL GREENGRANTS FUND

IPEN
a toxics-free future

สสส
Thai Health

TRANSITION

Sweden
Sverige

The impact of heavy metals from toxic hotspots in Thailand on inhabitants and the environment

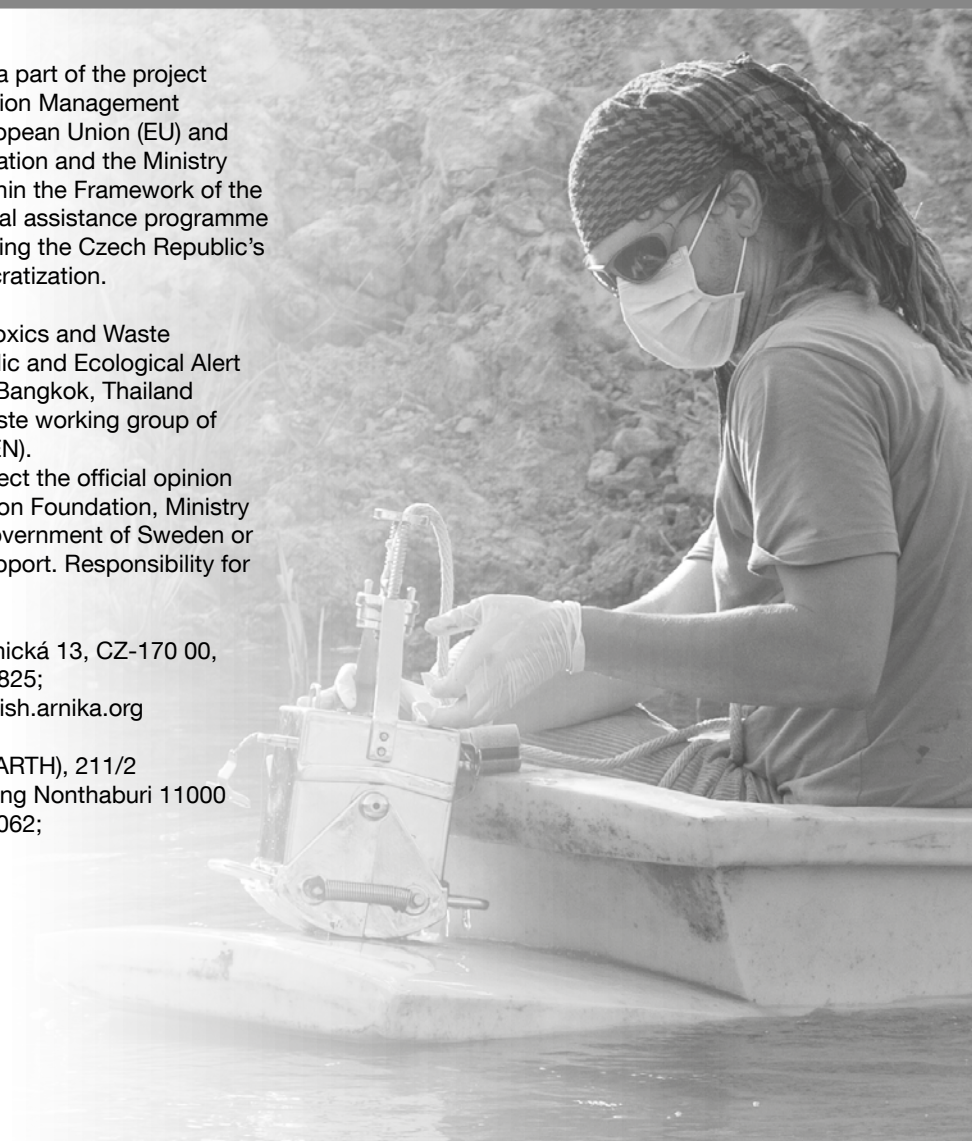
Authors: Vaclav Mach, Marek Sir, Akarapon Teebthaisong
Supporting data: Martin Bystriansky, Jindrich Petrlik, Autthaporn Ritthichat, Penchom Saetang, Jitka Strakova

This report was prepared and published as a part of the project "Increasing Transparency in Industrial Pollution Management through Citizen Science" funded by the European Union (EU) and co-funded by Thai Health Promotion Foundation and the Ministry of Foreign Affairs of the Czech Republic within the Framework of the Transition Promotion Programme – a financial assistance programme supporting democracy and human rights using the Czech Republic's experience with social transition and democratization.

The Project was implemented by Arnika – Toxics and Waste Programme based in Prague, Czech Republic and Ecological Alert and Recovery - Thailand (EARTH) based in Bangkok, Thailand as part of the work of Dioxin, PCBs and Waste working group of International POPs Elimination Network (IPEN).
The content of this publication does not reflect the official opinion of the European Union, Thai Health Promotion Foundation, Ministry of Foreign Affairs of the Czech Republic, Government of Sweden or any of the institutions providing financial support. Responsibility for the content lies entirely with authors.

Arnika – Toxics and Waste Programme, Dělnická 13, CZ-170 00, Prague 7, Czech Republic; tel. +420774406825;
email: toxic@arnika.org; website: http://english.arnika.org

Ecological Alert and Recovery - Thailand (EARTH), 211/2 Ngamwongwan Rd., Soi 31 Bangkhen, Muang Nonthaburi 11000 Thailand; tel: +6629525061, Fax: +6629525062;
website: http://www.earththailand.org/th/



EUROPEAN UNION

ARNIKA

IPEN a toxics-free future

Thai Health

TRANSITION

Sweden Sverige

1. Introduction

This study is focused on the presentation and discussion of the data related to contamination of soils and sediments by heavy metals. Environmental samples were obtained during a sampling campaign conducted in Thailand in February 2016.

Sampling campaigns represent an important part of the project "Increasing Transparency in Industrial Pollution Management through Citizen Science". This is a joint project of the Czech non-governmental organization Arnika Association and the Thai partner, Ecological Alert and Recovery – Thailand (EARTH). The main goals of the project are to increase the negotiating power of communities affected by industrial pollution in their demands for corporate and government accountability and to increase transparency in industrial pollution management policies and processes in Thailand. These goals comprise: 1) enabling communities affected by industrial pollution to generate scientific evidence, 2) broadening awareness about environmental and health damages from industrial pollution, and 3) promoting citizen right-to-know in Thailand and raise awareness on good practices of right-to-know legislation from the European Union, as a participatory mechanism for pollution reduction and prevention.

2. Sampling sites

Sediment and soil samples were taken on eight hot-spot areas in several regions of Thailand. The hot-spot areas are as follows: Loei, Khon Kaen, Map Ta Phut, Tha Tum, Samut Sakhon, Praeksa, Chachoengsao, and Rayong River Estuary. One sediment sample was taken in background locality in Chanthanburi Province. The detailed list of samples is presented in the Table 1 in Annex.

Loei

There were 20 samples of sediments and two crystallic samples taken on Wangsaphung location in Loei Province. Large sampling took place in the area below the dam of the settling pond where is a small brook (Lek brook) and agricultural land is located there.

Khon Kaen

There were 8 samples of sediments taken on Nam Phong location in Khon Kaen Province. Sampling took place in the area, which has a large number of factories (pulp and paper industry and power plants). Sampling was also focused on coastal sediment and fish ponds.

Map Ta Phut

There were 15 sediment samples upstream and downstream and 2 coastal sediment samples taken on Map Ta Phut Industrial Estate located in Rayong Province (power plants, chemical industry, oil rafineries). Large sampling took place in the area nearby heavy industrial development zone.

Tha Tum

There were 16 sediment samples and an ash sample taken on Tha Tum location, subdistrict in Prachinburi Province, which has a coal-fired power plant and various types of industries. Upstream and downstream sediments were taken on that site.

