MERCURY in Fish from Industrial Sites in Thailand

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Introduction

The main objective of this study is to interpret a data set obtained from an environmental sampling in different parts of Thailand that was carried out in February/March 2016 and February 2017. Samples originated from various sites which some of them served as control areas without any known sources of pollution and some samples originated from highly industrialized areas. Collected samples of fish and sediments were analyzed for content of mercury and methylmercury, secondary also for the content of some selected risk elements and data were further discussed and compared to national and international legal standards.

This sampling campaign is a part of “Increasing Transparency in Industrial Pollution Management through Citizen Science” project, and was conducted by a non-profit organization Arnika Association, Czech Republic and Ecological Alert and Recovery – Thailand (EARTH) Association.

Mercury contamination

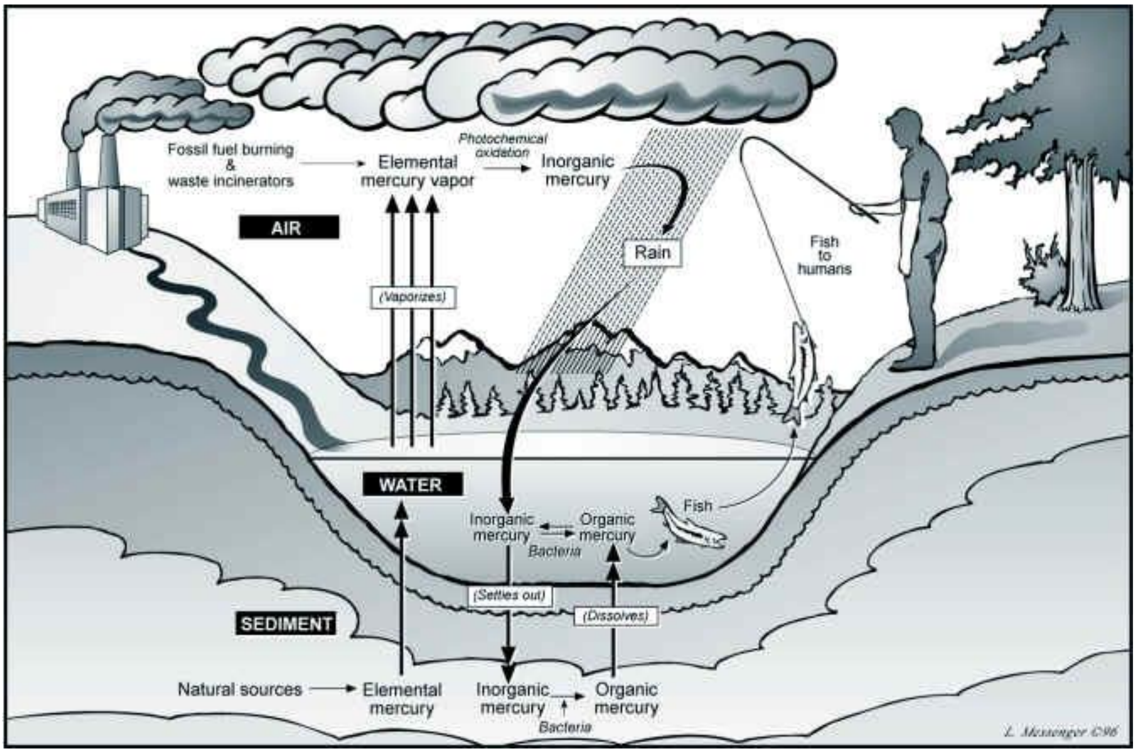
Mercury is a well-known toxin that has damaging effects on human health affecting mostly nervous and other body systems including cardiovascular, respiratory, gastrointestinal, hematologic, immune and reproductive systems [1]. Its neurotoxicity is most damaging for developing organisms and therefore for pregnant women. Fetuses are the most sensitive group while exposed to mercury in the environment of the mother [2]. A unique first ever peer-reviewed study on the economic burdens of mercury exposure by Transande et al. [3] states that mercury contamination that causes also a significant IQ reduction costs 77.4 – 130 million dollars per year in lost income potential. In the case of Thailand these costs to the community were enumerated in 278,000 – 480,000 dollars a year and it was just for Tha Tum industrial area. A dependence of the earning losts on mercury can be summed up as follows: higher mercury contamination = lower IQ = lower economical potential = higher community costs [4].

Sources of mercury contamination in the environment can be either natural or anthropogenic. Natural sources of mercury include volcanoes, forest fires or leaching of mercury contain minerals and rocks. Anthropogenic sources are mainly connected with industrial activities and levels of mercury in the environment are increasing due to discharge from hydroelectric, mining, smelting, cement and alkali, pulp and paper industries. Incineration of municipal and medical waste and emissions from coal power plants and using of fossil fuels also contribute to high levels of mercury. A problem with mercury is that it is able to travel long distances in the air and therefore able to contaminate places remoted from an initial source of pollution. Airborne mercury is then deposited into water and becomes accessible for bacterias in lakes, streams and ocean sediments that convert elemental mercury into highly bioavailable organic compounds such as methylmercury. The conversion of inorganic mercury to methylmercury is important for two reasons i) it is much more toxic than inorganic mercury compounds, ii) organisms require a long time to eliminate it and therefore it leads to bioaccumulation.

Bioaccumulation of mercury is a process where methylmercury producing bacterias maybe consume by a next higher organism up the food chain or the bacterias may release the methylmercury into the water where it can be adsorbed to plankton which can also be consumed by the organisms of higher trophic level. This pattern continues as small fish/organisms get eaten by progressively bigger and bigger fish until the fish is finally consumed by human or other animal. It is called biomangification and it means that mercury levels are gradually higher in the food chain, e.g. in carnivorous fish are usually higher than in lower segments of the food chain like in omnivorous and herbivorous species. Once in the fish´s body it binds to fish tissues including fat and muscles and is eliminated very slowly and persists in the body for a very long time [5].

Mercury in the environment is constantly cycled and recycled through a biochemical cycle shown in Figure 1 [6].

Figure 1: Biochemical cycle of mercury [6].



Sampling sites

This chapter provides a general description of studied areas. More detailed information is given in the description of samples and sites in Table 1 and Table 2.

Khao Hin Sorn

Khao Hin Sorn is a part of Chachoengsao Province that lies in the eastern part of Thailand. The total area of the province is 5,351 km^2 and has a total population of almost 701,000 registered inhabitants. Chachoengsao is further divided into 11 districts which one of them is Phanom Sarakham where Khao Hin Sorn subdistrict is located. Its total population counts 15,600 inhabitants and is the second most populated in the district [7]. In the studied area there are different sources of pollution, e.g. a number of small industrial facilities like an ash disposal site in nearby eucalyptus plantation or an aluminum smelting plant. Based on the data measured in previous study, high levels of arsenic, cadmium, nickel and chromium were found in the sediment collected at the effluent discharge point. Increased levels of arsenic and mercury were found in wetlands used for agricultural purposes which are expected to receive effluent water from the industrial discharge and the eucalyptus plantation respectively.

Khon Kaen

With its 10,886 km^2 is Khon Kaen the fifth-largest Thai province and is further divided into 26 districts with a total population of nearly 1,798,000 registered inhabitants. Sampling for this study took place in Nam Phong district. The sources of pollution in this area are a coal power plant and paper and pulp industry. One of biggest paper and pulp industrial areas in Thailand is located 30 kilometers north of the city Khon Kaen. The paper and pulp industrial area is surrounded by eleven villages in a radius of five kilometers and holds almost 1,400 households. Aside of factory space there is also waste landfill and eucalyptus forest. The industrial area has two paper and pulp production lines with the total production capacity of 240,000 tons per a year. As a part of the area there are chemical plants, including a chlor-alkali production plant, a chlorine dioxide production plant, a sulfur dioxide production plant, an oxygen production plant and also two power plants and a wastewater treatment plant.

The area is drained by a water stream Chot flowing through the eucalyptus forest and this water stream is a tributary of the Phong River. The river water is used not only for community and municipal water supply, industry, agriculture and aquaculture, but the river itself is also a recipient of waste water from communities and industries and runoff from agriculture [8]. Based on previously measured data increased levels, mainly of arsenic, mercury and cadmium were found in analyzed sediments originating from this area.

Loei

Loei is one of the most sparsely populated provinces of Thailand. It lies in the North East of the country in a fertile basin and is covered with mountains. The Loei River that flows through the province is a tributary of the Mekong which forms part of the northern boundary of the province with neighboring Laos. The province has a total area of almost 11,425 km^2 with over 638,800 registered inhabitants and is divided into 14 districts. Its economy is driven mostly by agriculture and gold ore mining.

Villagers in the Na Nong Bong community in Loei province live less than one kilometer from the mine and since it was open in 2006 they have filled numerous of complaints against the mine's license in the attempts to mitigate the contamination of their nearby villages. The gold mining company was accused of poisoning villagers´ land and water supplies and causing serious health problems. A government study of contamination in this area reported dangerous levels of contaminants in local rivers and creeks. They found cyanide, arsenic and mercury levels that exceeded safety standards in the blood of people living in its surrounding. Moreover, the mining operations have been accused of major environmental damage of that area too [9]. Samples analyzed in this study were taken in the industrial vicinity of this gold mine.

Map Ta Phut

Map Ta Phut Is a town located in Rayong Province and it is a site of Thailand's largest industrial area that consists of “Map Ta Phut Industrial Estate”, “Pha Daeng Industrial Estate”, “Hemaraj Eastern Industrial Estate (Map Ta Phut)”, “Asia Industrial Estate” and “R.I.L Industrial Estate” that cover area of almost 16.3 km^2. Rayong is a province that lies in the East of Thailand on the coast of the Gulf of Thailand. Although the north is hilly, the province consists mostly of low coastal plains. Some islands in the Gulf of Thailand belong to the province, including some popular tourist destinations. It has a total area of 3,552 km^2 with almost 675,000 inhabitants. The province is divided into 8 districts and the industrial estates lie in Map Ta Phut subdistrict, Mueang Rayong District. The town itself has a total population of over 62,000 people.

The industrial estate is the country's largest industrial estate and the world's 8^{th} largest petrochemical industrial complex. It was founded in 1990 and is managed by the Thai Ministry of Industry. Sampling took place in the area nearby the heavy industry development zone. Previously measured data in sediment samples show increased concentration of most risk elements, mainly arsenic, mercury, zinc, copper, nickel and chromium that were found in downstream sediments comparing to the upstream ones [10].

Rayong IRPC industrial zone

IRPC industrial zone belongs to Rayong province that was described above and is a part of Mueang Rayong district. If pollution occurs then the possible source may be most likely a petrochemical plant, a compounding plastics plant or several refineries that operate in the area.

Praeksa

Praeksa belongs to the Samut Prakan Province that lies at the mouth of the Chao Phraya River on the Gulf of Thailand. The total area of this province is 1,004 km^2, total population of 1,279,300 registered inhabitants and the province is ranked with 3^{rd} highest population density in the country. Samut Prakan is further divided into 6 districts and Praeksa is a part of Mueang district with population of 56,400 people.

There are over 6,576 factories in the area that produce motor vehicles, car parts and equipment, metal products, electronics, textiles, food products, chemicals, plastics, etc. There is also a dumping site of 0.24 km^2 and depth of 50 m that accumulate municipal solid waste and illegally also some industrial waste for over 20 years. In 2014 there was a massive fire that lasted for almost a week, in which about a ton of the dumped waste has uncontrollably burned [11].

Samut Sakhon

Samut Sakhon is located in the central of Thailand and with a total area of 872.3 km^2 belongs to the one of the smallest provinces. Its total population is nearly 545,400 registered inhabitants and the province is divided into 3 districts. It is a coastal province with a network of more than 170 canals flowing into Tha Chin River and the Gulf of Thailand. Local economy relies on industry, fishing, seafood processing, agriculture and it is a leading province for sea salt production [12]. Industrial activities in the studied area are represented mostly with high concentration of smelting and recycling factories that are located in Mueang Samut Sakhon district.

Tha Tum

Tha Thum is located in Prachinburi Province and covers a total area of 4,762 km^2 and its population reaches almost 482,200 inhabitants. The Province is geographically divided into two major parts, the low river valley of the Prachin Buri River, and the higher lands with plateaus and mountains of the Sankamphaeng Range. Tha Tum lies in Si Maha Phot district and has almost 17,400 registered inhabitants. Tha Tum is an industrial complex that consists of 304 industrial park and factories in its surrounding. There are many coal power plants and various types of industries in this area, including paper and pulp production, plastic production, car parts production, distillery, etc. [13]. Based on previously measured data, the location of Tha Tum shows increased concentrations of some risk elements like arsenic, cadmium and chromium.

Klong Dan

As mentioned above Samut Prakan Province lies at the mouth of the Chao Phraya River on the Gulf of Thailand. The total area of this province 1,004 km^2 and a total population of 1,279,300 registered inhabitants and therefore ranked as 3rd highest population density in the country. Samut Prakan is further divided into 6 districts. The part of the province on the west side of the Chao Phraya River consists mostly of rice paddies and shrimp farms as well as mangrove forests, while the eastern part is the urban center, including industrial factories.

