Health Risk Assessment of Contaminated Pesticides in the Main Rivers of Thailand
การประเมินความเสี่ยงต่อสุขภาพจากสารกำจัดศัตรูพืชปนเปื้อนในแม่น้ำสายหลักของประเทศไทย

Malisa Wetchayanon (มลิสา เวชยานนท์)* Dr.Nipapun Kungsakulniti (ดร.นิภาพรรณ กังสกุลนิติ)**
Dr.Naowarut Charoenca (ดร.เนาวรัตน์ เจริญค้า)** Dr.Chalongkwan Tangbanluekan (ดร.ฉลองขวัญ ตั้งบรรลือกาล)***

ABSTRACT

Long-term dietary exposure of pesticides poses serious human health risks. This study was conducted to provide a health risk assessment of pesticides in the Chao Phraya, Pa Sak, and Tha Chin rivers, Thailand. Water samples of these three Rivers were collected in both dry and wet seasons from 2009 to 2016. Gas chromatography was used for pesticide analysis including of organochlorines, organophosphates, carbamates, pyrethroids and triazines. The risks of non-carcinogenic and carcinogenic compounds were calculated using Hazard Quotient (HQ) and Risk (R) methods. The results revealed that organochlorines, organophosphates and triazines pesticides were detected in the range of 0.01 - 13.40 μg/L in the three rivers and that there was low potential risk from human exposure from drinking water (HQ < 1).

บทคัดย่อ

การรับสัมผัสสารกำจัดศัตรูพืชโดยการบริโภคเป็นระยะเวลานาน อาจส่งผลกระทบเป็นอันตรายต่อสุขภาพ การศึกษานี้จึงได้ทำการประเมินความเสี่ยงต่อสุขภาพจากสารกำจัดศัตรูพืชปนเปื้อนในแม่น้ำสายหลักในประเทศไทย ได้แก่ แม่น้ำเจ้าพระยา แม่น้ำป่าสัก และแม่น้ำท่าจีน โดยสุ่มเก็บตัวอย่างน้ำจากแม่น้ำทั้ง 3 สายในช่วงฤดูแล้งและฤดูฝน ตั้งแต่ปี 2552 - 2559 สารกำจัดศัตรูพืชตรวจวิเคราะห์ด้วยเครื่องแก๊สโครมาโตกราฟ ได้แก่ สารกลุ่มออร์กาโนคลอรีน ออร์กาโนฟอสเฟต คาร์บาเมท ไพรีทรอยด์ และกลุ่มไทรอาซีน การประเมินความเสี่ยงสารที่ไม่ก่อให้เกิดมะเร็งใช้สมการ Hazard Quotient (HQ) และการประเมินความเสี่ยงสารที่ก่อให้เกิดมะเร็งใช้สมการ Risk ผลการตรวจวิเคราะห์ พบว่าสารกำจัดศัตรูพืชกลุ่มออร์กาโนคลอรีน ออร์กาโนฟอสเฟต และไทรอาซีนปนเปื้อนในแม่น้ำทั้ง 3 สาย มีความเข้มข้นระหว่าง 0.01 - 13.40 ไมโครกรัมต่อลิตร และบ่งชี้ว่ามีความเสี่ยงน้อยที่จะเกิดผลกระทบต่อสุขภาพ (HQ < 1) ในการบริโภคน้ำจากทั้ง 3 แหล่งนี้

Keywords: Health risk assessment, Pesticide, River contamination
คำสำคัญ: การประเมินความเสี่ยงต่อสุขภาพ สารกำจัดศัตรูพืช การปนเปื้อนในน้ำ

** Student, Master of Science Program in Environmental Technology, Faculty of Public Health, Mahidol University*
*** Associate Professor, Department of Sanitary Engineering, Faculty of Public Health, Mahidol University*
**** Assistant Professor, Department of Forensic Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University*

Introduction

Thailand, a major food producing country, has gained much income from exporting agricultural commodities. In 2014, agricultural products with a value of $39,766 million were exported to foreign countries, accounting for 17.9 % of total exports (The Office of Agricultural Economics [OAE], 2015). The demand for increased agriculture productivity has caused a rapid increase in pesticide use to protect products lost to weeds, a multitude of pests and diseases. The reasons for extensive use of pesticide in Thailand are the wide variation in climate and crops. In Thailand, most pesticides used in the country are imported and their amount has increased significantly over time. The Office of Agriculture Regulation (OAR) reported that pesticide use was increased by 4 folds in the last decade with nearly 100,000 tons of active ingredients being imported into Thailand during 2004 to 2015. Herbicides were the largest proportion of imported pesticides (OAR, 2016).