Samut Sakhon

There were 16 sediments samples, 3 soil samples, and an ash sample taken on Muang location in Samut Sakhon Province. Large sampling took place in the province, which has a large number of foundries and mills, and large and medium sized of recycle factories. Sampling was also focused on coastal sediment and fish ponds.

Praeksa

There were 6 samples of sediments taken on location of the Praeksa landfill in Samut Prakan Province. Sampling took place in the area around the landfill – in water channels around the landfill, ponds for fishing and inhabited area.

Chachoengsao

There were 12 sediment samples and an additional sample of white gel taken on the Chachoengsao hot-spot. Three locations with different sources of pollution were sampled – surroundings of industrial park, ash disposal site in eukaliptus plantation and aluminium smelting plant.

Rayong River Estuary

There were 3 samples of coastal sediments near the IRPC Industrial Zone in Rayong Province.

Chanthanburi

There was one background sediment sample taken in Khao Chamao-Khao Wong National Park in Chanthanburi Province.

3. Sampling procedures and analytical methods

Samples of soils and sediments were usually taken as mixed samples formed by several partial samples taken in various places of the given locality. Soil samples were taken by means of a shovel into polyethylene containers with screw lids or into polyethylene bags. Sediment samples were taken by a core sampler into polyethylene containers. During soil sampling, the sampling shovel and core sampler were washed with tap water or with available river or lake water. Samples were stored in a cold and dark storage before analysis.

After the transport to the laboratory samples were homogenised and a representative part (50 g) was used for the determination of dry matter by a gravimetric method. Another representative part was taken for analysis of metals (cadmium, copper, chromium, lead, zinc, mercury, and arsenic) by mineralization procedure. Analytical procedure of mineralization

was as follows: 5 g of sample was placed into a beaker together with 30 ml of distilled water and 10 ml of concentrated nitric acid. Sample was boiled for the period of 2 hours. Then it was filtered through a fluted filter paper. Metals were determined in mineralize by atomic absorption and emission spectrometer SensAA. Mercury was measured directly in solid samples by AMA analyser (AMA254, Altec). The content of metals was expressed in mg/kg of dry matter.

4. Results

Results of analytical measurement of heavy metals are presented in the Table 2 in the Annex.

5. Discussion

Various legal standards and auxiliary evaluation criteria are presented in this chapter. Then the metals concentrations determined in samples from the investigated sites are compared to respective legal standards. Finally, target samples with high content of metals were chosen for calculation of cancerogenic and non-carcinogenic risks associated with them.

5.1 Legal standard

The pollutant concentrations determined in the samples from investigated sites were compared to maximum or approximate allowed concentrations of these pollutants as defined in national and international decree, norms and laws. The pollution criteria of heavy metals for sediments and soils are presented in the table 3.

First concentrations of pollutants in sediments were compared with values in a drafted regulation establishing Sediment Quality Criteria. There are two types of drafted Sediment Quality Criteria in Thailand. The first one is for purpose of benthic animal protection and the second for purpose of human health protection. The second one is expressed only in units of microgram per kilogram of total organic carbon. As we did not measured content of organic carbon in sediment samples, we used just Sediment Quality Criteria for protection of benthic animals. If the concentration of substance is not more than three times of the threshold, it shows that substances are likely to affect the benthic animals, so surveillance should be conducted. If the concentration of substance is more than three times of threshold, it shows that substances can affect benthic animals, so should control the release of hazardous substances from the source. In that case hazardous substances in contaminated sediments should be reduced by dredging or other methods.

Concentrations of pollutants in soils were compared with values of Soil Quality Standards established by Notification of National Environmental Board No. 25, B.E. (2004) issued under the Enhancement and Conservation of National Environmental Quality Act published in the Royal Government Gazette No. 121 in 2004. Different Thai Soil Quality Standards are used for agricultural and habitat soils than for soils with other purposes. As soil samples were not collected at agricultural soil or in wildlife habitats, Soil Quality Standards for soils with other purposes were applied.

For a comparison RSL (Regional Screening Levels) are also presented in the list of pollution criteria in Table 3. These levels were derived using exposure parameters and factors

representing the maximum justifiable chronicle exposure. This exposure is based on the direct contact with target compounds. Regional screening levels were derived by US EPA (United States Environmental Protection Agency) for some compounds that have CAS registration number. RSL are concentration of chemical compounds in the environment (soils, sediments, water or air). If RSL are exceeded, further exploration or removal of contamination should be carried out. Some specifics should be taken into account, when RSL are used - such as content of some substances as a result of geological conditions.

Table 3: Legal standards for sediments and soils (As arsenic, Hg mercury, Zn zinc, Cd cadmium, Cu copper, Cr chromium, Pb lead). The content of elements is given in mg/kg of dry matter.

	As	Hg	Zn	Cd	Cu	Cr	Pb
Sediment quality criteria for protection of benthic animals (Draft Regulation in Thailand)	10	0.2	80	0.16	21.5	45.5 (Cr^{Total})	36
Three times of threshold of sediment quality criteria for protection of benthic animals (Draft Regulation in Thailand)	30	0.6	240	0.48	64.5	136.5 (Cr^{Total})	108
Soil Quality Standards for Habitat and Agriculture (Thailand)	3.9	23	-	37	-	300 (Cr^{6+})	400
Soil Quality Standards for Other Purposes (Thailand)	27	610	-	810	-	640 (Cr^{6+})	750
Levels of pollution limits – industrial areas (based on US EPA)	2.4	43	310,000	800	41,000	5.6 (Cr^{6+})	800
Levels of pollution limits – other areas (based on US EPA)	0.61	10	23,000	70	3,100	0.29 (Cr^{6+})	400

5.2 Evaluation of pollutants levels

The overall mean value of the total arsenic for different soils is estimated as 6.83 mg/kg. The background contents of various soil groups range from <0.1 to 67 mg/kg. The background levels of mercury in soils are not easy to estimate due to the widespread mercury pollution.

Data reported for various soils on a worldwide basis show that mean concentrations of mercury in surface soils do not exceed 1.5 mg/kg. Most top soils contain increased amounts of mercury, especially near mining and smelting areas. The range of mercury in soils is usually between 0.004 to 0.3 mg/kg. The general values for the average total zinc contents in soils of different groups, all over the world, range between 60 and 89 mg/kg. Contents of zinc are closely associated with soil texture and usually are the lowest in light sandy soil. Its elevated concentration is often observed in calcareous and organic soils. The world average soil cadmium concentration is estimated as 0.41 mg/kg. The main factor determining cadmium contents of soils is parent material. The average contents of cadmium in soils lie between 0.2 and 1.1 mg/kg. The general values for the average total copper contents in soils of different groups all over the world range between 14 and 109 mg/kg. Contents of copper are closely associated with soil texture and usually are the lowest in light sandy soils and the highest in loamy soils. The world soil average content of chromium in soils has been established as 60 mg/kg. The overall mean value of total lead for different soils is estimated as 27 mg/kg. Its background average contents given for soils of different countries vary from 18 to 27 mg/kg. Background Thai concentrations of heavy metals in the sediment sample from Chanthanburi (notation CHA 1 in Table 2) are lower or in the worldwide ranges mentioned above.

Loei

Based on the measured data, location below the dam of the settling pond in the Loei hot-spot area shows increased concentrations mainly of arsenic, cadmium and copper. Several sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for arsenic, cadmium and copper. The highest concentrations of arsenic (162.17 mg/kg) and cadmium (39.25 mg/kg) were found in the upper part of sediment in sample LOE 8. Increased concentrations of metals are found in places where the probable leakage of water from the settling pond is identified. In context of the backrgound levels and pollution criteria, signicicantly increased concentrations of arsenic, cadmium, and increased level of copper were found in investigated samples on location Loei.