Klong Dan belongs to the Bang Bo district and with its almost 30,000 inhabitants is the biggest subdistrict in the area. It is also a site with never completed wastewater treatment plant financed partly by the Asian Development Bank. The 24 billion baht project was not completed due to opposition from local residents and charges of malfeasance levelled against those responsible for the project [14,15]. Samples collected for purposes of this study originated from a small fishing town without any significant source of pollution apart from fishing facilities and accumulation of all kinds of ships and boats.

Chanthaburi

Chanthaburi is a province in the east of Thailand. Its total area is 6,338 km^2 and a population of 531,000 inhabitants. The province is further divided into 10 districts [16]. While the southern part of Chanthaburi lies on the shore of the Gulf of Thailand and thus mostly consists of coastal alluvial plains the hinterlands in the north of the province are mountainous. Samples for this study were collected in the northwestern part of the province in the Kaeng Hang Maeo District. There is no significant source of pollution in this area and therefore amounts of risk elements in collected samples were expected to be relatively low for this reason.

Thap Lan National Park and Klong Yang Canal

The total area of Prachinburi is 4,762 km^2, the province is further divided into 7 districts and has a total population of almost 482,200 registered inhabitants. The Prachiburi Province is geographically divided into two major parts, the low river valley of the Prachinburi River and the higher lands with plateaus and mountains of the Sankamphaeng Range. In those areas are also placed two national parks, Khao Yai and Thap Lan National Park. In the south of the province is located 304 industrial park, coal power plants paper and pulp factory, ethanol production factory, sulphuric acid factory, a Rojana industrial park which one of its biggest tenants is Honda Automobile that has established there a 17.2 billion baht plant to manufacture sub-compact vehicles [17].

The areas of interest (Thap Lan National Park and Klong Yang Canal) are parts of Na Di District that lies in the northeastern part of the province and has a total of 51,600 inhabitants. The park consists of rare fan palm forests. It is also a source of many river streams and has many natural attractions such as cliffs and waterfalls. This 2,236 km^2 area was declared 40th national park of Thailand on 23rd December 1981 and therefore is kept as an industry-free zone [18].

Sampling material

Information about samples and sites that they originate from are given in Table 1 and Table 2.

Table 1: Description of fish samples and sampling sites. Length 1: fish total length (including a tail fin). Length 2: fish length without a tail fin., n: number of collected subjects.

Sample code	Date	GPS	Sampled Fish Latin Name Number of Subjects (n)	Sampled FishCommon Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Chanthaburi						
CHA3	2016-02-16	N12°58´12.500´´ E101°45´09.670´´	*Neolissochillus stracheyi* n=1	Pla Puang – Mahseer Barb Omnivore	Jungle waterfall	23 cm; 18.5 cm; 131 g; 1-2 years
CHA4	2016-02-16	N12°58´11.730´´ E101°45´07.819´´	*Neolissochillus stracheyi* n=1	Pla Puang – Mahseer Barb Omnivore	Jungle waterfall	36 cm; 29.2 cm; 558 g; 3 years
Khao Hin Sorn						
KHS6	2016-02-17	N13°41´13.200´´ E101°35´59.798´´	*Oxyeleotris marmorata* n=1	Pla Boo – Marble Goby Carnivore	Canal; (Illegal dumping of hazardous waste; Metal smelting)	28.5; 22.3; 340 g; 4 years
KHS10	2016-02-18	N13°42´52.499´´ E101°25´40.400´´	*Channa striata* n=1	Pla Chorn - Snakehead Carnivore	Canal; (Illegal dumping of hazardous waste; Metal smelting)	37.5 cm; 31.5 cm 431 g; 2 years
Khon Kaen						
KK-2017-2	2017-02-03	N16°41´49.459´´ E102°44´07.058´´	*Clarias batrachus* n=1	Pla Dook – Walking Catfish Omnivore	Canal; (Pulp and paper industry; Coal power plant)	29 cm; 26.5 cm; 204 g; 4 months
KK-2017-5	2017-02-03	N16°43´23.398´´ E102°44´52.444´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Canal; (Pulp and paper industry; Coal power plant)	40 cm; 34 cm; 598 g; 0-1 year
KK-2017-6	2017-02-03	N16°43´18.631´´ E102°45´04.939´´	*Clarias batrachus* n=1	Pla Dook – Walking Catfish Omnivore	Reservoir; (Pulp and paper industry; Coal power plant)	32 cm; 28 cm; 245 cm; 0-1 year
KK12/1	2016-02-20	N16°43´16.619´´ E102°45´04.370´´	Barbonymus gonionotus n=1	Pla Thapian – Silver Barb Omnivore	Canal; (Pulp and paper and pulp industry; Coal power plant)	19.2cm; 16.2 cm; 142 g; -

Sample code	Date	GPS	Sampled Fish Latin Name Number of Subjects (n)	Sampled FishCommon Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Khon Kaen						
KK14-1	2016-02-21	N16°43´16.612´´ E102°45´04.360´´	*Hampala macrolepidota* n=2	Pla Kasoop Kit – Hampala Barb Omnivore	Reservoir; (Pulp and paper industry; Coal power plant)	20.5/21 cm; 17.1/17; 121/127 g; 1 year
KK14-2	2016-02-21	N16°43´16.612´´ E102°45´04.360´´	*Channa micropeltes* n=1	Pla Chado – Giant snakehead Carnivore	Reservoir; (Pulp and paper industry; Coal power plant)	16.8 cm; 14.9 cm; 49 g; 1 year
Klong Dan						
KLO1-2	2016-02-13	N13°28´19.200´´ E100°48´51.001´´	*Bivalvia* n=1	Mussels -	Sea	-
KLO1-3/1-3	2016-02-13	N13°28´44.681´´ E100°48´09.760´´	*Polynemidae* n=3	Gulao – Threadfins Carnivore	River mouth	46/47/48.8 cm; 39/39/40.5 cm; 973/1087/1176 g; -
KLO1-3/4-6	2016-02-13	N13°28´44.681´´ E100°48´09.760´´	*Mugillidae n=3*	Pla Krabok – Mullet Omnivore	River mouth	24.5/24.6/24.5 cm; 20.5/20.8/19.9 cm; 174/170/165 g; -
Loei						
LOE14	2016-02-20	N17°21´07.769´´ E101°39´26.219´´	*Barbonymus gonionotus* n=2	Pla Thapian – Silver Barb Omnivore	Lek creek; (Gold mining)	29/30 cm; 22/23 cm; 370/380 g; -
LOE15	2016-02-20	N17°21´07.769´´ E101°39´26.219´´	*Channa striata* n=4	Pla Chorn - Snakehead Omnivore	Lek creek; (Gold mining)	25.5/36/18/19 cm; 21/29/15/15.5 cm; 170/800/100/105 g; -
LOE19	2016-02-20	N17°26´09.899´´ E101°37´48.601´´	*Oxyeleotris marmorata* n=2	Pla Boo – Marble Goby Carnivore	Huai river upstream; (Gold mining)	37/- cm; 31/- cm; 700/- g,; 2-3/0-1 year
LOE29	2016-02-21	N17°22´52.500´´ E101°37´27.100´´	*Channa striata* n=1	Pla Chorn – Snakehead Omnivore	(Gold mining)	20.5 cm; 17.5 cm; 92 g; 0-1 year
Map Ta Phut						
MTP-2017-1	2017-02-05	N12°39´02.171´´ E101°10´39.979´´	*Lutjanus johnii* n=2	Pla Kapong – Snapper Carnivore	Sea coast; (Coal power plant, Chemical industry)	41/34 cm; 34/29 cm; 857/654 g; 1/1 year
MTP-2017-2	2017-02-05	N12°39´02.171´´ E101°10´39.979´´	*Dasyatis pastinaca* n=1	Pla Kraben – Stingray Carnivore	Sea coast; (Coal power plant, Chemical industry)	51 cm; 175 cm; 4065 g; 1 year

Sample code	Date	GPS	Sampled Fish Latin Name Number of Subjects (n)	Sampled FishCommon Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Map Ta Phut						
MTP-2017-3	2017-02-05	N12°38´23.032´´ E101°09´24.001´´	*Acanthopagrus berda* n=1	Pla E-klud – Goldsilk Seabream Carnivore	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1315 g; 1 year
MTP-2017-5	2017-02-05	N12°38´08.452´´ E101°07´23.761´´	*Pomadasys kaakan* n=1	Pla Kapong Samea – Javelin Grunter Carnivore	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1140 g; 1 year
MTP-2017-8	2017-02-05	N12°40´30.500´´ E101°10´29.500´´	*Channa striata* n=1	Pla Chorn – Snakehead Omnivore	Sea coast; (Coal power plant, Chemical industry)	35 cm; 29 cm; 465 g; 0-1 year
MTP1-4	2016-02-14	N12°40´10.981´´ E101°10´46.700´´	*Bivalve* n=1	Mussels -	Sea coast; (Chlor-alki plant; Chemical plant; Coal Power plant)	-
MTP1-10/1	2016-02-14	N12°40´09.548´´ E101°09´29.070´´	*Belonidae* n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chlor-alki plant; Chemical plant; Coal Power plant)	94.5 cm; 86.5 cm; 1349 g; -
MTP1-10/2	2016-02-14	N12°40´09.548´´ E101°09´29.070´´	*Belonidae* n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chlor-alki plant; Chemical plant; Coal Power plant)	38.5 cm; 33 cm; 733 g; -
MTP2-1/1	2016-02-14	N12°45´32.011´´ E101°09´46.598´´	*Channa striata* n=1	Pla Chorn – Snakehead Omnivore	Canal Kvai Prow; (Chlor-alki plant; Chemical plant; Coal Power plant; Open burning of waste)	30 cm; 24.5 cm; 265 g; 1 year
MTP2-1/2	2016-02-14	N12°45´32.011´´ E101°09´46.598´´	*Trichogaster pectoralis* n=1	Pla Salid – Snakeskin Gourami Omnivore	Canal Kvai Prow; (Chlor-alki plant; Chemical plant; Coal Power plant;)	18.5 cm; 15.5 cm; 124 g; 1 year
MTP2-8	2016-02-14	N12°40´58.760´´ E101°09´17.791´´	*Clarias batrachus* n=3	Pla Dook – Walking Catfish Omnivore	(Chlor-alki plant; Chemical plant; Coal Power plant)	31/27.5/32.8 cm; 29/25/29.5 cm; 249/192/232 g; -
MTP2-9	2016-02-14	N12°40´58.760´´ E101°09´17.791´´	*Clarias batrachus* n=3	Pla Dook – Walking Catfish Omnivore	Chak Mark canal; (Chlor-alki plant; Chemical plant; Coal Power plant)	34.7/32.5/36 cm; 31.5/29.5/31.5 cm; 257/247/423 g; -

Sample code	Date	GPS	Sampled Fish Latin Name Number of Subjects (n)	Sampled FishCommon Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Rayong – IRPC industrial zone						
IRPC7	2016-02-16	N12°39´22.601´´ E101°16´54.098´´	*Bivalve* n=1	Mussels -	Port; (Petrochemical plant; Compounding plastics plant; Refineries)	-
Praeksa						
PR3	2016-02-13	N13°33´38.351´´ E100°38´34.660´´	*Channa striata* n=2	Pla Chorn – Snakehead Omnivore	Canal; (Municipal waste landfill; Hazardous waste landfill)	43/39.5 cm; 37.4/33.5 cm; 795/616 g; -
PR7	2016-02-13	N13°33´24.451´´ E100°38´25.649´´	*Anabas testudineus* n=2	Pla Mooh – Climbing Perch Omnivore	Fish pond; (Municipal landfill; Hazardous waste landfill)	19/17 cm; 16.6/13.8 cm; 142/110 g; 1-2/1-2 years
Prachinburi						
PRN-2017-1	2017-02-08	N14°12´19.400´´ E101°55´15.200´´	*Channa striata* n=1	Pla Chorn – Snakehead Omnivore	Water reservoir, Thap Lan National Park	44 cm; 38 cm; 586 g; 0-1 year
PRN-2017-2	2017-02-08	N14°14´29.900´´ E101°53´02.800´´	*Oxyeleotris marmorata* n=2	Pla Boo – Marble Goby Carnivore	Klong Yang Canal	23/22 cm; 20/18 cm; 156/127 g; 0-1/0-1 year
PRN-2017-3A+3B	2017-02-08	N14°12´19.400´´ E101°55´15.200´´	*Oreochromis niloticus* n=2	Pla Nil – Nile Tilapia Omnivore	Water reservoir, Thap Lan National Park	41/37 cm; 34/29 cm; 1349/1238 g; 1/1 year
Samut Sakhon						
SMS1-12/1	2016-02-11	N13°29´44.664´´ E100°21´21.456´´	*Polynemidae* n=2	Gulao – Threadfins Carnivore	Fish and Cockle farming ponds	33.8/31 cm;28.7/26 cm; 307/285 cm; -
SMS1-12/2	2016-02-11	N13°29´44.664´´ E100°21´21.456´´	*Ambassidae* n=2	Kaomao – Asiatic Glassfish Carnivore	Fish and Cockle farming ponds	16/17 cm; 13.8/14 cm;88/117 g; -
SMS1-12/3	2016-02-11	N13°29´44.664´´ E100°21´21.456´´	*Sillago sihama* *n=1*	Pla Sai – Silver Sillago Carnivore	Fish and Cockle farming ponds	18 cm; 16 cm; 53 g; -
SMS1-2	2016-02-11	N13°29´44.664´´ E100°21´21.456´´	*Mugillidae* n=3	Pla Krabok – Mullet Omnivore	Tha Chin river; (Metal smelting; Small industrial facilities; Open burning of waste)	24/25/23.5 cm; 20/21.5/20.5 cm; 180/190/160 g; 1/1/1 year