The Chao Phraya, Pa Sak, and Tha Chin are three of the main rivers of the central region of Thailand. The pollution in these rivers are mainly caused by discharge from the activities of agriculture, aquaculture and industries located along these rivers. Wastes from agricultural discharge are deposited in various environmental components of the aquatic ecosystem, particularly in the water column. Such pollutants are derived mainly from amounts of applied pesticides lost from fields and transported to surface water through surface runoff. Generally, the pesticide residues that are detected in water bodies are closely related to the agricultural practices of the nearby area. Pesticides seep into soils and groundwater which can end up in drinking water (Jaipieam et al., 2009). So, pesticides can enter the human body through oral intake by consuming water.

Long-term dietary exposure to pesticides may cause long term adverse effects. For example, organochlorines are wildly known to damage the central nervous system (Costa et al., 2008), thyroid and bladder and, chlorpyrifos induce neurotoxicity (Steenland et al., 2000). Endosulfan blocks chloride uptake induced by GABA in primary cultures of cortical neurons (Pomes et al., 1994; Vale et al., 2003). Atrazine induces aromatase and promotes the conversion of testosterone to estrogen, which could risk impaired sexual development in mammals (Haye et al., 2002).

Several studies monitored the presence of pesticide contamination in water of the Chao Phraya, Pa Sak, and Tha Chin rivers (Chulintorn et al., 2002; Chatrasuntiprapa et al., 2002). However, there are a lack of studies providing health risk assessments of dietary exposure to pesticides from water.

Objective

The aim of this study is to provide a health risk assessment of pesticides contamination in the Chao Phraya, Pa Sak, and Tha Chin rivers.

Materials and methods

1. Study area and sampling sites

The number and geographic location of the sampling points were decided upon consideration of the total length of each river and focused on locations in nearby agricultural areas in the river's basin. A global positioning system (GPS) was used to indicate the sampling locations as shown in Figure 1. Sampling was conducted from the

Chao Phraya, Pa Sak, and Tha Chin Rivers in the dry and wet seasons. In the Chao Phraya River, two samples were collected at each of 23 and 11 sampling sites in 2009 and 2016, respectively. In the Pa Sak River, two samples were collected at each of 26 sampling sites in 2010 and 2014. In the Tha Chin River, two samples were collected at each of 24 sampling sites in 2011 and 2015. Two samples were collected at each site, one each in the dry and wet seasons. Water samples were collected using a Kemmerer sampler at a depth of 100 cm below the water surface. Four 1-L water samples for composite sampling were collected in HDPE bottles at every sampling site. All samples were stored in an icebox at 4°C until transferred to the laboratory for analysis.