Khon Kaen

Based on the measured data, increased levels mainly of arsenic and cadmium were found in sediment samples in the Khon Kaen hot-spot area. One sample (KK 8) has also increased concentration of mercury (0.46 mg/kg). Few sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for arsenic and cadmium. The highest concentrations of arsenic (47.84 mg/kg) and cadmium (2.99 mg/kg) were found in the sediment samples KK 10 and KK 11, respectively. In context of the backrgound levels and pollution criteria, increased concentrations of arsenic, mercury, and cadmium were found in investigated samples on location Khon Kaen.

Map Ta Phut

Based on the measured data, increased average concentration of most of heavy metals, mainly arsenic, mercury, zinc, copper, and chromium were found in downstream sediments comparison to upstream in the Map Ta Phut hot-spot area. Several sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for mercury, zinc, cadmium, and copper. The highest concentration of mercury (1.48 mg/kg) was found in the sediment sample MTP 2-6 (1). The highest concentrations of zinc (1062.24 mg/kg), cadmium (2.95 mg/kg), and copper (23.56 mg/kg) were found in the

sediment sample MTP 1-17. In context of the backrgound levels and pollution criteria, increased concentrations of arsenic, cadmium and zinc (and also mercury in several cases) were found in investigated samples on location Map Ta Phut mainly in downstream sediments.

Tha Tum

Based on the measured data, location Tha Tum shows increased concentrations mainly of arsenic, cadmium, and chromium. Some sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for arsenic, cadmium, copper, and chromium. The highest concentrations of arsenic (47.77 mg/kg) and cooper (82.42 mg/kg) were found in the sediment samples TT 2-1 and TT 1-2, respectively. The highest concentrations of cadmium (12.17 mg/kg) and chromium (402.55 mg/kg) were found in the sediment sample TT 1-7. In context of the backrgound levels and pollution criteria, increased concentrations of arsenic, cadmium and chromium were found in investigated samples on the Tha Tum hot-spot area.

Samut Sakhon

Based on the measured data, high levels of all measured heavy metals were found mainly in sediments from the channels around factories in the Samut Sakhon hot-spot area. High concentration of mercury was also found in fishing pond nearby smelting plant. Many sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for one of traced metal (arsenic, mercury, zinc, cadmium, copper, chromium, and lead). Two soil samples (A3, SMS 1-2) exceeded soil quality standards of soils for other purposes for arsenic, chromium, or lead. The highest concentrations of arsenic (40.35 mg/kg), chromium (1701.75 mg/kg), and lead (18990 mg/kg) were found in the sediment samples SMS 2-7, SMS 2-1 and A3, respectively. The highest concentrations of mercury (2.39 mg/kg), zinc (1650.5 mg/kg), cadmium (18.65 mg/kg), and cooper (792.62 mg/kg) were found in the sediment sample SMS 2-6. In context of the backrgound levels and pollution criteria, increased concentrations of all traced metals (arsenic, mercury, zinc, cadmium, copper, chromium, and lead) were found in investigated samples on the Samut Sakhon hot-spot area.

Praeksa

Based on the measured data, location around landfill in the Praeksa hot-spot area shows increased concentrations mainly of arsenic, zinc, and cadmium and copper. The highest concentrations of heavy metals were found in canal along the landfill wall and then along the fish pond. Many sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for arsenic, zinc, cadmium, or copper. The highest concentrations of arsenic (51.94 mg/kg) and cadmium (4.42 mg/kg) were found in the sediment sample PR 1. The highest concentrations of zinc (1087.38 mg/kg) and copper (99.39 mg/kg) were found in the sediment sample PR 8. In context of the backrgound levels and pollution criteria, significantly increased concentrations of arsenic, cadmium, zinc and copper were found in investigated samples on location Praeksa. The highest risk on the locality is the leakage of hazardous leachate from the landfill. Highest concentration of heavy metals were found in channel where water flows in the direction to the dump site in high tide and rainy season and water flows naturally out from the dump site in low tide and dry season. Ongoing research should be carried out to detect the spread of contamination resulting in any toxic

threats to human health and environment in the future. In general, landfill leachates represent a risk to the environment due to their composition. A leachate collection and treatment system should be installed on any landfill site – for hazardous or municipal solid waste.

Chachoengsao

Based on the measured data, high levels of arsenic, cadmium, and chromium were found in sediment collected at the effluent discharge point. Increased levels of arsenic and mercury were found in wetlands used in agriculture, which are expected to receive effluent from the eucalyptus plantation. Several sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for arsenic, cadmium, copper, or chromium. The highest concentration of copper (51.94 mg/kg) was found in the sediment sample KHS 5. The highest concentrations of arsenic (136.39 mg/kg), cadmium (26.7 mg/kg) and chromium (437.02 mg/kg) were found in the sediment sample KHS 4. In context of the backrgound levels and pollution criteria, increased concentrations of arsenic, cadmium, copper, and chromium were found in investigated samples on the Chachoengsao hot-spot area. Further attention should be focused on the effluent discharge drainage near industrial park.

Rayong River Estuary

Based on the measured data, location around the IRPC Industrial Zone in Rayong Province shows increased concentrations mainly of cadmium. All three sediment samples exceeded three times of threshold of sediment quality criteria for protection of benthic animals for cadmium. The highest concentration of cadmium (1.96 mg/kg) was found in the sediment sample IRPC 2. In context of the backrgound levels and pollution criteria, increased concentrations of cadmium were found in investigated samples on the Rayong River Estuary hot-spot area. Ongoing research should be carried out to detect any threats resulting from this content of cadmium.

5.3 Health risk assessment

Health risk assessments is based on the assumption that, under certain specified conditions there is a risk of damage to human health, while the risk rate from zero to maximum is determined by type of activity, respectively staying on the location and conditions of the environment. Zero health risk is not really possible; however, the risk of damage must be minimized to an acceptable level in terms of health and environmental risks. To determine the risk, it is necessary to clarify the most important transport routes and then specify exposure scenarios potentially threatened recipients. There are two approaches to evaluate the dose effects – for substances with threshold (non-carcinogenic) and non-threshold (carcinogenic) effect.

For substances with non-carcinogenic effect it is anticipated the body repair processes which are able to successfully cope with exposure to a toxic substance, but only to a certain dose, then the effect is already apparent. Threshold, known as the NOAEL (No Observed Adverse Effect Level), is the exposure level at which no adverse effects is observed. Alternatively, values LOAEL (Lowest Observed Adverse Effect Level) can be used. They correspond to the lowest dose levels at which the negative health effects are observed. ADI (Acceptable Daily Intake) or RfD (Reference Dose) are derived using NOAEL or LOAEL values and relevant UF (Uncertainty Factors) or MF (Modifying Factors). These factors have to compensate for

all the uncertainty and variability in determining the NOAEL, respectively LOAEL values. The results of calculation (ADI or RfD) are usually much lower than NOAEL or LOAEL and represent the estimation of a daily exposure to the human population (including sensitive population groups), which is very likely to pose no risk of adverse effects to human health, even if it lasts throughout lifetime. In the case of carcinogenic substances, it is assumed that there is no such a dose that would not cause modifications at the molecular level and subsequently lead to the formation of malignant disease. Evaluation of the dose - effect relation uses parameter SF (Slope Factor), which indicates the possible top edge of the probability of malignant disease per unit of average daily dose received throughout lifetime.

For the calculation of risk exposure to substances with non-carcinogenic effect a received and absorbed dose with acceptable toxicological intake of the substance is compared (i.e. RfD – Reference Dose). The risk level then represents Hazard Quotient HQ. The calculation is performed according to the equation:

$$\mathrm{HQ} = \frac{E}{\mathrm{RfD}}$$

E – parameter Average Daily Dose (ADD) or Lifetime Average Daily Dose (LADD), respectively Chronic Daily Intake (CDI) (mg/kg.day);
RfD – Reference Dose (mg/kg.day).