Sample code	Date	GPS	Sampled Fish Latin Name Number of Subjects (n)	Sampled FishCommon Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age
Samut Sakhon						
SMS1F	2016-03-02	N13°36´38.660´´ E100°20´37.399´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)	33 cm; 28 cm; 274 g; -
SMS2F	2016-03-02	N13°36´38.660´´ E100°20´37.399´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)	28 cm; 24 cm; 178 g; -
Tha Tum						
TT-2017-1	2017-02-04	N13°57´36.850´´ E101°36´06.991´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Chalongweang Canal; (Pulp and paper industry; Thermal power plant)	51 cm; 44 cm; 1166 g; 2 years
TT1-1F	2016-02-21	N13°56´13.880´´ E101°35´36.841´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Industrial park wastewater pond; (Chemical plant; Pulp and paper industry; Coal power plant)	37 cm; 32 cm; 448 g; -
TT2-6	2016-02-18	N13°55´17.569´´ E101°35´10.118´´	*Oreochromis niloticus* n=3	Pla Nil – Nile Tilapia Omnivore	Discharge water; (Chemical plant; Paper and pulp industry; Coal power plant)	17.5/17/20 cm; 13.5/13.8/16.2 cm; 114/101/151 g; 0-1/0-1/0-1 years
TT2-7	2016-02-16	N13°55´17.569´´ E101°35´10.118´´	*Bivalve n=1*	Shellfish -	Discharge water; (Chemical plant; Pulp and paper industry; Coal power plant)	-
TT2-8	2016-02-17	N13°57´50.980´´ E101°36´03.229´´	*Channa striata* n=1	Pla Chorn - Snakehead Omnivore	Chalongweang Canal; (Chemical plant; Pulpp and paper industry; Coal power plant)	29 cm; 25.5 cm; 211 g; 0-1 year

Table 2: Description of sampling sites and their relevancy to fish samples.

Sample code	Date	GPS	Sampling Spot Description	Sampling Material	Description of the Sampling	Relevancy to Fish Samples
Chanthaburi						
CHA1	2016-02-16	N12°58´11.730´´ E101°45´09.670´´	Upstream creek in the middle of jungle; Rocky creek with wood and plants around	Sandy sediment with decomposed organic matter; Gray color; no odor	Core sampling device; Depth of sample extraction 3 cm	CHA3; CHA4
Khao Hin Sorn						
KHS7	2016-02-17	N13°41´13.200´´ E101°35´59.798´´	Illegal dumping of hazardous waste; Metal smelting; Downstream of the creek where wastewaters are released	Black mud; No odor	Core sampling device, 3 spots, Sampling depth 20 cm; 0.5 m water layer	KHS6
KHS1	2016-02-17	N13°41'19.91" E101°27'4.11"	Illegal dumping of hazardous waste; Metal smelting; Downstream of the creek where wastewaters are released	Light brown; No odor	Core sampling device, 3 spots, Sampling depth 10 cm; 0.3 m water layer	KHS10
Khon Kaen						
KK4	2017-02-03	N16°42´06.041´´ E102°44´18.611´´	Paper and pulp industry; Coal power plant; Taken from outflow (30 m) of wasted water reservoir; Water red colored probably caused by soil particles	Soilysand; Top layer – red-brown; Underneath gray; Odor anaerobic	Depth of sample extraction 10 cm; Stored in plastic 500 ml bottle	KK-2017-2
KK9	2017-02-03	N16°43´23.329´´ E102°44´52.699´´	Pond; Paper and pulp industry; Coal power plant	Black mud with brown top layer; Contains a lot of small stones; Odor slightly anaerobic	Stainless metal shovel, sampling depth 10 cm, pool from 3; Homgenisation; Stones removing (gravel); Stored in 250 ml plastic bottle	KK-2017-5; KK-2017-6; KK12; KK14-1; KK14-2

Sample code	Date	GPS	Sampling Spot Description	Sampling Material	Description of the Sampling	Relevancy to Fish Samples
Klong Dan						
KLO1-4	2016-02-13	N13°28´44.681´´ E100°48´09.760´´	Sediment from a dam	Dark gray, odorless sediment	Mixed from 5 point samples by shovel from a square of 5 m^2, water layer of 1 m; Sampling depth 10 cm	KLO1-3/1-3; KLO1-3/4-6
Loei						
LOE12	2016-02-20	N17°20´57.001´´ E101°39´34.301´´	Wetland on the side of soya field; Gold mining	Soilysand; Brown-gray; Water pH 5.05	Taken with a metal shovel, 5 samples; Water layer 20 cm	LOE14; LOE15
LOE27	2016-02-20	N17°22´52.500´´ E101°37´27.100´´	Upstream Puk creek lake; 0.5 m far away from bank with vegetation; Gold mining	Muddy clay; Black-brown-gray color	Core sampling device, 5 samples, 1 m distance; Sampling depth 10 cm	LOE19; LOE29
Map Ta Phut						
MTP1-14	2017-02-05	N12°40´12.421´´ E101°09´37.710´´	Sea; 120-150 m far away from eastern canal; Chlor-alki plant; Chemical plant; Coke plant; Government survey 300,000 t of this black mud in the bay	Black mud; Anaerobic H_2S odor	Core sampling device; pool sample from 3; Homogenisation	MTP-2017-1; MTP-2017-2; MTP-2017-3; MTP-2017-5
MTP1-1	2017-02-05	N12°40´33.442´´ E101°10´29.550´´	Hvai Yai Canal; Waters from petrochemical industry	Black sandy sediment with clay layer on the surface; Anaerobic odor	Core sampling device, 10 m line; Homogenization; Sampling depth 20 cm	MTP-2017-8
MTP1-6	2016-02-14	N12°40´10.981´´ E101°10´46.700´´	Ta Kuan Canal	Black clay thin gray layer on the surface; Slightly anaerobic odor	Taken with a metal shovel, pool of 3, homogenisation	MTP1-4
MTP1-8	2016-02-14	N12°40´10.949´´ E101°09´29.182´´	East from Chak Mak Canal; Chlor-alki plant; Chemical plant; Coke plant	Black mud mixed with sand; Small oil spots;Anaerobic oily odor	Core sampling device, pool of 5, 15 m line; Sampling depth 15 cm	MTP-10/1; MTP1-10/2

Sample code	Date	GPS	Sampling Spot Description	Sampling Material	Description of the Sampling	Relevancy to Fish Samples
			Map Ta Phut			
MTP2-2	2016-02-14	N12°45´32.101´´ E101°09´46.598´´	Shallow canal Hval Prow with vegetation; Chlor-alki plant; Chemical plant; Coke plant	Brown, very wet sediment	10 m line of 5 points, 1 m far away from the bank, 0.5 water layer; Sampling depth 20 cm	MTP2-1/1; MTP2-1/2
MTP2-6	2016-02-14	N12°40´30.500´´ E101°09´27.101´´	Canal near factory; Chlor-alki plant; Chemical plant; Coke plant	Gray brown clay sediment; Slight anaerobic odor	Core sampling device, 5 samples, 3 m distance; Sampling depth 10 cm; 0.5 water layer	MTP2-8; MTP2-9
			Rayong – IRPC industrial zone			
IRPC6	2016-02-16	N12°39´22.601´´ E101°16´54.098´´	Mangroves	Sandy with little pieces of black mud; Anaerobic odor	Taken with a metal shovel, pool from 5 samples; Sampling depth 10 cm; Homogenisation	IRPC7
			Praeksa			
PR2	2016-02-13	N13°33´38.351´´ E100°38´34.660´´	Canal around landfill; Municipal landfill; Industrial landfill; Hazardous waste landfill	Surface clay layer	Taken with a metal shovel; Mixed from 3 samples, 5 m distance; 0.5 m of standing water	PR3
PR5	2016-02-13	N13°33´20.279´´ E100°38´25.310´´	Canal around landfill; Municipal landfill; Industrial landfill; Hazardous waste landfill	Black mud with parts of brown clay; No odor	Core sampling device; 5 samples around canal´s outfall; Sampling depth 15-20 cm	PR7
			Samut Sakhon			
SMS1-9	2016-02-11	N13°29´44.664´´ E100°21´21.456´´	Pond close to farm; Small industry facilities; Open burning of waste; Metal smelting	Gray clay	Core sampling device, 5 samples, 3 m distance, 2 m from bank; Sampling depth 20 cm	SMS1-12/1; SMS1-12/2; SMS1-12/3

Sample code	Date	GPS	Sampling Spot Description	Sampling Material	Description of the Sampling	Relevancy to Fish Samples
			Samut Sakhon			
SMS1-3	2016-02-11	N13°30´45.072´´ E100°16´43.536´´	Tha Chin river; Close to sea; Small industrial facilities; Metal smelting	Gray sediment with a lot of trash; Orange colored water and oil layers near	Core sampling device, 4 samples. 3 m distance; Sampling depth 20 cm	SMS1-2
SMS2-11	2016-03-02	N13°36´38.601´´ E100°20´35.581´´	Soi Kong Panam canal; Receives water from factories; Open burning of waste; Metal smelting; Potential fecal pollution	Mud with visible oil pollution on the top; Petrol odor	Core sampling device; Pool sample from 3 samples, 3 m line; 1 m from the bank; 0.5 water layer; Sampling depth 20 cm; Stored in 500 ml plastic bottle	SMS1F; SMS2F
			Tha Tum			
TT1-9	2017-02-04	N13°57´36.850´´ E101°36´06.991´´	Water stream in cattle pasture; Chemical plant; Paper and pulp industry; Coal power plant	Dark gray-black clay with brown top layer; Anaerobic odor	Taken with a metal shovel, pool from 5 samples; Sampling depth 7 cm; Homogenisation	TT-2017-1; TT2-8
TT1-7	2016-02-21	N13°56´17.250´´ E101°35´42.389´´	Downstream of Shalong Waeng canal; Chemical plant; Paper and pulp industry; Coal power plant	Dark gray muddy clay; Muddy odor	Core sampling device, pool from 6 samples; 0.5 m from bank; Sampling depth 10 cm	TT-1F
TT1-5	2016-02-18	N13°55´11.600´´ E101°34´59.992´´	Waste water near wood chip plant; Coal power plant	Black mud	Taken with a metal shovel, pool from 5 samples; Homogenisation	TT2-6, TT2-7

Sampling procedures and analytical methods

Sediments were usually taken as mixed samples formed by several partial samples taken in various places of the ten given localities (Chanthaburi, Khao Hin Sorn, Khon Kaen, Klong Dan, Loei, Map Ta Phut, Praeksa, Prachinburi, Samut Sakhon, Tha Tum). Samples were taken by means of a shovel into polyethylene containers (V = 500 ml) with screw lids or into polyethylene bags or taken by a core sampling device into polyethylene containers (V = 500 ml). Mixed samples were homogenized in a steel bowl, some of them quartered after homogenization. During soil sampling, the sampling shovel and core sampler were washed with tap or water body water. Samples were stored in a cold and dark environment before analysis. Fish samples were obtained from local fishermen and kept in a freezer wrapped in two polyethylene bags until analyzed.

Analytical procedures for sediments were as follows: after transport to the laboratory, samples were homogenized 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 heavy metals (cadmium, copper, chromium, lead, zinc and arsenic) by mineralization procedure. The 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. The sample was boiled for a period of 2 hours. Then it was filtered through a fluted filter paper. Metals and arsenic were determined in the mineralizates by atomic absorption and emission spectrometer SensAA. Mercury was measured directly in solid samples by Advanced Mercury Analyser (AMA 254, Altec). Analyses were conducted using standard operating procedures (SOP) established at the University of Chemical Technology, Prague, Czech Republic.