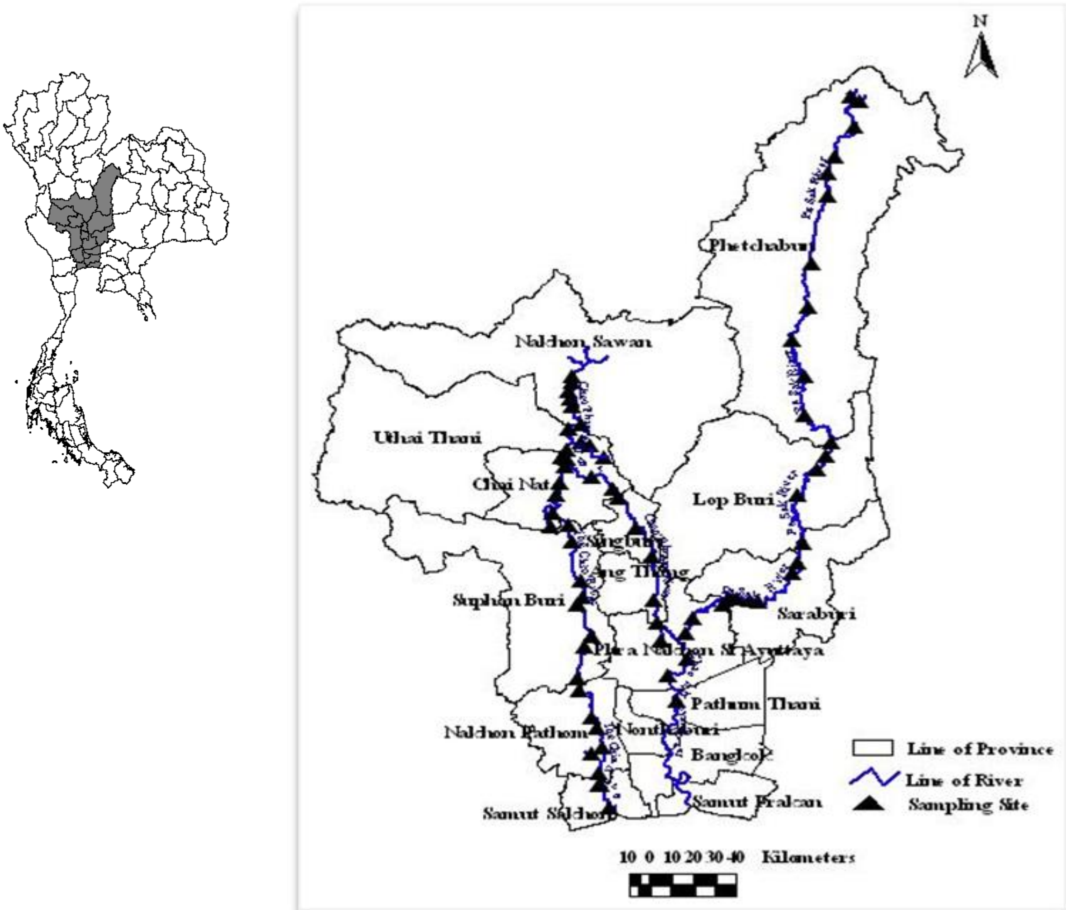

Figure 1 Sampling locations of water collected from the Chao Phraya, Pa Sak, and Tha Chin Rivers

2. **Analytical procedure**

Pesticide contaminates in water samples were extracted by liquid-liquid extraction and analyzed by Gas Chromatography (AOAC 990.06, 2005; Environmental Protection Agency 8141 A [EPA], 1994).

Pesticides analyzed included those of the organochlorines group: aldrin, α-hexachlorocyclohexane, α-endosulfan, β-endosulfan, dieldrin, endosulfan sulfate, endrin, γ-hexachlorocyclohexane, heptachlor, heptachlor epoxide, o,p'-DDE, o,p'-DDT, o,p'-TDE, p,p'-DDE, p,p'-DDT, and p,p'-TDE; organophosphates group: chlorpyrifos, diazinon, *O*-Ethyl *O*-(4-nitrophenyl) phenylphosphonothioate (EPN), ethion, malathion, methidathion, parathion methyl, pirimiphos methyl, profenofos, and triazophos; carbamate group: carbaryl, carbofuran, Isoprocarb, fenobucarb, metolcarb, and promecarb; pyrethroids group: bifenthrin, cypermethrin, cyfluthrin, λ-cyhalothrin, δ-methrin, fenvalerate, and permethrin; and triazines group: ametryn, atrazine, and metribuzin.

3. Quality assurance of analysis

A reagent blank was analyzed for each batch of samples to determine if there was any unforeseen contamination. The accuracy of the analytical process was confirmed using 3 replicates of each recovery. The mean recovery of pesticides through the analytical procedures used were between 70 and 109 %. The limit of detection (LOD) of all pesticides were in the range of 0.001 to 0.03 µg/L and the limit of quantitation (LOQ) were in the ranged from 0.005 to 0.05 µg/L (Table 1). Working standard solutions of 5 points in each pesticide were used and the concentration levels were between 0.01 and 2.50 µg/ml. The correlation coefficients (R^2) of all the calibration curves of the pesticides were in the range of 0.995 - 0.999.

Table 1 Quality assurance of analysis

Pesticide	LOD (µg/L)	LOQ (µg/L)	Intrabatch		Interbatch	
			Recovery (%)	CV (%)	Recovery (%)	CV (%)
Organochlorines						
Aldrin	0.001	0.005	70.3	2.5	71.6	2.6
α-hexachlorocyclohexane	0.001	0.005	79.2	4.5	74.9	5.7
α-endosulfan	0.002	0.005	77.1	3.3	77.8	2.9
β-endosulfan	0.003	0.005	80.2	4.8	80.3	4.1
Dieldrin	0.003	0.005	79.4	3.2	79.4	3.1
Endosulfan sulfate	0.003	0.005	78.9	4.3	79.5	4.8
Endrin	0.003	0.005	88.9	4.0	78.4	4.2
γ-hexachlorocyclohexane	0.002	0.005	72.6	3.4	73.0	3.1
Heptachlor	0.002	0.005	79.5	2.8	78.7	3.0
Heptachlor epoxide	0.002	0.005	77.4	2.9	77.7	2.9
o,p'-DDE	0.003	0.005	81.2	3.0	79.5	4.0
o,p'-DDT	0.003	0.005	81.8	2.9	76.9	3.7
o,p'-TDE	0.003	0.005	76.9	3.7	74.4	3.3
p,p'-DDE	0.003	0.005	80.5	3.2	80.0	3.5
p,p'-DDT	0.003	0.005	89.2	4.4	87.6	4.2
p,p'-TDE	0.003	0.005	78.4	3.6	76.5	4.4
Organophosphates						
Chlorpyrifos	0.010	0.050	82.1	1.4	88.9	2.8
Diazinon	0.010	0.050	88.1	2.5	89.5	4.7
EPN	0.030	0.050	94.2	3.2	95.6	2.5
Ethion	0.010	0.050	91.2	4.4	94.6	4.7
Malathion	0.030	0.050	89.0	3.9	92.9	6.1
Methidathion	0.030	0.050	99.9	5.2	103.4	3.7
Parathion methyl	0.020	0.050	95.4	1.3	97.0	2.5
Pirimiphos methyl	0.030	0.050	92.0	5.2	90.2	4.0
Profenofos	0.030	0.050	96.3	4.6	99.3	5.6
Triazophos	0.030	0.050	106.2	2.8	108.5	3.2

Table 1 Quality assurance of analysis (Cont.)