The calculation method for substances with carcinogenic effect uses parameter ELCR - Excess Lifetime Cancer Risk (dimensionless indicator corresponding to the probability of developing cancer with lifetime exposure, which can be described by the following equation:

$$\mathrm{ELCR} = \mathrm{CDI} \cdot \mathrm{SF}$$

$$\mathrm{ELCR} = \mathrm{LADD} \cdot \mathrm{SF}$$

CDI – parameter Chronic Daily Intake, respectively Lifetime Average Daily Dose (LADD) relative to lifetime exposure of 70 years (mg/kg.day);
SF – Slope Factor (mg/kg.day).

Table 4: Agents classified by the IARC monographs.

Group 1	Carcinogenic to humans
Group 2A	Probably carcinogenic to humans
Group 2B	Possibly carcinogenic to humans
Group 3	Not classifiable as to its carcinogenicity to humans
Group 4	Probably not carcinogenic to humans

The International Agency for Research on Cancer (IARC) recognizes: arsenic and inorganic arsenic compounds as Group 1 – Carcinogenic to humans, lead as Group 2B - Possibly carcinogenic to humans, inorganic compounds of lead as Group 2A - Probably carcinogenic to humans and organic compounds of lead as Group 3 - Not classifiable as to its carcinogenicity to humans.

5.4 RISC model

Risk-Integrated Software for Cleanups (RISC) is software developed to assess human health risks in contaminated areas. It can integrate up to fourteen possible exposure pathways, and calculates the risks associated with them, both carcinogenic and non-carcinogenic.

If the carcinogenic risk (ELCR) is $<10^{-6}$, it is considered that there are not significant adverse health effects. If it is between 10^{-6} and 10^{-4}, adverse effects may occur in the future, thus

factors need to be taken into consideration. Finally, if it is $>10^{-4}$, the risk is unacceptable and serious measures must be immediately taken. A hazard quotient (HQ) <1 is considered that there are not significant adverse health effects, whereas a HQ >1 implies that potential adverse health effects exist. More research must be done in order to determine any toxic threats. Results are based on standard calculation coefficients defined in Risk-Integrated Software for Cleanups (RISC). Results are related to the average population.

Samples collected on the hot-spot areas were used to perform human health risk assessment. On the basis of the toxicological data risk assessment using RISC software was performed for four heavy metals: arsenic, mercury, cadmium, and lead. Results of the calculation of human health risks which exceeded 10^{-6} for ELCR and 1 for HQ are presented in Tables 5 to 10.

Table 5: Results of the calculation of human health risks for adults associated with arsenic in selected samples - carcinogenic risk (ELCR).

Hot spot area	Sample	Concentration (mg/kg)	Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 7	39.18	4.7E-07	1.4E-07	1.3E-05	1.4E-05
	LOE 8	162.17	1.9E-06	6.0E-07	5.5E-05	5.8E-05
	LOE 1 D	42.23	5.1E-07	1.6E-07	1.4E-05	1.5E-05
Khon Kaen	KK 10	47.84	5.7E-07	1.8E-07	1.6E-05	1.7E-05
Tha Tum	TT 1-3	38.00	4.6E-07	1.4E-07	1.3E-05	1.4E-05
	TT 1-4	42.37	5.1E-07	1.6E-07	1.4E-05	1.5E-05
	TT 1-6	45.89	5.5E-07	1.7E-07	1.6E-05	1.6E-05
	TT 2-1	47.77	5.7E-07	1.8E-07	1.6E-05	1.7E-05
Samut Sakhon	SMS 1-8	31.93	3.8E-07	1.2E-07	1.1E-05	1.1E-05
	SMS 1-9	32.39	3.9E-07	1.2E-07	1.1E-05	1.2E-05
	SMS 2-2	117.96	1.4E-06	4.4E-07	4.0E-05	4.2E-05
	SMS 2-7	40.35	4.8E-07	1.5E-07	1.4E-05	1.4E-05
	SMS 2-12	35.28	4.2E-07	1.3E-07	1.2E-05	1.3E-05
	A3	28.200	3.4E-07	1.0E-07	9.6E-06	1.0E-05
Praeksa	PR 1	51.94	6.2E-07	1.9E-07	1.8E-05	1.8E-05
	PR 2	39.79	4.8E-07	1.5E-07	1.4E-05	1.4E-05
	PR 4	41.38	5.0E-07	1.5E-07	1.4E-05	1.5E-05
	PR 8	45.66	5.5E-07	1.7E-07	1.6E-05	1.6E-05
Chachoengsao	KHS 4	136.39	1.6E-06	5.0E-07	4.6E-05	4.9E-05

Table 6: Results of the calculation of human health risks for children associated with arsenic in selected samples - carcinogenic risk (ELCR).

Hot spot area	Sample	Concentration (mg/kg)	Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 4	12.91	3.5E-06	2.1E-07	6.6E-06	1.0E-05
	LOE 5	25.69	6.9E-06	4.1E-07	1.3E-05	2.0E-05
	LOE 6	19.21	5.2E-06	3.1E-07	9.8E-06	1.5E-05
	LOE 7	39.18	1.1E-05	6.3E-07	2.0E-05	3.1E-05
	LOE 8	162.17	4.4E-05	2.6E-06	8.3E-05	1.3E-04
	LOE 24	22.13	6.0E-06	3.5E-07	1.1E-05	1.8E-05
	LOE 1 D	42.23	1.1E-05	6.8E-07	2.2E-05	3.4E-05
Khon Kaen	KK 10	47.84	1.3E-05	7.7E-07	2.4E-05	3.8E-05
	KK 11	25.96	7.0E-06	4.2E-07	1.3E-05	2.1E-05
Map Ta Phut	MTP 1-7	27.72	7.5E-06	4.4E-07	1.4E-05	2.2E-05
Tha Tum	TT 1-2	25.82	7.0E-06	4.1E-07	1.3E-05	2.1E-05
	TT 1-3	38.00	1.0E-05	6.1E-07	1.9E-05	3.0E-05
	TT 1-4	42.37	1.1E-05	6.8E-07	2.2E-05	3.4E-05
	TT 1-6	45.89	1.2E-05	7.3E-07	2.3E-05	3.7E-05
	TT 1-9	25.90	7.0E-06	4.1E-07	1.3E-05	2.1E-05
	TT 2-1	47.77	1.3E-05	7.6E-07	2.4E-05	3.8E-05
Samut Sakhon	SMS 1-1	22.09	6.0E-06	3.5E-07	1.1E-05	1.8E-05
	SMS 1-3	27.59	7.4E-06	4.4E-07	1.4E-05	2.2E-05
	SMS 1-5	24.57	6.6E-06	3.9E-07	1.3E-05	2.0E-05
	SMS 1-6	24.87	6.7E-06	4.0E-07	1.3E-05	2.0E-05
	SMS 1-8	31.93	8.6E-06	5.1E-07	1.6E-05	2.5E-05
	SMS 1-8	24.01	6.5E-06	3.8E-07	1.2E-05	1.9E-05
	SMS 1-9	32.39	8.7E-06	5.2E-07	1.7E-05	2.6E-05
	SMS 1-10	23.55	6.4E-06	3.8E-07	1.2E-05	1.9E-05
	SMS 2-2	117.96	3.2E-05	1.9E-06	6.0E-05	9.4E-05
	SMS 2-7	40.35	1.1E-05	6.5E-07	2.1E-05	3.2E-05
	SMS 2-12	35.28	9.5E-06	5.6E-07	1.8E-05	2.8E-05
	A3	28.200	7.6E-06	4.5E-07	1.4E-05	2.2E-05
Praeksa	PRE 1-1	19.65	5.3E-06	3.1E-07	1.0E-05	1.6E-05
	PR 1	51.94	1.4E-05	8.3E-07	2.6E-05	4.1E-05
	PR 2	39.79	1.1E-05	6.4E-07	2.0E-05	3.2E-05
	PR 4	41.38	1.1E-05	6.6E-07	2.1E-05	3.3E-05
	PR 5	23.67	6.4E-06	3.8E-07	1.2E-05	1.9E-05
	PR 8	45.66	1.2E-05	7.3E-07	2.3E-05	3.6E-05
Chachoengsao	KHS 2	21.87	5.9E-06	3.5E-07	1.1E-05	1.7E-05
	KHS 4	136.39	3.7E-05	2.2E-06	7.0E-05	1.1E-04

Table 7: Results of the calculation of human health risks associated with arsenic in selected samples – hazard quotients (HQ).