Analysis of mercury and methylmercury in fish were conducted using standard operating procedures (SOP): 70.4 (AAS-AMA and AAS-CZL;S), 70.4.1 (AAS-CZL 2/13;S), respectively. Other risk elements were determined as follows: As using SOP 70.3, AAS-hydrides; other elements using SOP 70.2, AAS-flame and GF-AAS. All procedures were established at the State Veterinary Institute, Prague, Czech Republic.

Results

The results of the analytical measurements of mercury, methylmercury and marginally also other risk elements in collected samples are presented in the following tables (Table 3 – Table 4) and figures (Figure 3 – 8).

Table 3: Content of risk elements in analyzed fish and sediment samples. The content of elements is given in mg kg^{-1} of dry matter. NA: not analyzed. Contents of Zn, Cd, Sr, Ba, Cu, Co, Ni, Cr, Pb, Mo in fish that were below detection limits are not further mentioned in this table.

Fish Samples					Area Relevant Sediments			
Sample code	Mercury mg kg^{-1}	Methylmercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements	Sample code	Mercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements
CHA3	NA	NA	NA		CHA1	0.02	0.06	1.99 Cd/ 3.98 Cr
CHA4	0.316	0.226	<0.010	0.014 Cd/ 0.07 Cr/ 0.04 Pb				
KHS6	NA	NA	NA		KHS7	0.03	4.08	
KHS10	0.283	0.267	0.010					
KK-2017-2	0.024	0.0177	NA		KK4	<0.01	0.47	
KK-2017-5	0.269	0.202	NA		KK9	0.03	1.12	
KK-2017-6	0.00960.120	<0.0150.105	NA					
KK12	0.0091	<0.015	NA					
KK14-1	0.0356	0.0318	NA					
KK14-2	0.120	0.105	NA					
KLO1-3/1-3	0.197	0.18	0.240		KLO1-4	0.07	31.87	2.81 Cd/ 72.18 Cr
KLO1-3/4-6	NA	NA	NA					
KLO1-2	0.06	<0,015	0.98	0.018 Cd/ 0.57 Cr/ 0.22 Pb				

Fish Samples					Area Relevant Sediments			
Sample code	Mercury mg kg^{-1}	Methylmercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements	Sample code	Mercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements
LOE14	0.016	<0.015	NA		LOE12	0.04	3.80	
LOE15	0.020	<0.015	0.080					
LOE19	0.229	0.22	0.010		LOE27	0.05	1.49	
LOE29	NA	NA	NA					
MTP-2017-1	0.103	0.096	NA		MTP1-14	0.35	19.86	
MTP-2017-2	0.143	0.112	NA					
MTP-2017-3	0.500	0.483	NA					
MTP-2017-5	0.353	0.334	NA					
MTP-2017-8	0.168	0.144	NA		MTP1-1	0.03	1.53	
MTP1-4	0.042	0.016	1.510	0.011 Cd/ 0.29 Cr/ 0.20 Pb	MTP1-6	0.13	6.82	13.63 Cd
MTP1-10/1	1.027	0.988	NA		MTP1-8	0.03	2.30	
MTP1-10/2	0.119	0.112	NA					
MTP2-1/1	0.507	0.487	NA		MTP2-2	0.05	3.03	
MTP2-1/2	NA	NA	NA					
MTP2-8	0.124	0.112	0.020		MTP2-6	0.08	0.30	
MTP2-9	0.173	0.141	0.060					
PR3	0.021	<0.015	0.020		PR2	0.04	39.79	
PR7	NA	NA	NA		PR5	0.04	23.67	

Fish Samples					Area Relevant Sediments			
Sample code	Mercury mg kg^{-1}	Methylmercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements	Sample code	Mercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements
IRPC7	0.028	<0.015	6.720		IRPC6	0.01	2.03	1.92 Cd/ 4.79 Cr
PRN-2017-1	0.561	0.499	NA		-	-	-	
PRN-2017-2	0.177	0.158	NA					
PRN-2017-3A+3B	0.129	0.115	NA					
SMS1-12/1	0.145	0.109	0.470		SMS1-9	0.04	32.39	3.94 Cd/ 54.14 Cd
SMS1-12/2	0.054	0.038	0.740					
SMS1-12/3	0.012	<0.015	0.680	0.071 Cd/ 0.33 Cd/ 0.11 Pb				
SMS1-2	0.020	<0.015	0.680		SMS1-3	0.04	27.59	
SMS1F	0.009	<0.015	NA		SMS2-11	0.15	11.02	
SMS2F	0.017	<0.015	NA					
TT-2017-1	0.517	0.455	NA		TT1-9	0.04	25.90	
TT2-8	NA	NA	NA					
TT1-1F	0.450	0.376	NA		TT1-7	0.04	2.06	
TT2-6	0.006	<0.015	0.030		TT1-5	0.08	0.22	
TT2-7	0.009	<0.015	0.45	0.65 Cr/ 0.04 Pb				

Table 4: Correlation analysis between total mercury content and other measured parameters. Length 1 – Weight befits polynomic correlation. Methylmercury content befits linear correlation.

Parameter	Correlation coefficient (R)
Length 1 (with tail fin)	0.854
Length 2 (without tail fin)	0.851
Weight	0.671
Methylmercury content	0.998

Figure 3: Graph shows the relationship between total mercury content and fish length.

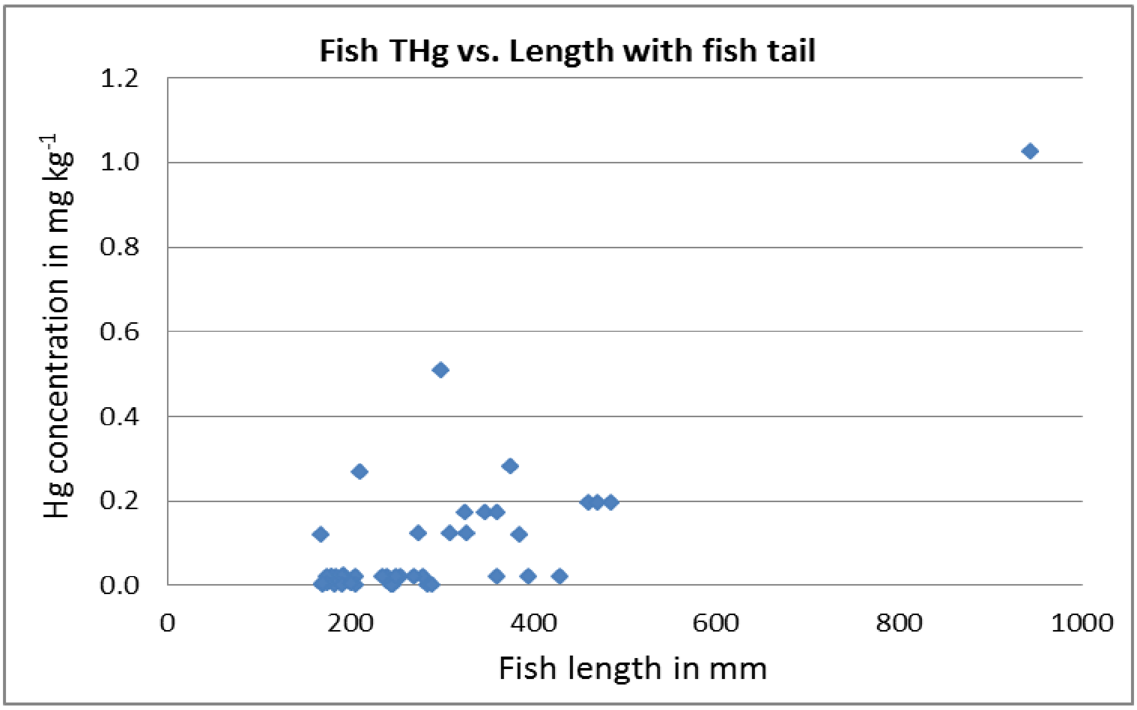


Figure 4: Graph shows the relationship between methylmercury content and total mercury.

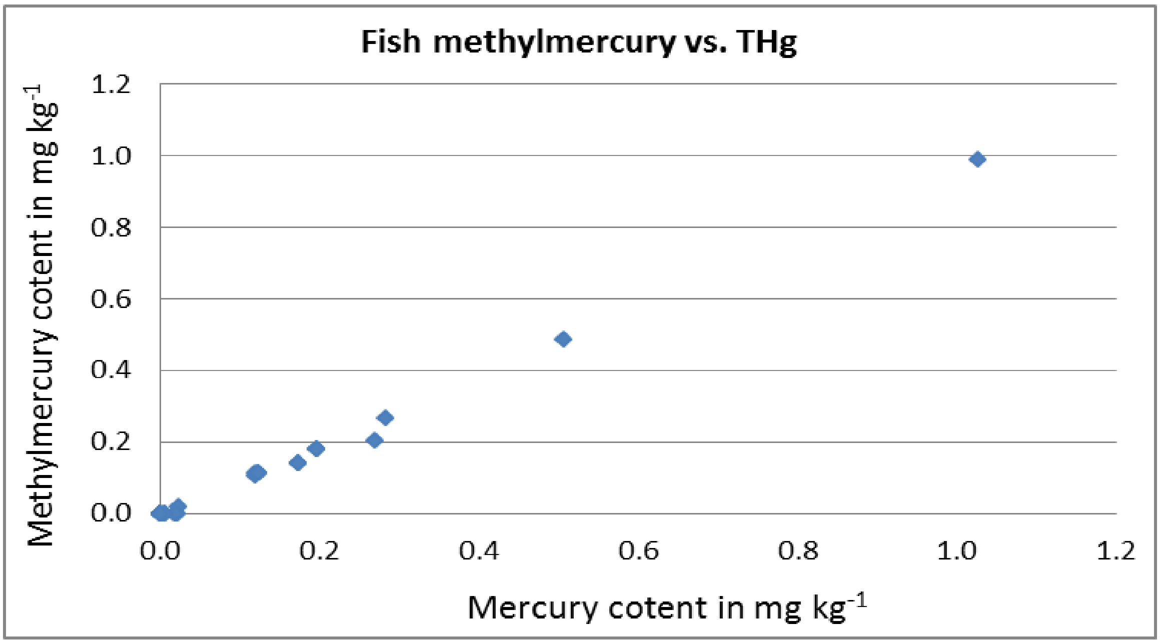


Figure 5: An average concentration of total mercury in individual fish species including standard deviation if available.

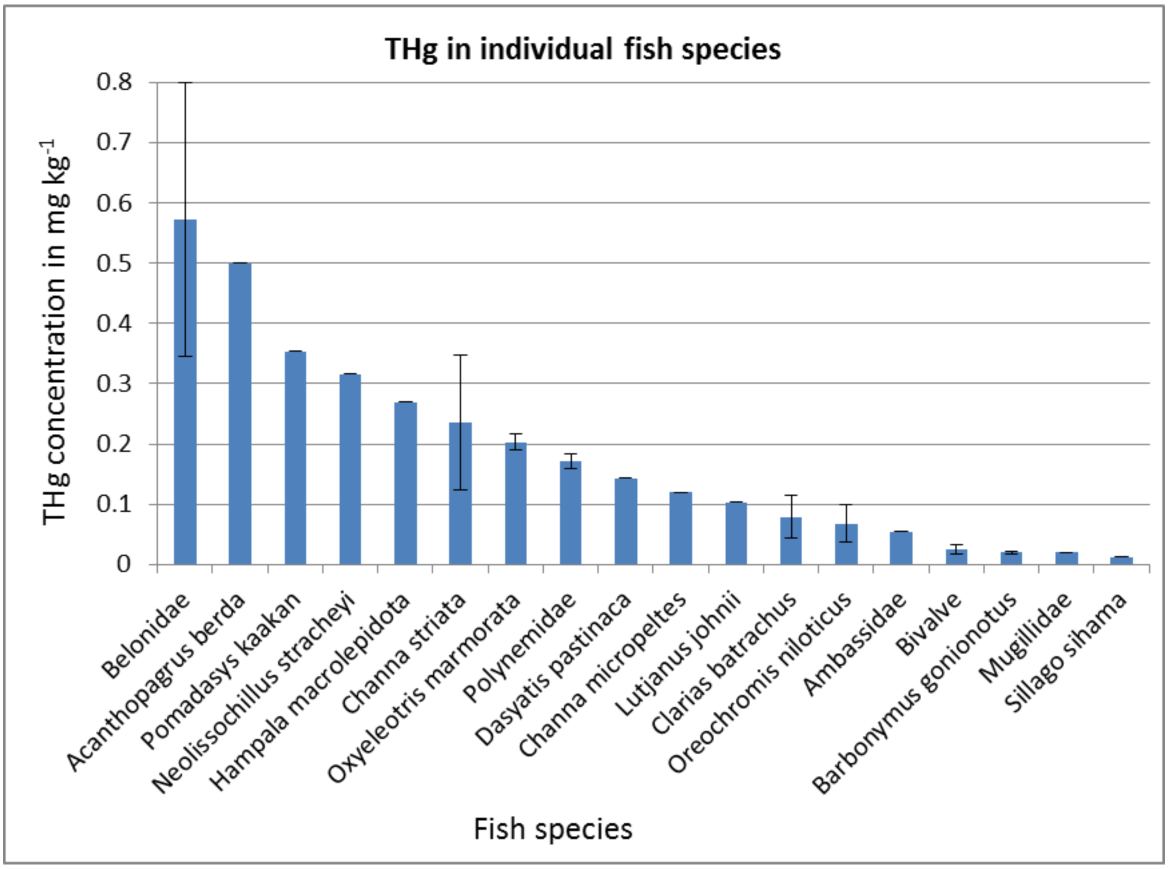


Figure 6:Concentration of total mercury in fish originating from different areas.