Pesticide	LOD (μg/L)	LOQ (μg/L)	Intrabatch Recovery (%)	Intrabatch CV (%)	Interbatch Recovery (%)	Interbatch CV (%)
Carbamates						
Cabaryl	0.005	0.100	76.3	3.8	72.6	2.2
Carbofuran	0.002	0.050	89.2	4.4	90.3	4.6
Isoprocarb	0.002	0.050	84.7	2.1	94.1	5.1
Fenobucarb	0.002	0.050	77.6	3.7	72.8	3.2
Metolcarb	0.002	0.050	80.1	1.6	83.4	3.7
Promecarb	0.002	0.050	97.4	2.2	92.3	5.5
Pyrethroids						
Bifenthrin	0.001	0.005	104.9	5.3	98.9	5.4
Cypermethrin	0.002	0.005	103.7	3.0	98.6	2.5
Cyfluthrin	0.003	0.005	102.5	4.8	97.1	3.2
δ-methrin	0.001	0.005	106.0	3.6	100.4	4.2
Fenvalerate	0.002	0.005	106.2	5.4	101.0	3.3
λ-cyhalothrin	0.002	0.005	108.8	6.5	101.0	5.7
Permethrin	0.002	0.005	101.9	1.3	99.2	3.7
Triazines						
Ametryn	0.005	0.020	97.3	2.5	93.6	3.8
Atrazine	0.003	0.020	92.9	3.3	90.1	5.2
Metribuzin	0.001	0.020	96.3	1.6	93.7	3.7

4. Statistical Analysis

Descriptive statistics were utilized to describe minimum, maximum, median, mean, and standard deviation values of concentrations found.

5. Health risk assessment

The non-carcinogenic and carcinogenic risk were determined for children and adults using a model described by the United States Environmental Protection Agency [U.S.EPA] (2011). The scenario considered was the consumption of raw river water. The hazard quotient (HQ) equation below was used to calculate the non-carcinogenic risk for humans by direct ingestion of surface water used as drinking water, (Eq. 1) (U.S.EPA, 2011).

$$HQ = \frac{ADI}{R_fD} \quad (1)$$

In the equation, ADI (average daily intake) represents the estimated amount of ingested pesticide per kilogram body weight, R_fD is the reference dose of the contaminant (mg/kg/day) via the oral exposure route. The ADI was calculated using Eq. 2 below (U.S.EPA, 2011).

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (2)$$

C is the maximum concentration (mg/L) detected for each pesticide in water sample from the river;

IR is the water ingestion rate (1 and 2 L/day for 6-year child and 70-year adult (U.S.EPA, 2000));

EF is the exposure frequency (350 days/year for both ages);

ED is the exposure duration (6 years for children and 30 years for adults);

BW is the body weight of the exposed person (15 kg for children and 70 kg for adults);

AT is the average time (10950 days for both ages).

After the calculation, if the HQ for a pesticide exposure was higher than 1, it implies that potential adverse effects was likely occurred; and if HQ was lower than 1, it implies that adverse effects were not likely occurred. For carcinogenic concerns, carcinogenic risk (R) was calculated by Eq. 3 (U.S.EPA, 2000).

$$\text{Risk (R)} = \text{ADI x CSF x ADAF} \qquad (3)$$

In the equation, CSF is the cancer slope factor (mg/kg/day), reflecting the probability of the individual substance producing cancer via the oral exposure route; ADAF is the age-dependent adjustment factor (10 for 0–2 years old, 3 for 2–16 years old and 1 for above 16 years old). ADAF values are default adjustments to the cancer slope factor that take consideration of the increased susceptibility to cancer from early life exposures.

After the calculation, R for the general population should exceed 10^{-6} and highly exposed populations should not exceed 10^{-4} (U.S.EPA, 2000).