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 8	162.17	A	3.4E-02	1.0E-02	9.6E-01	1.0
			C	1.2E+00	6.8E-02	2.1E+00	3.3
Samut Sakhon	SMS 2-2	117.96	C	8.4E-01	5.0E-02	1.5E+00	2.4
Praeksa	PR 1	51.94	C	3.7E-01	2.2E-02	6.8E-01	1.1
Chachoengsao	KHS 4	136.39	C	9.7E-01	5.7E-02	1.8E+00	2.8

Table 8: Results of the calculation of human health risks associated with mercury in selected samples – hazard quotients (HQ).

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Samut Sakhon	SMS 2-10	10.32	A	7.3E-02	1.4E-03	3.1E+00	3.2
			C	2.2E-03	2.2E-03	1.3E+00	1.3

Table 9: Results of the calculation of human health risks for adults associated with cadmium in selected samples – hazard quotients (HQ).

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 7	15.33	C	6.6E-02	9.8E-05	1.7E+00	1.8
	LOE 8	39.25	C	1.7E-01	2.5E-04	4.3E+00	4.5
			A	5.1E-03	5.1E-05	1.8E+00	1.8
	LOE 1 C	9.92	C	4.3E-02	6.3E-05	1.1E+00	1.1
	LOE 1 D	19.71	C	8.5E-02	1.3E-04	2.2E+00	2.3
Tha Tum	TT 1-7	12.17	C	5.2E-02	7.8E-05	1.3E+00	1.4
Samut Sakhon	SMS 2-6	18.65	C	8.0E-02	1.2E-04	2.1E+00	2.1
	SMS 2-1	19.67	C	8.5E-02	1.3E-04	2.2E+00	2.2
Chachoengsao	KHS 4	26.70	C	1.1E-01	1.7E-04	2.9E+00	3.1
			A	3.5E-03	3.5E-05	1.2E+00	1.2
	KHS 4a	22.73	C	9.8E-02	1.5E-04	2.5E+00	2.6
			A	3.0E-03	3.0E-05	1.0E+00	1.0

Table 10: Results of the calculation of human health risks associated with lead in selected samples – hazard quotients (HQ).

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Samut Sakhon	A1	2197	C	1.3E+00	2.6E-02	0.0E+00	1.3
	A3	18990	C	1.1E+01	2.3E-01	0.0E+00	11.4

The carcinogenic and non-carcinogenic risks from arsenic for local residents from several exposure pathways were evaluated in all the hot-spot areas. This included assessing exposure to heavy metals by ingestion of soil (including dust ingestion), dermal contact, and crops (vegetable) consumption. Values of arsenic Excess Lifetime Cancer Risk are for 19 and 36 samples between 10^{-6} and 10^{-4}, for adults and children respectively. In these cases adverse effects may occur in the future, thus factors need to be taken into consideration on relevant locations. Arsenic hazard quotients (HQ) which represent non-carcinogenic risk have exceeded value 1 in four and one sediment samples (from Loei, Samut Sakhon, Praeksa, Chachoengsao) for children and adults respectively. Arsenic health quotients in these sediment samples could inflict adverse health effect for children or adults.

The mercury, cadmium, and lead non-carcinogenic risks for local residents from several exposure pathways were also evaluated for sediment and soil samples collected on the hot-spot areas. Unacceptable risks (HQ >1) have been identified in one sediment sample for mercury (SMS 2-10) and in two samples for lead (ash A1 and soil A2), all from the Samut Sakhon hot-spot area. Cadmium hazard quotients for children have exceeded value 1 in nine sediment samples from four hot-spot areas (Loei, Tha Tum, Samut Sakhon, and Chachoengsao). Three samples have also exceeded cadmium hazard quotients for adults (one from Loei and two from Chachoengsao). These results make cadmium second most risky heavy metal for human health on the hot-spot areas.

6. Conclusions

This study focused on monitoring and evaluation of concentrations of heavy metals in sediments, soils, and ashes at eight industrial hot-spot areas in Thailand. A series of samples were taken at contaminated sites and compared with the legal pollution criteria.

There are several spots where hazardous levels of arsenic, mercury, lead, and cadmium were found in soils and sediments. These levels of pollutants represent significant threats to environment and human health. The high levels of heavy metals were observed in sediments and soils in all the hot-spot areas (especially arsenic and cadmium). Concentration of heavy metals exceed not only levels of sediment quality criteria for protection of benthic animals drafted for Thailand but in some cases also levels of pollution limits for industrial or general use based on US EPA.

Analysis using the Risk-Integrated Software for Cleanups (RISC) indicated the following results. The most risky heavy metal on the hot-spot areas was arsenic followed by cadmium. Several samples polluted with arsenic showed that adverse carcinogenic effects may occur in

the long term. Moreover some of samples polluted with arsenic and cadmium showed exceeded hazard quotient (HQ). A potential adverse health effects exist in this case. More research should be done in order to determine these toxic threats at the studied sites.

The severity of the risks identified on the hot-spot areas depends on the particular use of the local site. On some hot-spots with metallurgical industry, improved assessments for better environmental practices are recommended. In the case of the most contaminated samples, materials should be excavated and removed. Ongoing research should be carried out to detect the spread of contamination resulting in any toxic threats to human health and environment in the future.

7. Literature

US EPA. Regional Screening Levels. [online] http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/docs/params_sl_table_run_JAN2015.pdf

US EPA. Human Health: Exposure Assessment [online] http://www.epa.gov/oswer/riskassessment/human_health_exposure.htm

US EPA 2005. Guidelines for Carcinogen Risk Assessment, EPA/630/P-03/001F

International Agency for Research on Cancer. IARC Monographs on Evaluation of Carcinogenic Risks to Humans. [online] http://monographs.iarc.fr/ENG/Classification/

Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006

Notification of National Environmental Board No. 25, B.E. (2004) issued under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992) published in the Royal Government Gazette No. 121 Special Part 119 D dated October 20, B.E.2547(2004)

8. Annex

Table 1: List of samples taken on hot spots in Thailand.