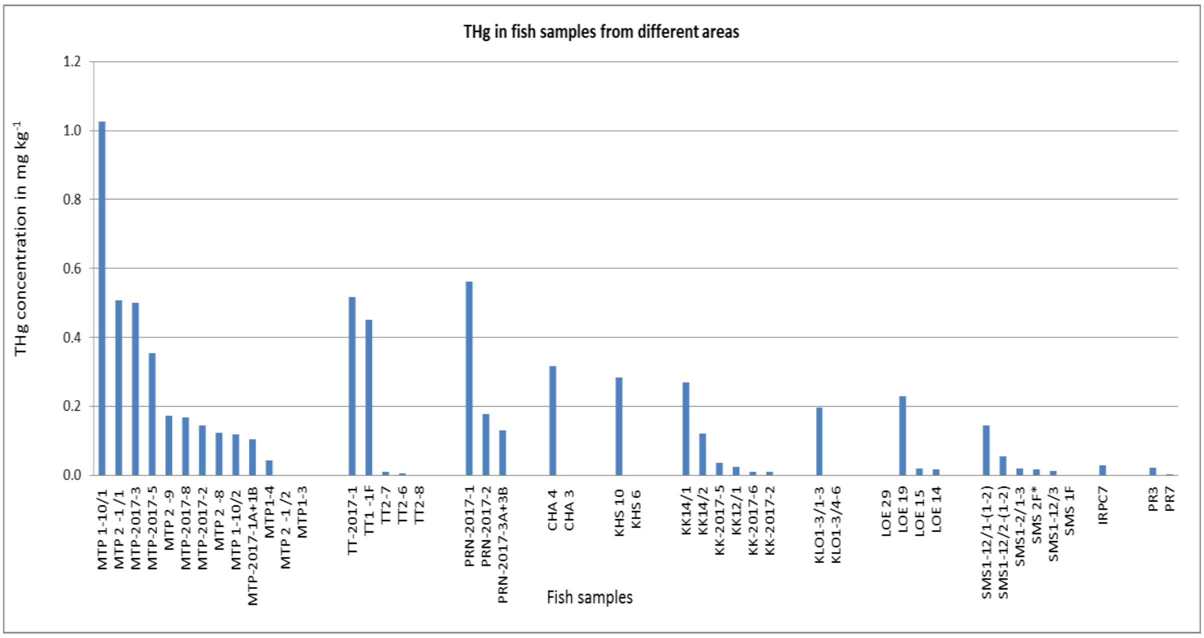


Figure 7: Graph shows a mercury content in fish originating from different sites of Map Ta Phut area.

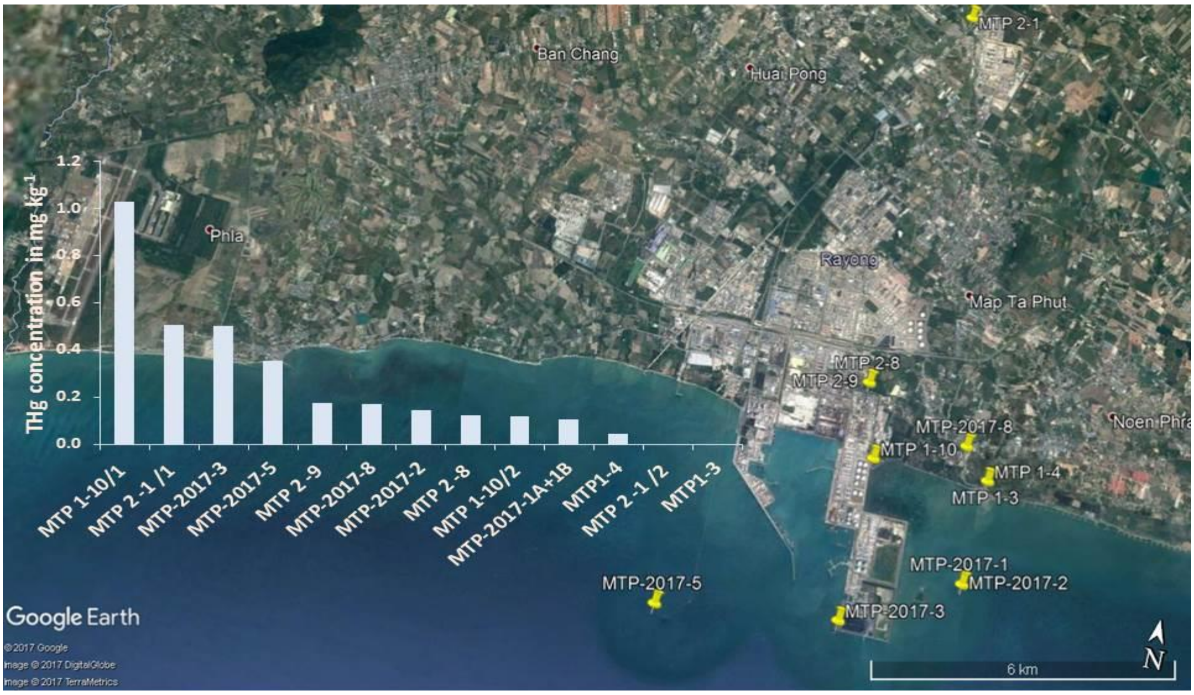
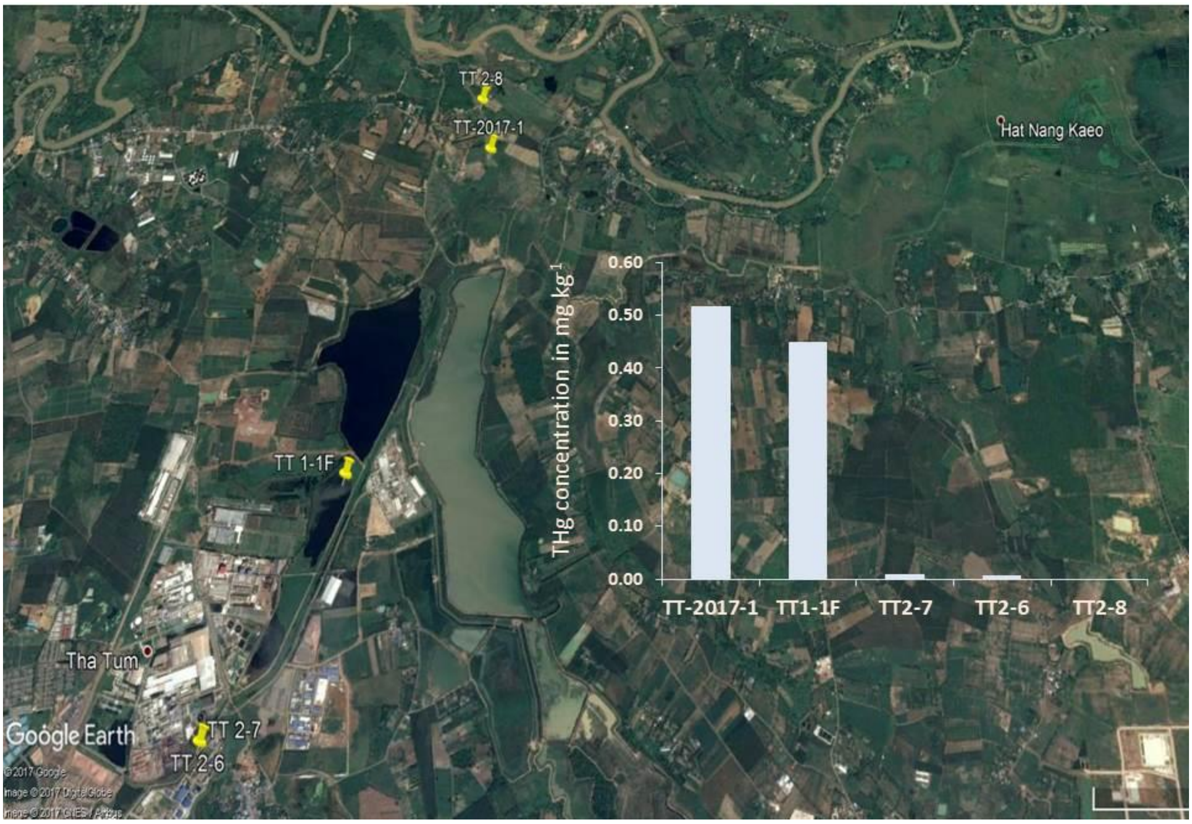


Figure 8: Graph shows a mercury content in fish originating from different sites of Tha Tum area. Sample TT2-8 was not analyzed.



Discussion

Main part of this chapter is an interpretation of data obtained from the conducted survey and their comparison to national and international standards. As well as drawing conclusions of what the results mean for people living around these areas and how it can affect their health. This chapter also tries to outline available options how to reduce risks associated with consumption of fish and fishery products originating from mercury polluted areas.

Legal standards and results of comparable studies

Content of pollutants in collected samples of fish and sediments was compared to the maximum, allowed or recommended levels of these pollutants as defined in national and international decrees, norms and laws (Table 5 – Table 8). Table 9 shows results of other comparable studies that have been conducted in the region of Thailand since 1970´s.

Sediment quality guideline for surface water by Thai Pollution Control Department (PCD) [19] gives the maximum recommended levels of risk elements in surface water sediments.

Supplementary guidance for developing soil screening levels by United States Environmental Protection Agency (US EPA) [20] sets regulatory standards of maximum contaminant levels in agricultural soils.

Because sediments may be washed out on surrounding land or for its suitable physico-chemical properties can be used as fertilizers or soil improvers there is Czech Decree No. 257/2009 [21] that regulates sediments application on agricultural soils. It defines the maximum possible content of selected risk elements in sediments that are intended to be used as soil improvers on agricultural soils.

Table 5: Legal standards and recommendations for heavy metals in sediments and soils. The content of elements is given in mg kg^{-1} of dry matter.

	Mercury	Arsenic
Sediment quality guideline (based on Thai PCD)	**0.18**	-
Regulatory standards in soils (based on US EPA)	**1**	0.11
Usage of sediments on agricultural soils (based on CZ Decree)	**0.8**	30

On the basis of US EPA Regional Screening Levels was created an edited version of Methodological guidelines of the Czech Ministry of Environment on Risk assessment of soil, soil, air and underground water [22] that gives criteria for industrial and other use areas that are not legally binding, however, often applied on a voluntary basis.

Table 6: Auxiliary criteria for soils. The content of elements is given in mg kg^{-1} of dry matter.

Criterion	Mercury	Arsenic
Industrial areas	43	2.4
Other areas	10	0.61

US EPA [23], Commission Regulation (EC) No. 1881/2006 [24], an advisory for consumers by Health Canada [25] and Ministerial Notification No. 98 of B.E. 2529/1986 [26] and its later issue No. 273 of B.E. 2546/2003 [27] limit the maximum levels of mercury in fish and fishery products in the European Union, respectively Thailand.

Table 7: Maximum allowable levels of mercury and arsenic in fish and seafood.

Foodstuffs	Maximum level of mercury (mg kg^{-1} of fresh weight)	Maximum level of arsenic (mg kg^{-1} of fresh weight)
Fishery products and muscle meat of fish (excluding species listed below)	**0.5**	**Not set**
Selected fishery products and muscle meat of fish: *Lophius* spp., *Anarhichas lupus*, *Sarda sarda*, *Anguilla* spp., *Hoplostethus* spp., *Coryphaenoides rupestris, Hippoglossus hippoglossus*, *Genypterus capensis, Makaira* spp., *Lepidorhombus* spp., *Mullus* spp., *Genypterus blacodes, Esox ivipa, Orcynopsis unicolor, Trisopterus minutus, Centroscymnes coelolepis, Raja* spp., *Sebastes marinus, S. mentella, S. iviparous, Istiophorus platypterus, Lepidopus caudatus*, *Aphanopus carbo, Pagellus* spp., *Carcharodon* spp., *Lepidocybium flavobrunneum*, *Ruvettus pretiosus*, *Gempylus serpens, Acipenser* spp., *Xiphias gladius*, *Thunnus*, *Euthynnus*, *Katsuwonus pelamis*. **(based on Commission Regulation (EC) No. 1881/2006)**	**1.0**	**Not set**
Fish and Seafood **(based on US EPA Fact Sheet No. 823-R-01-001/2001)**	**0.3 (total per week)** **0.2 (methylmercury per week)**	**Not set**
Level requiring special fish advisory for consumers **(based on Health Canada 2007: Human Health Risk Assessment)**	**0.2 (total mercury)**	**-**
Marine fish and Seafood **(based on Thai Ministerial Notification No. 98 of B.E. 2529/1986 and No. 273 of B.E. 2546/2003)**	**0.5**	**2 (inorganic)**
Other food (including freshwater fish) **(based on No. 98 of B.E. 2529/1986and Thai Ministerial Notification No. 273 of B.E. 2546/2003**	**0.02**	**2 (total)**

Table 8: Summary of average intakes from individual fish samples. For calculations was used an average daily intake of fish in Thailand of 0.061 kg and an average body weight of 60 kg [28].