Results

1. Pesticide determination

Results of the Chao Phraya River in 2009 revealed that chlorpyrifos and pirimiphos methyl were detected in both seasons. Endosulfan, *O*-Ethyl *O*-(4-nitrophenyl) phenylphosphonothioate, and malation were detected only in the dry season. Pyrethroid, carbamate and triazine were not detected in any sample or season. In 2016, atrazine was the most frequently detected pesticide. It had a detection frequency of 100% in both the dry and wet seasons. Atrazine had the highest concentration detected in both the dry and wet seasons 0.28 and 0.40 µg/L, respectively. Ametryn was detected in the wet season only at 0.04 µg/L (Table 2). The pesticide group of organochlorines, organophosphates, carbamates, and pyrethroids were not detected in either season (Figure 2).

Results of the Pa Sak River in 2010 showed that most of pesticides were detected in the wet season (Figure 3). Atrazine was the most frequently detected pesticide in both the dry and wet seasons. The detection frequency of 100% was found in both seasons. The highest concentrations detected in the dry and wet seasons were 0.22 and 3.23 µg/L, respectively. Carbaryl was detected at high concentrations in the wet season. In 2014, results showed that ametryn and atrazine were the most frequently detected pesticides in the wet seasons with a detection frequency of 52 and 67%, respectively. The highest concentrations of atrazine was detected in the wet season at 13.40 µg/L (Table 2).

In the Tha Chin River, results showed that atrazine was the most frequently detected pesticide in both seasons in 2011 and 2015 (Figure 4). Endosulfan is the POPs pesticide that was detected in both seasons, with a detection frequency of 46%. In the year 2015, ametryn was detected only in the dry season. Organochlorines, organophosphates, carbamates, and pyrethroids were not detected in any seasons (Table 2).

Table 2 Concentrations of pesticides detected in water samples from the three rivers.

River	Year	Fre. (%)	Pesticide	Pesticide concentrations (μg/L) Dry season Med.	Dry Min.	Dry Max.	Dry Mean(±SD)	Wet season Med.	Wet Min.	Wet Max.	Wet Mean(±SD)
Chao Phraya	2009* (n=46)	2	endosulfan	0.62	ND	0.62	0.03(±0.13)	ND	ND	ND	ND
		4	chlorpyrifos	0.05	0.05	0.06	0.01(±0.01)	0.01	0.01	0.02	0.01(±0.01)
		2	EPN	0.06	ND	0.06	0.01(±0.01)	ND	ND	ND	ND
		2	malathion	0.05	ND	0.05	0.01(±0.01)	ND	ND	ND	ND
		2	pirimiphos methyl	0.10	ND	0.10	0.01(±0.02)	0.09	ND	0.09	0.01(±0.02)
	2016 (n=22)	23	ametryn	ND	ND	ND	ND	0.02	0.01	0.04	0.01(±0.01)
		100	atrazine	0.24	0.13	0.28	0.23(±0.04)	0.31	0.01	0.40	0.30(±0.08)
Pa Sak	2010* (n=52)	4	endosulfan	0.02	ND	0.02	0.01(±0.01)	ND	ND	ND	ND
		2	chlorpyrifos	0.04	ND	0.04	0.01(±0.01)	ND	ND	ND	ND
		2	diazinon	0.06	ND	0.06	0.01(±0.01)	ND	ND	ND	ND
		2	ethion	0.05	ND	0.05	0.01(±0.01)	ND	ND	ND	ND
		6	carbaryl	ND	ND	ND	ND	0.35	0.19	0.44	0.04(±0.11)
		54	ametryn	0.05	0.01	0.06	0.02(±0.03)	0.29	0.08	8.04	0.66(±1.67)
		100	atrazine	0.06	0.02	0.22	0.07(±0.05)	0.40	0.05	3.23	0.66(±0.74)
	2014* (n=52)	52	ametryn	0.07	0.04	0.83	0.10(±0.16)	0.02	0.02	0.47	0.06(±0.15)
		67	atrazine	0.67	0.19	3.28	0.37(±0.74)	0.17	0.03	13.40	1.17(±3.05)
Tha Chin	2011* (n=48)	46	endosulfan	0.02	0.02	0.03	0.01(±0.01)	0.01	0.01	0.02	0.01(±0.01)
		4	chlorpyrifos	ND	ND	ND	ND	0.03	ND	0.03	0.01(±0.01)
		46	ametryn	ND	ND	ND	ND	0.55	0.22	0.79	0.49(±0.20)
		81	atrazine	0.17	0.06	0.29	0.12(±0.10)	0.33	0.24	0.42	0.31(±0.09)
	2015* (n=48)	10	ametryn	0.04	0.04	0.06	0.01(±0.02)	ND	ND	ND	ND
		46	atrazine	0.08	0.06	0.09	0.03(±0.04)	0.18	0.07	0.22	0.10(±0.09)

*Source: Department of Agriculture, Ministry of Agriculture Cooperatives, Thailand