Hot spot	Sample code	Matrix	Coordinates	Notes
Loei	LOE 1	sediment	17°22'02.1"N 101°40'20.3"E	Lakes in the middle of gold mine
	LOE 2	sediment	17°21'6.1"N 101°38'44.6"E	Pond, upstream the gold mine, Lek Creek
	LOE 3	sediment	17°21'5.0"N 101°38'51.0"E	Lek Creek, Little water stream in the fields (gold mine)
	LOE 4	sediment	17°21'13.8"N 101°39'4.3"E	Lek Creek with standing water in the abandoned rise fields (gold mine)
	LOE 5	sediment	17°21'14.6"N 101°39'7.99"E	Lek Creek, Wetland under dam (gold mine)
	LOE 6	sediment	17°21'14.1"N 101°39'8.3"E	Lek Creek (gold mine)
	LOE 7	sediment	17°21'13.3"N 101°39'14.8"E	Lek Creek, Wetland (gold mine)
	LOE 8	sediment	17°21'14.0"N 101°39'14.3"E	Lek Creek
	LOE 9	sediment	17°21'7.8"N 101°39'26.2"E	Pond (gold mine), TK1/1
	LOE 11	sediment	17°21'1.2"N 101°39'45.1"E	Pond for irrigation (gold mine)
	LOE 12	sediment	17°20' 57.0"N 101°39' 34.3"E	Lek Creek, Wetland on the edge of the field with soya beans (gold mine)
	LOE 20	sediment	17°20'24.9"N 101°40'2.6"E	Huai River, upstream the gold mine
	LOE 21	sediment	17°21'10.5"N 101°40'14.1"E	Huai River, Weir (gold mine)

Hot spot	Sample code	Matrix	Coordinates	Notes
	LOE 22	sediment	17°21'29.99"N 101°40'31.9"E	Downstream Huai River (gold mine)
	LOE 23	sediment	17°21'44.7"N 101°40'6.7"E	Small creek in the middle of field (gold mine)
	LOE 24	sediment	17°21' 31.8" N 101°38'40.1"E	Creek in the bamboo forest, upstream the gold mine
	LOE 25	sediment	17°21'05.9" N 101°38'22.7"E	Little stream upstream Ronghang Lin (gold mine)
	LOE 26	sediment	17°21'22.7" N 101°38'29.1"E	Spring upstream Lek creek in the rubber tree field (gold mine)
	LOE 27	sediment	17°22' 52.5"N 101°38' 27.1"E	Upstream Puk Creek lake (gold mine)
	LOE 28	sediment	17°21'48.2"N 101°39'47.6"E	Puk Creek in soya fields (gold mine)
	LOE 1 C	white crystals	17°22'02.1"N 101°40'20.3"E	Bank of gold mine lake
	LOE 1 D	yellow crystals	17°22'02.1"N 101°40'20.3"E	Bank of gold mine lake
Khon Kaen	KK 3	sediment	16°40'44.9"N 102°43'58.1"E	Chot canal; upstream from Paper and pulp industry; Coal power plant
	KK 4	sediment	16°42'6.04"N 102°44'18.61"E	Paper and pulp industry; Coal power plant; Taken from outflow (30 m) of wasted water reservoir; Water red coloured probably caused by soil particles
	KK 7	sediment	16°43'46.1"N 102°43'21.7"E	Phong river upstream from industry; (Paper and pulp industry; Coal power plant)

Hot spot	Sample code	Matrix	Coordinates	Notes
	KK 8	sediment	16°43'23.5"N 102°44'52.3"E	Chot Canal downstream from industry; (Paper and pulp industry; Coal power plant)
	KK 9	sediment	16°43'23.33"N 102°44'52.70"E	Pond; (Paper and pulp industry; Coal power plant)
	KK 10	sediment	16°43'39.6"N 102°45'04.7"E	Chot Reservoir before enter Phong river; (Paper and pulp industry; Coal power plant)
	KK 11	sediment	16°43'37.3"N 102°45'01.3"E	Rice paddy near Chot reservoir
	KK 13	sediment	16°43'56.02"N 102°45'38.12"E	Phong river; (Paper and pulp industry; Coal power plant)
Map Ta Phut	MTP 1-1	sediment	12°40'34.37"N 101°10'29.66"E	Huai Yai Canal; Waters from petrochemical industry
	MTP 1-6	sediment	12°40'10.98"N 101°10'46.70"E	Ta Kuan Canal
	MTP 1-7	sediment	12°41'30.89"N 101° 9'4.17"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant
	MTP 1-8	sediment	12°40'10.95"N 101° 9'29.18"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant
	MTP 1-12	sediment	12°40'40.75"N 101° 6'49.86"E	Sea; Sai Thong Beach
	MTP 1-13	sediment	12°40'44.52"N 101° 6'33.32"E	Bang Kraphrun Canal

Hot spot	Sample code	Matrix	Coordinates	Notes
	MTP 1-14	sediment	12°40'12.42"N 101° 9'37.71"E	Sea; 120-150 m far away from eastern canal; Chlor-alkali plant; Chemical plant; Coke plant; Government survey 300,000 t of this black mud in the bay
	MTP 1-15	sediment	12°41'26.22"N 101° 7'10.62"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
	MTP 1-16	sediment	12°41'23.50"N 101° 7'12.05"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
	MTP 1-17	sediment	12°40'43.67"N 101° 7'12.01"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
	MTP 2-2	sediment	12°45'32.06"N 101° 9'46.65"E	Canal Huai Phrao; upstream from RIL industrial estate
	MTP 2-3	sediment	12°44'3.23"N 101°10'7.09"E	Canal Huai Phrao; downstream from RIL industrial estate
	MTP 2-5	sediment	12°40'59.83"N 101° 9'46.08"E	East from Chak Mak Canal; Chlor-alkali plant; Chemical plant
	MTP 2-6	sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant
	MTP 2-6 (1)	sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant
	MTP 2-14	sediment	12°43'56.62"N 101° 6'1.24"E	Upstream Bang Kraphrun Canal

Hot spot	Sample code	Matrix	Coordinates	Notes
	MTP 2-15	sediment	12°43'17.11"N 101° 6'37.07"E	Upstream Chak Mak Canal
Tha Tum	TT 1-1	sediment	13°57'2.74"N 101°35'52.07"E	Effluent pond; (Chemical plant; Pulp and paper industry; Coal power plant)
	TT 1-2	sediment	13°57'3.16"N 101°35'50.34"E	Klong Tha Fuek Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
	TT 1-3	sediment	13°57'7.47"N 101°36'0.10"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
	TT 1-4	sediment	13°56'57.71"N 101°36'2.81"E	Supply water pond
	TT 1-5	sediment	13°55'11.60"N 101°34'59.99"E	Discharge water near wood chip plant;
	TT 1-6	sediment	13°55'28.26"N 101°35'17.08"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
	TT 1-7	sediment	13°56'17.25"N 101°35'42.39"E	Downstream of Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
	TT 1-8	sediment	13°55'19.76"N 101°36'32.05"E	Nong Kla Canal
	TT 1-9	sediment	13°57'50.48"N 101°36'2.96"E	Water stream in cattle pasture; (Chemical plant; Pulp and paper industry; Coal power plant)

Hot spot	Sample code	Matrix	Coordinates	Notes
	TT 1-10	sediment	13°57'44.11"N 101°36'46.99"E	Upstream Bang Pakong River
	TT 1-11	sediment	13°58'5.63"N 101°35'8.64"E	Downstream Bang Pakong River
	TT 2-1	sediment	13°54'1.34"N 101°34'48.15"E	Upstream Chalongwang Canal
	S1	sediment	13°57'52.0"N 101°36'02.9"E	near TT 1-9
	S2	sediment	13°55'28.4"N 101°35'17.0"E	near TT 1-6
	S3	sediment	13°55'55.6"N 101°35'34.6"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant; Coal stock pile)
	S4	sediment	13°55'45.1"N 101°36'19.1"E	Canal; South from supply water pond for industry
	S5	ash	13°45'23.6"N 101°36'40.5"E	Eucalyptus field
Samut Sakhon	SMS 1-1	sediment	13°30'46.21"N 100°16'48.07"E	Tha Chin River mouth
	SMS 1-3	sediment	13°30'45.08"N 100°16'43.54"E	Tha Chin River mouth
	SMS 1-5	sediment	13°29'18.25"N 100°19'48.06"E	Luang Sahakon Canal
	SMS 1-6	sediment	13°29'14.99"N 100°20'2.39"E	Sea; 400 metres East form Luang Sahakon Canal