Limit US EPA			RfD 0.3 mg THg kg^{-1}	RfD 0.2 mg MeHg kg^{-1}	0.006 mg MeHg-day*	
Sample	**THg**	**MeHg**	**Weekly THg intake ^{A}**	**Weekly MeHg intake ^{B}**	**Daily MeHg intake ^{C}**	**g of fish to reach daily limit^{D}**
CHA 4	0.316	0.226	0.135	0.097	0.014	26.5
IRPC7	0.028	<0,015	0.012			
KHS 10	0.283	0.267	0.121	0.114	0.016	22.5
KK12/1	0.024	0.018	0.010	0.008	0.001	339.0
KK14/1	0.269	0.202	0.115	0.086	0.012	29.7
KK14/2	0.120	0.105	0.051	0.045	0.006	57.1
KK-2017-2	0.009	<0,015	0.004			
KK-2017-5	0.036	0.032	0.015	0.014	0.002	188.7
KK-2017-6	0.010	<0,015	0.004			
KLO1-3/1-3	0.197	0.180	0.084	0.077	0.011	33.3
LOE 14	0.016	<0,015	0.007			
LOE 15	0.020	<0,015	0.009			
LOE 19	0.229	0.220	0.098	0.094	0.013	27.3
MTP 1-10/1	1.027	0.988	0.439	0.422	0.060	6.1
MTP 1-10/2	0.119	0.112	0.051	0.048	0.007	53.6
MTP 2 -1 /1	0.507	0.487	0.216	0.208	0.030	12.3
MTP 2 -8	0.124	0.112	0.053	0.048	0.007	53.6
MTP 2 -9	0.173	0.141	0.074	0.060	0.009	42.6
MTP1-4	0.042	0.016	0.018	0.007	0.001	375.0
MTP-2017-1A+1B	0.103	0.096	0.044	0.041	0.006	62.5
MTP-2017-2	0.143	0.112	0.061	0.048	0.007	53.6
MTP-2017-3	0.500	0.483	0.214	0.206	0.029	12.4
MTP-2017-5	0.353	0.334	0.151	0.143	0.020	18.0

Limit US EPA			RfD 0.3 mg THg kg^{-1}	RfD 0.2 mg MeHg kg^{-1}	0.006 mg MeHg-day*	
Sample	**THg**	**MeHg**	**Weekly THg intake ^{A}**	**Weekly MeHg intake ^{B}**	**Daily MeHg intake ^{C}**	**g of fish to reach daily limit^{D}**
MTP-2017-8	0.168	0.144	0.072	0.061	0.009	41.7
PR3	0.021	<0,015	0.009			
PRN-2017-1	0.561	0.499	0.240	0.213	0.030	12.0
PRN-2017-2	0.177	0.158	0.076	0.067	0.010	38.0
PRN-2017-3A+3B	0.129	0.115	0.055	0.049	0.007	52.2
SMS 2F*	0.017	<0,015	0.007			
SMS1-12/1-(1-2)	0.145	0.109	0.062	0.047	0.007	55.0
SMS1-12/2-(1-2)	0.054	0.038	0.023	0.016	0.002	157.9
SMS1-12/3	0.012	<0,015	0.005			
SMS1-2/1-3	0.020	<0,015	0.009			
TT1 -1F	0.450	0.376	0.192	0.161	0.023	16.0
TT-2017-1	0.517	0.455	0.221	0.194	0.028	13.2
TT2-6	0.006	<0,015	0.003			
TT2-7	0.009	<0,015	0.004			

** limit was calculated as US EPA limit 0.0001 mg MeHg kg-1 body weight per day times average body weight of 60 kg. Values of THg and MeHg intakes and g of fish to reach daily limit were calculated as follows: ^{A} 7 (days of the week) times an average fish consumption per person times total mercury content in individual fish samples. ^{B} 7 (days of the week) times an average fish consumption per person times methylmercury content in individual fish samples. ^{C} An average fish consumption per person times methylmercury content in individual fish samples. ^{D} US EPA limit related to an average body weight of 0.006 (see * note above) times 1000 (grams in one kilogram) divided by methylmercury content in individual fish samples*.

The results of this study are similar to the results obtained from studies previously carried out in the region of Thailand pointing to a long term mercury contamination of this area and its continuance.

Table 9: Overview of mercury content in fish of Thailand.

Study period	Location	Biota	Total mercury (mg kg^{-1})	Reference
1974	Bang Pra coast	3rd trophic level fish 4th trophic level fish	0.003 – 0.010 0.02 – 0.057	Menasveta (1976)
1976	Chao Phraya estuary	Fish and shellfish	0.009 – 0.205	Menasveta (1978)
1976 - 1977	Inner Gulf	3rd trophic level fish 4th trophic level fish	0.002 0.130 0.002 – 0.650	Cheevaparanapiwat and Menasveta (1979)
1977 - 1980	Inner Gulf	Fish and shellfish	0.002 – 0.206	Sivarak and co. (1981)
1979 - 1981	Inner Gulf	Fish and shellfish	0.012 – 0.051	Sidhichaikasem and Chernbamrung (1983)
1980	Mekong Ta Chin Chao Phraya Bang Prakong	Mullets	0.04±0.03 0.07±0.03 0.15±0.06 0.08±0.03	Menasveta and Cheevaparanapiwat (1981)
1990	Sichang Island Map Ta Phut Offshore (Erawan)	Fish	0.012 – 0.032 0.013 – 0.049 0.055 – 0.324	Menasveta (1990)
1997	Outer Gulf of Thailand	Demersal Fish	0.003 – 0.930	ARRI (1998)
2000	Offshore (Erawan)	Fish	0.045 – 0.892	Menasveta and Piyatiratitivorakul (2000)

Study period	Location	Biota	Total mercury (mg kg^{-1})	Reference
2008	Offshore (Erawan)	Fish	0.005 – 0.840	Menasveta and Piyatiratitivorakul (2008)
2013	Shalongwaeng Canal	Snakehead Fish	0.067 – 0.526	IPEN (2013)
2016 – 2017	Various sites	Fish	0.006 – 1.027	Results of this study

Evaluation of pollutant levels

The aim of this chapter is to evaluate data obtained from analyzing of fish and sediment samples that originate from different parts of Thailand and determine the degree of environmental and health burden it can cause. Following text is also a summary of results from each studied area and other generalizations resulting from analysis outcomes.

Chanthaburi

The mercury content in samples from Chanthaburi is in the case of CHA3 below Thai legal standards for fresh water fish (0.02 mg kg^{-1}) but in the case of omnivorous Masheer Barb (CHA4) it exceeds this limit almost 16 times. It also exceeds the US EPA limit 0.0001 mg MeHg kg^{-1} body weight per day by eating just 26.5 g of this Masheer Barb a day. Elevated content of mercury was found in spite of the fact that content of measured risk elements in sediment samples were under legal standard levels in all of them, including mercury and arsenic. Measured arsenic content is fish was bellow Thai legal threshold limit that is set for fresh water fish as 2 mg total arsenic kg^{-1}. Chanthaburi site was chosen as a control site,however, it is obvious that biomagnification of mercury can be a problem even in unpolluted areas. In this case it may be caused by a long transport deposition of mercury likely from Map Tha Put industrial area that is about 70 km far away. Figure 10 (Appendix 2) shows that prevailing winds from October to January blow from Map Tha Put in the direction of Chantaburi which supports the theory of the long range transport of mercury depositions.

Khao Hin Sorn

In the case of Khao Hin Sorn both mercury and methylmercury reached the maximum allowable levels in tissue of analyzed omninivorous Snakehead fish. Arsenic content, on the contrary, was within the Thai legal standard, although arsenic in sediments exceeded the auxiliary criteria for industrial and other areas given by the Czech Ministry of Environment (2.4 and 0.61 mg arsenic kg^1, respectively). In the vicinity of the sampling sites are placed smelting factories, a dumping of hazardous waste or an outflow of waste water, which all can be the source of the elevated content of arsenic in the environment.

Khon Kaen

Samples of fish (Cat fish, Snakehead fish, Silver Barb, Hampala Barb, Giant Snakehead fish) were taken from an outflow of a near paper and pulp factory and a coal power plant, and therefore the results show elevated levels of mercury in the samples, except samples of Catfish (KK-2017-2, KK-2017-6). Methylmercury reaches the US EPA legal standard for daily methylmercury consumption in samples of carnivorous Giant Snakehead fish and omnivorous Hampala Barb. Consumation of only 29.7 g and 57.1 g of the fish,respectively, would reach the US EPA daily limit of 0.0001 mg MeHg kg^{-1}-day. On the contrary, the content of arsenic in fish tissues were within the legal standards in all analysed samples from Khon Kaen area.

Klong Dan

Analysis of mussel, Threadfin and Mullet samples showed elevated levels of mercury and methylmercury only in the Threadfins (KLO1-3/1-3). Content of methylmercury in this sample exceeded the US EPA daily limit almost 2 times and total mercury content exceeded Thai legal standard for fresh water fish almost 10 times. Content of arsenic reached approximately a half of the legal standard in mussels and about one tenth in the case of Threadfins. , although measured amount of arsenic in sediments was above the maximum allowable arsenic content in sediments according to the Czech decree (30 mg arsenic kg^{-1} Thai PCD sediment quality guideline, on the other hand, does not set any maximum levels of arsenic in sediments.

Loei

Samples of carnivorous Marble Goby that were caught in the area of Loei gold mine show elevated levels of mercury and methylmercury as well. Only in the case of omnivorous Snakehead fish (LOE29) the mercury content did not reach the Thai legal standard. On the other hand Marble Goby (LOE19) exceeded the US EPA daily limit of methylmercury more than 2 times and consumption of just 27.3 g of this fish would be enough to exceed the daily allowable intake of methylmercury according to the US EPA limit. Arsenic content in fish did not reach the regulatory limits, although sediments from this area exceeds the US EPA regulatory standards for agricultural soils and the Czech auxiliary criteria too.

Map Ta Phut

Heavy industrialized area of Map Ta Phut shows elevated levels of mercury and methylmercury in tissues of collected fish samples (Goldsilk Seabream, Javelin Grunter, Needle fish, Snakehead fish) that belong mostly to the carnivorous type of fish. Amount of mercury in the samples varied between 0.042 – 1.027 mg total mercury kg^{-1} and 0.016 – 0.998 mg methylmercury kg^{-1}, respectively, and reaches the legal standard in all of them regardless type of their diet. The place of origin and measured concentration of total mercury in the samples shows Figure 7. Daily intake of methylmercury is exceed by all fish species, but not by mussels. Amount of fish or mussels to reach the US EPA daily intake of methylmercury limit varies between 6.1 – 375 g depending on the specie. The most toxic is carnivorous Needle fish and the least toxic are mussels that feed on plankton and other microscopic organisms which are free-floating in the water. Arsenic content in some sediments exceeded the US EPA regulatory standard more than 180 times, although this fact did not reflect on arsenic content in fish samples as arsenic in the samples did not reach the regulatory limits for arsenic in food.

IRPC industrial zone

Although the sample of mussels was taken near an industrial complex, the result of 0.028 mg THg kg^{-1} exceeded the Thai mercury limit for food only slightly. However, the legal standard for arsenic was in this case exceeded more than 3 times.

Praeksa

Samples from Praeksa come from surrounding of a large municipal and hazardous waste landfill, therefore the collected samples show elevated levels of mercury, but suprisingly slightly (0.021 mg THg kg^{-1} for PR3). All samples are within range of allowable weekly average intake of mercury and content of methylmercury were below detection limits in all analysed samples, therefore within legal standard of US EPA as well. Arsenic content in fish was below Thai legal standard for food.

Prachinburi

Samples originated from Thap Lan National Park and Klong Yang Canal should have served as a control, industry and pollution free areas with expected low mercury levels, however, the results show otherwise. High contents of mercury and methylmercury, both higher than maximum allowable levels, were found in allsamples (Snakehead fish,Marble Goby, Nile Tilapia)exceeding the Thai legal standards for food 6 – 28 times and US EPA daily methylmercury intake standard 1.16 – 5 times. The highest concentration of both mercury and metylmercury was found in omnivorous Snakehead fish (PRN-2017-1) reaching 0.561 mg kg^{-1} and 499 mg kg^{-1}, respectively.. Almost 90% of the mercury in the tissue of the Snakehead fish occurs as highly toxic methylmercury, which is consistent with results of US EPA [23]. The source of the pollution remains unknown, although a possible long range transport and atmospheric deposition and accumulation of the mercury from neighboring polluted areas like Prachinburi large Rojana industrial park can be discussed.