Note: n means number of sample

ND means not detected

Fre. means percentage of samples with detected pesticide

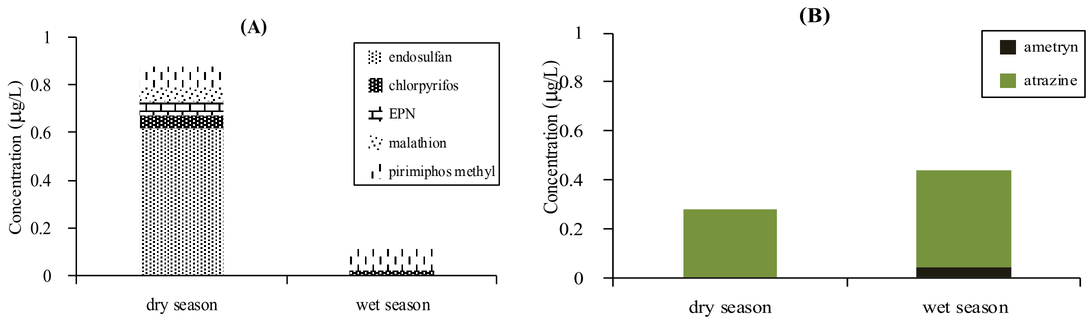

Figure 2 Pesticide concentrations in Chao Phraya river in 2009 **(A)** and 2016 **(B)** in different seasons

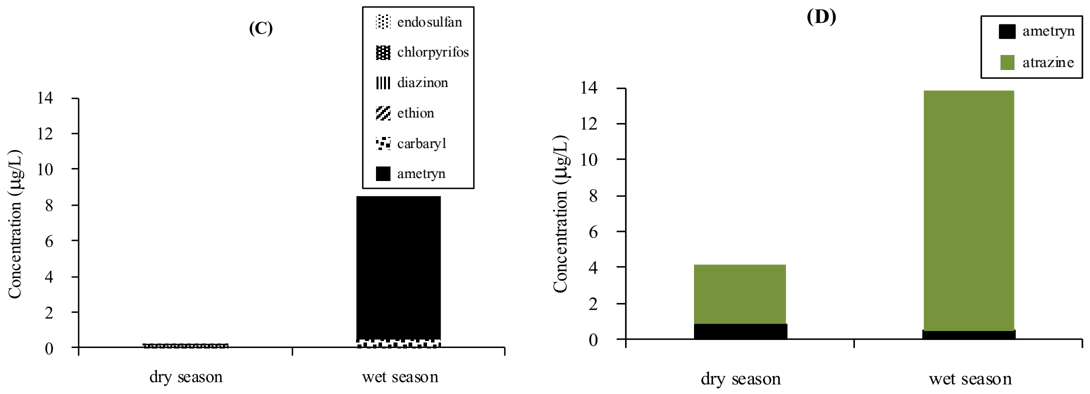

Figure 3 Pesticide concentrations in Pa Sak river in 2010 **(C)** and 2014 **(D)** in different seasons

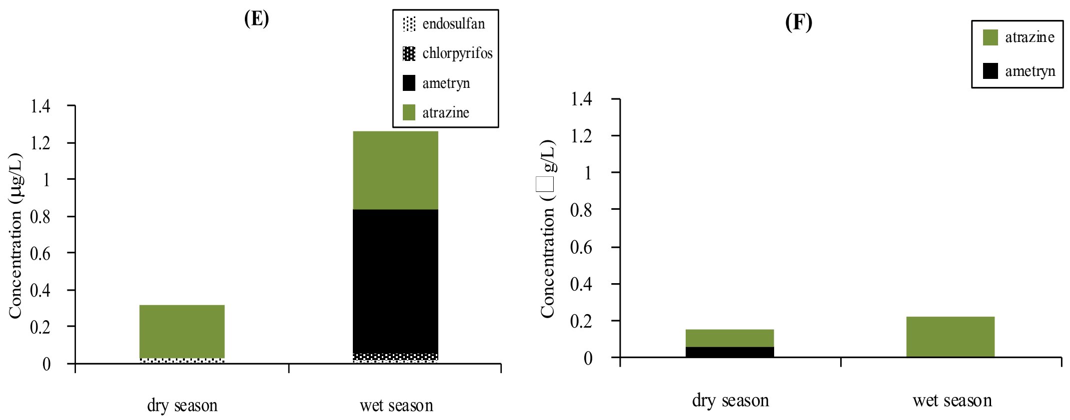

Figure 4 Pesticide concentrations in Tha Chin river in 2011 **(E)** and 2015 **(F)** in different seasons

2. Health risk assessment

The HQ of maximum pesticide concentrations in the three rivers are shown in Table 3. All of them are less than 1, suggesting that pesticides in river water for consumption poses a low risk to human health. The Chao Phraya river in 2009 in the dry season showed the highest risk index (child = 0.076, adult = 0.164) with *O*-Ethyl *O*-

(4-nitrophenyl) phenylphosphonothioate showing the highest risk for river water consumption. Whereas malathion had the lowest risk index (child = 0.000032, adult = 0.000068).