Hot spot	Sample code	Matrix	Coordinates	Notes
	SMS 1-8	sediment	13°29'24.40"N 100°21'21.01"E	Fish farm
	SMS 1-8	sediment	13°29'24.40"N 100°21'21.01"E	Fish farm
	SMS 1-9	sediment	13°29'44.68"N 100°21'21.22"E	Fish farm
	SMS 1-10	sediment	13°30'6.65"N 100°16'22.96"E	Tha Chin River mouth
	SMS 1-11	sediment	13°33'31.16"N 100°18'46.55"E	Luang Sahakon Canal
	SMS 1-14	sediment	13°37'33.61"N 100°21'36.54"E	Residential area; Metal smelting factory
	SMS 2-2	sediment	13°37'37.26"N 100°21'48.36"E	Residential area; (Metal smelting facilities)
	SMS 2-6	sediment	13°36'23.2"N 100°21'00.4"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
	SMS 2-7	sediment	13°36'29.16"N 100°20'48.24"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
	SMS 2-10	sediment	13°37'8.28"N 100°20'37.38"E	Soi Talab Thong 3 Alley; (metal smelting; small industrial facilities; open burning of waste)

Hot spot	Sample code	Matrix	Coordinates	Notes
	SMS 2-11	sediment	13°36'36.60"N 100°20'35.64"E	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)
	SMS 2-12	sediment	13°36'25.56"N 100°21'31.26"E	Bang Nam Chued Canal; (Metal smelting; Small industrial facilities; Open burning of waste)
	A1	ash	13°37'59.5"N 100°21'09.3"E	Soi Choed Mahachai 1 Alley; (small-scale brass smelting facility)
	A2	soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley, Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
	A3	soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley, Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
	SMS 2-1	soil	13°37'34.8"N 100°21'51.1"E	Drained coverage of former dam/wetland (metal smelting; small industrial facilities; open burning of waste)
Praeksa	PRE 1-1	sediment	13°33'25.4"N 100°35'49.9"E	Fishing pond next to the waste landfill
	PR 1	sediment	13°33'34.79"N 100°38'36.1"E	Outflow from the waste landfill into the channel
	PR 2	sediment	13°33'38.35"N 100°38'34.66" E	North stream with standing water (waste landfill)

Hot spot	Sample code	Matrix	Coordinates	Notes
	PR 4	sediment	13°33'15.89"N 100°38'23.07"E	Fish and vegetable (morning glory) pond on the West from the waste landfill. Water comes from channel which flows around the waste landfill.
	PR 5	sediment	13°33'20.28" N 100°38'25.31" E	Channel flowing around the waste landfill and long the people houses
	PR 8	sediment	13°33'19.04"N 100°38'48.76"E	East stream located at corner of the waste landfill wall
Chachoengsao	KHS 1	sediment	13°41'19.9"N 101°27'4.1"E	Downstream Rabom channel, in the channel meander behind the bridge, near waste water discharge (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 2	sediment	13°41'17.3" N 101°28'32.09" E	Wetland used for agricultural purposes, next to eucalyptus fields and cassava plantation (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 3	sediment	13°41'34.0"N 101°27'56.3"E	Creek with leachate from power plant ash, "304 industry" and house waste water (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 4	sediment	13°46'1.6" N 101°36'22.39" E	Wastewater aeration pond, outflow black water with strong smell, rocky channel with green algae (metal smelting, illegal dumping of waste, Khao Hin Sorn)

Hot spot	Sample code	Matrix	Coordinates	Notes
	KHS 4a	white gel	13°46'1.6" N 101°36'22.39" E	Wastewater aeration pond, outflow black water with strong smell, rocky channel with green algae (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 5	sediment	13°43'41.9"N 101°36'39.8"E	Creek going through a farm (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 7	sediment	13°41'13.2"N 101°35'59.79" E	Downstream of a creek where wastewaters are released, close before entering Rabom channel overgrowing pool (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 8	sediment	13°40'50.0" N 101°36'4.39"E	Rabom channel with water plants (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 9	sediment	13°40'50.9" N 101°35'48.9"E	Rabom channel after receiving wastewater, along banana and gum-tree plantation (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 2-2	sediment	13°47'44.96"N 101°29'3.75"E	Stream near aluminium plant (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 2-5	sediment	13°47'44.96"N 101°29'3.75"E	Pond near the aluminium plant (metal smelting, illegal dumping of waste, Khao Hin Sorn)

Hot spot	Sample code	Matrix	Coordinates	Notes
	KHS 2-7	sediment	13°47'30.25"N 101°28'33.56" E	Water flow with low water level near aluminium factory (metal smelting, illegal dumping of waste, Khao Hin Sorn)
	KHS 2-8	sediment	13°46'49.8"N 101°30'2.27"E	Canal going from the recycling plant and dump site (metal smelting, illegal dumping of waste, Khao Hin Sorn)
Rayong River Estuary	IRPC 2	sediment	12°39'08.3"N 101°18'4.0"E	Channel (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong)
	IRPC 3	sediment	12°39'16.3"N 101°17'19.0"E	River (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong)
	IRPC 6	sediment	12°39'22.6"N 101°16'54.09" E	Mangrove (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong)
Chanthanburi	CHA 1	sediment	12°58'11.73"N 101°45'07.82" E	Upstream creek in the middle of forest above waterfall. Rocky creek with wood and plants across it.

Table 2: Results of chemical analysis for the collected samples. The content of elements is given in mg/kg of dry matter. <LOD: analyte concentration was below limit of detection. NA: not analysed. Bold numbers indicate exceeded Thai pollution criterium.

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
LOE 1	6.695	0.004	40.780	**4.973**	**851.402**	41.774	NA
LOE 2	2.136	0.035	41.739	**0.971**	32.033	21.355	NA
LOE 3	5.006	0.015	36.346	**0.982**	22.593	16.699	NA
LOE 4	12.915	0.029	30.494	**2.951**	**149.518**	18.690	NA
LOE 5	25.688	0.032	48.134	**4.912**	**107.073**	23.576	NA
LOE 6	19.215	0.029	52.279	**4.932**	**99.625**	17.755	NA
LOE 7	**39.178**	0.038	93.870	**15.326**	**113.027**	24.904	NA
LOE 8	**162.166**	<LOD	15.699	**39.246**	<LOD	<LOD	NA
LOE 9	10.960	0.022	51.813	**1.993**	**121.562**	36.867	NA
LOE 11	1.186	0.021	22.736	**0.989**	40.530	37.564	NA
LOE 12	3.801	0.042	36.845	**0.996**	62.737	38.837	NA
LOE 20	0.188	0.017	21.799	**0.991**	5.945	15.854	NA
LOE 21	0.500	0.038	54.967	<LOD	16.990	44.973	NA
LOE 22	0.499	0.013	21.965	**0.998**	9.984	15.974	NA
LOE 23	1.873	0.036	50.266	**0.986**	62.093	24.640	NA
LOE 24	22.129	0.022	59.988	**7.998**	**73.985**	48.990	NA
LOE 25	3.376	0.034	56.604	**2.979**	63.555	28.798	NA
LOE 26	0.825	0.020	33.811	**0.994**	13.922	13.922	NA
LOE 27	1.491	0.046	91.469	**1.988**	29.827	21.873	NA
LOE 28	0.795	0.030	65.554	**0.993**	**137.068**	30.791	NA
LOE 1 C	9.300	<LOD	168.617	**9.919**	**10841.103**	29.756	NA
LOE 1 D	**42.231**	0.002	14.781	**19.708**	**847.458**	17.737	NA
KK 3	0.139	0.017	9.901	<LOD	13.861	35.644	NA
KK 4	0.470	0.004	10.767	**1.958**	1.958	11.746	NA
KK 7	1.139	0.011	25.097	<LOD	7.722	16.409	NA
KK 8	0.233	0.461	44.643	**0.970**	14.557	25.233	NA
KK 9	1.123	0.027	19.656	**0.936**	12.168	19.656	NA
KK 10	**47.842**	0.036	46.194	**1.848**	12.010	20.325	NA
KK 11	25.958	0.037	38.938	**2.995**	14.976	31.949	NA
KK 13	0.850	NA	18.782	<LOD	5.931	15.817	NA
MTP 1-1	1.530	0.032	64.070	**1.830**	14.644	3.661	NA
MTP 1-6	6.817	0.128	53.564	<LOD	26.295	13.635	NA
MTP 1-7	27.719	0.534	**742.004**	**2.132**	22.388	33.049	NA
MTP 1-8	2.298	0.026	133.065	<LOD	5.744	5.744	NA
MTP 1-12	2.332	0.020	38.865	<LOD	3.887	7.773	NA
MTP 1-13	0.213	0.011	30.930	<LOD	9.666	5.799	NA
MTP 1-14	19.861	0.351	**415.094**	**0.993**	29.791	35.750	NA
MTP 1-15	3.072	0.052	59.642	**1.807**	<LOD	15.362	NA
MTP 1-16	0.680	0.017	33.042	<LOD	7.775	15.549	NA