Samut Sakhon

The content of measured elements in Samut Sakhon fish samples is generally low, although some of the fish species belongs to carnivores. Threadfin, Asiatic Glassfish and omnivorous Mullet reached the Thai legal standard for total mercury in food. Threadfins also exceeded the US EPA daily intake limit for metylmercury 1.16 times. Arsenic in the fish tissues was present at levels about one fourth to one third of the legal standard, even though in some sediments were found elevated levels of this element.

Tha Tum

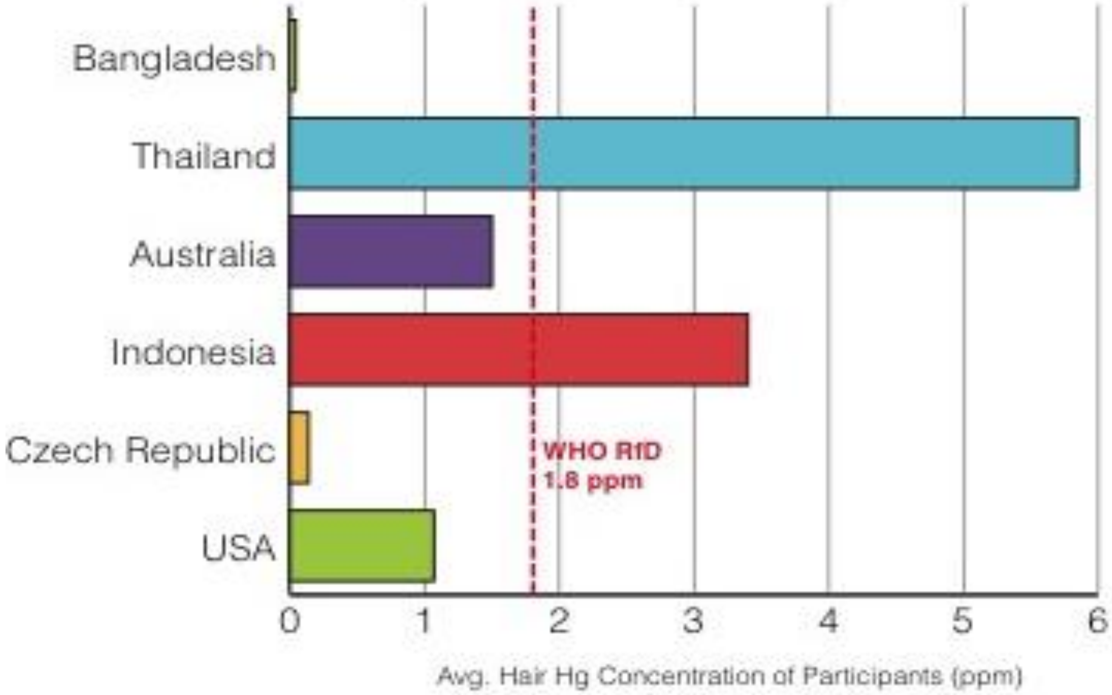
Although Tha Tum area belongs to the ones that are highly industrialized the results of mercury in fish tissues are ambiguous and results are affected by the place of origine (see Figure 8). The content of total mercury varies between 0.006 – 0.517 mg mercury kg^{-1}, i.e. from levels close to the detection limit (Nile Tilapia, Shellfish) to levels exceeding legal standards for fish and seafood given by US EPA, EU and Thai legal standards (Snakehead fish). All analyzed Snakehead fish samples were above regulatory standards for both total mercury and metylmercury as well. Thai legal standard for total mercury was exceeded more than 24 times and US EPA daily mercury intake limit more than 4 times. Sediment samples do not show exceeded levels except slightly elevated levels of arsenic in TT1-7 sample (2.06 mg arsenic kg^{-1}) and significantly elevated levels of arsenic in the sample TT1-9 (25.9 mg arsenic kg^{-1}), although this fact does not reflect on content of arsenic in fish samples.

Figure 5 shows an average concentration of total mercury in individual fish species that reaches 0.573±0.454 mg kg^{-1} for carnivorous Needle fish (*Belonidae*) to 0.0090±0.0002 mg kg^{-1} for Catfish (*Clarias batrachus*). Most often represented fish was a Snakehead fish (n=13) that occurs in 9 of the 11 studied areas and for its frequent occurrence can be considered as one of the most frequently eaten fish. An average content of mercury in the Snakehead fish is 0.235±0.222 mg kg^{-1}, median value of 0.168 mg kg^{-1}. 82% of the Snakehead fish samples exceed the Thai legal standard for mercury in food which together with its frequent occurrence may cause serious health effects.

Concentration of the total mercury in fish originating from different studied areas (Figure 6) shows that most toxic fish samples come from highly industrialized Map Ta Phut area and Tha Tum area, but suprisingly also from the area of Thap Lan National Park and Klong Yang Canal. The source of pollution in the case of Map Ta Phut and Tha Tum is obvious but in case of the Thap Lan National Park and Klong Yang Canal remains unknown. A possible long range transport and atmospheric deposition and accumulation of the mercury from polluted areas like Tha Tum industrial area can be discussed. Figure 11 (Appendix 2) shows that prevailing winds in this area from October to February blow from Tha Tum in the direction of Thap Lan National Park which is about 50 km far away, therefore may be the possible source of pollution in the National Park and its surroundings.

High content of mercury in the environment results also in higher concentration of this element in hair. Analysis of mercury in hair of Thais that were conducted by EARTH Association and that will be separately published in the fall 2017 (data given in Appendix 3) show that mercury in human hair samples originating from Tha Tum and Map Ta Phut are generally high. 65% of Map Ta Phut hair samples and 79% of Tha Tum hair samples have mercury content above US EPA standard for safe mercury level in hair that is set as 1 mg kg^{-1}. The content of mercury in hair from Map Ta Phut reaches 0.562 – 35.929 mg kg^{-1}, with mean and median values of 4.339±7.496 mg kg^{-1} , 1.598 mg kg^{-1}. In the case of Tha Tup the content reaches 0.625 – 10.093 mg kg^{-1}, 1.815±1.695 mg kg^{-1} and 1.367 mg kg^{-1}, respectively. This fact is also supported by a chart below that is using data on mercury concentration in hair previously published by the Arnika Association (Figure 9) that as a limit uses converted WHO and the US EPA guidance values for mercury that are 1.8 mg kg^{-1} and 1.2 mg kg^{-1}, respectively [29].

Figure 9: Mercury concentration in hair. Complied by Amanda Giang and Julie van der Hoop [29]**.**



The results of this study also confirm bioaccumulation and biomagnification of mercury higher in the food chain, resulting in the generally higher content of mercury in carnivorous fish. Correlation analysis of mercury content with measured parameters (Table 4, Figure 3 – 4) show that fish length (both with and without tail fin) correlates significantly (0.854 and 0.851, respectively) and less correlates weight of the fish (0.671). A strong correlation was found between total mercury content and methylmercury content (0.998) showing that methylation of mercury is one of the main biochemical pathways in studied fish species.

Health risk management

Fish are protein and other nutrient rich foodstuff that is recommended by the US EPA to be eaten 2 – 3 times a week, especially in case of children and women of childbearing age. Although US EPA points out that it is essential to choose cautiously what kind of fish to consume. It is reported by many studies that mercury levels varied between different fish species and areas where they come from. Big carnivorous fish from polluted areas are more likely to have much higher mercury levels comparing herbivorous fish from the same place. In general, King Mackerel, Shark, Tilefish, Marlin, swordfish, Orange Roughy and Big Eye Tuna belong to fish that should be avoided [30].

Mercury high toxicity for human and overall wildlife requests worldwide initiative to reduce the mercury contamination of the environment. The results of this study show that mercury can contaminate even places with no sources of pollution nearby. In this case the contamination pathway is most probably due to the long distance transport of atmospheric depositions and mercury persistence and accumulation in the environment [31, 32].

Within the EU emissions of mercury are controlled by the Convention on Long-Range Transboundary Air Pollution (CLRTAP). However, it is aimed exclusively on airborne mercury. In order to really eliminate the negative impact of the use and release of mercury worldwide, an international convention has to be applied.

In February 2009 at the 25th meeting of the United Nations Environment Program (UNEP) Steering Committee, representatives from more than 140 countries agreed to a launch of a new Global Mercury Convention. Negotiations began in fall 2009 and in October 2013 the Minamata convention was signed at a diplomatic conference in Japan. Its purpose is to limit mercury inputs to production processes, international mercury trade, mercury emissions, secure storage and address old environmental and mercury waste. Likewise, it should prevent the use of this toxic metal in the production of chlorine, but also in a wide range of medical devices. It should also contribute to the decrease of mercury emissions from coal power plants, waste incinerators and other sources, with using the best available technologies and procedures [33].

Conclusions

The main objective of this study is the evaluation of contamination in different parts of Thailand by mercury and other elements (As, Zn, Cd, Sr, Ba, Cu, Co, Ni, Cr, Pb, Mo). These elements were determined in a set of fish and sediment samples taken during February/March 2016 and February 2017. In collected samples only mercury and arsenic were found at significant levels. Although arsenic in sediments exceeded legal standards quite often, its contain in fish was elevated only in few samples. Also the occurrence of arsenic in water and especially marine organisms is not that crucial because most of the inorganic arsenic from the environment is transformed by the organisms into much less harmful organic compounds like arsenobetaine and arsenocholine that are often considered harmless. On the contrary, a main product of mercury methylation by organisms is highly toxic methylmercury. Another problem is high background concentrations of mercury in samples originating from unpolluted areas which can be caused by a long distance transport of mercury and its bioaccumulation and biomagnification further away from the original source of contamination. When it is counted with Thai average daily fish consumption per person of 0.061 kg and an average body weight of 60 kg then the amount of methylmercury in almost all fish samples were above the US EPA oral Reference Dose for methylmercury, which is set as 0.0001 mg methylmercury per kg body weight-day (see Table 8 *[,C]). The most contaminated samples originated from Tha Tum and Map Ta Phut areas. The situation is all the more serious when we take into consideration that such contaminated fish are sometimes eaten up to 2 – 3 times a day, and are eaten even by children, pregnant women and are intended for the local market. Using of mercury in the industry and subsequent mercury contamination causes health, ecological, economical and ethical burdens and should be further regulated on a national and international level.

Acknowledgement

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PHOTO 1 on the cover: http://www.mekongcommons.org/wordpress/wp-content/uploads/2015/08/2_fisherman-e1440581797804.jpg [15.9.2017]

PHOTO 2 on the cover: Karnt Thassanaphak [15.9.2017]

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Appendix 1:

Pictures

Picture 1: Chachoengsao Province

Picture 2: Khon Kaen Province

Picture 3: Loei Province

Picture 4: Prachinburi Province

Picture 5: Rayong Province

Picture 6: Samut Prakan Province

Picture 7: Samut Sakhon Province

Picture 8: Chanthaburi Province

Picture 9: Asiatic Glassfish

Picture 10: Climbing Perch

Picture 11: Giant Snakehead

Picture 12: Hampala Barb

Picture 13: Mullet

Picture 14: Needle Fish

Picture 15: Silver Barb

Picture 16: Snakehead Fish

Picture 17: Snakeskin Gourami

Picture 18: Threadfins

Picture 19: Walking Catfish

Picture 20: Sampling of MTP1-1 fish sample

Picture 21: Sampling site for MTP1-10

Picture 22: Sampling site KK4
reservoir at site KK4

Picture 23: Outflow of wasted water

Picture 24: Sediment sampling with

a shovel at KK4

Picture 25: Sampling site KK9

Picture 26: Sampling site MTP1-1

Picture 27: Sediment sampling with a core sampling device at MTP1-1

Picture 28: Sampling site MTP1-14

Picture 29: Sediment sampling with a shovel at MTP1-14

Picture 30: Sampling site SMS2-11

Picture 31: Sampling at SMS2-11

Picture 32: Sampling site TT1-5

Picture 33: Sampling site TT1-7

Picture 34: Sampling site TT1-9

Picture 35: Sampling at sampling site TT1-9

Pictures 1 – 8: Maps by NordNordWest WikiMedia Commons. Pictures 9 – 35: Photos by Arnika Association and EARTH 2016/2017.

Appendix 2:

Figure 10: Comparison of windrose graphs (Rayong, Huay Pong Station) of the area with mutual geographical location of Map Tha Put and Chantaburi.