Table 3 Hazard Quotient (HQ) for non-carcinogenic detected pesticides for 6-year old child and 70-year old adult.

River	Year	Pesticide	Hazard Quotient (HQ)			
			Dry season		Wet Season	
			Child	Adult	Child	Adult
Chao Phraya	2009	endosulfan	$1.32x10^{-3}$	$2.83x10^{-3}$	-	-
		chlorpyrifos	$2.56x10^{-3}$	$5.48x10^{-3}$	$8.52x10^{-4}$	$1.83x10^{-3}$
		EPN	$7.67x10^{-2}$	$1.64x10^{-1}$	-	-
		malathion	$3.20x10^{-5}$	$6.85x10^{-5}$	-	-
		pirimiphos methyl	$1.28x10^{-4}$	$2.74x10^{-4}$	$1.15x10^{-4}$	$2.47x10^{-4}$
	2016	ametryn	-	-	$5.68x10^{-5}$	$1.22x10^{-4}$
		atrazine	$1.02x10^{-4}$	$2.19x10^{-4}$	$1.46x10^{-4}$	$3.13x10^{-4}$
Pa Sak	2010	endosulfan	$4.26x10^{-5}$	$9.13x10^{-5}$	-	-
		chlorpyrifos	$1.70x10^{-3}$	$3.65x10^{-3}$	-	-
		diazinon	$3.07x10^{-4}$	$6.58x10^{-4}$	-	-
		ethion	$1.28x10^{-3}$	$2.74x10^{-3}$	-	-
		carbaryl	-	-	$5.63x10^{-5}$	$1.21x10^{-4}$
		ametryn	$8.52x10^{-5}$	$1.83x10^{-4}$	$1.14x10^{-2}$	$2.45x10^{-2}$
		atrazine	$8.04x10^{-5}$	$1.72x10^{-4}$	$1.18x10^{-3}$	$2.53x10^{-3}$
	2014	ametryn	$1.18x10^{-3}$	$2.53x10^{-3}$	$6.68x10^{-4}$	$1.43x10^{-3}$
		atrazine	$1.20x10^{-3}$	$2.57x10^{-3}$	$4.89x10^{-3}$	$2.45x10^{-2}$
Tha Chin	2011	endosulfan	$6.39x10^{-5}$	$1.37x10^{-4}$	$4.26x10^{-5}$	$9.13x10^{-5}$
		chlorpyrifos	-	-	$1.28x10^{-3}$	$2.74x10^{-3}$
		ametryn	-	-	$1.12x10^{-3}$	$2.40x10^{-3}$
		atrazine	$1.06x10^{-4}$	$2.27x10^{-4}$	$1.53x10^{-4}$	$3.29x10^{-4}$
	2015	ametryn	$8.52x10^{-5}$	$1.83x10^{-4}$	-	-
		atrazine	$3.29x10^{-5}$	$1.64x10^{-4}$	$8.04x10^{-5}$	$1.72x10^{-4}$

Discussion

The most frequently detected pesticides were herbicides. Herbicides are the largest proportion of imported pesticides in Thailand (OAR, 2016), and they are intensively used in plantations. Particularly, atrazine was detected in all rivers and in both seasons. It was detected in all sampling sites of the Chao Phraya River in 2016. It was pre-emergent herbicide used to control weed in maize and soybean during May to June, which could be associated with rainfall events when concentrations in the rivers result from pesticides in the soil after pesticide applications on crops leach out from the soil via runoff (Kristin et al., 2012). Most pesticides were detected in the wet season while pesticides were detected in low concentrations in the dry season due to some pesticides accumulating in sediment (Poolpak et al., 2008). However, this study did not analyze sediments that requires more complicated sampling. In addition, the period of water sampling from each river was not conducted in the same year, so results between rivers are not comparable. In Thailand, endosulfan was banned in 2004, but it was still remained in the river due to its persistent in the environment (Stockholm Convention on POPs, 2008). Similar results have been reported in the previous studies (Zheng et al., 2016).

All pesticides detected in the three rivers were non carcinogenic compounds and found at low concentration. The calculation of non-carcinogenic risk for HQ was less than 1, it implies that no adverse health effects occurring in children or adults.

In this study, pesticides were detected in low concentrations in water with a low risk index for drinking water. However, pesticides can accumulate and contaminate every part of the environment including sediments, fish, and other biota. These areas of bio-accumulations should also be investigated to determine if pesticide levels are increasing over time.