MTP 1-17	1.571	**0.963**	**1062.242**	**2.945**	**23.562**	56.941	NA
MTP 2-2	3.033	0.049	41.706	**1.896**	14.218	7.583	NA
MTP 2-3	1.266	0.383	**389.559**	**1.977**	7.910	11.865	NA
MTP 2-5	0.555	0.038	21.795	**1.981**	7.926	9.907	NA
MTP 2-6	0.299	0.079	55.866	**0.998**	3.990	7.981	NA
MTP 2-6 (1)	10.025	**1.479**	**349.913**	**0.964**	16.387	24.099	NA
MTP 2-14	NA	0.004	8.652	<LOD	1.923	2.884	NA
MTP 2-15	8.296	0.010	2.894	**1.929**	0.965	0.965	NA
TT 1-1	3.562	0.070	42.541	**0.989**	43.530	89.038	3.880
TT 1-2	25.819	0.083	115.194	**2.979**	**82.423**	**143.992**	3.580
TT 1-3	**38.000**	0.035	60.000	**4.000**	42.000	**141.000**	1.780
TT 1-4	**42.367**	0.098	36.985	**2.999**	25.990	82.967	3.740
TT 1-5	0.216	0.082	92.429	**5.900**	49.164	**316.618**	5.200
TT 1-6	**45.894**	0.043	122.473	**3.888**	28.188	141.913	3.910
TT 1-7	2.060	0.043	38.382	**12.170**	44.935	**402.546**	5.730
TT 1-8	0.578	0.151	17.354	**1.928**	23.139	61.705	2.980
TT 1-9	25.902	0.038	31.879	**1.992**	12.951	31.879	NA
TT 1-10	0.137	0.007	5.877	**1.959**	7.835	11.753	NA
TT 1-11	0.292	0.024	17.520	**1.947**	11.680	21.413	NA
TT 2-1	**47.772**	0.035	18.943	**4.510**	23.453	128.992	NA
S1	NA	0.026	NA	NA	NA	NA	NA
S2	NA	0.018	NA	NA	NA	NA	NA
S3	NA	0.029	NA	NA	NA	NA	NA
S4	NA	0.020	NA	NA	NA	NA	NA
S5	3.990	0.069	NA	0.295	NA	NA	20.600
SMS 1-1	22.091	0.066	54.228	**2.542**	23.725	42.366	NA
SMS 1-3	27.586	0.041	82.759	**2.956**	23.645	40.394	NA
SMS 1-5	24.570	0.058	212.940	**2.048**	21.499	46.069	NA
SMS 1-6	24.866	0.052	**843.535**	**1.913**	19.128	35.386	NA
SMS 1-8	**31.930**	0.041	46.312	**2.573**	15.437	45.455	NA
SMS 1-8	24.014	0.044	57.873	**3.991**	20.954	68.849	NA
SMS 1-9	**32.392**	0.037	59.067	**3.938**	16.736	54.145	NA
SMS 1-10	23.548	0.055	53.964	**2.943**	17.661	45.133	NA
SMS 1-11	0.975	0.098	351.014	**1.950**	**68.253**	87.754	NA
SMS 1-14	0.430	**1.327**	**767.575**	**1.793**	**426.829**	30.488	16.141
SMS 2-2	**117.958**	0.048	189.022	**3.204**	37.377	50.192	NA
SMS 2-6	9.138	**2.392**	**1650.504**	**18.650**	**792.615**	65.274	**484.894**
SMS 2-7	**40.353**	0.070	**544.991**	**3.921**	**133.307**	48.030	NA
SMS 2-10	1.256	**10.318**	233.207	**1.993**	49.831	51.824	NA
SMS 2-11	11.017	0.155	NA	NA	NA	NA	NA
SMS 2-12	**35.280**	NA	**371.423**	**2.940**	**100.941**	**203.842**	NA
A1	5.220	0.098	NA	4.060	NA	NA	2197.000
A2	1.890	0.046	NA	<LOD	NA	NA	58.500
A3	**28.200**	0.245	NA	3.980	NA	NA	**18990**

SMS 2-1	NA	NA	6088.924	19.673	1760.771	**1701.751**	373.795
PRE 1-1	19.650	0.026	68.776	**3.930**	16.703	38.318	NA
PR 1	**51.944**	0.031	69.923	**4.924**	26.591	69.923	NA
PR 2	**39.790**	0.042	96.042	**3.880**	44.626	48.506	NA
PR 4	**41.377**	0.023	62.905	**4.625**	18.501	59.204	NA
PR 5	23.666	0.036	121.063	**3.641**	25.487	77.371	NA
PR 8	**45.660**	0.087	**1087.384**	**3.936**	**99.390**	66.916	NA
KHS 1	4.314	0.031	32.821	**1.875**	14.066	30.945	NA
KHS 2	21.869	0.250	28.827	**0.994**	11.928	15.905	NA
KHS 3	2.048	0.014	7.803	**3.902**	11.705	37.066	NA
KHS 4	**136.389**	NA	58.335	**26.696**	55.369	**437.018**	NA
KHS 4a	0.455	0.095	22.727	**22.727**	**68.182**	45.455	NA
KHS 5	5.021	0.029	13.519	**0.966**	**206.643**	67.594	NA
KHS 7	4.077	0.029	29.121	**1.941**	10.678	28.150	NA
KHS 8	0.858	0.017	10.148	**2.768**	33.210	105.166	NA
KHS 9	0.410	0.025	6.841	**0.977**	5.864	22.478	NA
KHS 2-2	1.285	0.029	9.046	**1.809**	23.521	4.523	NA
KHS 2-5	1.381	0.159	77.661	**1.918**	**199.425**	29.722	NA
KHS 2-7	NA	0.017	21.743	**2.836**	4.727	4.727	NA
KHS 2-8	0.996	0.019	30.268	<LOD	13.669	61.511	NA
IRPC 2	3.928	0.073	56.952	**1.964**	7.855	9.819	NA
IRPC 3	2.148	0.034	163.054	**1.953**	5.858	10.740	NA
IRPC 6	2.300	0.009	18.206	**1.916**	5.749	4.791	NA
CHA 1	0.060	0.022	31.834	**1.990**	23.876	3.979	NA

EUROPEAN UNION

The European Union (EU) is made of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders. The European Commission is the EU's executive body.

This publication has been produced with the support of the European Union (EU) as a part of the project " Increasing Transparency in Industrial Pollution Management through Citizen Science". The content of this publication does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the publication lies entirely with the authors.