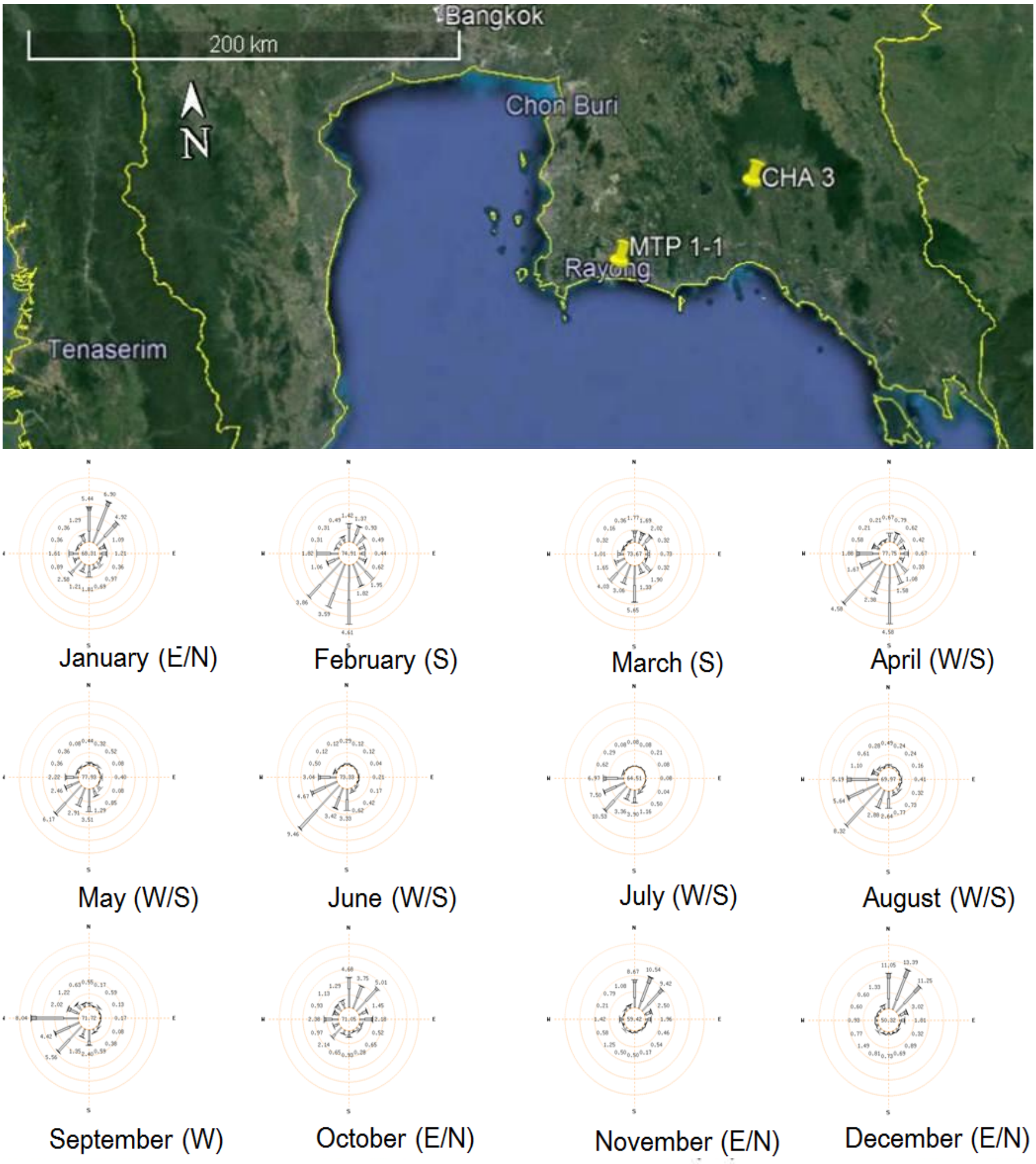
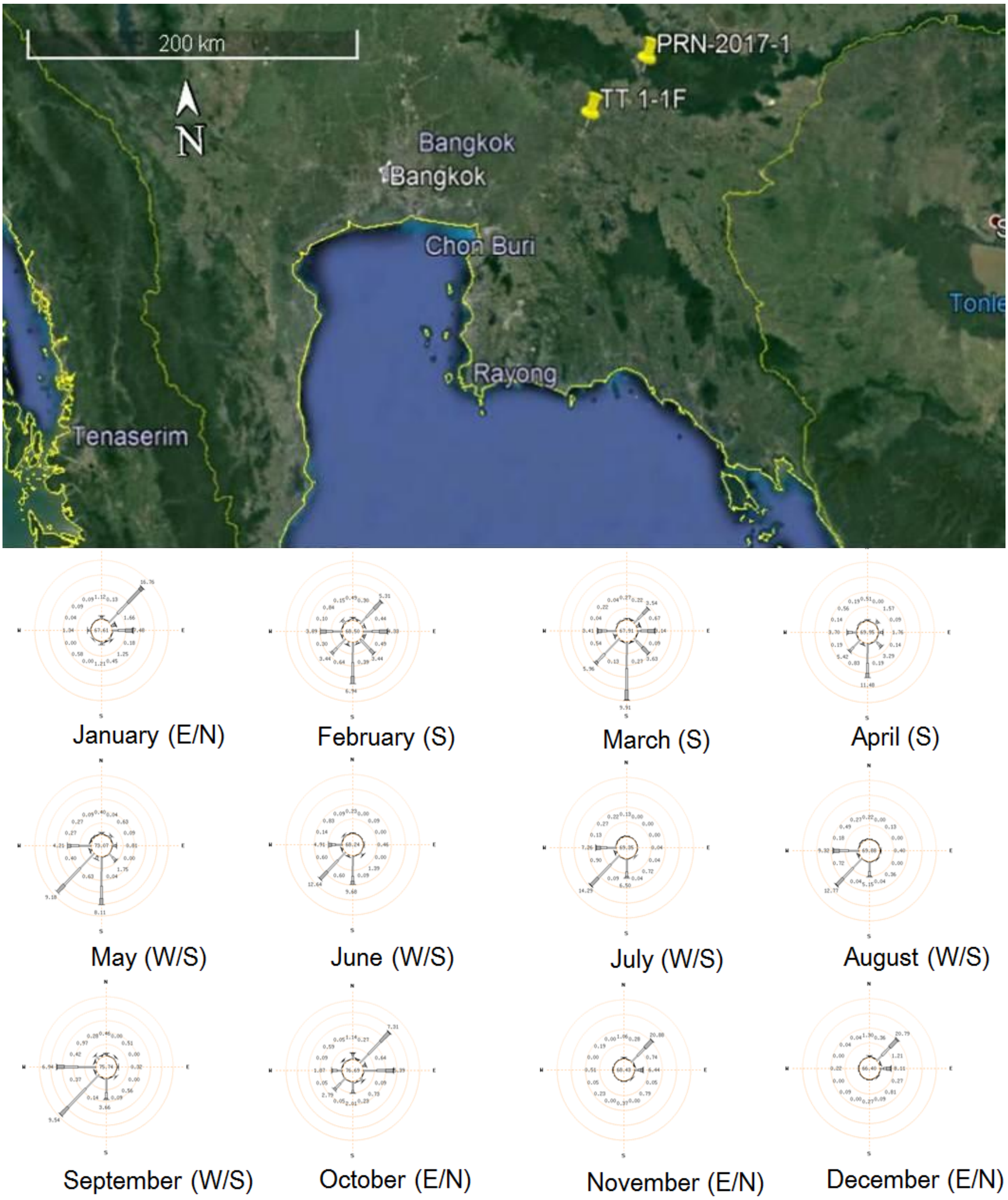


Figure 11: Comparison of windrose graphs (Kabinburi district, Prachinburi province) of the area with mutual geographical location of Tha Tum and Thap Lap National Park.



Appendix 3:

The mercury content in human hair collected from different communities in Thailand. Research was conducted by EARTH Association and will be published separately in September 2017. THA1 samples originating from Map Ta Phut area, THA2 from Tha Tum area.

Sample Code	Community	Mercury mg kg^{-1}	Sample Code	Community	Mercury mg kg^{-1}
THA-1-Hair-01	Krok Yai Cha	1.144	THA-2-Hair-01	Moo 1, Ban Tha Tum	4.472
THA-1-Hair-02	Wat Maptaphut	29.070	THA-2-Hair-02	Moo 1, Ban Tha Tum	1.393
THA-1-Hair-03	Wat Maptaphut	0.696	THA-2-Hair-03	Moo 4, Ban Hua Loh	1.346
THA-1-Hair-04	Wat Maptaphut	0.596	THA-2-Hair-04	Moo 3, Ban Lang Thum	1.026
THA-1-Hair-05	Soi Prapa 2	1.610	THA-2-Hair-05	Moo 3, Ban Lang Thum	2.636
THA-1-Hair-06	Soi Prapa 2	6.196	THA-2-Hair-06	Moo 4, Ban Hua Loh	1.805
THA-1-Hair-07	Soi Prapa 2	0.893	THA-2-Hair-07	Moo 4, Ban Hua Loh	0.725
THA-1-Hair-08	Wat Maptaphut	4.132	THA-2-Hair-08	Moo 3, Ban Lang Thum	0.776
THA-1-Hair-09	Wat Maptaphut	12.512	THA-2-Hair-09	Moo 4, Ban Tha Bung Kan, Haad Nang Kaew	2.399
THA-1-Hair-10	Wat Maptaphut	0.956	THA-2-Hair-10	Moo 2, Ban Haad Sung, Haad Nang Kaew	1.328
THA-1-Hair-11	Wat Maptaphut	7.414	THA-2-Hair-11	Moo 6, Ban Wang Ka Pong	1.656
THA-1-Hair-12	Noen Phra	0.687	THA-2-Hair-12	Moo 6, Ban Haad Ma Kok	1.231
THA-1-Hair-13	Laem Sa Nguan	1.892	THA-2-Hair-13	Moo 7, Ban Haad Ma Kok	1.855
THA-1-Hair-14	Laem Sa Nguan	1.328	THA-2-Hair-14	Moo 7, Ban Haad Ma Kok	1.085

THA-1-Hair-15	Takuan-Ao-pradoo	1.196	THA-2-Hair-15	Moo 7, Ban Haad Ma Kok	1.082
THA-1-Hair-16	Takuan-Ao-pradoo	2.839	THA-2-Hair-16	Moo 6, Ban Wang Ka Pong	4.564
THA-1-Hair-17	Takuan-Ao-pradoo	1.120	THA-2-Hair-17	Moo 6, Ban Wang Ka Pong	1.076
THA-1-Hair-18	Takuan-Ao-pradoo	4.287	THA-2-Hair-18	Moo 3, Ban Lang Thum	1.412
THA-1-Hair-19	Takuan-Ao-pradoo	0.906	THA-2-Hair-19	Moo 3, Ban Lang Thum	1.387
THA-1-Hair-20	Takuan-Ao-pradoo	1.278	THA-2-Hair-20	Moo 3, Ban Lang Thum	10.093
THA-1-Hair-21	Takuan-Ao-pradoo	1.828	THA-2-Hair-21	Moo 5, Ban Taam	0.668
THA-1-Hair-22	Takuan-Ao-pradoo	35.292	THA-2-Hair-22	Moo 5, Ban Taam	1.579
THA-1-Hair-23	Takuan-Ao-pradoo	0.883	THA-2-Hair-23	Moo 5, Ban Wung Bua Tong	1.723
THA-1-Hair-24	Takuan-Ao-pradoo	1.762	THA-2-Hair-24	Moo 4, Ban Wung Bua Tong	1.097
THA-1-Hair-25	Nong Tungmay	2.193	THA-2-Hair-25	Moo 4, Ban Wung Bua Tong	0.836
THA-1-Hair-26	Lao Market	1.892	THA-2-Hair-26	Moo 4, Ban Wung Bua Tong	1.155
THA-1-Hair-27	Lao Market	1.100	THA-2-Hair-27	Moo 4, Ban Wung Bua Tong	1.920
THA-1-Hair-28	Lao Market	0.562	THA-2-Hair-28	Moo 4, Ban Wung Bua Tong	1.604
THA-1-Hair-29	Lao Market	0.874	THA-2-Hair-29	Moo 4, Ban Wung Bua Tong	0.964
THA-1-Hair-30	Lao Market	1.585	THA-2-Hair-30	Moo 4, Ban Wung Bua Tong	0.643
THA-1-Hair-31	Lao Market	1.325	THA-2-Hair-31	Moo 4, Ban Wung Bua Tong	2.227
THA-1-Hair-32	Lao Market	9.914	THA-2-Hair-32	Moo 4, Ban Wung Bua Tong	1.130
THA-1-Hair-33	The mouth of the Takuan Canal	3.550	THA-2-Hair-33	Moo 4, Ban Wung Bua Tong	2.176
THA-1-Hair-34	Krok Yai Cha	4.007	THA-2-Hair-34	Moo 5, Ban Taam	0.625

Appendix 4

Advisory chart and recommendations of US EPA for fish consumption [30].

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.

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