Conclusion

Herbicides comprised the vast majority of detected pesticides. Atrazine was detected in all rivers with different frequency of detection. Pesticides detected in the Chao Phraya, Pa Sak, and Tha Chin River pose a low potential risk to humans through consuming drinking water from the rivers.

Acknowledgement

This study was kindly supported by the Pesticide Research Group, Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand.

References

Chatrasuntiprapa P, Harutaitanasunti P. Distribution of endosulfan residues in the main rivers of the central region. The fourth technical conference of agricultural toxic substances division, 2002 July 22-25, Krabi, Thailand. p. 74-79. [in Thai].

Costa L, Giordano G, Guizzetti M, Vitalone A. Neurotoxicity of pesticides: brief review. Journal of Front Bio Sci. 2008; 13: 1240-1249.

Chulintorn P, Sakulteingtrong S, Tangnipol W. Distribution of pesticides from agricultural area to the main rivers in Thailand. The fourth technical conference of agricultural toxic substances division, 2002 July 22-25, Krabi, Thailand. p. 55-63.[in Thai].

Environmental Protection Agency. Organophosphorus Compounds by Gas Chromatography Capillary Column Technique 8141A Revision 1; 1994.

Hayes TB, Collins A, Lee M, Mendoza M, Noriega N, Aaron A. Hermaphroditic, demasculinized frogs after exposure to the herbicide atrazine at low ecologically relevant doses. Proc. Natl. Acad. Journal of Sci. U.S.A. 2002; 99 (8): 5476-80.

Jaipieam S, Visuthismajarn P, Sutheravut P, Siriwong W, Thoumsang S, Borjan M, Robson M. Organophosphate Pesticide Residues in Drinking Water from Artesian Wells and Health Risk Assessment of Agricultural Communities, Thailand. Journal of Hum Ecol Risk Assess 2009; 15 (6):1304-1316.

Kristin B, Nicholas J, Julien M, Mikaela G, Jenny K. Pesticide run-off to Swedish surface waters and Appropriate mitigation strategies-a review of the knowledge focusing on vegetated buffer strips. [online] 2012 [cited 2016 May 1]. Available from: https://www.slu.se/globalassets/ew/org/centrb/ckb/publikationer/ckb-rapporter/runoff-report-eng.pdf

Office of Agricultural Economics of Thailand, Ministry of Agricultural Cooperative. Agricultural Statistics of Thailand 2014. [online] 2015 [cited 2016 May 5]. Available from: http://www.oae.go.th/oae_report/export_import/export_import_all_result.php

Official Methods of Analysis of AOAC International. Organochorine pesticide in water: Gas chromatographic method 990.6. 18th ed. AOAC international; 2005.

Pomes A, Rodriguez-Farre E, Sunol C. Effects of organochlorine pesticides on 36Cl- flux in primary neuronal cultures. Journal of Neurotoxicology 1994; 15: 745-749.

Poolpak T, Pokethitiyook P, Kruatrachue M, Arjarasisikoon U, Thanwaniwat N. Residue analysis of organochlorine pesticides in the Mae Klong river of central Thailand. Journal of Hazardous Materials 2008; 156: 230-239.

Steenland K, Dick R.B, Howell R.J, Chrislip D.W, Hines C.J, Reid T.M. Neurologic function among termiticide applicator sex posed to chlorpyrifos. Journal of Environ Health Perspect. 2000; 108: 293-300.

Stockholm Convention. The POPs. [online] 2008 [cited 2016 May 5]. Available from http://www.chm.pops.int/the convention/the pops.

The Office of Agriculture Regulation, Department of Agriculture. Statistical of pesticide. [online] 2016 [cited 2016 May 1]. Available from: http://www.doa.go.th/ard/

United States Environmental Protection Agency. Supplementary guidance for conducting health risk assessment of chemical mixtures. Risk Assessment Forum Technical Panel. Office EPA/630/R- 00/002. [online] 2000 [cited 2016 Sep 2]. Available from https://www nepis.epa.gov/

United States Environmental Protection Agency. Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment. Washington DC. EPA/600/R-09/052F.[online] 2011 [cited 2016 Sep 2]. Available from https://www nepis.epa.gov/

Vale C, Fonfria E, Bujons J, Messeguer A, Rodriguez-Farre E, Sunol C. The organochlorine pesticides gamma-hexachlorocyclohexane (lindane), alpha endosulfan and dieldrin differentially interact with GABA (A) and glycine-gated chloride channels in primary cultures of cerebellar granule cells. Journal of Neuroscience 2003; 117: 397-403.

Zheng S, Chen B, Qiu X, Chen M, Ma Z, Yu X. Distribution and risk assessment of 82 pesticides in Jiulong River and estuary in south China. Journal of Chemosphere 2016; 144: 1177-1192.